

Reduction of Surface Friction on The Size of Dimples on AISI 1016 Steel Surface

Mohd Rahimi Ramli^{1*}, Norasiah Abd Razak¹, Fazida Akhtar Abdullah¹

¹Department of Mechanical Engineering, Politeknik Mukah, KM 7.5 Jalan Oya, 96400 Mukah, Sarawak, Malaysia

*Corresponding author: asiahrak@pmu.edu.my

Abstract

This study discusses the relationship between the wear effects caused by friction and dimples and their influence on the friction factor, which consists of four types of dimples with the diameter and depth are 1 mm, 2 mm, 3 mm and 4 mm. The samples used in this study are made of AISI 1016 carbon steel. In these samples, the dimples produced have the same diameter and depth, i.e. 1 mm to 4 mm. The dimples were created using a 3-axis milling machine and a ball-end nose tool. These dimples also have different diameters, that is, 4 mm, 3 mm, 2 mm, and 1 mm. This testing contains variations in diameter ranging from 1 mm to 4 mm. The dimples were then analyzed by using microscopy and image analysis. The samples were further analyzed using a Universal Testing Machine (UTM) equipped with the ASTM 1894 apparatus. The samples were tested using ISO-168 hydraulic oil volume under face-to-face contact conditions. The results for static friction can be stated that the larger of depth of the dimples can affect to reduction of friction. The kinetic friction for a sample also reduces friction for the largest dimple. constant but for the sample distance plays a role where the closer the distance the lower the kinetic friction. For sample B, the distance for the closest dimple to the same diameter for kinetic friction showed an ability to reduce friction compared to a higher distance. The results of the tests conducted showed remarkable effects of the resulting friction from these dimple surfaces. The test results found that a larger-diameter sample had a higher ability to reduce friction compared to a smaller diameter. This will prolong the lifespan of mechanical and automotive components.

Keywords: - Textured surface, dimples, surface friction

1. Introduction

Various mechanical system issues stemming from vibrations, friction, material wear, and fatigue. Friction between two surfaces has caused changes in the shape of both surfaces. These changes are due to material wear, defined as losing the original dimensional shape. Surface friction reduction is one of the areas of study in tribology (Liakopoulos et al., 2016). According to Wong & Tung (2016), various methods for reducing surface friction have been reported in previous studies. These include using lubricants, surface coatings, and textured surface generation.

Recently, research on surface texturing has gained interest among researchers due to its ability to reduce surface friction without lubricants (Rosenkranz, 2021). Textured surfaces can be produced using various methods, including turning, laser machining, and forging. The type of material that often experiences wear due to friction in mechanical machines is AISI 1016 steel. This study focuses on generating textured surface dimples on AISI 1016 steel to reduce friction on its surface (Niu et al., 2019). When two material surfaces slide against each other due to shear forces and wear, the wear will continue to increase rapidly, causing both surfaces to wear out. However, when these two surfaces interact with a

lubricant, a reduction in friction is observed (Wong & Tung, 2016). In this experiment, dimples are also used as components to help reduce friction and create spaces to separate the two surfaces (Prasad, 2022).

2. Literature Review

Suppose a reduction in friction occurs in a system. In that case, it is considered to decrease the system's efficiency, leading to energy loss, component resistance, and a lack of confidence in the system. For instance, the energy loss due to friction in a car is estimated to account for 40% of the total power generated by the internal combustion engine (Ali et al., 2016).

Studies conducted in several industrialized countries have shown that 1.0% to 1.4% of the gross national product can be saved by introducing better tribological practices, which require investment in research and development at a rate of one in 50 retrievable deposits (Holmberg & Erdemir, 2015). In the field of mechanical engineering, friction mechanisms and control are crucial. Various approaches have been employed to reduce friction, including using lubricants, coatings, and surface modifications such as texturing, which is the focus of this study (Gachot et al., 2017).

3. Methodology

The difference in friction caused by surface texturing is investigated in this methodological study through experimental inquiry. This difference is examined under varying sizes of textured dimples with different diameters and quantities. An experimental design is employed to investigate these effects. Four samples of AISI 1016 mild carbon steel are used in this study.

The surface texture of this mild carbon steel is machined to dimensions of 60mm × 50mm × 10mm using a milling machine. The cutting speed and feed rate are kept constant during the machining process. The surface roughness of these samples is approximately $R_a = 1.5 \mu\text{m} \pm 0.05 \mu\text{m}$, measured using Confocal Microscopy. This instrument is a high-precision laser microscope (LEXT Olympus). The computer numerical control (CNC) machining method creates textured dimples on these experimental samples. The cutting tool used is a ball-end nose, and the dimples' depth corresponds to the cutting tool's radius. Four different cutting tool sizes are used, namely 4 mm, 3 mm, 2 mm, and 1 mm.

The spindle rotational speed for creating these textured dimples is set at 1000 rotations per minute (RPM), while the feed rate is maintained at 950 mm/min. The overall density of the dimples is contingent upon the spacing distance between each dimple.

The table below represents the density values for the dimples, where Fig. 1 corresponds to a 1 mm interval and contains 529 dimples, Fig. 2 has a 2 mm interval and 225 dimples, Fig. 3 has a 3 mm interval and 121 dimples, and finally, Fig. 4 has a 4 mm interval and 81 dimples. All four samples were tested to observe the shear effect during the shear test. Each sample produced different readings.

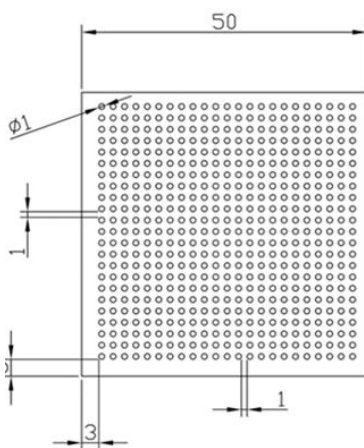


Fig. 1. 1 mm and 529 dimples

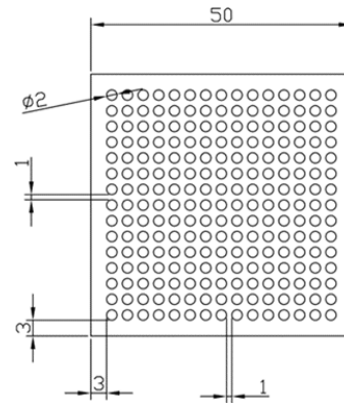


Fig. 2. 2 mm and 225 dimples

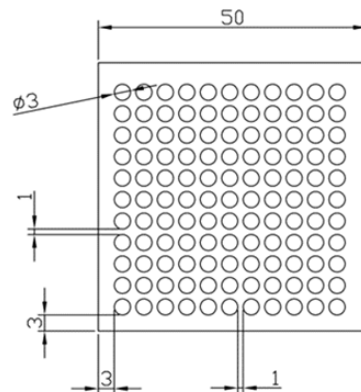


Fig. 3. 3 mm and 121 dimples

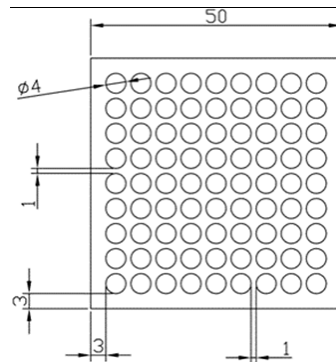


Fig. 4. 4 mm and 81 dimples

The Universal Testing Machine (UTM) is suitable for conducting this shear test. ASTM D1894 is the standard test method used to evaluate the readings of the coefficient of friction for both sliding and non-sliding conditions. The testing equipment includes a sample size, material slide base, string gripper, reference plane, weighing scale, and force measuring device by this standard. The UTM is equipped with specialized apparatus provided for this purpose. The connecting rope between the sample and the binder is set at a load of 50 kN on the UTM, passes through the pulley, and is attached to the sample placed on the sliding base.

4. Result and Discussion

Fig. 5 consists of dimples on samples ranging from 1 mm to 4 mm in size. The diameter of Fig. 5 is 4 mm, Fig. 6 is 3 mm, Fig. 7 is 2 mm, and Fig. 8 is 1 mm. Each dimple is spaced 1 mm apart for all samples and has a different number of dimples. Fig. 5 contains 81 dimples, Fig. 6 contains 121 dimples, Fig. 7 contains 225 dimples, and Fig. 8 contains 324 dimples.

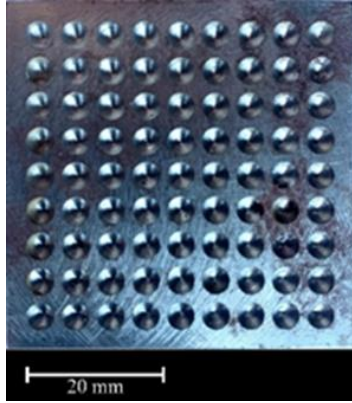


Fig. 5. Diameter of 4 mm and 81 dimples

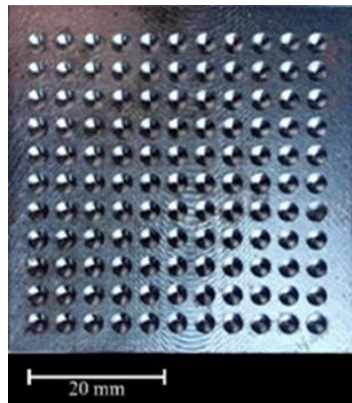


Fig. 6. Diameter 3 mm and 121 dimples

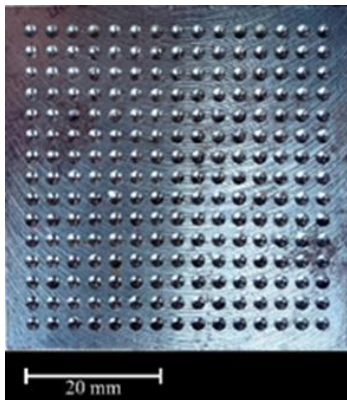


Fig. 7. Diameter 2 mm and 225 dimples

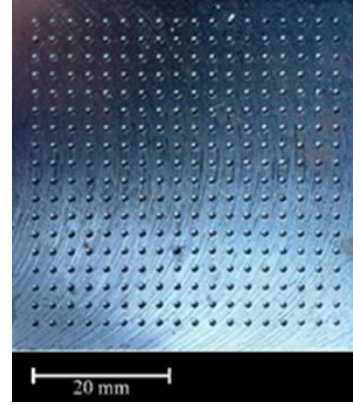


Fig. 8. Diameter 1 mm and 324 dimples

4.1 Different Diameters Based on Static Friction

All samples were tested for static friction under two conditions: dry (without lubricant) and wet (with lubricant). Based on Table 1 below, it is found that the largest diameter of 4 mm yielded a significantly low coefficient of friction reading under wet and dry conditions, which was 0.2112 and 0.2974. This was followed by the 3 mm diameter dimples, which had a reading of 0.2680 and 0.1707. The 2 mm diameter dimple provided the third lowest reading, 0.2195 and 0.1482 and the last dimple is 1 mm diameter with the highest coefficient 0.1293 and 0.2003.

This sample explains the results for the friction coefficient for the number of dimples produced. Table 1 shows the size of the sample with a diameter of 4 mm, which means the number of dimples is 81 and has the lowest coefficient of friction. The sample with a diameter of 1 mm despite having the number of dimples is 324 dimples. It was observed that larger-diameter dimples had a significant effect on reducing the coefficient of friction (see Fig. 9). This can be seen from the reduction in readings for the 4 mm, 3 mm, 2 mm, and 1 mm diameter dimples.

Table 1. Static friction readings in dry and wet lubricated conditions

Sample Number	Total Number of Dimples	Sample Dimple Size (mm)	Friction Coefficient		
			Dimple Distance	Wet	Dry
1	81	4	1	0.1293	0.2003
2	121	3	1	0.1482	0.2195
3	225	2	1	0.1707	0.2680
4	324	1	1	0.2112	0.2974

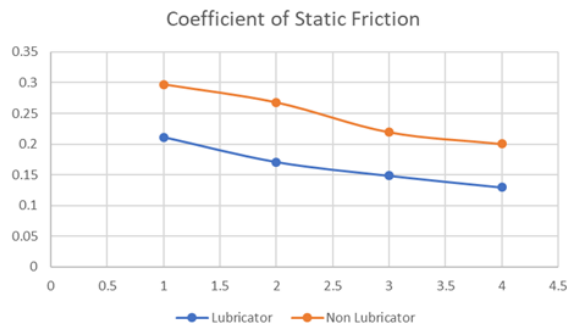


Fig. 9. Coefficient of Static Friction

4.2 Different Diameters Based on Kinetic Friction

Table 2 shows the results for kinetic friction under dry (without lubricant) conditions for samples ranging from 4 mm to 1 mm in diameter. In terms of friction, the 4 mm diameter dimple exhibited the lowest reading of 0.1277 among the samples, followed by the 3 mm diameter dimple with a reading of 0.1830, the 2 mm diameter dimple with a reading of 0.2007, and lastly, the 1 mm diameter dimple with a reading of 0.2316. When considering wet conditions (with lubricant), the 4 mm diameter dimple demonstrated the lowest reading of 0.1620, followed closely by the 3 mm diameter dimple with a reading of 0.1622. The third lowest reading is for the 2 mm diameter dimple at 0.1855, and the last is for the 1 mm diameter dimple at 0.2315.

These results indicate that the largest dimple diameter under wet conditions is the 4 mm diameter dimple with the lowest friction. The lowest reading for kinetic friction indicates that the 4 mm diameter dimple under wet conditions has the lowest coefficient of friction, which is 0.1620. It is found that the coefficient of friction for static (see Fig. 9) and kinetic friction shows a similar trend, where larger dimples tend to have lower coefficients of friction compared to more minor dimples, regardless of whether they are in dry or wet conditions. This can also be observed by referring to Fig. 10.

Table 2. Kinetic friction readings in dry and wet lubricated conditions

Sample Number	Total Number of Dimples	Sample Dimple Size (mm)	Friction Coefficient		
			Dimple Distance	Wet	Dry
1	81	4	1	0.1620	0.1277
2	121	3	1	0.1622	0.1830
3	225	2	1	0.1855	0.2007
4	324	1	1	0.2315	0.2316

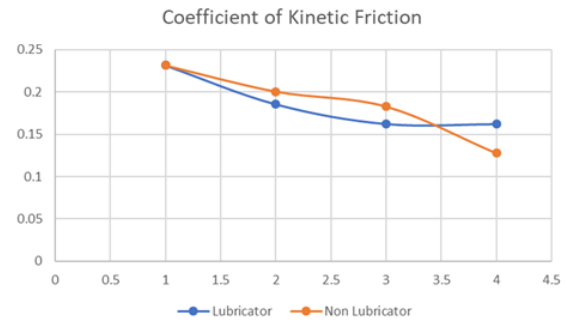


Fig. 10. Coefficient of kinetic friction

5. Conclusion

Based on the study's findings, it is evident that the dimples created on the steel surface can reduce friction. In the case of varying diameters, ranging from 1 mm to 4 mm, it can be concluded that larger diameter dimples have a lower coefficient of friction values, even though they have fewer dimples. Furthermore, based on observations, it can be inferred that surfaces generating higher hydrodynamic pressure can yield lower coefficients of friction, as seen in the case of the four mm-diameter dimples.

References

- Ali, M. K. A., Xianjun, H., Mai, L., Bicheng, C., Turkson, R. F., & Qingping, C. (2016). Reducing frictional power losses and improving the scuffing resistance in automotive engines using hybrid nanomaterials as nano-lubricant additives. *Wear*, 364, 270-281.
- Gachot, C., Rosenkranz, A., Hsu, S. M., & Costa, H. L. (2017). A critical assessment of surface texturing for friction and wear improvement. *Wear*, 372, 21-41.
- Holmberg, K., & Erdemir, A. (2017). Influence of tribology on global energy consumption, costs and emissions. *Friction*, 5, 263-284.
- Liakopoulos, A., Sofos, F., & Karakasidis, T. E. (2016). Friction factor in nanochannel flows. *Microfluidics and Nanofluidics*, 20, 1-7.
- Niu, J., Liu, Z., Ai, X., Huang, W., Wang, G., & Duan, R. (2019). Characteristics of machined surface integrity in face milling Al-Li alloy 2A97 with carbide inserts. *The International Journal of Advanced Manufacturing Technology*, 101, 839-848.
- Prasad, K. N., Syed, I., & Subbu, S. K. (2022). Laser dimple texturing—applications, process, challenges, and recent developments: a review. *Australian Journal of Mechanical Engineering*, 20(2), 316-331.
- Rosenkranz, A., Costa, H. L., Baykara, M. Z., & Martini, A. (2021). Synergetic effects of surface

texturing and solid lubricants to tailor friction and wear—a review. *Tribology International*, 155, 106792.

Wong, V. W., & Tung, S. C. (2016). Overview of automotive engine friction and reduction trends—Effects of surface, material, and lubricant-additive technologies. *Friction*, 4, 1-28.