

Use of Nanotechnology in Reduction of Friction and Wear

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Abstract— *The potential opportunities promised by nanotechnology for enabling nanopolymer composites as lubricants. Lubricants are required to reduce the all basic issues of friction, wear and adhesion in any fast moving interacting surfaces where rapid actuation is required. When the traditional fluid and grease lubricants fail the applications of polymer composites are enhanced which have a superior tribological performance to conventional polymer composites. This review provides an insight into the capabilities offered by nanopolymer composites to use as lubricants. It discusses polymer-based nanocomposite materials, nanoscale fillers and provides examples of the actual and potential uses of polymer nanocomposites as lubricant.*

Keywords— *Nanotechnology, Polymer-based nanocomposites, lubricants, friction and wear.*

I. INTRODUCTION

Nanotechnology enhances the revolutionary technological changes and the research emphasis which are directly related to improvement of nanopolymer composites as lubricants. The polymeric materials have to exhibit good abrasion and wear resistance by mechanical strength, lightness, ease of processing, versatility and low cost, together with acceptable thermal and environmental resistances which are suitable for tribological applications. The viscoelasticity of polymeric materials demerit this target and make the analysis of the tribological features and the processes involved in such phenomena quite complicated [17-19]. Hence by accumulating miniature inorganic particles in the polymer matrices the mechanical properties can be effectively enhanced. The development of composite materials is derived from a combination of properties possess a high stiffness, toughness and wear resistance which are essentially valid for tough operational conditions as slide bearings. Apart from this the reinforcing effect depends on composite materials which are strongly affected by the microstructure represented by the filler size, shape, homogeneity of distribution/ dispersion of the particles within the polymer, and filler/matrix interface extension, plays a crucial role which cannot be achieved by either components alone since composite material is derived from a combination of properties. The improvement of nanocomposites showing high tribological features requires a deep investigation on their micro-to-nanostructure, aiming to find synergistic mechanisms and reinforcement effects exerted by the nanofillers.

II. INTRODUCTION OF NANOTECHNOLOGY IN LUBRICATION

During recent years, nanocomposites have fashioned much research interest due to notable enhancements in the various composite properties at very low volume fractions. In emphasizing the area of miniaturization, factors such as materials surface characteristics are particularly important, since very low adhesion and friction forces must be achieved here. Introducing nanoparticles in lubricants is a complex task because of size, shape, concentration and of course the materials itself are all very important factors to influence the lubrication performance of a specific system [1-3]. The significant parameters in lubricants is the concentration of nanoparticles, since both wear scar diameter and friction coefficient were found to be dependent on the concentration of additives. Heat is produced as a result of friction, such that lubricants are required to have higher temperature degradation points. Addition of inorganic nanoparticles significantly improves their lifetime and performance, although nanomaterials tend to manifest a sharp decrease in their melting point at around or below 50 nm. To improve the friction and wear behaviour for a range of systems, low concentration of less than 2wt% was found to be optimal where the addition of nanoparticles of more than 1% was not achieved in any studies on different fractions of nanoparticles in various circumstances and more damage can be found in High concentrations easily.

III. IMPORTANCE OF LUBRICANTS

Beginning with the first mechanical device, lubrication has been an essential design parameter for any mobile parts involved in machinery, mechanical tools, and transport means [11]. The microscopic complicated and multiplex sets of interactions are the major to cause friction and wear when two contacting bodies slide, roll, or separate with respect to each other, a force referred to as friction is produced at their interface which opposes their movement. These interactions are the result of the materials, the geometrical and topographical characteristics of the surfaces, and the overall conditions under which the surfaces are made to slide against each other, e.g., loading, temperature, atmosphere, type of contact, etc. This friction force is usually accompanied by wear, the removal of material from either or both of the contacting surfaces.

Both friction and wear may be aggravated by corrosion, contamination, or unusual environmental conditions, but both are minimized by the process of lubrication. The main purpose of a lubricant is to keep the moving/sliding surfaces apart, so that friction and consequent destruction of material is minimized. The process of reducing friction between moving/sliding surfaces, by the introduction of lubricants in between them, is called lubrication. The main function of the lubricants is to reduce wear and tear of the surfaces by avoiding direct metal to metal contact between the rubbing surfaces and to reduce expansion of metal due to frictional heat and destruction of material [13]. It also acts as coolant of metal due to heat transfer media. All mechanical,

physical, chemical, and geometrical aspects of the surface contact and of the surrounding atmosphere affect the surface interactions and thereby also the tribological characteristics of the system. Hence the friction and wear are the tribological unique characteristics. All lubricants are classified into three types 1.) Liquid lubricants: These are having the characteristics of high melting and low freezing points. Liquid lubricants usually used in bearings are mineral oils and synthetic oils.

2.) Semi-liquid lubricants: these are usually greases which are the combination of lubricating oils with thickening grease. The internal resistance of grease is much higher than the lubricant oils, having higher viscosity than the oils. The grease is employed where slow speed and heavy pressure exit.

3.) Solid lubricants are useful for conditions for when conventional lubricants are inadequate in maintaining the pressures and temperatures they should be softer than materials being lubricated. Graphite and molybdenum disulphide (MoS₂) are the predominant materials used as solid lubricant. They are used either in the dry powder form or with binders to make them stick firmly to the metal surfaces while in use. Properties of Lubricants:

(1) Viscosity (2) Flash Point and Fire Point (3) Cloud Point and Pour Point (4) Aniline Point and (5) Corrosion Stability

(1) **Viscosity:** The viscosity of a fluid is a measure of its resistance to gradual deformation by shear stress or tensile stress [5]. It is the property of liquid by virtue of which it offers resistance to its own flow measured in poise. It is the most important single property of any lubricating oil, because it is the main determinant of the operating characteristics of the lubricant. If the viscosity of the oil is too low, a liquid oil film cannot be maintained between two moving/sliding surfaces. On the other hand, if the viscosity of the oil is too high, excessive friction will result.

(2) **Flash Point and Fire Point:** Flash point is the lowest temperature at which the lubricant oil gives off enough vapours to support a momentary flash when a tiny flame is brought near it within 6mm at the surface of the oil [5]. Fire point is the temperature at which oil gives off sufficient vapour to burn it continuously when ignited. A good lubricant should have flash point at least above the temperature at which it is to be used.

(3) **Cloud Point and Pour Point:** The temperature which offers the lubricant oil to terminate the flow or pour is called its pour point and the temperature at which it becomes cloudy or hazy in appearance is said to be its cloud point [5]. Low temperature functioning lubricant oils retain low pour point to evade the jamming of machine which is found in lubricants possessing wax.

(4) **Aniline Point:** Aniline point of the lubricant oil is defined as the minimum equilibrium solution temperature for equal volumes of aniline and lubricant oil samples. It gives an indication of the possible deterioration of the lubricant oil in contact with rubber sealing; packing, etc. Aromatic hydrocarbons have a tendency to dissolve natural rubber and certain types of synthetic rubbers. Consequently, low aromatic content in the lubricant oil is desirable. A higher aniline point means a higher percentage of paraffinic hydrocarbons and hence, a lower percentage of aromatic hydrocarbons. Aniline point is determined by mixing mechanically equal volumes of the lubricant oil samples and aniline in a test tube. The mixture is heated, till homogenous solution is obtained.

(5) **Corrosion Stability:** Corrosion stability of the lubricant oil is estimated by carrying out corrosion test. A polished copper strip is placed in the lubricant oil for a specified time at a particular temperature. After the stipulated time, the strip is taken out and examined for corrosion effects. If the copper strip has tarnished, it shows that the lubricant oil contains any chemically active substances which cause the corrosion of the copper strip. Good lubricant oil should not affect the copper strip. To retard corrosion effects of the lubricant oil, certain inhibitors are added to them. Commonly used inhibitors are organic compounds containing P, As, Cr, Bi or Pb.

IV. POLYMER NANOCOMPOSITES

A composite material with a polymer matrix and filler particle that have at least one dimension less than 100nm are called as polymer nanocomposites. To improve the strength of nanocomposites the inorganic nanofillers ranging from 1 to 50nm were incorporated in the polymeric matrix and to enhance the ductile polymer to be more stiff and resistant for abrasion. The low density, high corrosion resistance, ease of fabrication and low cost are major properties of these engineering composites [21]. Polymer nanocomposites are polymers (thermoplastics, thermosets or elastomers) which are reinforced with small quantities less than 5% by weight of nanosized particles having high aspect ratios ($L/h > 300$). The polymer nanocomposites are exemplified by discrete constituents on the order of a few nanometres where the conventional composites which are reinforced on the order of microns. Polymer nanocomposites enable immense retention of the inherent processibility and neat resin due to less filler of (1-5 vol%). These are classified into four types and are explained in brief.

A. Nanoclay reinforced composites

The hydrous aluminosilicates which are characterized by crystal sizes less than 2 μm in diameter are called as clay minerals, these are phyllosilicates like micas, chlorites, and serpentines, are characterized by a sheet structure made by layers of Si-O (\pm Al) tetrahedral (sharing 3 of their 4 oxygen's) [4], alternating with layers of octahedral or some other types of polyhedral of cations as Fe²⁺, Mg²⁺, Al³⁺, and Fe³⁺ with higher coordination numbers. The finest part of clay is similar to colloid, with fine grain size, stickiness, and plasticity characteristics when wet which are classified into two main structures as

i) 1:1 kaolinite and ii) 2:1 layer silicates

i) 1:1 Kaolinite

Kaolinite is the major component of clay which varies slightly in composition, which is a purest form of clay. Kaolinite is hydrophobic as it does not absorb water and does not expand when it is contact with water hence it is preferred for the ceramic

industry. Kaolinite group includes kaolinite, dickite, nacrite, and halloysite, formed by the decomposition of orthoclase. Kaolinite contains hexagonally arrayed layers of silicate tetrahedral which is usually white in colour. Kaolinite is called as 1:1 type of layered mineral that is composed of a tetrahedral silica sheet and an octahedral alumina sheet. The tetrahedral and octahedral sheets are connected with shared oxygen atoms. The charge within the layers is nearly balanced, and the chemical formula is $Al_4[Si_4O_{10}](OH)_8$ or $2Al_2O_3 \cdot 4SiO_2 \cdot 4H_2O$

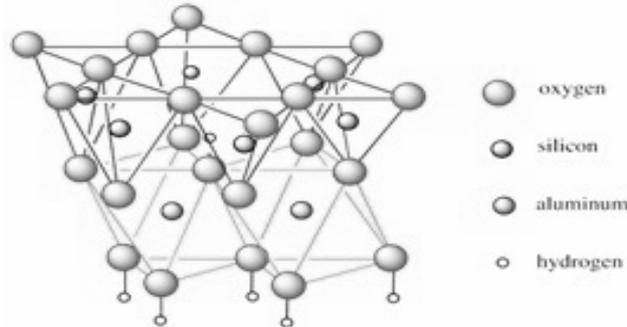


Fig 1: Structure of 1:1 Kaolinite.

Phyllosilicate consist of two layers (one tetrahedral “t” and one octahedral “o”) known as “t-o” structures, other type consist of three layers known as “t-o-t” structures. The layer groups (t-o or t-o-t) are often held together by “interlayer cations” as K^+ , Na^+ , Ca^{2+} , or Mg^{2+} , or hydrogen bonds arising from water molecules occupying these sites [9].

ii) 2:1 layer silicates

2:1 phyllosilicate clays having permanent layer charge because of the isomorphous substitution in either the octahedral sheet (typically from the substitution of low charge species such as Mg^{2+} , Fe^{2+} , or Mn^{2+} for Al^{3+}).

The crystal layers of these minerals are characterised by an octahedral sheet reinforced between two tetrahedral sheets. These are classified as:

a) Expanding type: Smectite group and vermiculite b) Non expanding type: mica group (illite).

a) Expanding type

Smectite Group: The unique property of interlayer expansion and swelling when in contact with water is known for the smectite group of minerals. The flake-like crystals of smectite are composed by an expanding lattice 2:1 type clay minerals (eg. Montmorillonite $((1/2Ca,Na)(Al,Mg,Fe)_4(Si,Al)_8O_{20}(OH)_4.nH_2O)$), the most common smectite. An octahedral sheet is reinforced between two tetrahedral sheets, in each layer where water and exchangeable cations are present in variable space between the layers. The clay mineral smectite having 2:1 expanding crystal lattice is shown in Figure 2. The structural unit is a layer consists of tetrahedral sheets pointing inwards and an octahedral sheet with central alumina. In contrast to the continuous length and width directions of the layers, the expansion in third direction is observed by the bond between layers by allowing water and other molecules to enter between the layers. The internal surface exceeds the external surface of the clay crystal. The minerals show high cation exchange capacity, swelling and shrinkage properties, when montmorillonite substituted to negative charges.

Vermiculites: The weathering products of mica (illite), a high-charge 2:1 phyllosilicate clay material is known as vermiculite where an octahedral sheet occurs between two tetrahedral sheets. In most soils vermiculites, the octahedral sheet is aluminium dominated (di-octahedral), although magnesium dominated (tri-octahedral) vermiculites are also

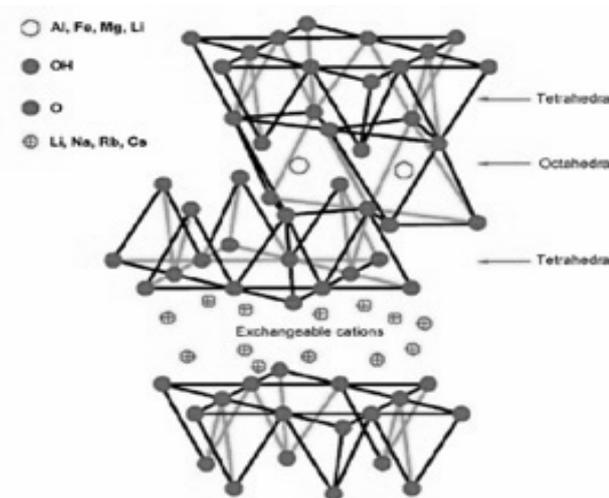


Figure 2. Structure of 2:1 layered silicate [8,9]

present. The very high net negative charge in vermiculites is due to the substitution of aluminium by silicon in the tetrahedral sheet. The degree of swelling is considerable less for vermiculites than for smectite due to the water molecules, along with magnesium and other ions [5], are strongly adsorbed in the interlayer space of vermiculites which acts as bridges holding the units together rather than as wedges driving them apart. The very high negative charge in the tetrahedral enhances the “cation exchange capacity” (CEC) compared to all other silicate clays including montmorillonite.

b) Non expanding type

These are particles larger than smectite which are fine-grained micas have a 2:1 type crystal structure. Muscovite and biotite of mica are minerals of this group. A net negative charge in the tetrahedral sheet much higher than in vermiculites

Table 1. Comparative properties of silicate clay minerals

Property	Montmorillonite	Illite	Kaolinite
Structure	2:1 lattice	2:1 lattice	1:1 lattice
	Substitution in octahedral sheet by Mg or Fe	Substitution in Tetrahedral sheet by Al	No Substitution
Shape	Irregular flakes	Irregular flakes	Hexagonal crystals
Total surface area (m ² g ⁻¹)	700-800	100-120	5-20

is resulted due to aluminium atoms occupy about 20% the silicon sites. To satisfy this charge, potassium ions are strongly attracted in the interlayer space and are just the right size to fit into spaces in the adjoining tetrahedral sheets. The expansion of the crystal is prevented by the potassium which acts as a binding agent. The properties such as hydration, cation adsorption, swelling, shrinkage and plasticity are less intense in fine grained micas than in smectite but are more than kaolinite due to the presence of interstratified layers of smectite or vermiculite. Fine grained mica crystals are intermediate in size between the smectite and kaolinite. Their specific surface area varies from 70 to 100 m² g⁻¹, about one eighth that for the smectite.

B. CARBON NANOTUBES REINFORCED COMPOSITES

The high mechanical strength of carbon nanotubes (CNTs) plays a major role in strengthening the composite by considering nanoscale fibers to enhance the performance of polymer composite materials. The most important application of CNTs is to be polymer nanocomposites [23-27]. In polymer nanocomposites (PNCs) the reinforcements of filler is in the order of few nanometres in contrast to conventional system which is of microns. The high structural performance can be obtained from Single walled nanotubes (SWNTs) and multi walled nanotubes (MWNTs), the former contains single graphite sheet which is wrapped into a cylindrical tube and the lateral consist an array of nanotubes which are made in nested like rings. Polymers such as epoxy, thermo plastics, gels and polymethylmethacrylate (PMMA) are extensively used as matrix. The axial electrical conductivity offers the potential fabricating conducting polymers. The mechanical properties of a composite are improved by load transfer across CNT matrix interface which is acquired by good interfacial bonding.

C. INORGANIC PARTICLE REINFORCED COMPOSITES

Dispersion of nanoparticles develops the high-performance polymer nanocomposites. The properties of polymer nanocomposites are highly dependent on how uniformly the nanoparticles are distributed within the matrix. The 3D interfacial region in polymer matrix due to more interfacial area than traditional composites results significantly different from those of the bulk polymer. The interfacial should be deliberate to know the effects of nanoscale fillers on polymer behaviour. Let us consider a pure thermoplastic polymer film interacting with a very flat inorganic surface. The surface/polymer interactions greatly influence the glass transition temperature (mobility, relaxation spectra) of thin polymer films. Different particles have been used to prepare polymer/inorganic particle nanocomposites, including [6,22]:

- . Metals (Al, Fe, Au, Ag, etc.)
- . Metal oxides (ZnO, Al₂O₃, CaCO₃, TiO₂, etc.)
- . Nonmetal oxide (SiO₂)₅₂
- . Other (SiC)

The vastly improved toughness suggests that the resulting polymer nanocomposites could be promising for structural and high-performance impact applications. Inorganic fullerene-like WS₂ nanoparticle- (IF-WS₂) reinforced nylon 12 nanocomposites have been prepared through effective ultrasonic mixing without using any surfactant, followed by molding at 220 °C had

revealed the excellent dispersion of IF-WS2 nanoparticles in the nylon 12 matrix. X-ray diffraction (XRD) analyses have confirmed that a phase transition from α' -phase to a more stable γ -phase took place during the sintering of nylon 12, regardless of the amount of IF-WS2 added to the matrix. At a very low IF-WS2 content of 2 wt%, the tensile strength and bending strength of the composites increased slightly by 27% and 28%, respectively. In an epoxy resin matrix, IF-WS2 simultaneously increased both the shear and peel strengths of the nanocomposites, as well as the toughness, which was attributed to a C-S bond formed between the IF-WS2 nanoparticles and the epoxy resin, as evidenced by the detection of an R-SO₃ or RSO₃H band at 1246 cm⁻¹ in the FT-IR spectrum.

V. POLYMER NANOCOMPOSITES AS LUBRICANTS

i) Abrasion and Wear Resistance

Although it is well known that the abrasion resistance of filled polymers depends on particle size, the incorporation of nanoscale fillers has led to unexpected results. For filler particles that are larger than the abrasive particles, most of the filler particles are stable and increase the abrasion resistance of the composite. As the filler size is decreased to a size similar to that of the abrading particles, filler particles are removed, and the abrasion resistance is compromised. This does not happen on the nanoscale. For example, the addition of nanoscale CaCO₃ to PMMA resulted in a significant decrease (factor of 2) in material loss due to abrasion at only 3 wt. % of filler [23]. In addition, nanoparticles can simultaneously improve wear resistance and decrease the coefficient of friction. With larger-scale fillers, increased wear resistance is accompanied by an increased coefficient of friction, which has been observed for silica/Nylon as well as for polyetheretherketone matrix composites filled with ZrO₂, SiC, SiO₂, and Si₃N₄ [24-26] and for sheet silicates in polyimide. The coefficient of friction measured as dry sliding against steel decreased monotonically with increasing weight percent of fillers.

ii) Kaolinite as a lubricant in Newsprinting

Newsprint tends to have a low coefficient of friction (COF) because it contains high levels of mechanical or de-inked fibers. This is caused by the presence of naturally-occurring hydrophobic molecules which reduce the polar surface energy of the paper, and which act as lubricant [14]. The molecules usually have straight alkyl chains which can align as the two paper surfaces slide over one another. This low friction causes telescoping in the reel building process and gives problems at the printing press as the web can "run ahead" or "walk" causing misregister between printing stations. Using the correct filler is a valuable tool for the papermaker to increase COF. To study the effect of fillers on COF, a sliding test is performed with one sheet of paper fixed while a second is pulled across it at a fixed speed. The force required to do this is a measure of the friction between the surfaces.

iii) Nanoclay reinforced composites as lubricants

Bentonite or montmorillonite referred to clay having a structure similar to kaolinite, decomposed from volcanic ash and occasionally from lava has high plasticity. Apart from the different molecular structures, the kaolinite is the repetition unit of gibbsite-silica and silica-gibbsite-silica in montmorillonites.

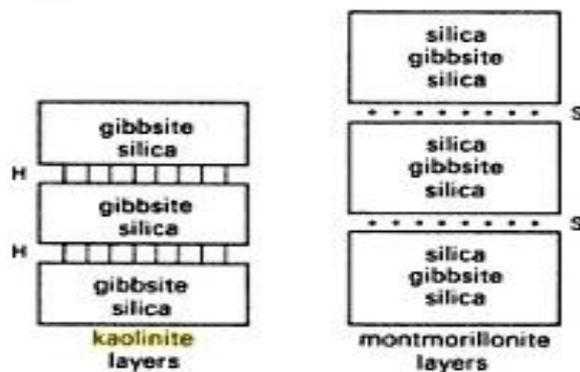


Figure Kaolinite and montmorillonite layers

The weak hydroxyl bonds from the gibbsite of one layer to the silica of next helps the layers to held together in kaolinite. The absence of hydroxyl bonds and availability of oxygen atoms of the silica on the outside of the layers in montmorillonites allows the layers to slide past one another by restricting to have hold on another. This gives the bentonite a greasy property which can be used as a lubricant in well drilling. The absence of bonds between the layers in betonies allows the water to enter and divide the particles. The particles of bentonite can be separated to colloidal size or even to molecular units which results in absorption of vast amount of water. One kilogram of betonies can absorb 2.4 litres of water and still not to be liquid but in turn swells and produces a greasy mass with lubricant properties. The deficiency of positive charge obtained by the presence of sodium or calcium cations on the surface of the layers by replacing silicon with aluminium. Sodium cations keep the layers at a wide distance apart which helps water to penetrate quickly.

iv) Detonation Nanodiamonds (DND) as lubricants

Nanodiamond particles with the smallest monocrystalline size of about 4nm are produced by detonation of carbon-containing explosives, so called Detonation Nanodiamonds (DND). It is possible to produce inorganic fullerene-like (IF) nanoparticles of tungsten sulphide (WS₂), which have a characteristic structure like a hollow onion [10]. By adding small quantities of WS₂ [15] nanoparticles (about 100 nm) to two polymer matrices such as epoxy and polyacetal, it was possible to reduce coefficient of dry friction between polymer and a steel disc to less than half in both the cases. If a simple lubricant was present, friction coefficient was further reduced significantly. Fracture toughness of the epoxy was also improved. Numerous applications of DND are under development including high precision polishing, wear resistant additives to metal coatings, anti-friction additives to lubricants and oils, polymer nanocomposites and coatings with enhanced strength, impact resistance, and scratch resistance.

v) PTFE as a lubricant

Polytetrafluoroethylene (PTFE) is synthetic fluoropolymer of tetrafluoroethylene a fluorocarbon solid, it is a high molecular weight compound consisting wholly of carbon and fluorine. PTFE has a well-defined footprint in the lubrication engineering with impressive performance profile in greases, chain oils, dry-film lubricants, etc. due to the low surface energy of PTFE, stable unflocculated dispersions of PTFE in oil or water can be produced. Contrary to the other solid lubricants PTFE does not have a layered structure. The macro molecules of PTFE slip easily along each other, similar to lamellar structures. PTFE shows one of the smallest coefficients of static and dynamic structures down to 0.04. Recognition of potential to reduce friction and wear has led to use of PTFE as a dry-film lubricant and friction modifier, PTFE-fortified oils and greases are known to exhibit higher welding loads, higher load wear indexes, and reduced stick-slip.

vi) Graphite as a lubricant

Graphite is structurally composed of planes of polycyclic carbon atoms that are hexagonal in orientation [16]. Like other lamellar solids such as molybdenum disulphide (MoS₂), is known to be a good solid lubricant which provides greater cleanliness compared to oil lubricants, and can provide lubrication at extreme temperature, under vacuum conditions or in the presence of strong radioactivity [7-8]. The distance of carbon atoms between planes is longer and therefore the bonding is weaker. Graphite is best suited for lubrication in a regular atmosphere. Water vapour is a necessary component for graphite lubrication. The adsorption of water reduces the bonding energy between the hexagonal planes of the graphite to a lower level than the adhesion energy between a substrate and the graphite. Graphite is a well-known solid lubricant with lamellar morphology used in all the industrial lubrication system. It is available in the form of amorphous, natural and synthetic grades. It needs moisture for good lubricity. The low-friction performance is attributed to their low resistance to shear between neighbouring atomic layers of these materials.

vii) Molybdenum disulphide as lubricant

Molybdenum disulphide (MoS₂) is one of the most widely used solid lubricants [20], a good example of layered solids with friction coefficient less than 0.05 in dry conditions. Fullerene structures MoS₂ can withstand very high loads and speed, but they also oxidize beyond 450°C and become ineffective. Coated films enhanced properties of scuffing resistance. MoS₂ particle sizes in the range of 1-100 micrometre are a common dry lubricant, few alternatives exist that can confer the high lubricity and stability up to 350°C in oxidising environments. Sliding friction tests of MoS₂ using a pin on disc tester at loads 0.1 to 2 newton gives friction coefficient of values of less than 0.1. Molybdenum disulphide is often a component of blends and composites where low friction is sought. A variety of oils and grease are used, because they can retain their lubricity even in cases of almost complete oil loses, thus finding a use in critical applications such as aircrafts engines. When added to plastics, MoS₂ forms composites with improved strength as well as reduced friction. Polymers that have filled with MoS₂ include nylon, Teflon and vespel. Self-lubricating composite coatings for high temperature applications had been developed consisting of MoS₂ and Titanium nitride by CVD.

viii) Nanocomposites for Hard coatings

The major coatings are made from TiN, TiC, TiAlN, CrN, diamond-like carbon (DLC), WC/C, MoS₂, Al₂O₃, etc. Lower friction, increased life time, increased toughness, higher thermal stability are the properties of the nanocomposite materials. The superior properties to single-phase materials can be obtained from nanoscale entites such as multilayers or even isotropic coatings of nanocomposites [12]. The specific alloying elements in single-phase coating such as to improve hardness can be achieved from nanocomposites. These coatings consist of two or more phases combined as multiple layers or as homogeneous isotropic multiphase mixtures with a thickness of few micrometres of more than three layers which offer better tribological properties. The super lattice effects can enhance the hardness and other properties of the coatings when the thickness of each layer is in nanometer scale. The hardness increase in these nanoscale multilayer films results mainly from hindering dislocation movements across the sharp interfaces between two materials having vastly different elastic (particularly shear modulus) properties and lattice mismatch (coherency strain). Hard coatings such as TiN and Ti-C-N/DLC are applied in aerospace systems; these coatings also resist attack by corrosive fluids that are used (as engine oils or lubricants) in aircraft engines and parts.

CONCLUSION

The use of nanotechnology in the lubricants shows enhanced properties in the mechanical field. We have selectively summarized the tribological applications of hybrid polymer nanoparticles as lubricant additives. It has been able to leverage its development by utilizing many technologies. The magnitude of the interactions between two surfaces mediated by a lubricant has been found to be strongly affected by the size, aspect ratio and concentration of hybrid nanoparticles present in it, due to their enhanced steric contribution, packing efficiency and tendency for aggregation.

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