

Insight on the Effect of Nanoparticles addition in Oil Lubrication: A Review

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ABSTRACT

The goal of this literature review was to assess, organize, and synthesize the growing body of research on the use of nonmaterial's as lubricant additives and to help provide more effective guidelines for future study and development in this area. Through statistical comparison, the chemical, physical, and morphological characteristics of nanoparticles performance were investigated. Analysis was done on how those particles affected friction, wear and thermal conductivity. Using information gathered from the literature, mechanisms of lubrication using nanoparticles were examined. Energy saving, pollution reduction, and environmental preservation all benefit greatly from the use of lubricants with addition of nanofillers to reduce friction and wear. Nanolubricant compounds have seen substantial advances in both academic study and commercial use as a result of these two trends. This article provides an overview of the various types of nanofillers addition in lubricating oil to form compounds and provides examples of their tribological characteristics. Survey also focused that, based on the data, nanofluids have much higher heat transmission than the basic oil. It's more than just up-to-date with the latest tech.

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1. INTRODUCTION

An essential component of mechanical engineering is making sure that the various mobile components in mechanical systems operate smoothly, consistently, and for long-term. This is often accomplished by using lubrication methods and type of lubricants [1]. After the years of research and advancement, still it is found that out of total energy consumption in world about twenty third of total, is consumed or waste in friction and wear in machine parts as

per [2]. So it became essential to properly manage and get full or at least partial control over wear and friction reducing phenomenon which will ultimately results in cost saving and also effective in emission control of carbon due to mechanical components/assemblies. According to calculations by Holmberg and Erdemir, the reduction of worldwide energy losses brought on by friction and wear over the course of 15 years might result in savings of up to 40%, or 1.4% of yearly global GDP and 8.7% of worldwide energy ingesting [2].

The use of lubricants is widespread in a number of significant fields and businesses, including manufacturing, oil-food-gas production, pharmaceutical, shipping, and power breeding. The significant conveyance business presently accounts for over 60% of the emollient marketplace demand, and it is anticipated that it will continue to play a significant role in the creation of new lubricants [3]. This industry has highlighted the electrification of automobiles as a key solution for meeting upcoming vehicle emission regulations. The focus of lubrication is anticipated to drastically and fundamentally shift from load-carrying to torque-transferring during the transition from internal combustion engines (ICEs) to electrical vehicles (EVs), most likely by adopting base fluids with lower viscosities [4]. Lowering the viscosity of the lubricant improves cooling performance, which is especially important given the greater torque and operating speeds of tribological equipment in EVs. As the lubrication conditions shift from the hydrodynamic lubrication domain to the elasto-hydrodynamic and boundary lubrication zones, however, it is predicted that the reduced viscosity of the lubricant would increase the severity of surface contact and wear [5]. Because of this, decreasing the viscosity of the lubricant is a method that, ideally, should be combined with more powerful antiwear and friction-reduction additives [6]. To make the change to EALs, we need to identify suitable lubricant additives and new base fluids.

Products that meet the criteria for the European Ecolabel must have minimal negative effects on land and water bodies, low CO₂ emissions, high raw material and renewable content percentages, and minimal usage of hazardous compounds [7]. To put it another way, in the future, lubricant systems will have to adhere to ever-stricter rules and environmental standards, to the point where it would be necessary to switch out the harmful ingredients in the lubricant with ones that are safer for the environment.

In the tomb of the ancient Egyptian monarch Tehut-tomb Hetep [8], one of the first mentions of the usage of liquid lubricants is found: olive oil was applied to wooden planks to help move huge stones. Animal fats and vegetable oils remained the most popular lubricants even after the modern petroleum industry had developed. Because of this, lubricants derived from

petroleum quickly gained popularity in several new industries, including construction, transportation, and power generation. Increases in the purity and thermal stability of synthetic oils have contributed to the expansion of the lubricant industry in recent years. They could work much better if supplemented with additives. The "additive package" and the base fluid of today's lubricant formulations work together to provide the desired performance characteristics. Functional additives are packaged together to change the viscosity and oxidative stability of the lubricant base fluid or to add properties like resistance to emulsification, corrosion, or foaming. Table 1 displays the many categories into which lubricant additives may be classified based on the functions they perform.

By applying a layer with low shear strength between moving, contacting surfaces, lubrication may reduce friction and keep wear under control. Tribology study is crucial and important because it examines lubricating coatings to assess their efficacy, improve their capacity to avoid damage and minimize friction, and identify potential areas of improvement [1]. Lubricants are defined as "any material that decreases friction and wear, ensuring smooth motion and an acceptable operating lifetime of a tribosystem" [9]. Depending on the system and the application, lubricants might be liquids, semi-solids, or even gases. Liquid lubricants may also serve as a shock absorber, transfer particles of wear, reduce friction and wear, and prevent corrosion [10]. Using physical factors such as sliding velocity, fluid viscosity, and normal load, the Stribeck curve in Figure 1 visually depicts the friction behaviour of these three lubrication regimes [3].

Lubricant films should be thick enough to maintain full tribosurface isolation. However, depending on the system and the operating requirements, this may not always be achievable. There are three distinct lubrication regimes that may be achieved with various lubricants. These include the boundary lubrication regime, the mixed lubrication regime, and the hydrodynamic lubrication regime. The friction behaviour of these three lubrication regimes may be shown in respect to physical factors using the Stribeck curve shown in Figure 1.

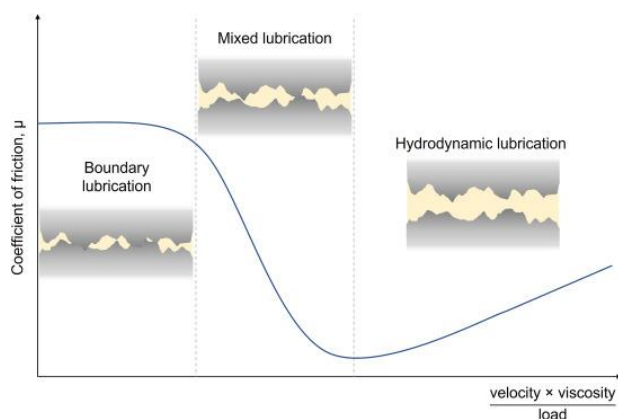


Fig. 1. Illustrations of the three most common types of liquid lube [3].

It is the viscosity of the lubricant that is the most essential physical property in the hydrodynamic lubrication regime, when the lubricant completely isolates the tribosurfaces. In this case, it is common practice to use polymers with a high molecular weight in order to improve lubrication. Tribosurfaces in the boundary and mixed lubrication regimes are in direct touch with one another, as shown in Figure 1. There is a heightened importance on friction modifiers and antiwear compounds in this context [11]. These surface-active additives adhere to the tribosurfaces or generate coatings that hide the tribosurfaces from direct metal-to-metal contact, therefore reducing wear and friction at the interface.

There has been a lot of research on solid granules and nanofillers structures over the last two decades as prospective aspirants for a new breed of lubricant property enhancer that reduce friction and wear. Nanoparticles are defined as "any material or structure having at least one dimension on the nanoscale scale" [12]. Nanostructures have been shown to have a significant effect on the properties of the fluid in which they are dispersed, even at very low concentrations [13]. Figure 2 indicates the exponential development in the number of annual publications on the issue over the last 22 years as well as the rising usage of nanoparticles in the lubricants industry from 2001 to 2022 [3]. The combination of "nanoparticle" and "lubricant" in the ISI Web of Science database. Prior to the advent of other nanostructured materials, scientists mostly focused on metals, metal oxides, and carbon-based nanostructures [13–18].

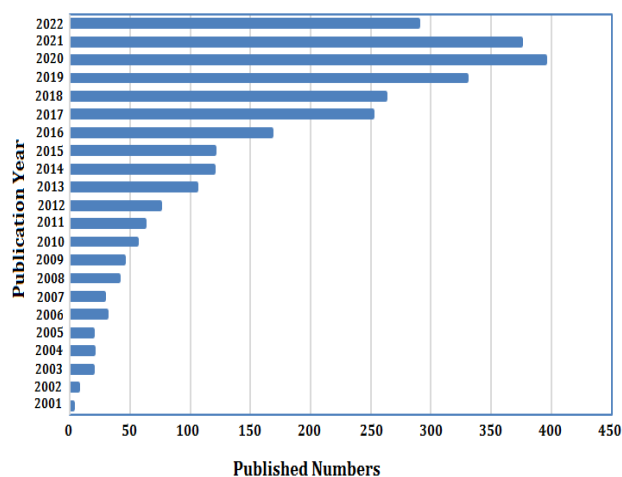


Fig. 2. The quantity of yearly publications including the lubricant and nanoparticle [3].

Carbon nano-onions, fullerenes, graphene, CNTs, carbon quantum dots, nano-diamonds are all examples of carbon nanostructures. Tribology has recently seen a surge in attention due, in large part, to carbon nanostructures' amazing properties, which make them suitable for tribological improvement of both surface coatings and bulk materials, as well as lubricant additives [19]. They should be lauded for their exceptional toughness, thermal stability, chemical inertness, and thermal conductivity. The curiosity of scientists in the use of carbon nanostructures in tribology was likely stoked by the extensive usage and economic success of graphite, a different carbon allotrope that has been widely investigated and utilized as a solid lubricant in the industry for millennia. Carbon nanostructures are the root cause of the impending stricter rules on automobile emissions. Lubrication is expected to undergo a dramatic and fundamental change from load-carrying to torque-transferring, most likely by employing base fluids with lower viscosities, as part of the transition from internal combustion engines (ICEs) to electrical vehicles (EVs) [3]. Lowering the viscosity of the lubricant improves cooling performance, which is especially important given the greater torque and working speeds of rheological components in EVs. However, it is predicted that transitioning from the hydrodynamic lubrication regime to the elasto-hydrodynamic and boundary lubrication domain, where the viscosity of the lubricant is much lower, would result in more severe surface contact and wear as observed in figure 1 [5]. This means that stronger anti-wear and friction-reducing compounds should ideally be used in

tandem with reducing the viscosity of the lubricant [6]. To make the change to EALs, new base fluid replacements and suitable lubricant additives must be found.

Despite extensive study on the lubricating performance of carbon nanostructures over the past few decades, a complete understanding of the mechanisms by which they reduce friction and wear is still lacking. The majority of experimental investigations into the tribological behaviour of functionalized carbon nanostructures have, to until, focused solely on reporting on the friction and wear behaviour without delving into deeper depth on the cause of the observed behaviour. Few of the many theoretical lubricating processes that have been proposed in the literature have actually been examined or validated. Contrary to the common idea that their nanoscale dimensions should facilitate dispersibility through Brownian motion, carbon nanostructures are naturally difficult to disperse and have a predisposition to congregate because of their high surface energy [20]. The functionalization of carbon nanostructures is required to create stable and uniform dispersion in the lubricant base fluid, it has been recognized for this reason. However, aside from improving dispersibility, little study has focused on how functionalization affects the ability of the nanoadditives to lubricate. Although preliminary findings suggest that variables like adsorption properties and the chemical reactivity of surface functional groups are significant, their impact has not yet been thoroughly investigated. All of this makes it challenging to choose nanostructures and surface functional groups with knowledge and intention for future studies.

Although carbon nanostructures' lubricating performance has been the subject of much research over the last several decades, the exact methods by which they do this remain unclear. Up until now, the vast majorities of experimental studies on the tribological behaviour of functionalized carbon nanostructures have only reported on friction and wear behaviour without going further into the source of the observed behaviour. Very few of the several suggested theoretical lubricating methods in the literature have ever been tested. Energy saving, pollution reduction, and environmental preservation all benefit greatly from the use of lubricants with

addition of nanofillers to reduce friction and wear. Nanolubricant compounds have seen substantial advances in both academic study and commercial use as a result of these two trends. This article provides an overview of the various types of nanofillers addition in lubricating oil to form compounds and provides examples of their tribological characteristics. Carbon nanostructures are notoriously difficult to disperse and have a tendency to collect due to their high surface energy [20], despite the widespread belief that their nanoscale size should assist dispersibility via Brownian motion. It has been acknowledged that stable and uniform dispersion in the lubricant base fluid requires the functionalization of carbon nanostructures. However, the effect of functionalization on the lubricating capacity of the nanoadditives has received comparatively less attention than its effect on dispersibility. The full extent of the influence of factors such as adsorption characteristics and the chemical reactivity of surface functional groups has not yet been explored, although early results show they are substantial. This makes it difficult to choose nanostructures and surface functional groups for future investigations with forethought and expertise. In this regard, present work aims to provide guidelines for future research and development in the field by reviewing and organizing the expanding body of information on the effectiveness of carbon nanostructures as lubricant additives.

2. IMPACT OF THE CHEMICAL MAKEUP OF NANOPARTICLES ON THE EFFECTIVENESS OF LUBRICATION

The interaction between lubricants and surfaces is influenced by the chemical and physical properties of nanoparticles with varying chemical compositions. There are three questions that need to be addressed. Which substances function best as nanolubricants? When it comes to lubrication, how does this one ingredient compare to others, and what part did it play in each lubrication mode? What role does the chemical makeup of a nanolubricants play in how well it performs in tribological conditions?

Minimum friction coefficient (MFC), maximum friction reduction (MFR), and minimum wear reduction (MWR) are our primary concerns

(MWR). Our goal in doing this literature review and correlation analysis is to shed light on the precise nature of nanolubricants' performance. For effective guess and analysis two strategies were implemented. First is MFC and MFR for friction presentation to find out fuel efficiency. And second, maximum MWR for optimum wear performance. Despite decades of research into nanofillers like carbon nanotube greasing properties, the exact processes by which they lessen friction and attrition remain unclear. Until now, the vast majorities of laboratory studies on the tribological activity of functionalized carbon nanomaterials have merely reported on the friction and wear behavior, rather than investigating the root cause. Following the chemical composition shown in figure 3, we classified the reported nanoparticles into seven groups: carbon and its derivatives, metals, metal oxides, sulphides, rare earth compounds, nanocomposites, and others. The molecular sheet, tube, and onion forms of carbon and its derivatives were shown to be the primary determinants of their tribological activity. The part wouldn't go further into the consequences of carbon-containing additions. The transition metal family was the most abundant for metals and oxides. The sulphides MoS₂, WS₂, CuS, and NiMoO₂S₂ were all suitable representatives. It was formerly believed that among rare earth elements, Y, La, and Ce were the most promising candidates for use as lubricant additives. They created a novel type of nanocomposites by combining several elements. There was also boron nitride, silicon dioxide, zinc aluminium oxide, zeolite, calcium carbonate, zirconium dioxide, polytetrafluoroethylene, and serpentine.

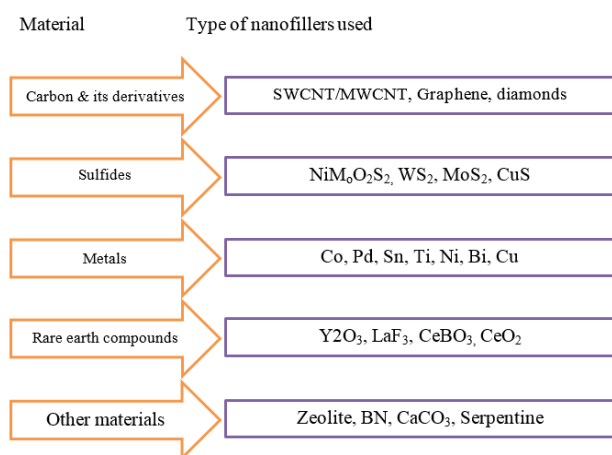


Fig. 3. Summary of nanoparticles as lubricant additives.

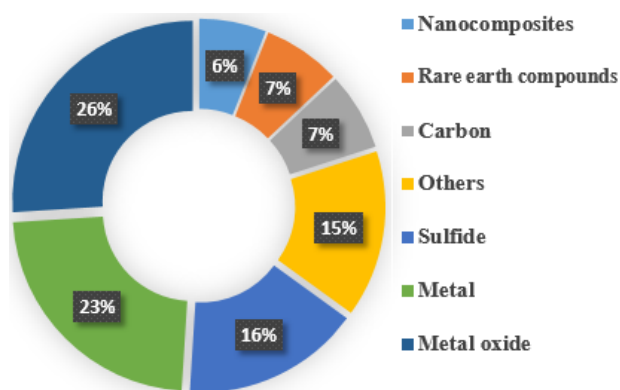


Fig. 4. Type of nanoparticles lubricants as additives.

Some items on the inventory were obviously much more common than others. Figure 4 is a pie chart showing the breakdown of reports for one category, based on the data we obtained (figure 3). Figure 4 tried to explain the percentage advancement occurred in research with the utilization of the various nanoparticles in base material with the help of figure 3. Nanolubricants were found to mostly consist of metal oxides, metals, and sulphides. We did not characterise other structural aspects of the nanoparticles that pertain to the chemical components and tribological activity in order to better understand the lubricating process. JMP was used to determine the degree of association. It measured how closely two factors were related to one another. A positive or negative correlation value indicates a positive or negative relationship between the two factors, respectively. High connectivity between two factors is indicated by a correlation coefficient with an exact number close to 1. Conversely, if the absolute value of the correlation coefficient between two values is near to 0, then the correlation between those parameters is weak. In the following subsections, we have compiled a summary of the additional information regarding nanoparticle lubricants.

2.1 Sulfide

Metal sulphides have been used as additives in both solid and liquid lubricants for a very long time. The lubricating mechanisms of MoS₂ have been studied extensively. Tribochemical reactions would occur when heat and high contact pressure were generated by the nanoparticles and their environments. Sulfur had a significant effect not only on the laminar structure of the particles, but also on the interaction between the particles and the molecules of the lubricant (substrate,

lubricants, atmosphere, among other). After some time, a tribofilm formed on the frictional surface. It is envisaged that tribofilms would have different chemical compositions on various substrates. Tribofilms have unique properties, such as hardness, adhesion, and roughness, which often make them superior to their substrate. The existence of a tribofilm facilitated adsorption [21]. The soaking layer is made up of a combination of lubricants, MoS₂ and their chemically bonded components. Complex -S-Mo-S-OCOR was formed when nano-MoS₂ interacted with lubricants to produce a fiber-like substance. Afterwards, lubricant fragments would be imbedded here to form a film of adsorption, as illustrated in Figure 5 [21].

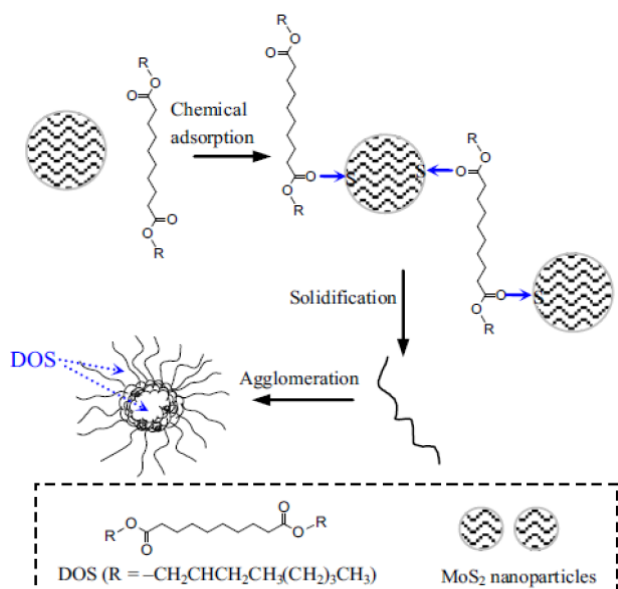


Fig. 5. The formation of adsorption layer using MoS₂ nanoparticles [21].

Their remarkable tribological performance was greatly influenced by the tribofilm that was generated on the metal surface [22]. The composition of MoO₃ and MgS in a tribofilm on a magnesium alloy was discovered to be true by XPS spectrum analysis in the same study.

2.2. Nanocomposites

It has been suggested that nanostructures are used in the process of making lubricant ingredients. Due to the synergistic effects of various kinds of nanoparticles, composites often perform better than individual nanoparticles in a given application. The various lubricating processes associated with nanocomposites are outlined in figure 6.

Nanocomposites	Mechanism Working
Al ₂ O ₃ /TiO ₂	Sliding action to rolling Movement transaction In the friction mode [23].
Serpentine/La(OH) ₃	Tribofilm formed containing Fe, Si and O The content La acts as a catalyst [24].
Cu/SiO ₂	Surface repairing effect of Cu nanoparticles released from nanocomposites [25].
Al ₂ O ₃ /SiO ₂	Synergic effect of Al ₂ O ₃ and SiO ₂ [26]
Cu/Graphene Oxide	Synergic effect of Al ₂ O ₃ and SiO ₂ [27].

Fig. 6. The lubricating mechanisms of nanocomposites detailed.

We must note that silica is one of the nanocomposites that is used most often as a lubricant additive (SiO₂). It is not natural for oil and nanoparticles to combine. One of the most common coupling agents used for improving nanoparticles dispersion is silane. The surface features of nanoparticles shift from being hydrophilic to being lipophilic, which is beneficial for the tribological performance of the material [23-27].

2.3. Metals

Because of their chemical and physical characteristics, metallic nanoparticles make good lubricants [28]. Cu, for example, has less shear stress than ceramics (oxides). Metallic nanoparticle lubrication mechanisms include: a) Adsorption or tribological development of film development. Nanoparticles made these films roll between sliding surfaces, lowering friction and wear; c) friction caused nanoparticles to condense on the worn track. These coatings may change surface properties and separate contacting surfaces, improving tribology. This was called "sintering" or "healing." Table 1 lists metallic nanoparticles and lubrication mechanisms. Tribological performance improvement is nothing but wear prevention and friction reduction and this can be achieved by utilizing metallic nanofillers like Fe (20-70 nm), Co and Sn (30-60 nm) [14,29], Ag [31], Bi [30,34], Cu [32,35], Pd & Au [33,36] addition in base lubricants. Cu, Ag, Ni, Pd forms a protecting layer over base material which helps in preparing guard film.

Table 1. Summary of lubrication mechanisms of metal nanoparticles.

Nanofillers	Utilization	Size	Ref.
Fe	Wear prevention	20 nm to 70 nm	[10,23,29]
Co and Sn	Thin shear preventive layer, also reduce frictional force	30 nm to 60 nm	[10,29]
Ag	Protecting against wear by forming guard film	6 nm to 7 nm spherical particles	[23,31]
Bi	Reducing friction by creating protecting with sintering method	7 nm to 65 nm spherical particles	[30]
Cu	Self-revamping film	20 nm to 130 nm spherical particles	[23,32]
Pd & Au	With forming transfer layer, splits counter faces	7.5 nm to 28.5 nm spherical particles	[33,36]

2.4. Oxides

Numerous metal oxides, such as TiO₂, CuO, Fe₃O₄, ZnO, and Al₂O₃, have been used as lubricant additives. Their lubricating mechanisms, including as the creation of tribofilms or adsorption films, rolling effect, and sintering or repair effect, are

comparable to those of metallic nanoparticles. Table 2 lists suggested lubricating mechanisms and these metal oxides are abrasive particulates that, when placed between tribological surfaces, perform the function of small spheres and rollers. Polishing is another impact that the abrasive particulates are capable of displaying.

Table 2. Lubricating mechanisms of metal oxides.

Nanofillers	Mechanisms for Lubrication
TiO ₂ [37]	Friction modification and surface repairing effect
CuO, Al ₂ O ₃ [38]	tribo sintering effect of CuO
La doped TiO ₂ [39]	A lubricating film produced was composed of iron oxide and titanium oxide.
Fe ₃ O ₄ [40] and Al ₂ O ₃ [41]	Friction mode change: nanofillers roll
ZnO [42] and CuO [43]	ZnO deposits on war track and Tribofilm formed on wear track

2.5. Constituents of rare earth elements

Numerous studies have been done on the tribological effects of rare earth elements on lubrication. La and Ce were the most widely used components. They could be added to

lubricants or drugged into further nanofillers, such TiO₂, to make them more effective. Their primary means of lubrication consisted of the production of tribofilm or an adsorption film. Table 3 is a list of the associated lubricating mechanisms [44-46].

Table 3. Lubricating mechanisms of rare earth compounds.

Nanofillers	Mechanisms for Lubrication
LaF ₃ [44]	Tribolayer formed of Fe ₂ O ₃ , LaF ₃ . Absorption film formed contains LaF ₃
CeBO ₃ [45]	Tribolayer formed of B ₂ O ₃ , CeO ₂ , Fe ₂ O ₃
CeO ₂ [46]	Tribolayer formed of Ce ⁴⁺ , TiO ₂ , Iron oxide and other organic compounds

Minimum friction coefficient (MFC), maximum friction reduction (MFR), and maximum wear reduction assess nanoparticles tribological performance (MWR). Sulphides had the lowest MFC, MFR, and MWR. Sulphur was believed to improve tribological performance. Although successful, the high sulphur content will likely be abandoned owing to environmental concerns [47]. The next section discusses how morphology affects MoS₂ lubrication.

Rare earth compounds with composite nanoparticles have similar MFC and MFR. MWR composites outperformed rare earth compounds. Cu, Al was helpful nanocomposites (Fe may come from the substrate). Rare earth elements La and Ce were beneficial. When a tribofilm's chemical composition and physical properties were considered, metal components were more favourable than rare earth elements.

Metal nanoparticles lubricated by adsorption films and tribofilms. Preventing oxidation of metal nanoparticles during lubrication maintained their chemical activity. Oxides are more inert than metal particles. Lubrication mechanisms include rolling contact and adsorption. Chemical composition showed a much greater connection with MWR (0.21), according to [27] than MFR (0.13) and MFC (0.161). This means chemical components have a modest influence on frictional performance and more on wear resistance. It follows that the impacts of molecular components on mechanical performance are minor, while they are more closely linked to wear resistance.

Chemical composition affects tribofilm quality, which may impair antiwear performance. Chemical composition affects tribological performance based on tribofilm properties. Nanolubrication relies on tribofilm's physical and chemical properties. Few articles explore tribofilm characteristics. Roughness, Interaction angle, modulus property, thickness, stiffness, micron, adhesion and crystal structure affect tribo-performance. This issue warrants more study.

3. PRACTICAL DIMENSIONAL ANALYSIS (SIZE EFFECT) AND ROLE OF NANOPARTICLE SHAPE

Nanoparticles smaller than 100 nm in size are spherical, tubular, or lamellar. Due to their size, they can readily lubricate and load-bear contact surfaces. High surface-to-volume ratio helps them to respond to surroundings. Size impacts tribological performance.

Optimized particle size depends on working conditions. Larger CaCO₃ nanoparticles functioned well at higher frequency (a different lubrication regime), whereas smaller ones performed better at higher load and lower frequency. Once recirculated, different-sized nanoparticles in IF-MoS₂ behaved similarly [48]. The nanoparticles were feeding the contact area. Smaller nanoparticles penetrated the surface more easily than bigger ones [49], reducing friction [50]. From the presented results in Table 4 [27], it is very much clear that it is mandatory to have clear study over size-to-tribological-performance relationships. According to the correlation coefficient, size had little effect on

friction and wear. The relationships between appearance and tribological results were tabulated (Table 4). A strong link between morphology and MFR was observed. The impact on antiwear behaviour is modest, however, due to the low association rate with MWR.

Table 4. Relationships between size and tribological presentation.

Relationship	MFC	MFR	MWR
Chemical composition	-0.161	0.13	0.21
Size	-0.1	0.1	0.3
Morphology	0.08	0.3	1 × 10 ⁻⁴
Aspect ratio	-0.08	0.26	0.05

Figure 7 shows nanoparticle morphological statistics. It shows spherical, granular, sheet, onion, and nanotube nanoparticles. After nucleation, particles form crystals to minimize surface energy. Isotropic surface energy favors the sphere [51].

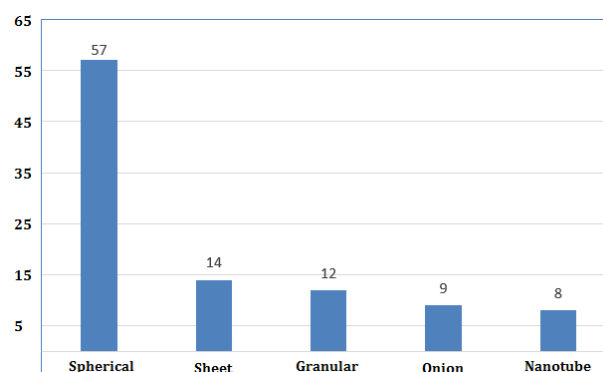


Fig. 7. Statistics of the nanoparticles morphology.

Onion morphology is lamellar within and spherical exterior. Tribological performance relies on onion morphological stability. Stable onion morphology is spherical. If not, it exfoliates and becomes morphology-like [52]. Structure and performance have been studied [53]. Its spherical shape and lack of hanging connections were benefits [54]. Rolling systems like spherical forms. Differences in atom counts between neighboring layers make dislocations easier to develop. Absence of dangling connections enhanced chemical inertia by reducing particle contact with environment. This situation would reduce particle adhesion. Dangling bonds were more likely to be passivated by the environment, causing chemical reaction friction. Instead of slipping, rolling would lubricate.

Rolling, sliding, and exfoliation comprise IF NP's lubrication mechanism [55]. Due to rolling friction, NPs must have a spherical shape and stable structure. Slipping friction necessitates a robust structure and little surface stickiness. Multilayered IF NP reduces friction and wear due to layer movement. Rolling friction predominated in low-contact circumstances. High contact pressure caused sliding and exfoliation. M. Kalin [56] and colleagues say MoS₂ lubricates due to nanotube exfoliation and distortion during boundary lubrication. Rapport [57] said the IF-lubrication WS₂ mechanism depended on lubrication regimes. Nanoparticle-thick films retain their spherical form. Sliding-rolling contact should lubricate most. Thinner than nanoparticles, a transferred film forms. Inner sheet-like structure was considered dominating. Flawed MoS₂ lubricated better [58]. If MoS₂ was flawed, its outer layer would tear off under pressure. Flawless crystalline structures needed higher contact pressure to exfoliate than flawed ones. Exfoliated layer may represent third-body friction. Ideal conditions approximated rolling friction.

Friction decreased gradually. Crystal structures affect lubrication. IF-MoS₂ particles with varying crystallinity levels were compared tribologically [58]. Poorly crystalline particles' tendency to exfoliate, generating a sheet-like tribofilm, was assumed to be the origin of their lubricating characteristics.

Sheet-like particles include graphene, MoS₂ nanoplatelets, BN, Y₂O₃, and ZrP. To understand how sheet-like nanoparticles lubricate, two types of interactions are considered [59]. Interactions between layers affect nanoparticle friction. Shear pressures readily exfoliate two neighbouring graphene and molecular silicon layers due to weak van der Waals forces. Sliding layers reduce friction. Y₂O₃ and ZrP, which have a strong interlayer van der Waals force [60], are difficult to exfoliate. Aligning nanoparticles with fluid reduces drag, say scientists. Another outer layer-substrate interaction illustrates the basal plane's surface energy and an environmental feature.

There is proof that the layer numbers and spacing between the layers affect tribological

behaviour. As the number of layers is reduced, issues with the puckering and wrinkle effect, inclination angles, and interlayer spacing will all worsen [61]. Due to its decreased interlayer spacing, ZrP shown a potential effect in reducing friction in the boundary lubrication regime. Table 4 summarizes the connections between morphology-aspect ratio-tribological performances. Morphology and MFR had a strong association, indicating that morphology has an impact on frictional performance. Furthermore, there is a slight impact on antiwear behaviour due to the poor correlation coefficient with MWR. It demonstrated a comparable pattern in the morphological relationship.

4. EFFECT OF NANOFILLERS ON THERMAL PROPERTIES

Adding nanoparticles to a fluid changes its temperature characteristics, and this knowledge can be put to use in hydrodynamic journal bearing uses. Only a fraction of the available research focuses on how nanoparticles in lubricants affect hydrodynamic bearings. New studies [62,63] have shown that incorporating nanoparticles into lubricants not only increases their stickiness but also boosts their weight bearing ability and other performance qualities. The tribological and temperature characteristics of bearing oil were the focus of many studies by experts. Adding an appropriate ingredient is one way to enhance the oil's performance. Nanoscale materials have recently appeared as a lubricant component that improves the oil's tribological and heating properties [64].

Nanoparticles of copper and copper oxide are embedded in motor lube fluid and their tribological and thermal characteristics are studied empirically. Oil with an SAE 20 W40 base is infused with nanoparticles of copper and copper oxide 40 nm in size at a quantity of 0.1% and 0.05%, respectively. The findings demonstrated that the heat conductivity was improved by 4.2% when using Copper and by 2.1% when using Copper Oxide micro lube. The findings show that the lube oil's tribological and heating characteristics are enhanced by the addition of Copper and Copper oxide micro particles [64,65].

Table 5. Thermal conductivity variation between regular oil and oil containing nanofillers.

Type of fluid/oil	Base oil (B _o)	B _o + C ₆₀	B _o + graphene nanosheets	B _o + MWCNT	B _o + CNB
Thermal conductivity (w/mk)	0.1654	0.1735	0.1800	0.1858`	0.1954

Based on the data, nanofluids have much higher heat transmission than the basic oil. The fact that carbon nanoparticles have a much greater heat transmission than motor lubricant may be to blame for this occurrence. Table 5 displays the outcomes of thermal conductivity measurements for both the basic fluid and the nanofluids [66]. The sample with carbon nanoball (CNB) particles showed the greatest rise in heat conductivity, with an increase of 18%. The heat conductivity value of the fullerene nanoparticles sample was the least increased compared to that of the basic oil.

5. CONCLUSIONS AND FUTURE SCOPE

A literature research and statistical analysis were conducted on the effect of nanoparticles addition over oil lubrication. It was discovered that a number of factors impacted tribological performance. The chemical makeup of nanoparticles has a small but noteworthy impression on antiwear performance. In the boundary lubrication regime, wear opposition was closely correlated with the characteristics of the tribofilm. Tribofilms benefited from the presence of metals. Nanoparticle sizes have observable impacts on wear and friction. The precise operating conditions and lubrication regimes controlled size optimization. The morphology of nanoparticles had a slight impact on antiwear performance but was crucial for reducing friction. Other morphologies were outperformed by onion- and sheet-like dissection. It was noticed that, physical networking and nanoparticle affect more over frictional enactment. The environment's chemical reaction with nanoparticles was the main factor in antiwear performance. The make-up of nanoparticles has been thoroughly explored by numerous experts. It has demonstrated excellent efficacy in a wide variety of settings and mediums. So far, no one has looked into whether or not nanoparticles are compatible with surface materials. Study also revealed that addition of nanofillers significantly affects base oil performance in terms of thermal conductivity. Future studies in the area of micro

lubrication will need to address this knowledge deficit. Future research may focus on a portion of nanoparticles between 31 nm and 60 nm in size, as this region has been shown to enhance the oil's properties.

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