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Exploring Wear Characteristics of AISI 1045 Steel under Variable Disc Rotation Speeds: A Tribological Investigation

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Abstract

Reliable mechanical components are the desired final product. When mechanical components come into contact, there is a possibility of failure. Contact between components can result in friction, leading to wear. Friction and wear can be studied through the science of tribology. This paper aims to investigate the wear of AISI 1045 steel using a pin-on-disc tribometer with varying disc rotation speeds (rpm) to calculate the values of wear volume and specific wear rate. This research demonstrates that variations in speeds of disc rotation. It influences changes in sliding distance, wear width, wear volume, and specific wear rate on the AISI 1045 steel pin. The conclusion derived from this study is that the overarching observed pattern suggests that as the disc rotation speed increases, there is an increase in wear volume, accompanied by a decrease in the specific wear rate.

Keywords: *AISI 1045 steel; disc rotation speeds; specific wear rate; tribology; wear volume*

1. Introduction

Friction, wear, and lubrication on the surfaces of moving objects are explored in the scientific discipline of tribology. From ancient times to the emergence and development of various branches of science today, tribology remains an integral part (Urbakh *et al.*, 2004). Friction is a common phenomenon that occurs when two objects come into contact. The impacts of friction can vary widely, such as increased surface temperature or wear. According to the report by Jost (1966), the leading cause of wastage is wear resulting from friction. Heat from friction can soften the material and potentially damage the surface contact.

Friction typically occurs between two surfaces of contacting objects, whether exposed to air, water, or solid substances. Sliding contact occurs when two objects or surfaces have relative speed at the contact point in the tangential direction (D.S., 1970). As one object's surface slides against another's surface, both generate frictional forces. The frictional force on the moving object always acts opposite to the direction of its motion. In addition to impeding the movement of objects, friction can also lead to wear and damage.

Tribology plays a pivotal role in contact mechanics, encompassing the processes of sliding and rolling. Wear can manifest when two objects interact at their surfaces, resulting from sliding or rolling contact, or a combination of both, referred to as rolling sliding contact (Syafa'at *et al.*, 2010). Wear is a prevalent phenomenon in the field of engineering. Per the ASTM definition, wear denotes surface damage to an object, typically arising from material loss due to relative motion between the object and its contacting substance (Blau, 1997). Within this context, wear mechanisms are classified into two groups: those induced by mechanical behavior and those caused by chemical behavior (Komvopoulos *et al.*, 1986).

Friction and wear can be analyzed using a pin-on-disc tribometer. This tribometer is a testing instrument consisting of a pin and a disc designed for evaluating friction and wear. The pin-on-disc tribometer has been widely employed in research to assess the tribological properties of various materials. Some studies have

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utilized the tribometer to determine wear rates and friction coefficients (Aksulu & Palabiyik, 2009), investigate the relationship between contact temperature and wear (Kennedy *et al.*, 2015), and test lubricant performance (Syahrullail & Ismail, 2013). Crucial parameters in friction and wear tests include contact pressure and sliding distance between the contacting surfaces (Archard, 1953).

AISI 1045 steel, medium carbon steel, is widely employed in the manufacturing industry for machining various components such as levers, crankshafts, spindles, gears, shafts, bolts, and connecting rods (Akhyar & Sayuti, 2015; Trung, 2020). These components are intricately involved in direct interactions with other elements in performing their functions. Wear is likely to occur when two objects interact on a contacting surface due to relative motion between the objects and the substance in contact (Blau, 1997; Syafa'at *et al.*, 2010). Various treatments have been applied to enhance the wear resistance of AISI 1045 steel, including the utilization of a two-step plasma treatment (Lu *et al.*, 2017), a combination of laser transformation hardening and ultrasonic impact strain hardening (Lesyk *et al.*, 2020), and a hybrid treatment involving plasma nitriding and post-oxidation (Naeem *et al.*, 2022). Several research studies have investigated the wear characteristics of AISI 1045 steel. In the study conducted by Maleque *et al.* (1998), an analysis of wear and friction on surface-hardened AISI 1045 steel was performed using a tri-pin-on-disc tribometer with a lubricant contaminated by palm oil diesel. The experiment involved testing AISI 1045 steel pin pairs (treated and untreated) against an AISI 01 steel disc subjected to a load of 10 kg at a machine speed of 500 rpm. The results revealed that the surface-hardened steel specimen exhibited enhanced wear resistance when exposed to a 4% biofuel-contaminated lubricant. Santos *et al.* (2018) conducted an alternative wear test utilizing the ball cratering abrasive wear test to assess the tribological behavior of AISI 1045 steel when interacting with an AISI 52100 ball under dry conditions. The ball's sliding rotation rate was maintained at 230 rpm, and an average contact load of 1.4 N was applied. The findings revealed that extended sliding distances resulted in a decline in the wear resistance of AISI 1045, indicating a potential decrease in its wear resistance efficiency over time. Elhadi *et al.*, (2021) studied the influence of varying normal loads. They applied hardness on the wear of AISI 1045 pins in contact with AISI 1055 steel discs using a pin-on-disc tribometer under dry sliding conditions. Each test lasted 3600 seconds, with the normal load fluctuating between 5N and 40N while maintaining a consistent linear sliding speed of 0.5 m/s. The results show that the quenching and tempering enhance pegs, making them more wear-resistant. AISI 1045 treated steel is ideal for durable mechanical parts in dynamic contact.

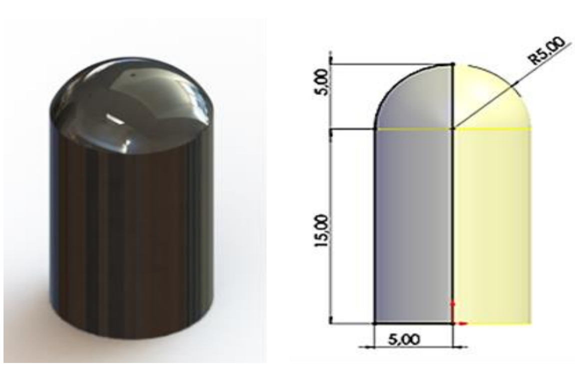

Figure 1. Dimensions of AISI 1045 steel pin (all measurements in mm).

There is limited evidence regarding the use of material couples in contact involving AISI 1045 and AISI 52100. Further investigation is needed to understand the wear patterns at different rotation speeds. The progression of scientific knowledge demands acquiring both quality and adequate data. Hence, in this study, a pin-on-disc tribometer is employed to examine the wear characteristics of AISI 1045 steel under dry conditions, with variations in disc rotation corresponding to sliding distance. This research examines the wear behavior of AISI 1045 steel using the pin-on-disc tribometer by adjusting the motor rotation speed, which impacts the disc rotation. The outcomes of this analysis will be specifically utilized for the computation of wear volume and its specific wear rate.

2. Materials and method

In this study, a wear test was carried out following the ASTM G-99(05) standard, utilizing a pin-on-disc tribometer testing apparatus. The dry sliding wear examinations were performed under ambient air conditions, with temperatures at approximately 25 ± 2 °C. This tribometer consists of a pin and a disc, where the pin comes in various shapes and sizes, commonly in the form of a ball or cylindrical rod. The material chosen for the pin is AISI 1045 steel, which is a medium-carbon steel with a weight composition of 0.45% carbon, 0.18% silicon, 0.52% manganese, 0.031% sulfur, 0.032% phosphorous, and 98.787% iron, exhibiting a hardness level of 35 HRC on the Rockwell C scale (Elhadi *et al.*, 2021; Lu *et al.*, 2017). AISI 1045 steel, also known as hardened steel, finds extensive applications in various fields such as tanks, shipping, bridges, and machining. Medium-carbon steel possesses higher strength than low-carbon steel, with properties making it resistant to bending, weldable, and challenging to cut (Iriandoko *et*

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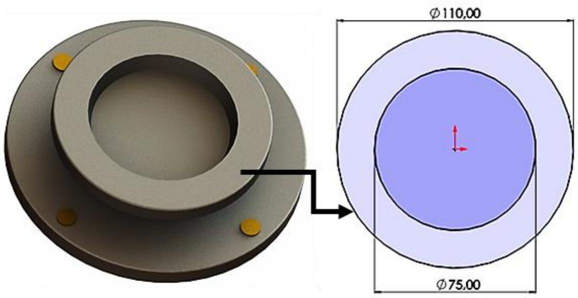

Figure 2. Dimensions of AISI 52100 steel disc (all measurements in mm).

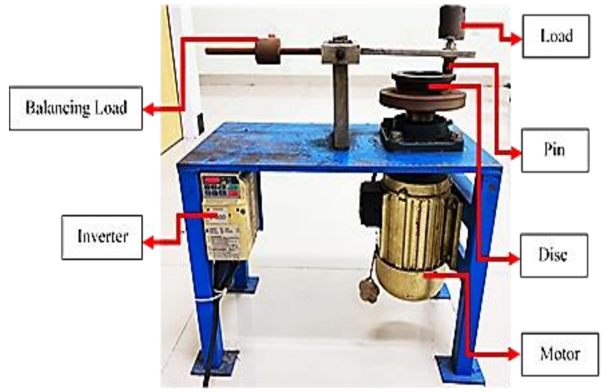

Figure 3. Pin-on-disc tribometer.

al., 2020; Sardjono, 2009). Specific details regarding the size of the pin specimen can be observed in Figure 1.

Meanwhile, the disc or plate on the pin-on-disc tribometer is a flat plate with a specific diameter, as seen in Figure 2. The disc in this study is made of AISI 52100 steel, classified as high carbon steel, with a hardness level on the Rockwell C scale of 62 HRC (Guo & Liu, 2002). The pin-on-disc tribometer is commonly used to test wear in sliding and rolling conditions. The coefficient of friction between the pin and disc (test plate) can be measured using this apparatus. The frictional force and load on the pin allow for the calculation of the coefficient of friction, which, in turn, enables the evaluation of the wear rate. An illustration of the pin-on-disc tribometer used can be seen in Figure 3.

An electric motor powers the tribometer testing apparatus to rotate the disc. At the same time, the pin is positioned on a holder attached to a hinged arm and subjected to a load of 0.95 kg. The motor is equipped with an inverter to control the disc's rotational speed. The rotational speed of the induction motor can be adjusted by altering the frequency using the inverter (Nasution & Hasibuan, 2018).

This study aims to analyze the influence of varying motor rotational speeds on the wear characteristics of the pin. The motor rotational speed is adjusted using an inverter with 10 Hz, 20 Hz, and 30 Hz frequencies. These frequencies result in disc rotations of 251.2 rpm, 554.7 rpm, and 847.3 rpm, respectively. Nine pin specimens are used in this research, with three specimens for each disc rotation. All surfaces of the specimens that will come into contact with the disc were smoothed using silicon carbide abrasive paper with grades ranging from 100 to 2000, followed by polishing with a microfiber cloth. Data is collected every 5 minutes for 15 minutes. The collected and analyzed data include sliding distance, wear width, wear volume, and specific wear rate. The disc rotation speed and testing time determine sliding distance. The wear width of the pin is determined by measuring the worn contact diameter from the microscopic examination of the worn pin surface. The width of the wear scar is used to calculate the pin wear volume using equation (1) (Bayer, 2004).

$$V_p = \frac{\pi W^4}{64 R_p} \tag{1}$$

Where $V_{.P.}$ is the volume of wear, W is the width of the pin wear, and $R_{.P.}$ is the radius of the pin. Meanwhile, the specific wear rate (*SWR*) can be calculated using the following equation (Bale, 2009).

$$SWR = \frac{Vp\ (mm^3)}{load\ (N)\ x\ sliding\ distance\ (m)} \tag{2}$$

3. Results and discussion

Wear testing using a pin-on-disc tribometer has been conducted with the pin made of AISI 1045 steel and the disc made of AISI 52100. This testing was performed under dry conditions without lubrication. Figure 4 illustrates the relationship between test time and sliding distance at each disc rotation speed. At all disc rotation speeds, the sliding distance increases with test time. For each disc rotation speed, an immense sliding distance obtained was at the 15-minute mark, namely 946.52, 2090.11, and 3192.63 meters at 251.2, 554.7, and 847.3 rpm, respectively. This phenomenon occurs because distance is directly proportional to speed. It is evident that the higher the rotation speed, the greater the sliding distance.

The relationship between the wear width of the pin and the sliding distance at each disc rotation speed can be observed in Figure 5. The graph shows an increase in the wear width of the pin as the sliding distance increases, occurring at all disc rotation speeds. The longer the disc rotates and interacts with the pin, the larger the wear width that appears on the pin. The disc rotation speed also affects the wear width of the pin. A higher disc rotation speed causes an increase in wear width. However, the

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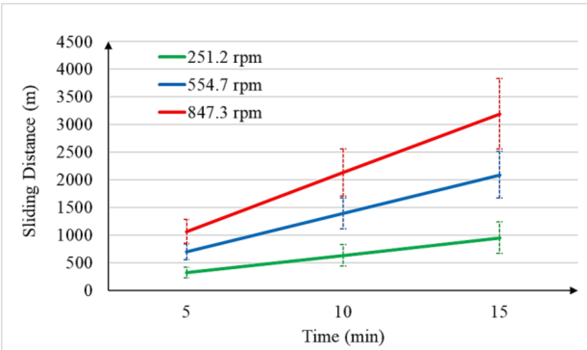

Figure 4. The relationship between sliding distance and test time at each disc rotation speed.

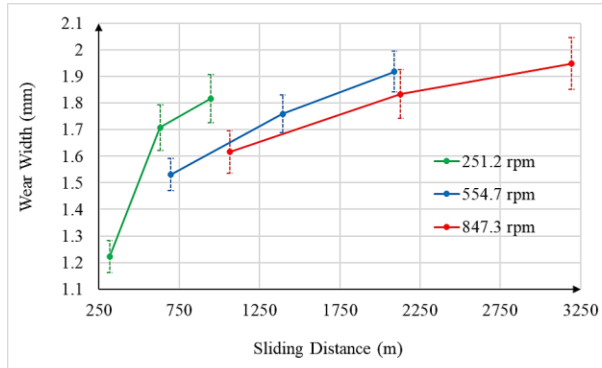

Figure 5. The relationship between the wear width of the pin and sliding distance at each disc rotation speed.

graph shows that the increase in wear width at high disc rotation speeds is smaller than at low disc rotation speeds. The most significant increase in wear width occurs at a disc rotation speed of 251.2 rpm from a sliding distance of 315.51 m to 631.01 m, with an increase in wear width from 1.222 mm to 1.7081 mm (39.78%). The smallest wear width is 1.222 mm at 251.2 rpm, while the largest wear width is 1.949 mm at 847.3 rpm.

Figure 6 below illustrates the relationship between the wear volume of the pin and sliding distance at each disc rotation speed. As the sliding distance increases, the pin experiences an increase in wear volume. Meanwhile, higher disc rotation speeds increase the wear volume on the pin at each test point. The highest wear volume occurs at a disc rotation speed of 847.3 rpm with a sliding distance of 3192.63 m, amounting to 0.1510 mm^3. On the other hand, the lowest wear volume occurs at a disc rotation speed of 251.2 rpm with a sliding distance of 315.51 m, measuring 0.0233 mm^3. The increase in wear volume on the pin at high disc rotation speeds is smaller than at low disc rotation speeds. This phenomenon is similar to wear width since wear volume is proportional to wear width. The most significant increase in wear volume occurs at a disc rotation speed of 251.2 rpm, with the sliding distance progressing from 315.51 m to 631.01 m, going from a wear volume of 0.0233 mm^3 to 0.0891 mm^3 (282%).

The obtained pin wear volume and sliding distance are used to calculate the specific wear rate. Figure 7 illustrates the relationship between particular wear rate and sliding distance at each disc rotation speed. At a disc rotation speed of 251.2 rpm, a pattern of specific wear rate initially increasing and then decreasing with the sliding distance is observed. Meanwhile, at disc rotation speeds of 554.7 and 847.3 rpm, the specific wear rate decreases as the sliding distance increases.

In this study, abrasive wear is highly likely to occur. When a solid object is subjected to loading against particles of a material with equal or greater hardness, abrasive wear will occur (Kovaříková *et al.*, 2009). As observed in the test materials employed in this research, the pin and disc materials exhibit hardness levels that

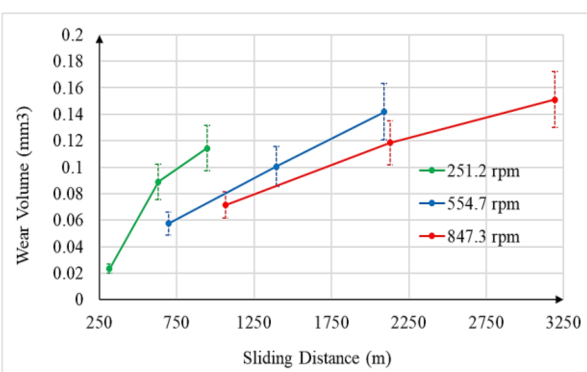

Figure 6. The relationship between pin wear volume and sliding distance at each disc rotation speed.

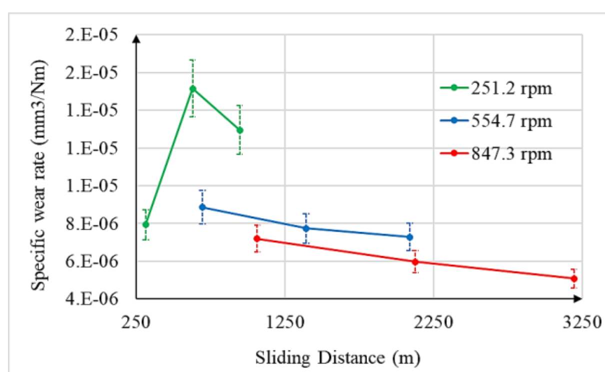

Figure 7. The relationship between specific wear rate and sliding distance at each disc rotation speed.

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differ nearly two-fold. Increasing specific wear rates at low disc rotation speed may be attributed to the dominant abrasive wear mechanism associated with a relatively high specific wear rate (Bale, 2009). This event occurred when untreated specimen pins were used in this research, consistent with the findings of the previous study (Elhadi *et al.*, 2021; Maleque *et al.*, 1998), which reported that a higher wear rate was found in untreated specimen pins compared to surface-treated specimen pins, despite exposure to lubricant. This is attributed to the ability to control abrasive wear resistance through surface treatment of the pins to enhance their hardness.

The experimental findings of Andersson & Salas-Russo (1994) concern the relationship between sliding speed and applied load. It was observed that as sliding speed increases, the applied load decreases. According to Archard's wear model (Archard, 1953), the applied load is proportional to the wear volume. Therefore, at low sliding speeds, the applied load operates at its maximum, leading to a higher wear volume and causing an increase in the specific wear rate.

Changes influence the wear rate in the pin weight (Besihi *et al.*, 2013). The weight change of the pin due to wear is closely related to the shift in wear volume. The change in wear volume affects the specific wear rate. Initially, the pin and disc have relatively high surface roughness when they come into contact, leading to significant friction during disc rotation and subsequent wear. As time progresses, the contacting surface roughness wears down, resulting in a lower wear rate.

4. Conclusion

In this study, an investigation was conducted on the wear characteristics of AISI 1045 steel using a pin-on-disc tribometer with variations in disc rotation. The aim was to calculate the wear volume and specific wear rate. The research revealed that disc rotation speed, sliding distance, test duration, and wear width influence the volume and specific rate of the wear. The comprehensive pattern discerned from the study indicates that higher disc rotation speeds correspond to a greater sliding distance, contributing to an increase in wear volume and concurrently causing a reduction in the specific wear rate for AISI 1045 steel.

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