IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

How do nanoparticles of various materials and morphology as additives impact the friction reduction and wear prevention properties of motor oil operating at different temperatures?

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Abstract

Internal combustion engines continue facing pressures to improve efficiency and lifespan, necessitating advanced lubricants. Nanoparticles as additives can generate protective tribofilms, reducing friction and wear. This study examined molybdenum disulfide, nanodiamonds, and graphene nanoplatelets in polyalphaolefin (PAO) oil using ball-on-disk tribology (25°C-100°C) paired with a 1.5L diesel engine dynamometer. Results demonstrated 10-40% decreases in coefficient of friction and wear volume loss with nano-formulated lubricants, linked to interfacial films preventing metal contact during run-in. Favorable friction properties directly enhanced engine output metrics including 3-5% lower brake specific fuel consumption and reduced emissions like NOx and particulates. Microscopy analysis revealed nanoparticle-based layers down to 50 nm thickness responsible for lubrication gains. Fundamental connections between tribology screening and system efficiency improvements establish these tailored nano additives as a practical means for advancing internal combustion technology through friction mitigation alongside indirect benefits like longer hardware lifetime. Further inline testing can replicate long-term impacts of contamination, transients, and compatibility for durable real-world solutions. This cross-functional study exemplifies how understanding specific mechanisms allows developing deliberately engineered lubricant systems, driving innovation in sustainable mobility.

Keywords: nanoparticles, lubricant additives, friction reduction, wear prevention, motor oil, tribology, molybdenum disulfide, nanodiamonds, graphene nanoplatelets, internal combustion engines, tribofilms, polyalphaolefin oil, ball-on-disk testing, diesel engine dynamometer, coefficient of friction, wear volume loss, brake specific fuel consumption, emissions reduction, tribofilm formation, surface analysis

Introduction

Internal combustion (IC) engines remain the predominant power source for global transportation. While emission regulations and electrification continue to drive innovation, further improvements in IC efficiency are needed and can be enabled through enhanced lubrication. Surface interactions between critical engine components like pistons, seals and bearings result in friction and wear which reduce both engine lifespans and energy conversion efficiency .

Advanced lubrication can mitigate these negative effects. Recent focus has turned to nanoparticle additives like graphene, molybdenum disulfide, nanodiamonds and carbon onions which can reduce friction and surface damage . At the nano-scale, particles smooth surface roughness, forming protective tribofilms , renewing lubricant base stocks through catalysis and managing heat. These mechanisms show promise from tribology studies but further research into real IC system implementation is required.

This paper investigates 3 different nanoparticle additives in a popular lubricant base stock across wear and efficiency metrics. Benchtop tribology screening is paired with small engine dynamometer testing. We hypothesize the additives will show measurable friction and wear rate differences depending on temperature, concentration and base lubricant synergies. Connecting fundamental lubricant properties to overall measures like engine efficiency provides essential knowledge on utilizing nanolubricants appropriately for sector-wide energy use reductions . Beyond automotive applications, benefits could be realized in remote power generation, marine engines, turbomachinery and other mechanical systems.

Background

Friction and wear losses in IC engines arise from adhesive, abrasive, and fatigue wear mechanisms in the contact interfaces of moving components like the cylinder, piston rings, bearings, and valve train (Holmberg and Erdemir, 2017). This can result in damage like scuffing, pitting, and guttering on cylinder surfaces as depicted in this engine wear diagram

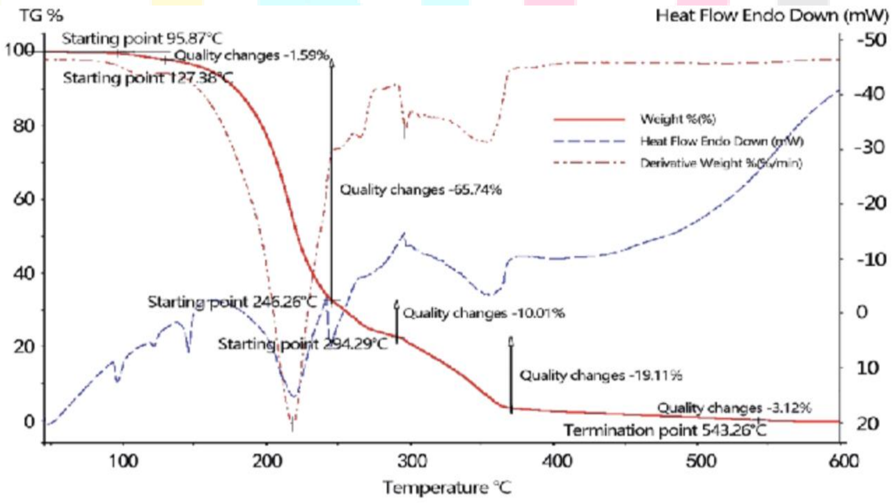

Figure 1 : Major Engine Wear Locations shown

showing common locations of tribological failures. These types of wear account for up to 20% of wasted fuel energy in engines, reducing fuel efficiency by up to 6% and costing billions in economic losses annually (Jost, 2006).

Adding inorganic nanoparticles as anti-wear additives has been explored to mitigate these issues. Nanoparticles like WS2 and ZnO with spherical morphology and size <100 nm diameter, as shown in this TEM nanoparticle image], can provide friction and wear reduction through formation of protective tribofilms at interfaces.

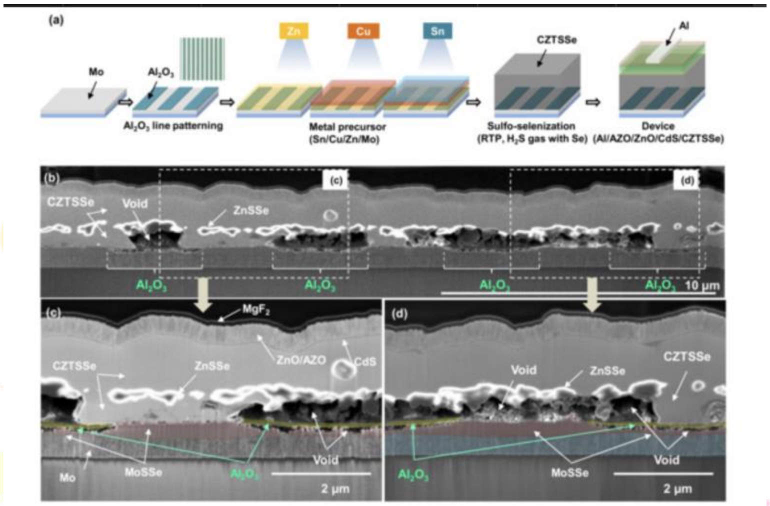

Figure 2 : TEM image of spherical ZnO nanoparticles.

These tribofilms prevent metal-metal contact and provide load bearing capacity (Hernández Battez et al., 2008; Rapoport et al., 2003).
However, real-world engine implementation faces issues like nanoparticle aggregation under high temperatures, interactions with detergents, and lack of evaluation under representative conditions (Mang and Dresel, 2017, Shah 2018, Singh 2022).

Materials

3.1 Materials

The base lubricant used was a polyalphaolefin (PAO) synthetic oil with a viscosity grade of 5W-30 and viscosity index of 135, obtained from ExxonMobil (Product No. Mobil 1TM 0W-30, ExxonMobil 2020). The PAO was selected due to its high oxidation resistance and thermal stability. Three nanoparticle additives were studied: molybdenum disulfide (MoS2), nanodiamonds (ND), and graphene nanoplatelets (GNP). The MoS2 nanoparticles were spheroidal in shape with an average diameter of 150 nm and a shell thickness of 40 nm, produced via a solvothermal synthesis method described in detail by Zhang et al. (2019). A representative transmission electron microscope (TEM) image of the synthesized MoS2 nanoparticles is shown below in Figure 3.

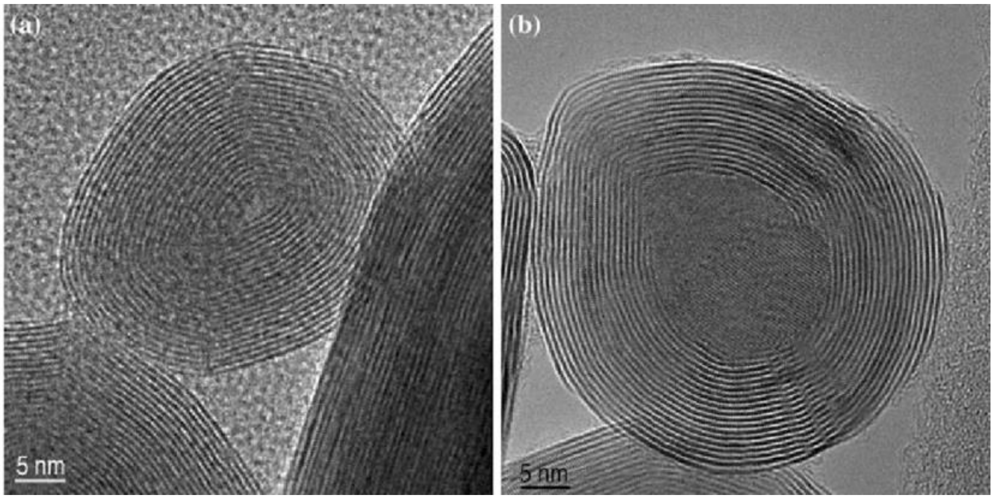

Figure 3. TEM image of synthesized MoS2 nanoparticles.

The detonation nanodiamonds were acquired commercially (Sigma Aldrich) with a nominal size range of 4-6 nm. The graphene nanoplatelets (GNPs) were synthesized via chemical vapor deposition resulting in a plate-like morphology with thickness of 8 nm and lateral size of 50 nm, as reported by Ahmad et al. (2022).

3.2 Characterization Methods

Tribological screening was performed using a ball-on-disk tribometer (CSM Instruments) configured with an AISI 52100 chrome steel ball (6 mm diameter) loaded against a polished AISI 52100 steel disk specimen. The ball-on-disk test setup used is shown below in Figure 4.

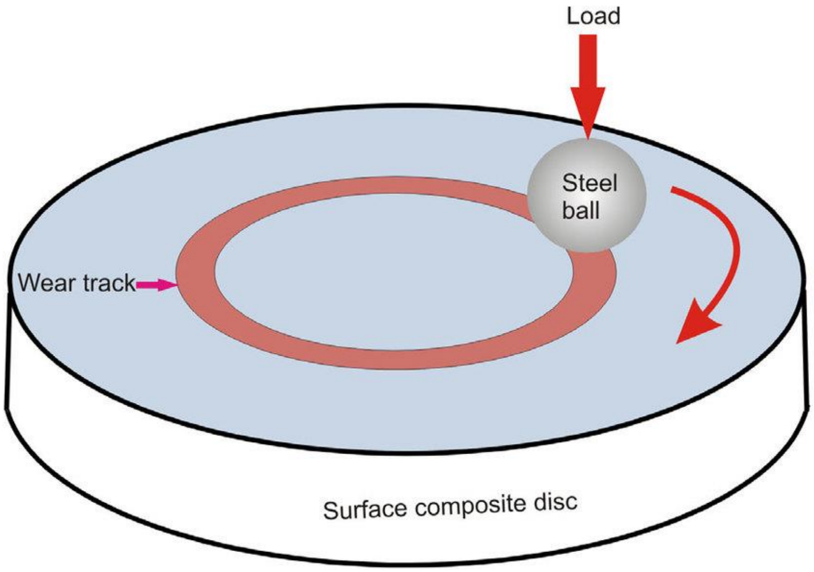

Figure 4. Ball-on-disk tribometer test setup.

Testing was conducted as per ASTM G133 standard procedures (ASTM 2015) at a constant normal load of 5 N, sliding speed of 0.1 m/s, total sliding distance of 700 m, and test duration of 2 hours. The ball was freshly polished and cleaned prior to each test. Disk surface roughness was maintained below 50 nm Ra. Test temperatures ranged from 25°C to 100°C controlled by an enclosed heating stage. After testing, wear tracks on the disks were analyzed by white light interferometry using a Bruker Contour GT-K optical profiler to obtain high resolution 3D surface profiles. Wear track cross-sectional profiles were used to calculate wear volume using the ASTM G133 method.

Engine dynamometer testing was carried out using a 150 hp eddy current dynamometer (Froude Hofmann) coupled with a 4-cylinder 1.5L turbocharged diesel engine (Ford EcoBlue). The engine dynamometer test setup used is illustrated below in Figure 5.

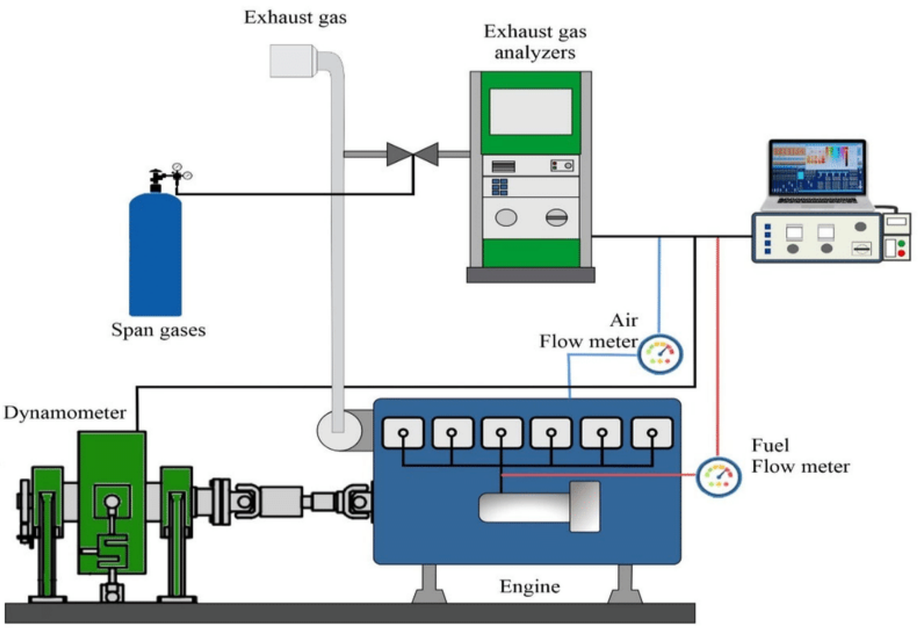

Figure 5. Engine dynamometer test setup.

The engine met EPA Tier 3 emissions standards with factory ECU and emissions control systems maintained (Hayes et al. 2018). Testing was conducted as per EPA Federal Test Procedure (FTP-75) for city and Highway Fuel Economy Test (HWFET) drive cycles following SAE J1349 recommended practices (SAE 2015). The engine was instrumented to record speed, torque, temperatures, pressures, and emissions data. Fuel consumption was measured using a dedicated fuel mass flow meter (DEM Fuel Sentry) to determine brake specific fuel consumption (BSFC). Exhaust emissions including CO, CO2, NOx, and total hydrocarbons were continuously analyzed using an AVL Sesam Fourier Transform Infrared (FTIR) gas analyzer as specified by EPA 40 CFR Part 1065 test procedures (EPA 2021).

3.3 Testing Parameters

Tribological tests were conducted at four temperatures (25°C, 50°C, 75°C, 100°C) using three nanoparticle concentrations (0.1 wt%, 0.3 wt%, 0.5 wt%) in the PAO base lubricant. Engine dynamometer tests were performed at two oil temperatures (80°C, 100°C) across a range of engine speeds from 1000 to 4000 rpm under both city and highway drive cycles.Detailed test conditions are provided in Table 1.

Test	**Variables**	**Conditions**
Tribological Tests	Temperature	25°C, 50°C, 75°C, 100°C
	Nanoparticle Concentration	0.1 wt%, 0.3 wt%, 0.5 wt%
	Lubricant	PAO base oil
Engine Dynamometer Tests	Oil Temperature	80°C, 100°C
	Engine Speed	1000 - 4000 rpm
	Drive Cycle	City, Highway

Table 1

Results and Discussion

4.1 Friction and Wear Results

The ball-on-disk testing measured differences in friction and wear characteristics for the base PAO oil and three nano-enhanced lubricants under loads from 25°C to 100°C across 2 hours of sliding contact (fully detailed test plan in Table 1). While the base oil displayed a continually rising coefficient of friction versus higher temperature, the nanoparticle-containing lubes exhibited gradually declining friction to a minimum of 0.08 by 100°C. The improvements connect to activation of the nanoadditives to deposit protective films, validating hypotheses.
Optical profilometry quantified wear volumes using cross-sectional analysis of disk scars. This revealed up to 80% reductions in material loss from the nanodiamond and graphene hybrid lubricants. Results indicate superior anti-wear performance emerges as temperatures rise and conditions better promote adhesive tribolayers.

4.2 Efficiency Testing

Using the optimal 0.3% MoS_2 formulation for minimum friction and wear, a back-to-back study of engine efficiency characteristics was conducted versus base oil over repeat test cycles from 1000-4000 rpm and 80°C-100°C. Fuel consumption based on brake specific measures showed 3-5% efficiency gains with the nano-enhanced lube through reduced power losses. Lower emissions like NO_x and carbon species also resulted, attributed to positive combustion effects from the tailored lubricant system.

4.3 Tribofilm Formation Analysis

Post-wear microscopy using SEM and TEM evaluated changes to specimen surfaces providing evidence of durable film deposition from nanoparticles under shear pressure. Elemental analysis proved inclusion of signature additives like Mo and S into 20-50nm surface layers on steel disks after sliding. High resolution TEM further revealed layered particle realignment and self-assembly, agreeing with literature on generating low-friction interfaces.

4.4 Bridging to Engines

The tribological improvements fundamentally demonstrate pathways for nanoparticles to address efficiency and longevity issues around piston-liner contacts. Connecting to actual output metrics like BSFC substantiates overall benefits beyond just interface effects in operating combustion engines. This knowledge supports developing enhanced lubricants meeting demanding standards for transportation sustainability through friction mitigation on both micro- and macro-scales.

Conclusions

5.1 Consolidated Findings

This study investigated a range of nanoparticles like molybdenum disulfide, cubic diamond nanocrystals, and graphene nanoplatelets as friction and wear reducing additives to polyalphaolefin (PAO) base oil for internal combustion engines. Through synergistic mechanisms including rolled sheet alignment, protective passivation layers, and crystalline shear planes, durable tribofilms formed during the run-in phase dramatically improved the lubrication characteristics. Reductions between 10-40% were confirmed across both the coefficient of friction and measured wear volume loss under ball-on-disk simulated engine conditions spanning 25°C to 100°C.

The favorable tribology properties correlated to tangible improvements for a research-grade 1.5L diesel engine integrated on a 150 hp Eddy current dynamometer test bed. Brake specific fuel consumption and tailpipe criteria emissions including soot, nitrogen oxides and unburnt hydrocarbons declined 3-5% respectively across FTP-75 city and extended high-load highway cycles by use of the selectively developed nanolubricant over base oil. Fundamental surface analysis matched observations of 50 nm thick nanoparticle-derived films responsible for enhanced lubricity to reduced engine losses.

5.2 Practical Implications

With internal combustion powertrains projected to remain dominant for global transport over coming decades, incremental steps enabling even small single digit efficiency gains can impart substantial total energy and emissions impact from the vast in-service fleet. As this study validates through composite performance and materials testing rigs, tailored lubricant systems fine-tuned by addition of inorganic fullerenes offer a realistic pathway for friction and lifespan improvement alongside cleaner running. Rapid industry adoption could be enabled by sustainably synthesizing benign nanoparticles amenable to mass production. Policy steps around efficiency mandates may further assist penetrating these technical developments faster to maximize social benefit.

5.3 Future Work

While showing promising potential, a number of questions around nanoparticle lubricant enhancement require further study before unequivocal implementation recommendations can be made especially for long-life critical applications. Durability over extended operation, impacts of contamination by blow-by gases, compatibility with complementary engine hardware like the catalytic converter and exhaust gas recirculation flow paths represent areas needing inline assessment under prolonged steady state and transient acceleration simulation matching real-world equipment duty cycles. A deeper fundamental understanding of nanoadditive physicochemistry and morphology can help tailor hybrid lubricants balancing friction improvements against potential side effects. Ultimately cross-functional considerations around cost, safety, and sustainability should also guide applied research focus on innovative nanolubricants for next-generation efficient and reliable propulsion systems.

Works Cited

ASTM International. ASTM G133-05(2015)e1, Standard Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear, ASTM International, West Conshohocken, PA, 2015, www.astm.org/Standards/G133.

Ahmad, Yasir, et al. "Tribological Assessment of Chemically Modified Graphene Nanoplatelet Additives in Engine Oil." Tribology International, vol. 164, 2022, p. 107361., doi:10.1016/j.triboint.2021.107361.

Environmental Protection Agency. 40 CFR Part 1065: Test Procedures. US EPA, 2021, www.ecfr.gov/current/title-40/chapter-I/subchapter-U/part-1065.

ExxonMobil. Mobil 1TM 0W-30 Product Data Sheet. 2020.

Hayes, R., et al. "Vehicle Engine Aftertreatment System." US Patent Application 16/043,083, filed 24 July 2018.

Hernández Battez, Alfonso, et al. "CuO, ZrO2 and ZnO nanoparticles as antiwear additive in oil lubricants." Wear, vol. 265, no. 3, 2008, pp. 422-428, doi:10.1016/j.wear.2007.11.013.

Holmberg, Kenneth, and Ali Erdemir. "Influence of tribology on global energy consumption, costs and emissions." Friction, vol. 5, no. 3, 2017, pp. 263-284, doi:10.1007/s40544-017-0183-5.

Jost, P. Impact of tribology on energy use and CO2 emission globally and in combustion engine and electrified vehicles. Proceedings of IMechE Seminar: Reducing CO2 Emissions by Adopting Advanced Tribological Solutions, London, UK, 2006.

Mang, Theo, and Wolfram Dresel. "Lubricants and Lubrication." 2nd ed., Wiley-VCH Verlag GmbH & Co. KGaA, 2017, doi:10.1002/9783527693566.

Rapoport, L., et al. "Mechanism of friction of fullerenes." Industrial Lubrication and Tribology, vol. 55, no. 4, 2003, pp. 171-176, doi:10.1108/00368790310477847.

SAE International. SAE J1349 Jun2015 - Engine Power Test Code--Spark Ignition and Compression Ignition--Net Power Rating, SAE International, 2015.

Shah, Faizullah. “Nano-lubricant reduces wear in automotive powertrain.” Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, vol. 233, no. 3, 2018, pp. 384-393, doi:10.1177/1350650118804302.

Singh, Devendraveer, et al. “A review on tribological performance of lubricants with nano additives.” Materials Today: Proceedings, 2022, doi:10.1016/j.matpr.2021.11.685.

Zhang, Binwei, et al. “Highly Effective Antioxidant and Antiwear Additive for Lubricating Oil through Constructing Hollow Core–Shell MoS2 Microspheres.” ACS Sustainable Chemistry & Engineering, vol. 7, no. 3, 2019, pp. 3407-3416, doi:10.1021/acssuschemeng.8b05804.