FOUR BALL TEST: RELEVANCE OF A 100-YEAR-OLD METHOD FOR MODERN LUBRICANTS

Lubricants and their requirements

At its core, a lubricant's purpose is simple: reduce friction and wear between moving surfaces. It forms a protective film that prevents direct metal-to-metal contact, lowers operating temperatures, resists corrosion, and helps flush out contaminants. This basic role hasn't changed for centuries, but how lubricants achieve it has evolved remarkably (Figure 1).

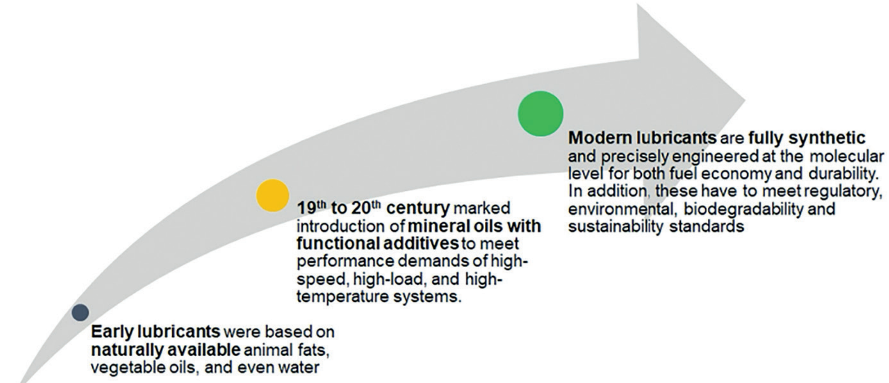


Figure 1. Timeline of lubricant evolution from naturally available animal fats to mineral oil with additives and currently, modern synthetics lubricants that are engineered at molecular level

Modern lubricants are the result of complex formulation engineering, balancing base oils, thickeners and performance additives for desired performance. Lubricants, oil-based, are formulated from base oils and additives. The grease-based counterparts have thickeners, in addition to base oil and additives. Base oils typically make up 70–90% of a lubricant and determine its fundamental properties, such as viscosity and thermal stability. According to the American Petroleum Institute (API), base oils are categorized into five groups Group I (mineral oils) to Group V (esters, synthetics). Additives, which typically account for 10–25% of the formulation, enhance or modify base oil performance to meet specific requirements. Common additive categories include anti-wear agents, detergents, dispersants, antioxidants, viscosity index improvers and friction modifiers. Additives can be categorized as surface-active and bulk-active depending on their interaction (Table 1)

Table 1. Different categories of lubricant additives and their function's

Additives In Lubricant	
Surface-active	**Bulk-active**
Chemically react or physically adsorb onto metal surfaces under boundary lubrication conditions	These additives work within the oil itself, modifying the physical or chemical properties of the lubricant as a whole, not by interacting with surfaces.
1. Friction modifiers - Reduce friction by forming molecular films (e.g., molybdenum compounds, fatty acids).	1. Viscosity Index Improvers – Help oil maintain viscosity over wide temperature ranges (e.g., - PMA, polymethacrylates)
2. Anti-Wear additives – react with surfaces to form a protective layer (e.g., ZDDP – zinc dialkyldithiophosphate).	2. Antioxidants – Prevent oil oxidation, thickening and sludge formation (e.g., phenolic and amine based).
3. Extreme Pressure (EP) Additives – Form sacrificial films under high load and temperature (e.g., sulphur-phosphorus compounds).	3. Corrosion Inhibitors – Protect against chemical degradation of ferrous and non-ferrous surfaces (e.g., calcium sulfonate)
	4. Detergents & Dispersants – Keep engines clean by suspending contaminants
	5. Anti-foam Agents: Reduce the formation of foam, which can interfere with lubrication (e.g., organic based fatty acid esters)

Such lubricants are designed not only for compatibility with materials and operating conditions but also to meet regulatory, environmental and sustainability standards. With greater complexity comes a greater need for reliable, repeatable testing.

Tribological testing provides quantifiable insights into how a lubricant performs under various conditions in terms of friction, load, motion, and temperature. Among the different standardized tests, four ball is considered the workhorse of any lubricant lab. Four ball test can be conducted over a wide range of conditions with loads from 5 to 1000 kg, speeds from 10's of rpm to 1000's of rpm, elevated temperatures and additional modules (e.g., KRL) to investigate the entire Stribeck curve and understand impact of base oil and additives on different performance metrics (Figure 2).

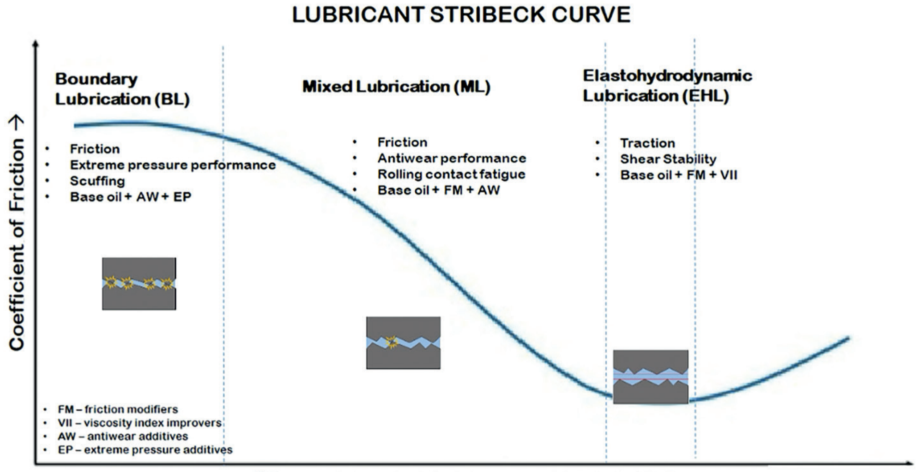


Figure 2. Stribeck curve showing different regimes of lubrication, the required properties corresponding to the regime and components of lubricants that influence performance in each regime. Base oil, FM and VII influence the EHL response and shear stability, base oil, FM and AW additives influence mixed lubrication characteristics

Four-ball testing remains one of the most widely used methods for assessing lubricants. Its ability to replicate severe point-contact conditions makes it indispensable for evaluating load-carrying capacity, wear resistance, and friction behaviour for all lubricants. This article provides a structured overview – from lubricant fundamentals to understanding four ball test methods and using such methods to interpret lubricant performance.

Introduction to Four-Ball Test

Four Ball Tester (FBT) was first introduced in 1933 by Gerrit Daniel Boerlage for the purpose of studying the behavior of lubricants under extreme pressure. As its name suggests, the tribometer is built around four steel balls that are the specimens used for testing the lubricants. Since its invention almost 90 years ago, the basic design and principle of operation have not changed. Three balls, stationary, are clamped inside a lubricant cup, filled with the lubricant under investigation (Figure 3a). The fourth ball is clamped in a holder (chuck or collet), loaded against the bottom balls and rotated at high speed, according under prescribed test protocols. The instrument is at the heart of numerous standards that have been developed across organizations such as ASTM, CEC, DIN, ISO and IP. A representative setup in a modern day four ball tester is shown in Figure 3b

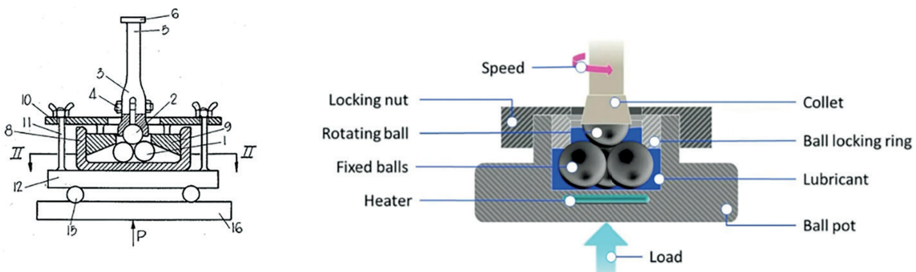


Figure 3a. Drawing from the original 4-ball tester patent (1934) Figure 3b. Different components of the four ball setup

The arrangement forms a self-aligning tetrahedron offering a simple and repeatable contact configuration (Figure 4)

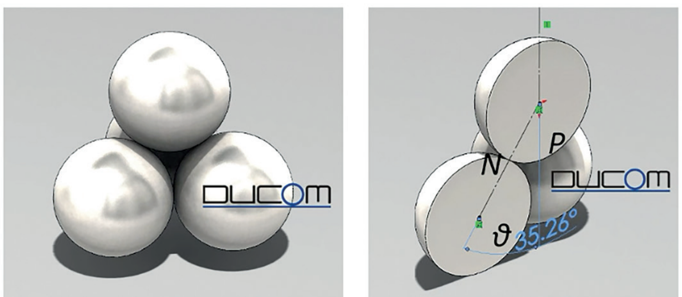


Figure 4. Four ball test configuration showing the tetrahedral geometry and off-axis loading between any ball pair

In the early days, friction was measured by means of a pivoted arm with a counterweight and a pointer connected to a pen, that would draw a friction graph on a rotating drum (Figure 5a). Today's advanced systems use precision sensors with patented technologies (Figure 5b) that offer accurate lubricant friction at the extremes, i.e., coefficient of friction, CoF as low as 0.03 (at loads as low as 5 kg) to CoF as high as 0.5 (at loads as high as 1000 kg). Such innovations (Ref. 1) help in accurately testing modern engineered lubricants that aim to achieve low friction over the entire Stribeck regime.

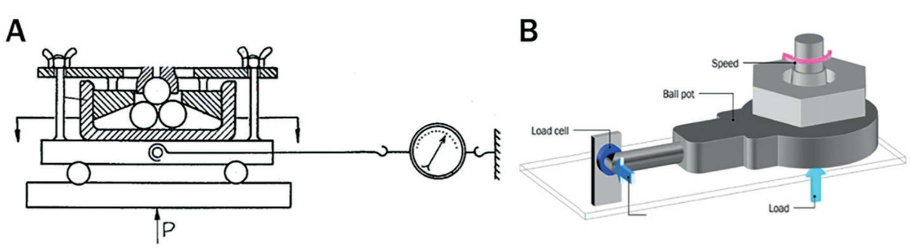


Figure 5A. Friction measurement in the original 1934 four ball tester Figure 5B. Friction torque measurement in a modern system, FBT-3

Lubricant Test Methods on Four Ball Configuration

The contact between the rotating ball and the three stationary balls simulates sliding contact between lubricated surfaces. There are different categories of tests depending on the objective:

- **Wear Preventive (WP) tests** (e.g., ASTM D2266, ASTM D4172, other ISO, DIN tests) assess the long-term wear under moderate loads.
- **Extreme Pressure (EP) tests** (i.e., ASTM D2783, D2596, other ISO, DIN tests) that determine lubricant's ability to withstand increasing loads without causing surface damage or seizure. This method simulates short-duration, high-load contact conditions until lubricant failure, so called Weld Load
- **Coefficient of friction (CoF) tests** (i.e., ASTM D5183) evaluates a lubricant's friction-reducing properties and its ability to prevent metal-to-metal contact under slow speed conditions compared to WP and WP tests. Test are conducted on an existing scar of defined size, with load increased in steps till incipient seizure with friction being measured continuously throughout the test.

Four ball is widely used within the lubricant industry in the early stages of formulation and development, benchmarking against similar lubricant categories and also quality assurance at production scale. (Table 2)

Table 2. Use of four ball testing within the lubricant industry

What Four-Ball testing is used for?	
1. Evaluating base oils	Oil lubricity evaluation, comparing different base oils at the same test conditions.
	Thermal and oxidative effects evaluation, to investigate on their degradation.
	Oil viscosity evaluation, to reveal the one which can guarantee better boundary lubrication under load.
2. Optimizing additive packages	Anti-wear and extreme pressure additives evaluation
	Friction modifiers such us molybdenum compounds, organics
	Additives synergy and/or antagonism: investigate on the interactions between different additives packages.
3. Guiding in lubricant selection and quality assurance	Benchmarking formulations against industry standards or competitor products.
	Application-oriented tailoring to identify for what a formulation is better suited.
	Cost-performance balance to meet both performance and cost targets.

Though the four ball test does not perfectly mimic every industrial system, it provides a standardized way to compare lubricants and detect changes in formulation or contamination. While other tribological methods exist, the four-ball test remains uniquely useful for benchmarking greases and oils against industry norms.

Wear Preventive vs. Extreme Pressure Test

Let's examine two most widely used test methods viz., wear preventive (WP) such as those described in ASTM D2266 (grease), ASTM D4172 (oils) and extreme pressure (EP) tests according to ASTM D2783 (oil), ASTM D2596 (grease). Table 4 summarizes and compares WP vs. EP test

Table 3. Comparing EP vs WP test methods

	WEAR PREVENTIVE TEST	EXTREME PRESSURE TEST
Standards	**ASTM D2266 / ASTM D4172**	**ASTM D2783 / ASTM D2596**
Overview of the method	In a WP test, the test is conducted under moderate loads at a prescribed temperature, speed and duration to assess lubricant's ability to minimize wear of sliding metal-to-metal contacts.	In an EP test, the test is conducted under gradually increasing loads at prescribed speeds, under ambient temperature and shorter durations. The load-carrying capability (anti-seizure) of the lubricants is assessed. Furthermore, the ability of a lubricant to minimize surface damage/wear under steadily increasing loads is estimated.
Conditions	• Load(s): 15kg (147N) & 40 kg (392 N) • Rotational speed: 1200 rpm • Duration: 60 minutes • Temperature: 75 °C	• Load is increased in steps as prescribed until welding occurs. • Rotational speed: 1760 rpm • Duration per load: 10 seconds • Temperature: ambient
Outputs	• Mean Wear Scar Diameter (MWSD), is the average diameter of six measurements (parallel and perpendicular to the wear striations) on the lower three balls without removing them from the ball pot.	• Weld point indicates the maximum load-carrying capacity of a lubricant before complete failure due to welding: it is the lowest applied load (in kilograms-force, kgf) at which the rotating ball in the Four-Ball EP tester welds to the stationary balls and causes extensive surface damage. • Load-wear index (LWI) is a calculated value that represents the overall load-carrying ability of the lubricant through a weighted average of the loads and corresponding wear scar sizes at each load step before welding. • Last non-seizure load (LSNL) is the highest applied load (in kgf) at which the balls in the Four-Ball tester do not seize and often used to define the starting point of lubricant failure (i.e., when MWSD > 5% of compensation line)
Other important outputs	• Though not prescribed in the standard, accurate measurement of friction is important to understand the interactions between anti-wear additives and friction modifiers	• Though not prescribed in the standard, accurate measurement of friction is important to understand the interactions between anti-wear additives and extreme-pressure additives. • Furthermore, accurate measurement of temperature change helps understand the the cooling capability of the lubricants under high contact pressures

The best lubricant based on the additive chemistry and concentration provides the lowest friction, lowest temperature change, lowest wear and the highest last non-seizure load and weld load.

Understanding Test Results - Applications

Four ball test results provide quantifiable insights into a lubricant's performance under defined conditions. While the raw numbers – such as wear scar diameter, weld point, and load-wear index – are valuable, their real power lies in contextual interpretation. While evaluating the results, these principles may guide the interpretation:

- Application relevance: For high-load applications (e.g., gears, heavy bearings), the weld point and LWI are often more critical. For high-duty-cycle environments, low wear scar diameters take priority.
- Additive impact: Differences in anti-wear AW) or EP additives will show up distinctly in these metrics.
- Test-to-test consistency: Always interpret results in the context of repeatability and standard deviation, especially when values are close

Here are several case studies using the EP and WP test methods

Case Study 1: Differentiating anti-wear and extreme-pressure additives using ASTM D2783 EP test

A mineral oil with two different additives, ZDDP-10% and Polysulfide-10% were mixed separately and tested as per ASTM D2783 to evaluate extreme pressure properties. The results are summarized in Figure 6. Polysulfide exhibits better EP properties with ~250% enhancement in the load wear index, last non-seizure load and weld load compared to ZDDP. Read the full article here (Ref.2)

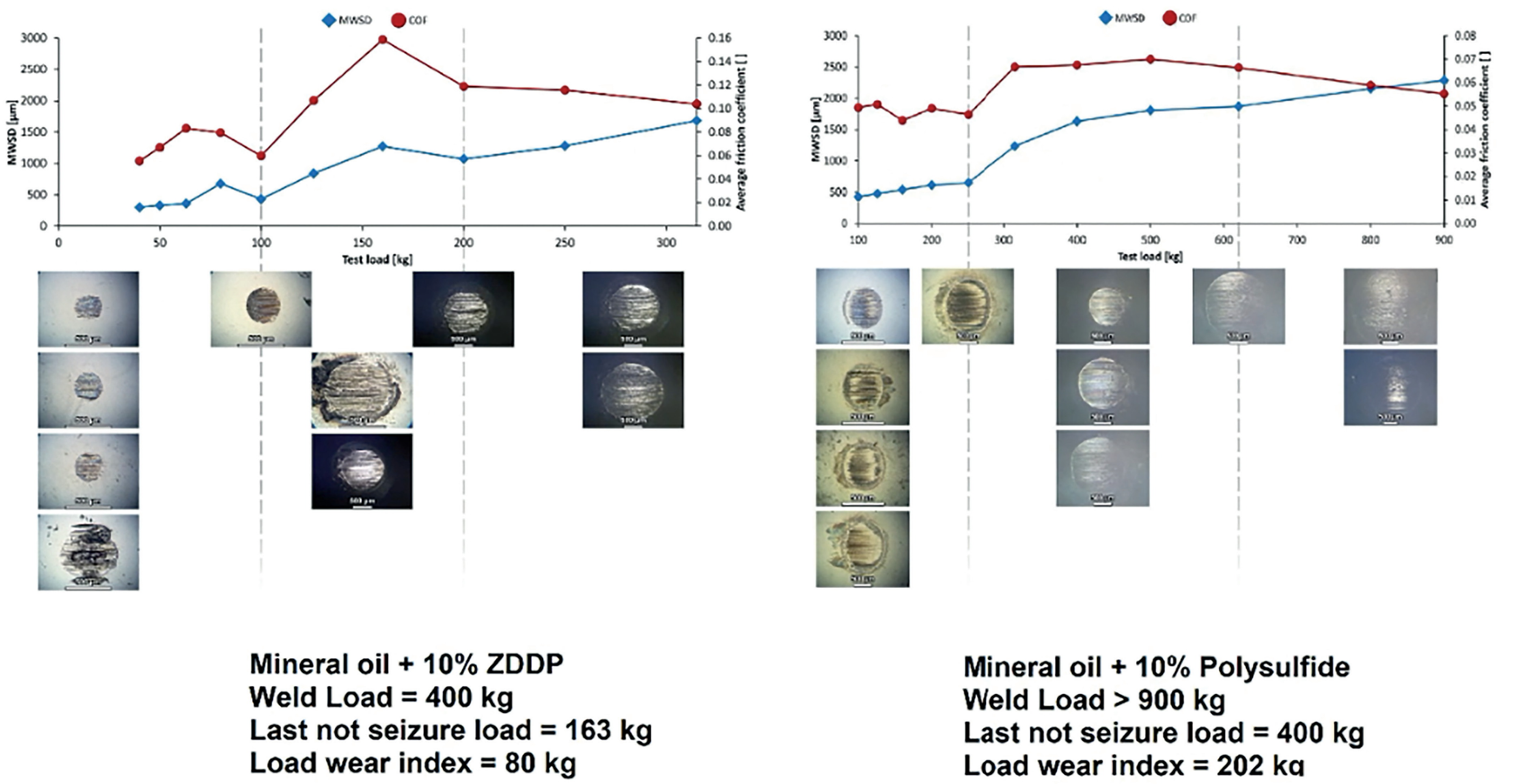
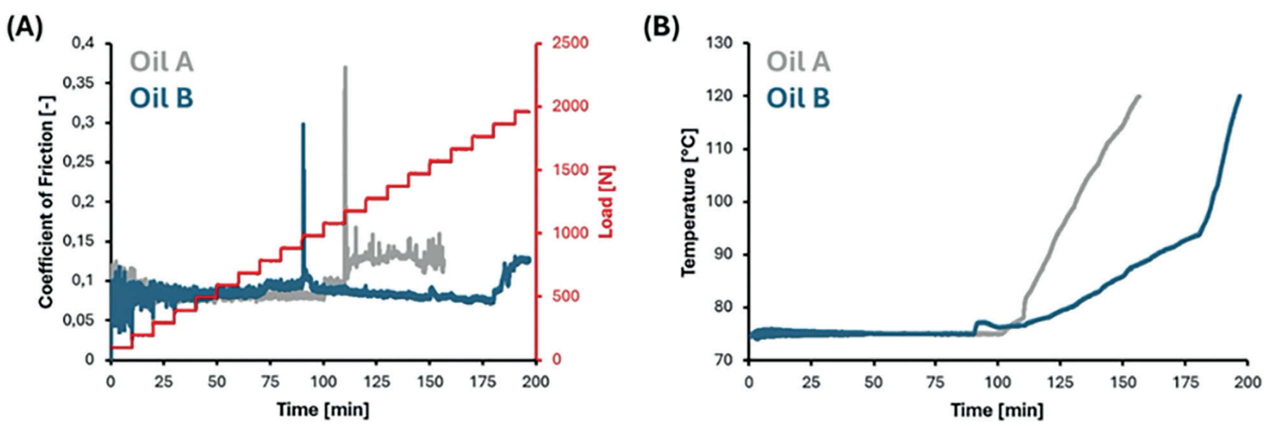


Figure 6. Comparing weld load, las non seizure load and load wear index of two different additives, ZDDP vs. Polysulfide using ASTM D2783 method



Case Study 2: Friction measurement of low viscosity compressor oils using ASTM D5183

In this study, two oil formulations with lower viscosities of 5.5 cSt were used, Oil A having anti-wear additives to naphthenic base oil and Oil B having anti-wear additives to paraffinic base oil. These were tested using ASTM D5183 method with a run-in phase followed by a test phase with increasing load till incipient seizure. Oil B exhibited the best overall performance in terms of lower friction coefficient, better temperature stability, higher incipient seizure load and smaller mean wear scar diameter (Figure 7a, 7b). Read the full article here (Ref. 3)

Summary

Four-Ball testing continues to be still relevant for modern energy efficient and durable lubricants. Advances in technology such as high precision friction force measurements, more responsive temperature sensors provide more accurate measurements into material-lubricant interactions Whether testing wear resistance, extreme pressure tolerance, or both, the method guarantees clear and standardized data to guide decisions in formulation, quality control and product benchmarking.

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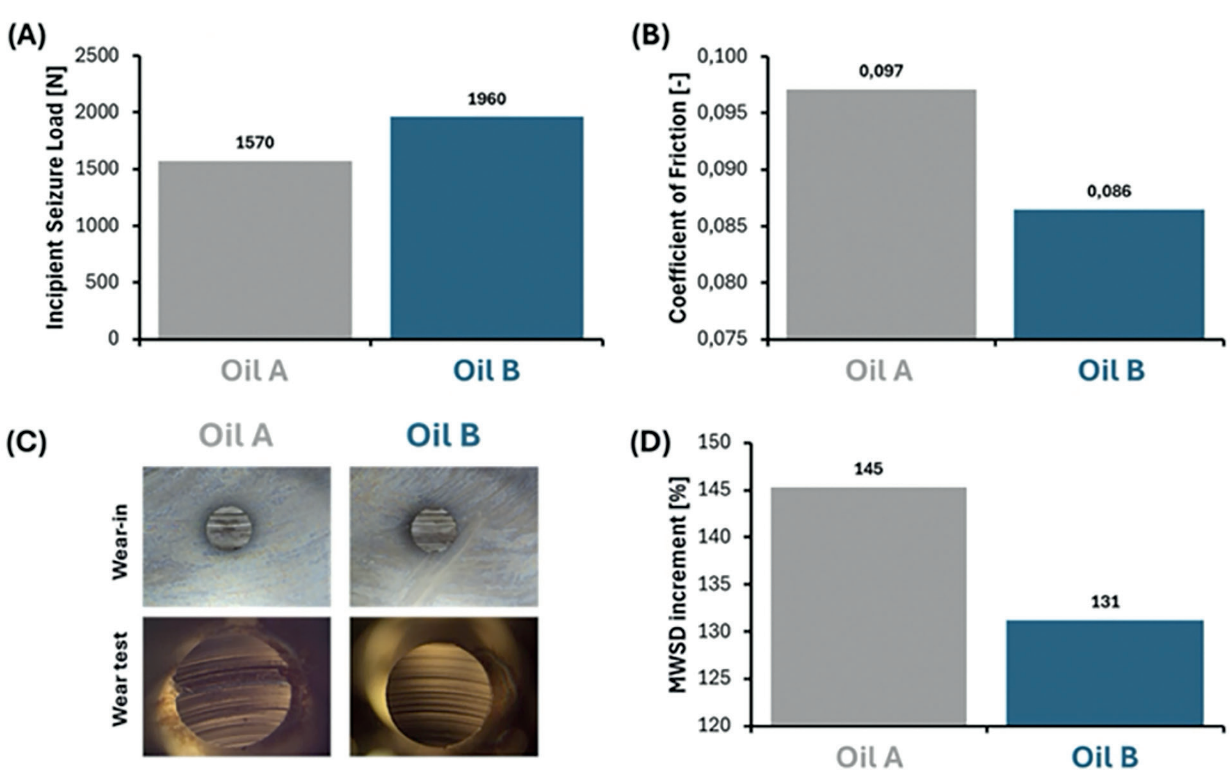

Figure 7b. Incipient seizure load (A), % increase in wear scar diameter (B), wear scar images (C) and % increment In terms of mean wear scar diameters (MWSD) (D) of the two oils as per ASTM D5183 method

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