Jurnal Vokasi Mekanika, Vol. 7, No. 4, November 2025
e-ISSN 2656-1697; p-ISSN 2656-2812

Experimental Study Of Wear Testing Of ASTM 440C Steel On A Ball-On-Disc Tribometer Using Variations Of Lubricants

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Received September 25th 2025; Revised Oktober 13th 2025; Accepted Oktober 22th 2025

Abstract

Bearings are critical industrial components that reduce friction between moving parts to enable smoother, more efficient motion. Nevertheless, sliding/rolling contact can induce wear on bearing surfaces. This study analyzes the wear volume, wear-track width, and wear rate of ASTM 440C steel under three lubricants: SAE 10W-30, SAE 10W-40, and SAE 140 at rotational speeds of 180, 270, and 310 rpm. Tests were performed on a ball-on-disc tribometer with a constant duration of 10 minutes (600 s) per run. The results show that the lowest wear-track width was achieved by SAE 10W-40 at 180 rpm (259.806 µm), whereas the highest also occurred with SAE 10W-40 at 270 rpm (417.894 µm). The lowest wear volume was 0.0225 mm^3 (SAE 10W-40, 180 rpm), while the highest was 0.0942 mm^3 (SAE 10W-40, 270 rpm). For wear rate, the lowest value was 0.50×10^{-8} $g \cdot mm^{-2} \cdot s^{-1}$ (SAE 140, 180 rpm), and the highest was 1.58×10^{-8} $g \cdot mm^{-2} \cdot s^{-1}$ (SAE 10W-40, 270 rpm). Overall, SAE 10W-40 is more suitable at low speed, while SAE 140 is recommended at high speed due to its higher viscosity and superior resistance to wear.

Keywords: ball-on-disc tribometer; bearings; lubricants; wear; tribology

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Studi Eksperimental Uji Keausan Baja ASTM 440C Pada Tribometer Ball-On-Disc Menggunakan Variasi Pelumas

Abstrak

Bearing merupakan merupakan komponen industri yang krusial untuk menurunkan gesekan antarbagi-an bergerak sehingga pergerakan menjadi lebih halus dan efisien. Namun, kontak luncur/menggelinding dapat menimbulkan keausan pada permukaan bantalan. Penelitian ini menganalisis volume aus, lebar jejak aus, dan laju keausan pada material ASTM 440C dengan tiga jenis pelumas: SAE 10W-30, SAE 10W-40, dan SAE 140 pada kecepatan putar 180, 270, dan 310 rpm. Pengujian dilakukan menggunakan tribometer ball-on-disc dengan durasi konstan 10 menit (600 s) per pengujian. Hasil menunjukkan lebar jejak aus terendah diperoleh pada SAE 10W-40 di 180 rpm (259,806 µm), sedangkan tertinggi juga terjadi pada SAE 10W-40 di 270 rpm (417,894 µm). Volume aus terendah adalah 0,0225 mm^3 (SAE 10W-40, 180 rpm), sementara tertinggi 0,0942 mm^3 (SAE 10W-40, 270 rpm). Untuk laju keausan, nilai terendah adalah $0,50 \times 10^{-8}\ g \cdot mm^{-2} \cdot s^{-1}$ (SAE 140, 180 rpm) dan tertinggi $1,58 \times 10^{-8}\ g \cdot mm^{-2} \cdot s^{-1}$ (SAE 10W-40, 270 rpm). Secara umum, SAE 10W-40 lebih sesuai untuk putaran rendah, sedangkan SAE 140 direkomendasikan untuk putaran tinggi karena viskositasnya lebih besar dan ketahanan aus yang lebih baik.

Kata kunci: tribometer ball-on-disc, bearing, pelumas, keausan, tribologi

I. INTRODUCTION

The rapid development of industrial technology, particularly in the automotive sector, demands machine components that operate under high-friction conditions (Witoyo, 2021). Friction between interacting parts, such as piston-cylinder assemblies or ball bearings, can lead to wear, performance degradation, and even operational failure (Sutriyani, 2018). Wear is the progressive loss of material due to sliding contact and is influenced by several factors, including load, lubrication, sliding speed, and material properties (Wahid, 2013).

According to data from the Central Statistics Agency (2018–2022), the number of motorcycles in Indonesia increased markedly to approximately 148.2 million units-around 85% of total vehicles. This surge directly correlates with rising demand for lubricants, which play a critical role in reducing friction and maintaining machine performance (Yulianda, Maksum, & Fernandez, 2015). In industrial contexts, the service life of ball bearings strongly depends on material durability against wear (Vrček et al., 2020). Consequently, wear testing is essential for evaluating both material performance and lubricant effectiveness under realistic operating conditions (Rahman, 2012).

Previous studies have employed tribotesters to investigate the effects of material type, applied load, lubricant, and sliding speed (Vladescu et al., 2025). For example, Syafa'at et al. (2021) showed that abrasive wear dominates in hard-chrome-coated cast iron, while TS, Darmanto, and Syafa'at (2020) highlighted the pronounced effect of load on the wear behavior of ST70 steel. Similarly, Roziqin (2023) reported that SAE 140 produced lower wear than SAE 10W-40, and Prabowo (2022) emphasized the importance of lubricant viscosity in enhancing wear resistance. Collectively, these findings indicate that variations in lubricant type and operating parameters can substantially influence wear mechanisms.

Building on this background, the present study analyzes the wear behavior of ASTM 440C steel using a ball-on-disc tribometer, examining three lubricants SAE 10W-30, SAE 10W-40, and SAE 140 at rotational speeds of 180, 270, and 310 rpm.

The objective of this research are as follows (i) compare wear-track width, wear volume, and wear rate across lubricant–speed combinations; (ii) evaluate the influence of rotational speed on wear responses for each lubricant; and (iii) identify the lubricant that most effectively suppresses wear in ASTM 440C bearing applications.

II. METHOD

The study was conducted experimentally using a modified ball-on-disc tribometer adapted from a bench-top drill machine (Frantoni Aji et al., 2024). This low-cost, repurposed-equipment approach leveraging fundamental laboratory hardware to enable measurements that would otherwise require expensive instrumentation has been adopted by other researchers as well. For example, a related strategy added modular components to existing heat-transfer rigs to create affordable, instruction- and research-ready platforms (Alfian et al., 2024). The test material was ASTM 440C stainless steel, supplied as plates with an initial size of 600 × 40 × 3 mm. The chemical composition conformed to ASTM A276. Specimens were then sectioned to 60 × 40 × 3 mm using a mechanical saw to avoid heat-affected microstructural changes associated with thermal cutting.

Figure 1 ASTM 440C steel before cut and before ground

The specimen surfaces were prepared by sequential grinding using silicon-carbide abrasive papers with grits 240, 600, 1000, 1500, and 2000 to obtain a flat, smooth finish. This preparation ensured uniform initial conditions across specimens and minimized the influence of surface roughness on the wear-test outcomes.

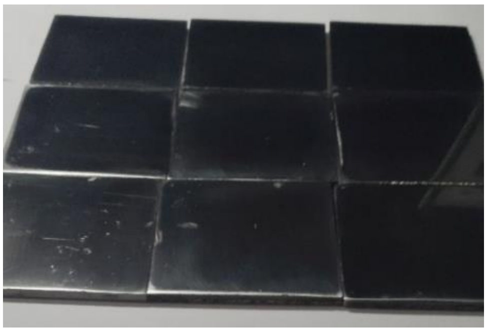

Figure 2 ASTM 440C steel after cut and after ground

As the lubrication medium, three oils were used; SAE 10W-30, SAE 10W-40, and SAE 140, applied directly to the contact zone to evaluate the effect of lubricant viscosity on wear behavior (Reeves et al., 2021; Szpunar et al., 2021; Kumar & Kumar, 2023). The counterface was an 8 mm-diameter chrome steel ball, serving as the mating partner in the sliding contact.

Prior to testing, the normal load calibration on the tribometer spindle was verified with a digital scale using a constant applied mass of 1.5 kg. Rotational speed was varied at 180, 270, and 310 rpm, while the test duration was held constant at 600 s. After each run, wear scars were examined using a trinocular metallurgical microscope at 20×-50× magnification to measure wear-track width. Wear volume and wear rate were then calculated according to ASTM G99-17 procedures.

Test equipment used includes :

1. Ball-on-disc tribometer results modification machine drill, as tool main testing wear and tear.

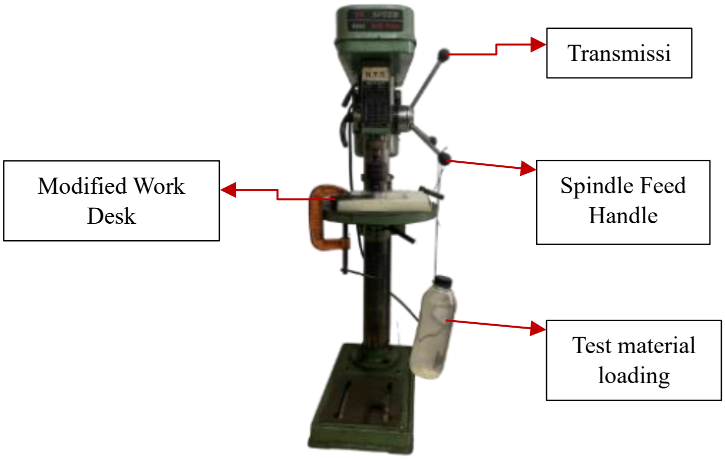

Figure 3. HTS drill machine (ZJQ4116) modified into a ball-on-disc tribomete

2. Optical microscope (trinocular metallurgical) for measuring wear-track width and examining wear morphology (typical magnification: 20×-50×).

Figure 4 Trinocular Metallurgical Microscope.

3. Digital scale for calibrating the applied load on the tribometer spindle.

   Experimental procedure. ASTM 440C steel specimens and chrome steel balls were first prepared as described, then the selected lubricant was introduced into the specimen receptacle according to the test matrix. The rig was operated at rotational speeds of 180, 270, and 310 rpm under a constant normal load of 1.5 kg applied to the spindle. Each run was conducted for 600 s for every lubricant-speed combination. The resulting datasets enable direct comparison of wear responses and assessment of how lubricant type and rotational speed influence the tribological performance.

III. RESULTS AND DISCUSSION

Before testing, the specimens were surface-finished by sequential grinding with silicon-carbide papers of grit 240, 600, 1000, 1500, and 2000 until a smooth, contaminant-free surface was obtained. The specimens were then tested on a simple, modified ball-on-disc tribometer. All wear tests were performed at the Fabrication Workshop Laboratory and the Materials Engineering Laboratory, Institut Teknologi Sumatera (ITERA). Figure 5 shows the wear-track width measurements acquired using a trinocular metallurgical optical microscope at the ITERA Materials Engineering Laboratory, with a 2× objective and a 10× eyepiece (total magnification 20×).

Wear-track width tests on ASTM 440C steel using SAE 10W-30, SAE 10W-40, and SAE 140 lubricants were conducted at 180 rpm, 270 rpm, and 310 rpm. The results indicate a pronounced combined effect of rotational speed and lubricant type on wear-track width. In general, higher-viscosity lubricants afforded better protection at medium to high speeds, whereas lower-viscosity oils tended to produce larger wear values under low-speed conditions (Berglund et al., 2021; Boidi et al., 2021).

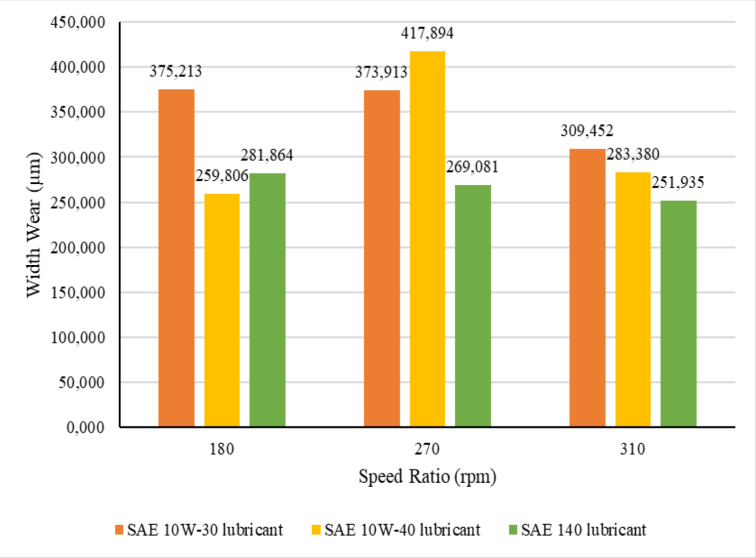

Figure 5. Wear Width Comparison SAE 10W- 30, SAE 10W-40 and SAE 140 lubricants

For the SAE 10W-30 lubricant, the average wear-track width decreased with increasing rotational speed: the highest value, 375.21 µm, occurred at 180 rpm, while the lowest, 309.45 µm, was observed at 310 rpm. This trend suggests that at low speed the lubricant film is not fully developed, so boundary lubrication dominates and metal–metal contact increases. At higher speed, the lubricant is entrained more effectively, promoting hydrodynamic film formation and reducing friction, in accordance with the Stribeck curve transition from boundary to hydrodynamic regimes (Londa et al., 2023).

In contrast, SAE 10W-40 displayed a non-monotonic response: wear was relatively low at 180 rpm (259.81 µm), spiked at 270 rpm (417.89 µm), and then declined at 310 rpm (283.38 µm). The mid-speed spike likely reflects partial film failure in the mixed/boundary region during the speed-transition phase, consistent with reports that SAE 10W-40 can be less stable under transitional kinematics (Surawan & Mulyadi, 2019).

Meanwhile, SAE 140 exhibited the most stable performance, with wear width decreasing from 281.86 µm (180 rpm) to 251.93 µm (310 rpm). The higher viscosity aids robust film formation across the tested speeds, while a hydrodynamic wedge at higher entrainment speeds further strengthens the load-bearing capacity of the lubricant layer. These observations align with findings that SAE 140 can maintain film stability and reduce friction at elevated speeds (Roziqin, 2023; Farfan-Cabrera et al., 2023).

Overall, the results indicate that SAE 140 achieved the lowest and most stable wear widths, SAE 10W-40 ranked second but showed instability at medium speed, and SAE 10W-30 improved with speed yet still produced comparatively higher wear at low speed.

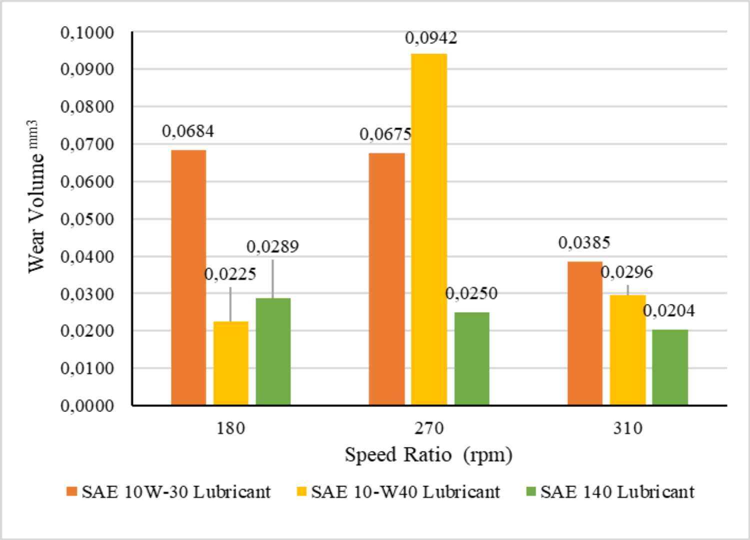

Figure 6. Wear volume of SAE 10W-30, SAE 10W-40, and SAE 140 lubricants

In Figure 6, the wear volume (V) is computed from the specimen's wear-track geometry. Specifically, the track length is taken as *2πR* (with *R* the wear-track radius), and the cross-sectional area of the track is obtained from the spherical geometry defined by the ball radius *r* and the measured wear-scar diameter *d*. Thus, *V* is the product of *2πR* and the cross-sectional area derived from *r* and *d*, following Equation (1) used in ASTM G99-17 and related literature (ASTM G99-17, 2020; Chipise et al., 2021).

$$\mathrm{DVL} = 2\pi \mathrm{R}\left[\mathrm{r}^2 \sin^{-1}\left(\frac{\mathrm{d}}{2\mathrm{r}}\right) - \left(\frac{\mathrm{d}}{4}\right)(4\mathrm{r}^2 - \mathrm{d}^2)^{\frac{1}{2}}\right] \tag{1}$$

Wear volume is a key indicator for quantifying the amount of material lost due to sliding friction. The results show that lubricant type and rotational speed strongly affect the wear volume. At 180 rpm, the highest wear volume was observed with SAE 10W-30 (0.0684 mm³), while the lowest occurred with SAE 140 (0.0385 mm³). This confirms that the lower viscosity of SAE 10W-30 is insufficient to form a stable protective film at low speed; as a result, boundary lubrication dominates and direct asperity contact increases material removal.

At the medium speed (270 rpm), the highest wear volume was recorded for SAE 10W-40 (0.09425 mm³), whereas the lowest was found for SAE 10W-30 (0.0225 mm³). The sharp increase for SAE 10W-40 suggests lubrication instability in the mixed/boundary regime, consistent with partial film breakdown during speed transition (Lu-Minh et al., 2022; Michelberger et al., 2021). At the high speed (310 rpm), the pattern shifts again: the highest wear volume appeared with SAE 10W-30 (0.0288 mm³), and the lowest with SAE 140 (0.0248 mm³). These outcomes indicate that at elevated speed, the higher viscosity of SAE 140 better sustains hydrodynamic film formation and load-carrying capacity (hydrodynamic "wedge" effect), thereby reducing real area of contact and wear.

Overall, these results align with prior studies showing that wear volume can increase cumulatively during running-in when the lubricating film is not yet fully developed (Gasni & Napitupulu, 2019) and that increasing speed can accelerate material loss, particularly with low-viscosity oils (Yustar Afif et al., 2024). Accordingly, SAE 140 proves more effective in maintaining stable, low wear volumes across the tested conditions than the other lubricants.

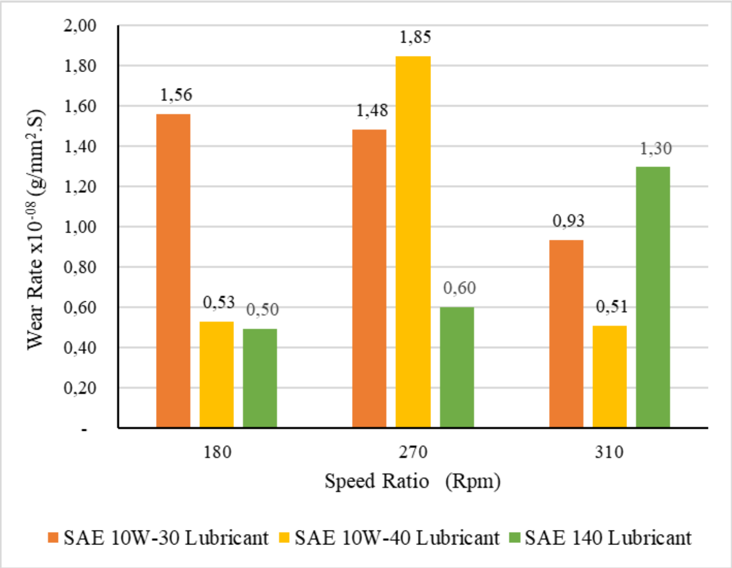

Figure 7 Comparison of wear rate for SAE 10W-30, SAE 10W-40, and SAE 140 lubricants.

In Figure 7, the wear rate is computed as the mass of material lost divided by the contact area and test time. The mass loss is obtained from the product of the material density *(ρ)* and the wear volume *(V)*. The contact area *(A)* is the annular area of the wear track, given by the difference between the outer and inner circle areas. Accordingly, Equation (2) can be written as:

$$W = \frac{\rho \times V_{wear}}{(A_{outer} - A_{inner}) \times t}\left(\frac{g}{mm^2}.s\right) \qquad (2)$$

Wear rate quantifies the rate of material loss per unit time and contact area. The results show a fluctuating pattern across the three lubricants, governed by the combined effects of rotational speed and lubricant viscosity. At 180 rpm, the highest wear rate was recorded with SAE 10W-30 (1.56×10^{-8} $g \cdot mm^{-2} \cdot s^{-1}$), whereas the lowest occurred with SAE 140 (0.50×10^{-8} $g \cdot mm^{-2} \cdot s^{-1}$). Under these low-speed conditions, SAE 140 can form a protective film, while SAE 10W-30 does not establish a sufficiently stable film, leading to increased asperity contact in the boundary regime.

At the medium speed (270 rpm), SAE 10W-40 exhibited the highest wear rate (1.85×10^{-8} $g \cdot mm^{-2} \cdot s^{-1}$), substantially higher than the other oils at the same speed. This mid-speed surge is indicative of partial film breakdown in the mixed/boundary region, consistent with the Stribeck transition behavior (Michelberger et al., 2021; Lu-Minh et al., 2022). At the high speed (310 rpm), the highest wear rate was observed for SAE 140 (1.30×10^{-8} $g \cdot mm^{-2} \cdot s^{-1}$). This outcome can arise from a hydrodynamic wedge condition in which the lubricant film becomes sufficiently thick to alter contact mechanics; depending on alignment and load distribution, such conditions can occasionally yield measurably higher wear rates than expected under ideal hydrodynamic lubrication.

These trends align with prior findings that wear rate can increase or decrease with changes in rotational speed and lubricant formulation (Fajar Ahmad Shobrowi et al., 2022; Cahyono et al., 2022), and that higher-viscosity oils such as SAE 140 generally produce lower specific wear under many conditions (Roziqin, 2023).

Overall, SAE 140 provided the most stable wear-rate performance across speeds, though isolated high-speed conditions can induce wedge-related effects; SAE 10W-30 improved with speed but was less effective at low speed, and SAE 10W-40 showed instability at medium speed, consistent with mixed-regime film failure (Nassef et al., 2024).

IV. CONCLUSION

Wear testing of ASTM 440C steel on a ball-on-disc tribometer with SAE 10W-30, SAE 10W-40, and SAE 140 lubricants at 180, 270, and 310 rpm shows that both lubricant grade and rotational speed significantly affect tribological performance. The low-viscosity SAE 10W-30 produced the highest average wear-track width (352.86 µm) and wear volume (0.0582 mm^3), with an average wear rate of 1.33×10^{-8} $g \cdot mm^{-2} \cdot s^{-1}$, indicating sub-optimal protection, particularly at high speed-due to an insufficiently thick film. SAE 10W-40 exhibited inconsistent behavior, peaking at 270 rpm with a wear width of 417.89 µm, wear volume of 0.0942 mm^3, and a maximum wear rate of 1.85×10^{-8} $g \cdot mm^{-2} \cdot s^{-1}$, consistent with transient film breakdown in the mixed/boundary regime. In contrast, SAE 140 delivered the most effective and stable performance, with an average wear width of 267.63 µm, wear volume of 0.0248 mm^3, and the lowest wear rate of 0.80×10^{-8} $g \cdot mm^{-2} \cdot s^{-1}$ across the tested conditions. In general, higher-viscosity oils form more stable load-bearing films and better suppress wear—especially at elevated speeds. Accordingly, SAE 140 is recommended for high-speed, heavy-duty applications within the bounds of the tested loads/speeds, whereas SAE 10W-40 is more appropriate for low- to medium-speed operation.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of the Institut Teknologi Sumatera laboratories, whose facilities and assistance made this research possible.

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