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COMPARATIVE TRIBOLOGICAL ANALYSIS OF NEW AND USED DIESEL ENGINE OILS

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Abstract: *This study investigates the tribological behaviour of aluminium samples lubricated with new and used SAE 10W-40 and SAE 30 engine oils under controlled laboratory conditions. Tribological testing was performed using a block-on-disc configuration on a TPD-95 tribometer, following ASTM G77 standards. All tests were conducted at a sliding speed of 0.5 m/s, an applied load of 20 daN, and a test duration of 600 seconds, with continuous lubrication provided. Results show that, for both oil types, the used oils exhibited a lower coefficient of friction compared to the new oils throughout the entire sliding distance. In the case of SAE 10W-40, used oil led to both reduced friction and significantly lower material loss, while in the SAE 30 group, despite lower friction, the used oil resulted in a slightly larger wear scar and increased worn volume compared to the new oil. These findings suggest that oil degradation products can temporarily enhance lubrication performance but may compromise long-term wear protection.*

Keywords: *aluminium alloys, engine oils, tribological behaviour, wear analysis, oil degradation*

1. INTRODUCTION

Aluminium is increasingly being used in the construction of internal combustion engines, particularly in the production of sliding bearings, pistons, and connecting rods, due to its low specific weight, corrosion resistance, good thermal conductivity, recyclability, and contribution to improved fuel efficiency. However, its mechanical properties—especially its limited wear resistance—require special attention with regard to surface protection, where the quality of engine oil plays a crucial role [1].

The quality of engine oil has a significant and multifaceted impact on the wear of aluminium surfaces. Wear is one of the primary mechanisms of material degradation in engine blocks, and several factors contribute to this process: the presence of hard particles and chemicals in cooling and lubricating fluids causes abrasive and corrosive wear; the impact of hot air and gases leads to erosive wear; friction between the cylinder wall and piston rings can induce adhesion even in the presence of oil; and material fatigue also plays a considerable role. High-quality engine oils reduce friction, ensure optimal viscosity, and contain additives that protect aluminium components from wear and corrosion [2, 3].

Engine oil plays a multifaceted role in maintaining engine functionality. It forms a thin lubricating film between metal components, reducing direct contact and friction, which directly decreases wear and extends engine lifespan. SAE30 oil is a traditional, single-grade lubricant designed for stable and warm operating conditions, whereas 10W-40 is a multigrade product that offers a significantly broader temperature range and improved engine protection under various conditions, including cold starts and heavy engine loads [4].

During operation, engine oil naturally undergoes degradation as it is exposed to high temperatures, pressures, and the chemical effects of fuel combustion. Throughout this process, the oil changes colour, loses clarity, darkens, and develops an unpleasant odour—these being the initial indicators of oil aging and contamination. Changes in kinematic viscosity are particularly critical. Reduced viscosity leads to a drop in oil pressure and results in increased friction, thereby accelerating the wear of piston rings, bearings, and other vital engine components. On the other hand, excessively high viscosity impairs oil circulation and hinders the proper formation of the lubricating film at frictional contact points [5–7].

The recycling of engine oils plays a key role in the sustainable use of resources, environmental protection, and the mitigation of ecological problems caused by toxic substances present in used oils. The main challenge in recycling SAE30 and SAE10W-40 engine oils lies in their complex chemical structure and the contamination that occurs during use. These oils contain additives and chemicals that undergo reactions during engine operation, producing harmful by-products that require specialized processes for their removal [8]. In their study, Hisham et al. investigated a mixture of waste cooking oil and SAE 10W-40, aiming to reduce wear and friction on the aluminium piston skirt. They concluded that increasing the concentration of waste cooking oil reduces the viscosity of the bio-lubricant, which leads to increased friction, likely due to corrosive wear [9].

Given the complexity of oil degradation processes and their impact on tribological performance, the present study focuses on a comparative analysis of the wear behaviour of aluminium samples lubricated with new and used SAE 10W-40 and SAE 30 engine oils under standardized laboratory conditions.

2. MATERIALS AND METHOD

This study examined two types of commercial motor oils for their tribological potential during the experiment. The tested oils were SAE 10W-40 and SAE 30. Table 1 presents the main characteristics of all motor oils used for experimental testing in this study.

Table 1. Physicochemical Properties of SAE 10W-40 and SAE 30 Motor Oils

Property	SAE 10W-40	SAE 30
Viscosity Index	155	95
Density (g/ml @ 15.6°C, ASTM D4052)	0.86	0.88
Flash Point (°C, ASTM D93)	212	210
Pour Point (°C, ASTM D97)	-45	-30

Experimental testing was conducted using the TPD-95 tribometer, which is equipped with computer-controlled precision to maintain consistent and repeatable test conditions. The testing procedure followed the ASTM G77 standard, which outlines methods for assessing the wear characteristics of materials. The tribometer operates based on a block-on-disc configuration, where a stationary block is pressed against a rotating disc under a defined load. This setup effectively replicates practical friction and wear scenarios. It enables precise evaluation of tribological parameters such as wear rate and coefficient of friction, thereby providing dependable data for analysing material behaviour under sliding contact. The disc is made of EN 25CrMo4 steel, featuring a hardness of 60–64 HRC and ground surface finish, while all test blocks are made of EN AW-

6060 aluminium alloy. The disc has a diameter of 35 mm, and the block dimensions are 15 × 10 × 6.35 mm, in accordance with ASTM G77 standards.

Prior to testing, all aluminium blocks were subjected to a standardized surface preparation process to ensure uniform initial conditions. Each block was ground sequentially on all sides using a mechanical grinder. The grinding procedure was performed at a rotational speed of 500 revolutions per minute, with each side being ground for a duration of 1 minute. To achieve a progressively finer surface finish and minimize surface roughness, the following grades of silicon carbide abrasive papers were used in succession: P600, P1200, and P2000. This preparation ensured consistent surface conditions across all samples, which is critical for the reliability and repeatability of tribological testing.

All tribological tests were conducted under identical operating conditions to ensure the comparability and repeatability of results. The applied normal load was set to 20 daN, while the sliding speed was maintained at 0.5 m/s. Each test was performed over a total sliding duration of 600 seconds, corresponding to a well-defined sliding distance. Continuous lubrication was provided throughout the testing process via a reservoir system with a total capacity of 30 ml, ensuring a stable supply of lubricant to the contact interface. Accordingly, four distinct test groups were defined and labeled as follows:

1. **Al-10W-40-N** sample test: This group represents aluminium samples tested using new SAE 10W-40 multigrade engine oil. The oil was unused prior to the experiment, providing a baseline for evaluating the tribological performance of fresh lubricant under defined test conditions.
2. **Al-10W-40-U** sample test: In this group, aluminium samples were tested using used SAE 10W-40 oil, collected after extended service. The aim was to assess the effect of oil degradation and contamination on friction and wear characteristics.
3. **Al-SAE30-N** sample test: This group involved testing aluminium samples with new SAE 30 monograde oil. As with the first group, the oil was in its original, uncontaminated state, allowing for a controlled evaluation of tribological properties.
4. **Al-SAE30-U** sample test: This group consisted of tests performed using used SAE 30 oil, previously employed in engine operation. The test was intended to simulate real-world conditions in which the lubricant has undergone thermal and mechanical degradation.

The volume of the worn material was calculated using the following expression:

$$V = \left(\frac{306.25}{2} \cdot 2arcsin\left(\frac{b}{35}\right) - \frac{\sqrt{306.25 - \frac{b^2}{4}} \cdot b}{2} \right) \cdot 6.35 \quad (1)$$

where:
b – width of the wear mark
306.25 – square of the disc's radius
6.35 – width of the block in mm.

This formula accounts for the geometric characteristics of the block-on-disc contact and is based on the analytical calculation of the worn area profile. Specifically, it first determines the cross-sectional area of the wear scar generated by the curved contact surface between the block and the disc, treating the disc as part of a circular arc. Multiplying this cross-sectional area by the known width of the block (6.35 mm) yields the volume of material lost due to wear.

The arcsine function captures the curvature effect of the disc in the contact zone, while the second term corrects for the material removed outside the direct contact area, ensuring a precise estimation of volumetric wear. This approach provides a more accurate evaluation compared to simple approximations, particularly when the wear scar spans a significant portion of the disc's surface.

3. RESULTS AND DISCUSSION

Figure 1 presents the coefficient of friction (μ) as a function of sliding distance (s) for aluminium samples lubricated with new and used SAE 10W-40 engine oil. Each curve represents the average trend from three individual measurements conducted under identical tribological conditions.

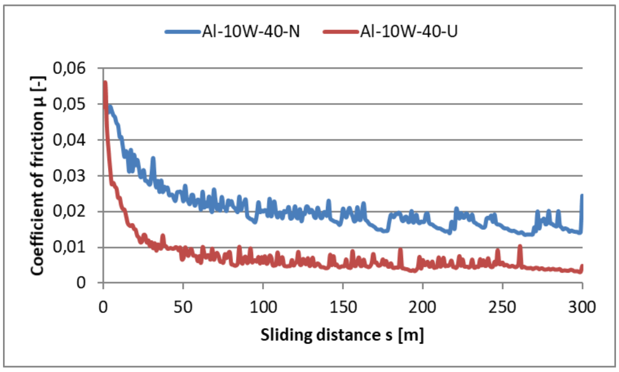

Figure 1. Coefficient of friction as a function of sliding distance for Al-10W-40-N and Al-10W-40-U samples

The Al-10W-40-N sample (blue curve) demonstrates an initially high coefficient of friction, which rapidly decreases during the running-in phase and stabilizes around a value of approximately 0.02–0.025. In contrast, the Al-10W-40-U sample (red curve), lubricated with used oil, exhibits significantly lower friction values throughout the entire test, stabilizing below 0.01 after the initial sliding distance. Both curves show small oscillations, but the used oil consistently yields lower friction levels compared to the new oil.

Notably, the used oil (Al-10W-40-U) exhibited a consistently lower coefficient of friction compared to the new oil (Al-10W-40-N) across the entire sliding distance. This trend may initially seem counterintuitive, as new oil is generally expected to provide superior lubrication due to the full presence of additive packages and stable viscosity. It is important to note that the present investigation represents preliminary research conducted under controlled laboratory conditions, at temperatures lower than typical engine operating temperatures. As such, the tribological behaviour observed for the used oil at these conditions may not necessarily reflect its performance at elevated, real-world temperatures. Further testing under operational thermal loads is required to validate whether the same frictional trends persist in actual service conditions.

Figure 2 shows the variation of the coefficient of friction as a function of sliding distance for aluminium samples lubricated with new and used SAE 30 monograde oil (Al-SAE30-N and Al-SAE30-U, respectively).

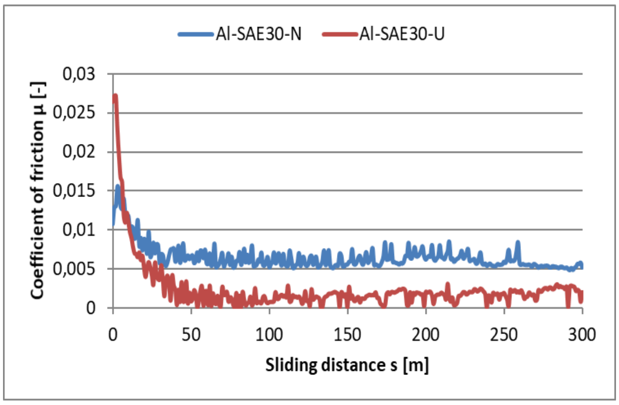

Figure 2. Coefficient of friction as a function of sliding distance for Al-SAE30-N and Al-SAE30-U samples

Similar to the trends observed with SAE 10W-40, the used oil again resulted in a lower friction coefficient throughout the test duration. The Al-SAE30-N sample displayed an initial peak followed by a steady-state friction coefficient around 0.006–0.007, while the Al-SAE30-U sample stabilized below 0.004. Each curve represents the average behaviour recorded across three repeated measurements.

The results obtained for SAE 30 oils further reinforce the trend observed with multigrade SAE 10W-40 oil, where the used lubricant consistently produced a lower coefficient of friction. In the case of SAE 30, which inherently lacks the viscosity modifiers present in multigrade oils, the difference in friction between new and used conditions appears even more pronounced in the steady-state region.

It should be emphasized that this study is part of an initial investigation carried out at ambient temperatures. While the results suggest that used oil may offer lower friction in controlled environments, such behaviour may not be maintained under real engine operating conditions. Additional testing at elevated temperatures and in the presence of thermal cycling is necessary to assess the full tribological implications of oil degradation.

The average width of the wear scar (in mm) was measured for each test group and is presented below:

1. Al-10W-40-N sample test: 2.643 mm
2. Al-10W-40-U sample test: 2.000 mm
3. Al-SAE 30-N sample test: 1.429 mm
4. Al-SAE 30-U sample test: 1.616 mm

The measured wear scar widths provide additional insight into the wear mechanisms involved in the tribological contact. For both oil types, the used oils not only exhibited lower friction coefficients but also resulted in narrower wear scars, with the exception of SAE 30, where the used oil produced a slightly wider scar than the new oil.

The Al-10W-40-U sample demonstrated a reduction in wear scar width of approximately 24% compared to the new oil, indicating that the aged oil maintained sufficient lubricating capacity to reduce material removal. This is consistent with the observed lower coefficient of friction and may be attributed to the formation of boundary films composed of oxidation and degradation products that offer partial surface protection.

On the other hand, the Al-SAE 30-U sample showed a slightly increased wear scar width relative to the new SAE 30 oil, despite its lower friction. This discrepancy suggests that while used SAE 30 oil may reduce friction due to altered viscosity or surface-active degradation by-products, its diminished additive content may fail to prevent wear progression effectively. This highlights the complex and sometimes non-linear relationship between friction and wear, where reduced friction does not always guarantee improved wear resistance.

Figure 3 presents the comparison of worn material volumes for all tested aluminium samples lubricated with new and used SAE 10W-40 and SAE 30 engine oils. The Al-10W-40-N sample exhibited the highest worn volume, reaching approximately 0.559 mm³, whereas the Al-10W-40-U sample showed a significant reduction, with a worn volume of 0.242 mm³.
In the case of SAE 30 oils, the new oil (Al-SAE30-N) resulted in the lowest recorded worn volume of 0.088 mm³, while the used oil (Al-SAE30-U) showed a slightly higher worn volume of 0.128 mm³.

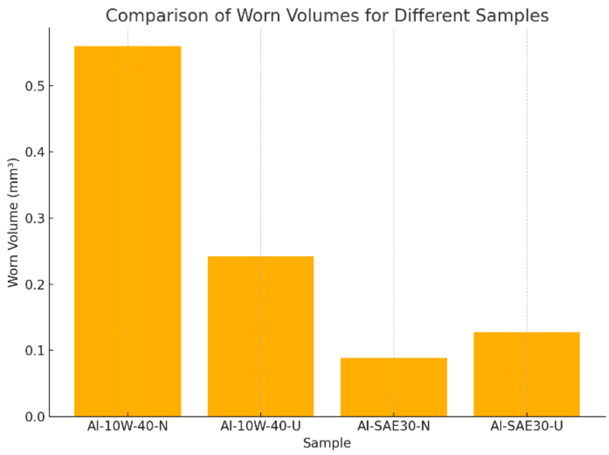

Figure 3. Comparison of worn volumes for Al-10W-40-N, Al-10W-40-U, Al-SAE30-N, and Al-SAE30-U samples

The analysis of worn volumes provides important insights that complement the friction measurements. For the SAE 10W-40 oil group, the used oil not only produced a lower coefficient of friction but also substantially reduced material loss, indicating that under the given test conditions, degraded oil maintained a protective boundary layer that effectively minimized wear.

In contrast, for the SAE 30 oil group, although the used oil exhibited a slightly lower friction coefficient, the worn volume increased compared to the new oil. This suggests that in the case of SAE 30, degradation processes during service may have led to insufficient replenishment of protective additives, resulting in less effective wear resistance despite the reduced friction.

These findings confirm that friction reduction alone cannot be considered a sufficient indicator of lubricant performance. The complex interplay between viscosity, chemical composition, and surface interactions must be taken into account to fully understand the behaviour of new and used oils under tribological loading.

4. CONCLUSION

The tribological performance of new and used SAE 10W-40 and SAE 30 engine oils was evaluated under identical test conditions using a block-on-disc tribometer. In both oil categories, the used oils demonstrated a consistently lower coefficient of friction compared to their new counterparts. This trend was evident across the entire sliding distance and observed in all three repeated measurements per group.

The reduced friction in used oils may be attributed to the presence of degradation products and polar compounds formed during service, which can act as surface-active agents and temporarily enhance lubricity. However, this apparent advantage must be interpreted with caution, as it does not necessarily correlate with superior overall performance or wear protection. The depletion of critical additives in used oils can increase the risk of corrosive or abrasive wear mechanisms, particularly under elevated temperatures and dynamic operating conditions.

The complex relationship between friction and wear: a lower coefficient of friction does not inherently guarantee superior anti-wear performance. The chemical stability, additive retention, and viscosity behaviour of the lubricant are critical factors that must be evaluated alongside friction measurements to obtain a complete understanding of its tribological effectiveness.

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