The Advances of Tribology in Materials and Energy Conservation and Engineering Innovation

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Abstract. Tribology has been significantly contributing to materials, energy conservation and engineering innovation. This paper elaborates the development of tribology considering in detail in energy factor, tribological role of efficiency in the society by introducing lubricants which reduces the effective friction while moving the mass which significantly improves overall efficiency of the process all though it was primitive. The objectives of the study of The American Society of Mechanical Engineers (ASME) are working to expand energy conservation, particularly through tribology, by doing things like evaluating the realistic effects of tribological innovation on conserving energy and trying to promote advanced energy technologies, identifying fields the application's location of new or existing Knowledge of tribology is anticipated to result in significant direct or indirect benefits, and so on. The strategy focuses on fluid film and rolling element bearings, consistently sophisticated metal processing, wear and friction reduction, variable power transmission, sealing technologies, automobile engines, and energy technologies. Additionally, the potential savings for various areas are detailed, as is a summary demonstrating the advantages that may be obtained with cutting-edge industrial machinery and processes, and comparing the prospective cost savings with the benefits ratio of the many key program features. road transportation for increasing energy efficiency. It was regarded as the most appropriate and advantageous aspects of tribology at the time to increasing productivity. Since then, numerous studies have focused on the study of industry-based machine and method-specific materials. Also, continuous variable transmissions are now found in many automobiles to enhance vehicle efficiency. Some future challenges were also looked at to plan and see how they can be tackled. The implementation of next level materials in different aspects of technology can lead to growth in the efficiency, quality of engineering parts and machines. This paper is a summary of the improvement in high performance materials both inorganic and organic based. It involves thin hard coverings of their growing importance in tribological improvements for tribo- engineering implementations are looked at and studied. Results from research concerning ceramics and ceramic properties, polymers and polymer properties as well as hard coatings and show the friction and wear attributes and their potential implementation for tribo- engineering. Greasing and friction have a strong relationship with wear. The study of these three topics is essentially what tribology entails. It deals with moving, interacting surfaces in science and technology. To better regulate friction and wear, hard or soft film coating, alloying, and composite structures have all been enhanced. It is accomplished by enhancing the lubricity and wear life of materials

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and surfaces using novel, modified lubricants and ideas that have been put to the test in challenging tribological applications. The development of new generations of self-lubricating coats with multilayered architecture due to recent advances in thin film deposition methods treatments. The field of tribology is crucial to lowering the levels of emissions from various industries because it is being used to cut down on the amount of unnecessary energy used by mechanisms. Understanding the functions of friction and wear between two surfaces that come into contact has been the domain of tribology for many decades. They have applied this knowledge to make mechanisms more energy efficient by only using what is necessary to power them and reducing the amount of energy lost through wear and friction.

1 Introduction

Tribology is study of surfaces in contact that are in corresponding motion. The learning and applications of the concept of wear, greasing, and friction are all part of it. Tribology is a subfield of materials science and mechanical engineering. Material loss from the surface may occur as a result of the exposed face of a hard surface's tribological interactions with substances and the surroundings. Wear is the process that results in material loss wearing, friction (adhesion and cohesion), erosion, and corrosion are the most common types of wear. Abrasion and wear occur in all machine systems with operational constituents in connection (Hwang & Horng, 2016). These phenomena are major causes of system dependability and efficiency degradation due to surplus power utilization and growing material loss(Khadem *et al*., 2017). Using greasing (for frictional or adhesive wear) or make alterations to the surface components of solids through a single or multiple "surface engineering" methods (surface finishing) can reduce wear. Micro- and nanotribology have recently gained popularity. The evolution of brand-new products in electronics, chemistry, biological sciences, sensors, and, in addition, most recent technology is becoming increasingly dependent on frictional interactivity in microscopically small properties. The best product or machinery performance, standard and cutting-edge methodologies and processes are used in the major fields of mechanical, production, automotive, and industrial engineering. As a result, the idea of tribology has been put into practice to improve performance even more. Today, it is critical that tribological knowledge be applied at every stage of design and manufacturing to reduce frictional and wear losses, which will ultimately serve as the best option for the country's economic growth(Hassan *et al*., 2018). Tribologists are currently contributing significantly to the same direction.

The information on tribology helps diminish the unnecessary grinding and wear between two rubbings surfaces or tribo-pair. Utilizing tribology fitting grease and oil instrument can be taken on to limit the grinding and dispense with wear which would lessen the wastage of energy and upgrade the working existence of tribo-pair. The field of tribology is crucial to lowering the levels of emissions from various industries because it is being used to cut down on the amount of unnecessary energy used by mechanisms(Holmberg & Erdemir, 2017a). Understanding the functions of friction and wear between two surfaces that come into contact has been the domain of tribology for many decades. They have applied this knowledge to make mechanisms more energy efficient by only using what is necessary to power them and reducing the amount of energy lost through wear and friction(Efficiency, 2010). An "all hands-on deck" strategy is required to address the significant global threat posed by climate change as the need to prevent and reverse it grows more pressing. This means that all strategies that can reduce emissions need to be implemented simultaneously.

Conservation of Energy can be characterized as an endeavor to cut back on the consumption of unnecessary energy and the use of energy services. This can be done through changing behavior to use fewer services or by using energy more efficiently (using less energy for continuous services) (e.g., driving less). Energy efficiency is a way to save energy and has various advantages, including lowered greenhouse gas emissions, a smaller carbon footprint, lower costs, and water and energy savings.

In the design and construction of buildings, energy conservation is crucial. Since the 1970s, it has gained prominence as buildings now utilize 40% of the country's energy. Energy conservation has grown more crucial as the effects of climate change and global warming have come under scrutiny. Energy can neither be created nor destroyed but can change from one form of energy to another. (“Law of conservation of energy - Energy Education”) For example, when thermal energy is converted to power a vehicle, or when the kinetic energy of a water stream is converted from hydroelectricity to electricity But energy must be transformed by machinery from one kind to another. This machine experiences extremely high energy losses as a result of the friction and wear of its parts during operation, as well as extremely high associated expenses. These losses can be reduced by using green engineering techniques to extend component life cycles. Since 1991, December 14 has been designated as Energy Conservation Day. Energy conservation - the law of energy balance, ways to preserve

Energy can be conserved through reducing waste and loss, improving operations, and maintaining equipment more effectively.

Energy savings can be achieved by modifying user behavior through user profiling or user activity, monitoring devices, off-peak load shifting, tuning devices, and providing energy savings recommendations. Observing device usage, profiling energy consumption, and revealing energy consumption patterns in situations of underutilization can help identify users' energy consumption habits and behaviors. Creating an energy profile for your devices helps you identify inefficient devices with high energy consumption and energy load. By adjusting these devices or switching to off-peak hours, users can see the energy consumption of their devices before deciding on energy-saving measures. Seasonal variations also have a large impact on energy loads, requiring cooling in the warmer months and heating in the colder months. Balancing energy load and user comfort is complex, but essential for energy savings. On a global scale, stabilizing population growth can also reduce energy consumption.

On a larger scale, a variety of factors affect patterns in energy use, such as international politics, population expansion or decline, technological advancements, economic progress, and environmental concerns.. On a small scale, the following factors affect energy-saving capabilities, including seasonal variations and instrument accuracy, accuracy, and recall. Other important attributes that impact energy savings include user activity detection, user energy consumption profiling, user comfort, device energy consumption profiling, device weight, off peak scheduling, energy scenario planning, seasonal variations, and energy saving recommendations. Seasonal variations have a significant impact on energy consumption, as energy demand for cooling increases in the summer. Seasonal energy consumption fluctuates and must be considered when developing energy-saving technologies.

a committee of the Organization for Economic Co-operation and Development defined a new scientific field called tribology. It focuses on friction, wear and lubrication of surfaces interacting in relative motion. The word 'tribology', which means 'rubbing' or 'sliding', comes from the Greek word 'tribos'. Tribology is concerned with understanding the behaviour and performance of machine and equipment components whose surfaces are subject to relative motion from other components or loose materials [1]. Therefore, as shown in Figure 1, tribology has different uses in different industries. For example, it can be used in medicine to better understand how joints between bones work [2]. Tribology is a broad field, and the three basic elements of tribology are friction, lubrication and wear (because they are the most important). However, tribological research also includes mechanics of surface in contact, surface damage and optimization processes. These three fundamental areas are of paramount importance as they provide properties and interactions that also help enable customization of tribological systems and maximize system effectiveness, performance and reliability. However, for this paper, wear and different methods of reducing wear will be our primary objective.

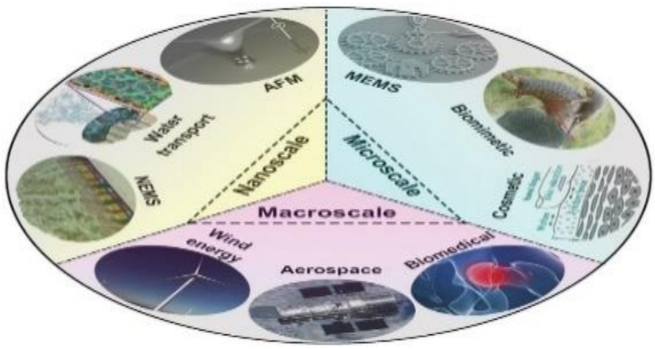

Figure 0. Applications of Tribology [3]

2 Literature Review

2.1 Wear

By definition, wear is the removal of material from a surface. It is the gradual deterioration of one or more solid surfaces in contact as a result of relative motion [4]. Friction causes wear, and the higher the friction, the greater the wear. As shown in Figure 2[5], there are several mechanisms by which wear occurs, and surfaces can wear due to one or more of these mechanisms simultaneously.

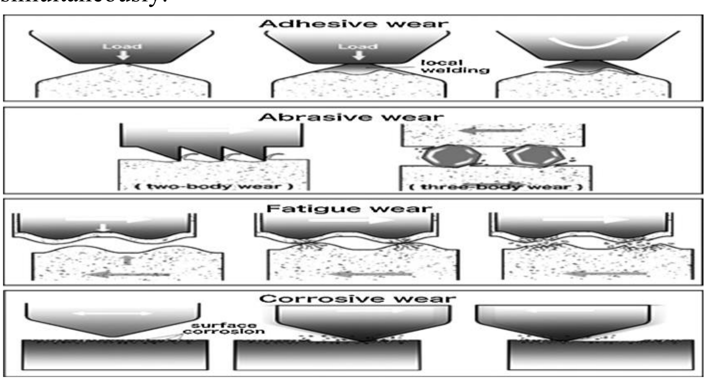

Figure 0. Types of wear

One of these mechanisms is called adhesive wear. This is when wear occurs as a result of the adhesion of two colliding material surfaces [6]. This type of wear result in material gain on one surface and loss of material on the other surface, or vice versa. This type of wear mechanism is amplified, when there is an increase in surface energy, and this amplification depends on the adhesive property of the materials in contact. Materials with low adhesive force might not undergo adhesive wear. Upon contact, most solids adhere somewhat. However, naturally occurring contaminants such as oxide films, oils, and contaminants generally prevent adherence. Also, uncontrolled exothermic chemical reactions between surfaces usually lead to low-energy states of the surfaces in contact. Another type of wear is the abrasive wear, and this occurs when a harder material surface rubs against a softer material under load, the softer material degrades over time due to abrasion [7]. There is also a type of wear which is dependent on cyclic stresses on surfaces, this type of wear is called fatigue wear. This is when crack initiation and propagation are caused by frequently repeated localized stresses between two surfaces. Debris is produced when material flakes off the surface of a crack after a certain number of cycles. High-cycle fatigue and low-cycle fatigue are the two recognized mechanisms of fatigue wear. High cycle fatigue typically results in longer part life due to the higher number of cycles before fatigue occurs [6]. Low-cycle fatigue causes parts to fail more quickly, with fewer cycles going through before failure occurs. There is also the corrosive wear, in which deterioration of the surface of a material is caused by exposure to corrosive environments. Corrosive wear can occur in dry or wet conditions as long as the environment is corrosive. Oxide layers usually protect metal surfaces, act as film between metal surfaces in contact, and prevent adhesions from forming, which also reduces the chance of adhesive wear. In this regard, oxides help reduce the rate at which metallic materials wear. However, material properties and contact conditions have a significant impact on whether such positive effects can be obtained. If the hardness of the metal under the oxide layer is low, or if the contact load is higher than average, the metal will plastically deform and the hard surface flaws will penetrate the thin oxide layer to replace normal metal-to-metal contact (Swain et al, 2020). Depending on the mechanical and chemical properties of the contacting metal, this can lead to abrasion or adhesion. Wear can only be reduced, but it cannot be prevented. There are different methods in reducing wear, which is dependent on the area of application of the surfaces in contact. Some of the methods are briefly explained.

2.1.1 Effects of wear

Finding effective wear prevention strategies is one of the key goals of tribology because of the significant impact that wear has on a product, machine, tool life, and the operators [4]. The failures brought on by wear can have significant negative effects on the economy, the environment, and public safety. Friction causes wear and a significant amount of energy is lost to friction between contact surfaces. Further waste occurs due to wear between contacting materials because it takes a lot of energy to replace a part. One of the effects of wear is noise pollution; wear increases the distance between various machine parts, causing mating parts to collide and generate continuous noise. Wear also leads to low quality work and reduces the efficiency of a machine because when there is an increase in clearance due to wear, it reduces the rigidity of the machine, prevents the machine from performing at its maximum capacity, and ultimately reduces the quality of the product [4]. There are several effects of wear on machines and one major and often effect of wear on machines is vibration; this occurs when machine clearance settings change, which causes vibration and result to improper operation and poor-quality output. Due to vibration, misalignment among machine parts occurs. Misalignment occurs when wear (in the case of shaft and bearing assembly) increases the clearance between the bushing and the shaft, increases the load on the ball and roller bearings, and causes the shaft to become misaligned. Vibration also leads to leak development, were wear of parts causes loosens nuts on couplings and flanges, which eventually cause leaks [8]. Wear also causes overheating; if the temperature of a machine is higher than the designed working temperature, the machine is said to be overheating. Overheating weakens components, leading to malfunctions, changing of the metal structure of parts and eventual machine failure.

2.1.2 A Review on the Smoothing of Surfaces to Prevent Wear

The measurement of a material's surface roughness is its closely spaced micro-irregularities. In the field of tribology, rough surfaces frequently have higher coefficients of friction and wear more quickly [9]. Roughness is frequently a reliable indicator of how well a mechanical component will perform since surface irregularities may serve as places for the start of cracks or corrosion. The risk of wear and deformation increases with increasing surface roughness because friction between surfaces increases. The lifespan of an object can be greatly increased by being aware of the causes of how surface roughness increases, how to avoid them, and how to reduce surface roughness. A work piece's surface roughness can be caused by or increased by a variety of circumstances throughout an operation. A few of these are; Feed marks of cutting tools, vibrations during the manufacturing process which leaves chatter marks on the workpiece, surface irregularities brought on by workpiece material rupturing during a metal-cutting operation, surface changes brought on by the workpiece's deformation from the force of the cutting action and unevenness in the machine tool itself, such as crooked guiding ways [9]. In a metal removal process such as machining there are different methods of reducing wear such as variation of cutting speed and feed rate, material of cutting tool etc.

2.1.3 A Review on the Use of Nanotechnology to Prevent or Reduce Wear

Applications of nanotechnology are fulfilling the promise of nanotechnology to help society after more than 20 years of fundamental study in the field and more than a decade of committed Research and Development study [10]. Nanotechnology can be seen applied in areas like industries, medical sectors and for energy uses. It is also applied in the area of material science because of its durability and resistant to wear. These are just a few of the technological and industrial domains that nanotechnology is significantly advancing, if not revolutionizing. Nanotechnology advances scientific advancements and research priorities that are directly relevant to the development of lubricant-grade nano-polymer composites. The polymeric materials must have allowable environmental, heat and thermal resistances that are standard and acceptable for tribological and engineering applications, as well as good mechanical strength, lightness, ease of processing, adaptability, and cheap manufacturing costs. The properties of polymer matrices, especially the mechanical properties, can be significantly improved by collecting tiny inorganic particles. A combination of qualities such as good toughness, stiffness, and high wear resistance, led to the development of nano-composite materials. The development of nano-composites with highly enhanced tribological properties necessitates a thorough analysis of their nanostructure and the effects of nano-fillers. Due to significant advancements made in recent years, nanocomposites have recently gained a lot of scientific interest. The nano structure, geometry, and the material itself are the factors that affect the efficiency of lubricating elements in a system. Introducing nanoparticles into lubricants is a difficult and complex operation. Since friction coefficient, wear, scar diameter are all dependent on additive concentration, also the level of nanoparticles in lubricants is an important factor [11]. When friction occurs, heat is generated, which leads to a higher temperature breakdown point for lubricants. The performance and useful life of lubricants are considerably enhanced by the addition of inorganic nanoparticles

2.1.4 A Review on Wear Resistant material and material modification to prevent wear

The most frequent reason for material replacement in the industrial sector is probably wear. In all applications, wear is a universal constant in moving equipment [12]. The ability of a material to withstand loss of materials caused by a mechanical action is referred to as wear resistance. A material can be tough and wear-resistant but not particularly hard, and a hard material can be tough but not particularly wear-resistant. In some applications, the use of certain materials with higher wear resistance (copper-based alloys, for instance) is constrained, for example in applications such as food processing. Specific alloys have been created for these applications to get rid of specific wear, such as galling, without contacting vital parts of the process (food). A variety of "dairy metals" have been developed for purposes in food processing to prevent this type of wear. Specifications for high-performance cobalt-based alloys are common where corrosion resistance is the main issue. Wear is material removal between moving surfaces in contact. Apart from hard surfaces, liquids, and abrasive particles, can all be considered contacting substances. Processes like machining, cutting, grinding, and polishing can all lead to wear. Wear is a very expensive problem since it causes components to degrade or fail, which is extremely undesirable in the majority of technological applications. It is frequently not as dangerous in terms of safety (or as sudden) due to the fact that wear is typically anticipated, like a fracture [12].

2.1.5 Typical Wear Resistant Materials Design Methods

Since wear is material removal between surfaces in relative motion there are different materials which can reduce wear, but it is dependent on the mode of application. These wear resistant materials, are dependent on different factors (temperature, contact pressure, materials combination, environment,). The hardness of a material is directly proportional to the wear resistance of the material, that is the higher the material hardness, the higher the wear resistance and the lower the material hardness the lower the wear resistance which implies that the wear rate is high. Therefore, wear resistance is dependent on material hardness. Certain materials have unique wear properties, and one of such materials is Ni_3Al – Alloy. This alloy of nickel and aluminium known as nickel aluminide has metallic and ceramic properties. Its high strength, low density and high thermal conductivity make it perfect for specialized applications like coating gas turbine and jet engine blades [13]. Tungsten Carbide is another type of these wear resistant materials. In the mining and mineral processing industry, the main aim of such industries is to reduce impact wear caused by the collision of high energy interacting bodies in order to increase the life-span of equipment. Therefore, in this industry the finest wear-resistant materials must be used. For instance, tungsten carbide is widely utilized in mining, roller-cutters, plow chisels, tunnel boring machines etc. For high temperature applications, Silicon carbide can be utilized. SiC is a crystalline silicon and carbon combination that is extremely hard and is created synthetically. Silicon carbide is nearly as hard as a diamond. Therefore, due to its hardness, they are suitable for grinding wheels. Silicon carbide is useful where high-temperature is required because of its high thermal conductivity and resistance to different form of chemical reaction. Apart from other compounds, alloys can also be coated to a desired wear resistant property. Alloying elements introduced by diffusion techniques help martensite develop after intermittent quenching. During this procedure, at the surface of the steel, the concentration of the alloying element increases. Different types of diffusion methods can be used to coat metals, or alloys, one of such is carburizing.

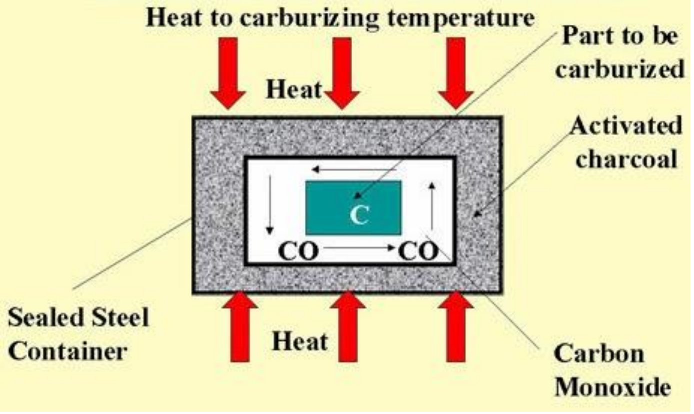

Figure 3. Carburising Process [14]

As shown in Figure 3, carburizing is a procedure whereby diffusion from the environment raises the carbon concentration at the surface of a ferrous alloy (often low-carbon steel). Carburizing creates a product with a medium case depth, hard, highly wear-resistant surface, and a high bending strength. Nitrogen can also be diffused to the surface of a metal, and this process is called nitriding. Nitriding, is a case hardening procedure whereby diffusion from the surrounding environment raises the surface nitrogen concentration of a ferrous alloy to produce a case-hardened surface. Nitriding creates alloys with high wear resistance (shallow depth cases), high bending strength and high capacity to withstand surface load. Amongst other types of hardening, there are titanium-carbon and titanium-nitride hardening, which can be applied to tools to increase their performance and lifespan. There are also case-hardened steels, which is based on martensitic transformation to increase their wear resistance [15]. One of the most popular ways of hardening, generally utilized for steels, is martensitic transformation hardening (i.e., stainless steels and carbon steels).

Thermal hardening is another method of increasing the hardness property of materials, there are various types and they are dependent on the mode of heating. Flame hardening is a type of thermal hardening. In this type of hardening a single torch is used to quickly heat the metal, which is cooled rapidly using water [15]. As a result, the object's surface develops a layer of martensite, but its interior core continues to be tough and elastic. 0.3 to 0.6 weight percent concentration of carbon is required for this method of hardening. Induction hardening is a type of surface thermal hardening method that rapidly heats the metal using induction coils before swiftly cooling it, typically using water. As a result, martensite forms a "case" on the surface. This type of hardening requires a carbon concentration of between 0.3 and 0.6 weight percent. Another method of thermal hardening is the laser hardening. A laser beam is used which quickly heats the metal before cooling (generally by self-quenching). As a result, the object's surface develops a "case" of martensite, but its interior core continues to be strong and elastic.

2.1.6 Application of Diamond-like coatings (DLC) to prevent wear

DLC is a type of amorphous carbon coating with a bond network similar to that found in graphite and diamond, and the amount of these bonds greatly affects both the physical and chemical properties of the coating. High hardness, good wear resistance, high corrosion resistance, high temperature, chemical resistance and low friction are typical properties of DLC layers. Due to their superior tribological performance, DLC coatings are widely used in automotive engine components and other engineering and medical applications to meet the growing demand for fuel efficiency and a clean environment. Environmental factors such as temperature, relative humidity, etc. greatly affect the friction performance of DLC. The use of DLC in automotive engines is essential, as automotive components operate in environments that promote high temperatures, high loads, partial lubrication, and oxidation. Since temperature and other environmental factors have a great influence on the friction and wear stability of DLC coatings, lubricating oil is used to protect the coating from an aggressive environmental condition and it also act as a coolant to keep the temperature within acceptable limits. Additionally, the DLC coating and lubricant additives interact to form a low-friction, wear-resistant tribo-film [4]. Most of the lubricants produced are engineered to form tribo-films that stick to ferrous materials. Engineering or developing new lubricants for DLC coatings (non-ferrous type coatings), is fundamental to understanding their interactions with lubricant additives.

The use of diamond-like carbon (DLC) coatings in automotive valve trains, especially camshaft drive assemblies, is being explored. A variety of power transmission mechanisms can be found in power train assemblies such as cam follower assemblies [16]. Power transmission devices operate in harsh tribological contact environments with maximum hertzian stress near 1 GN/m^2 and temperatures between 100 and 150^oC. The thermochemical properties and surface finish of parts are essential for proper operation, as they are often partially deficient in lubrication. For motorsport applications, DLC offers better wear resistance than steel alone. For passenger cars, the high hardness DLC imparts to steel mating surfaces and the corresponding low coefficient of friction improves fuel economy and reduces wear. DLC has the advantage of reducing disc wear, but increases camshaft wear. The wear mechanism of DLC depends on the type of oil.

2.1.7 Application of wear resistant materials

Materials used in the aerospace industry have high tolerance, optimum density and other desirable mechanical properties. Materials mostly used are Aluminium, Magnesium, Nickel and Titanium based alloys. Fretting wear is a major challenge faced in the aerospace industry most especially in bearing shafts and bolted connections; an effective solution to this problem is to utilize thermally stable wear resistant coatings with desirable reinforcements over an alloy [3]. The properties of the reinforcement used is very important, because the particle, size and uniformity in reinforcement distribution (a homogenous distribution within the matrix has been shown to have an outstanding effect) have a significant effect on the wear resistance of coatings. [17] performed analysis on the wear resistance and strength of Aluminium, zinc, magnesium and copper alloys by adding 7.5wt% of boron carbide and 2.5wt% to 10wt% of silicon carbide. Potassium titanium fluoride was used as a bonding additive to enhance the bonding between the reinforcement and the matrix, the outcome of the analysis showed increased wear resistance and strength of the alloy.

Wear resistant materials also find application in the automobile industry. Steel and aluminium alloys are the most used materials in the transportation industry (automobile). About 82 exajoules of energy is used by road vehicles, and about 32% of this energy is used to overcome friction, were about 10% is energy consumption caused by wear [18]. Therefore, there is rising need for the use of wear-resistant materials (Additive manufacturing metallic materials) and superior lubrication methods. Additive manufacturing metallic materials are usually infused with zirconium nanoparticles as crystal nuclei which improves their wear resistance and strength [19]. Use of wear resistant materials is very important in the design of wind turbines; due to high loading condition and harsh environmental conditions, the turbine blades undergo fretting, abrasion and erosion wear, which affects its performance. According to statistics, the first two years of wind turbine in operation, about 25% of its efficiency is lost due to wear [20]. Therefore, a number of wear resistant coatings such as cobalt, nickel and nickel-aluminium based alloy coatings are used to protect the surface of the blade from severe wear.

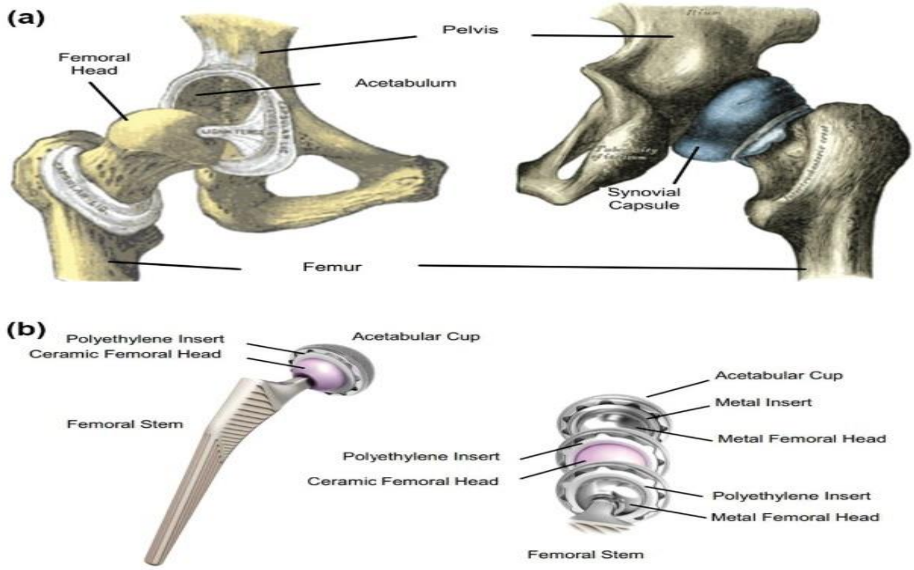

Figure 4. Body Implants[3]

Wear resistant materials also find use in the biomedical industry; Figure 4, describes the anatomy of hip joints and shows an example of artificial joints which can be used as hip replacements. Body implants could get corroded due to the chemical composition of its environment, wear increases the damage of implants by depleting the protective oxide films used for body implants which could cause cytotoxic and genotoxic effect [21]. Cobaltchromium-molybdenum and ceramics combined with hard coatings, also titanium alloys are commonly used materials for implants because of their high wear, corrosion resistance property, and high strength

2.2 Lubrication

Lubrication is another method of reducing wear, and if not done properly, there will be little to no reduction in wear. Adequate lubrication depends on the type of oil, lubrication method, location selection, and lubrication amount. To increase the smoothness of the friction surface and avoid metal-to-metal contact between surfaces in contact (mating surfaces), lubrication creates a lubricating film in the gap between the mating surfaces [8]. Lubrication is a wear reducing mechanism that reduces the wear of surfaces moving in close proximity to each other by introducing a substance called a lubricant between the surfaces to carry the load [22]. Due to the lubricating fluid's frictional and viscous resistance to movement between surfaces, the applied load is usually supported by the pressure generated within the fluid. Properly lubricated equipment can operate smoothly and continuously without experiencing excessive wear, excessive loads, or seizure of bearings. When lubrication fails, metal or other material types can rub against each other violently, causing heat generation, failure, and catastrophic damage. According to [23], mixed lubricants take advantage of the properties of different lubricants. These are practical lubricants that provide the best protection for whatever application (as they made based on the area of application) while minimizing the wear and friction caused by sliding between the two contact surfaces. Preventing overloads is important as it has a large impact on the wear rate of parts. Overloaded lubricant blows off the oil film between parts and increases the forces on the wear surface. If the gap is too small, a lubricating oil film cannot form on the wear surface, resulting in metal-to-metal contact. Motion is lost when the space between contact faces increases. Lack of lubrication causes parts to wear out quickly, causing machines to vibrate and make noise.

2.2.2 Oxidation and Thermal Failure

When oxygen and the base oil in the lubricant react, oxidation failure happens. If the oil has anti-oxidant and anti-foam additives, the oxidation process can be slowed down; but, if not, the process will accelerate, especially in the presence of water and components like copper and iron, which will cause the oil to be oxidized. Molecules of hydrocarbon in the oil will oxidize and produce a greasy sludge that contains hazardous corrosive acids [24]. The results of these include increased specific gravity, acidity, lubricant viscosity, oil darkening, foul odour, quick additive depletion, and wear on the bearing surfaces. They will also hasten the oil's degeneration and lessen its lubricating qualities. Thermal failure may result from the transfer of a localized or external heat source to the lubricant or from the adiabatic compression of bearings and air bubbles in pumps. According to Boyle's law, entrained air undergoes this process when it is compressed and heated. The lubricant decomposes as a result of the heat produced, and the hydrogen loss that results produces carbon deposits and sludge [24]. Reduced lubricant viscosity, oily suspensions that smell like burned food, a drop in lubricant viscosity, coking and varnishing on the bearing surfaces are the symptoms of these impacts.

2.2.3 Liquid Lubricants

There are several ways to categorize liquid lubricants, but the most popular way is based on the type of base oil utilized. mineral oils (gotten from crude oil), water, vegetable oils (produced from animals and plants), and synthetic oils are notable base oil kinds. Lanolin, a natural water repellent found in wool grease, is another. Liquid lubricants are usually viscous fluids that need to be circulated through the various machine components using mechanical rotary systems like bearings or gears [24]. Over the course of a system's intended life, a liquid lubricant's main job is to reduce friction, wear, and surface damage. Liquid lubricants' secondary purposes include the removal of heat, filth, and wear debris, as well as the prevention of corrosion. In some situations, such as hydraulic systems, liquid lubricants can be used to transmit energy or force.

[25] conducted an experimental investigation on the wear prevention properties of a trimethylolpropane (TMP) ester based on palm oil as an engine lubricant; The biodegradable palm oil used to make the TMP ester has high lubricity qualities, including viscosity index (VI) and a high flash point temperature. The three different lubrication regimes of hydrodynamic, elasto-hydrodynamic, and boundary lubrications were all examined. Under these test conditions, numerous TMP samples' friction and wear characteristics were evaluated. It was discovered that adding up to 3% of a TMP ester made from palm oil to a regular lubricant can reduce friction by up to 30% and reduce the maximum amount of wear scar diameter. The highest load carrying capability (220 kg) was also discovered from the 3% TMP contamination. The addition of 7% TMP to hydrodynamic lubrication minimizes friction up to 50%.

In order to determine the effects of additives on water-based lubricants, [26] performed experiments, in which; Anti-corrosion properties friction and anti-wear, were examined for separate solutions of anti-microbial agents; amines (ethanolamine oligomers, ethylamine oligomers), anti-foaming, anti-corrosion and friction modifiers; glycols. The result showed a considerable improvement in the tribological characteristics of water at the tested concentrations of the additives. The substance with no corrosion and the least friction was triethylamine, which also performed the best. The anti-wear properties of ethylene glycol and 1,4-butylene glycol were not excellent, but they greatly reduced friction. Ethanolamines, which have characteristics of both amines and alcohols, increased wear and corrosion but greatly decreased friction.

2.2.4 Solid Lubricants

Anti-wear coatings, solid lubricants, and self-lubricating composites are used in spacecraft design where greases and oils cannot be used due to the need to prevent volatility of lubricant and where the application calls for accelerated testing, higher electrical conductivity, significant temperature variation, or operation in boundary conditions [27]. Solid lubricants are mostly grease, powders or semisolid suspensions of liquid and solids. Tungsten disulphide (WS_2), graphite (C) and molybdenum disulphide (MoS_2) are a few of the more well-known powder lubricant ingredients. Grease is a sophisticated semisolid lubricant made of a liquid base oil and a variety of thickening agents made of soap or other materials. Various additives, such as powder form lubricants, can be added to grease, and has a viscosity very similar to paste. They come in a variety of viscosities and are referred to as block greases since they can range from being semisolid to being solid. Due to the particular equipment needed for their production, greases are frequently processed in specialized grease-making facilities [24].

Because friction has negative consequences on durability and environmental compatibility, The reduction of mechanical failures in moving mechanical systems caused by wear and friction has drawn more attention. [28] researched on using graphene as a self-lubricating solid or as a lubricant additive. Due to graphene's two-dimensional structure, graphene exhibits unique friction and wear properties not found in commonly used materials. The key advantages for its exceptional tribological behaviour are its excellent chemical inertness, incredible strength, and easy shear capability on its densely packed and atomically flat surface. Graphene can be utilized as a colloidal liquid or solid lubricant. It may be used in micro or nano-scale systems, such as nano electromechanical systems (NEMS) and microelectromechanical systems (MEMS), with oscillating, rotating, and sliding contacts to reduce stiction, friction, and wear because of its ultrathin and multi-layered structure.

2.2.5 Gaseous Lubricants

Compared to liquid or solid lubricants, gases have a far lower viscosity, higher compressibility and a lower heat capacity. Air, other gases, steam, and the vapours of liquid metals are a few examples of gaseous lubricants [24]. Identification of wear and friction processes of gases used in non-lubricated DIN 100Cr6 (AISI 52100) bearing steel contacts under difficult operating conditions (high-frequency oscillation at high contact pressure) was studied by [29]. The gas atmospheres of nitrogen (N_2), argon (Ar), and carbon(iv)oxide (CO_2) were used, with the atmosphere of air serving as a reference. In order to establish a connection between the properties of various tribo-chemical products and the observed friction and wear processes, the chemical reactivity of the gases with the steel surfaces was investigated. When compared to air atmosphere, it was discovered that N_2 and CO_2 atmospheres significantly reduced wear, with a wear reduction comparable to the usage of a liquid lubricant. Although friction was 60% less in the CO_2 environment than in the air environment, it was measured to be somewhat greater in the N_2 atmosphere. In comparison to the air environment, the Argon (Ar) atmosphere had a bit more wear and friction.

2.2.6 Nano Lubricants

All mobile parts utilized in machinery, mechanical tools, and transportation methods have had lubrication as a major design consideration. The resistance to motion of two touching object as a result of minute complex interactions at their surfaces is referred to as surface friction. The topography and geometry of the surfaces as well as the overarching factors that allow them to slide past one another, such as loads, temperature, atmosphere, etc., have an impact on these interactions. Wear frequently occurs in combination with this friction force. Corrosion, pollution, and other environmental factors can exacerbate wear and friction, although lubrication reduces both of these factors.

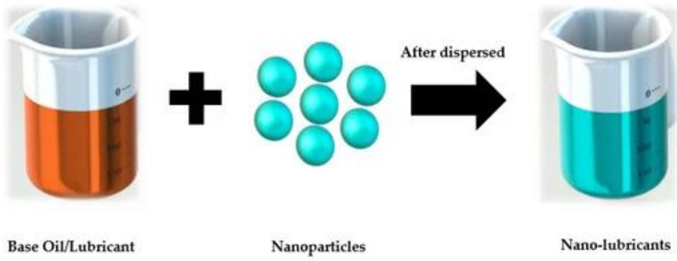

Figure 5. Nano-particles as an additive

The basic aim of applying lubricants is to keep a reasonable distance between the moving and sliding surfaces, in order to minimize friction and material damage. Lubricants can lessen the amount of surface wear and tear, metal expansion, and material deterioration by preventing direct metal to metal contact that may exist between rubbing surfaces. Lubricants can also serve as a coolant for metals because of its ability to transmit heat and additives, also play an important role in the properties of a lubricant as shown in Figure 5, nano-particles can be added to base oils to improve the tribological properties of the oil. The general geometrical aspects of the environment and the surface contact can affect the tribological characteristics of a system. There are several properties of lubricants that determines the mode of application of a lubricant. Viscosity is one those properties. Viscosity is a fluids resistance to flow; liquids have the property of offering resistance to their own flow. The greater the viscosity, the more friction can occur and the lower the viscosity the lower the possibility of friction. So, there is a directly proportional relationship between friction and viscosity [30]. The flash point of an oil is also an important property, it is the heat intensity at which the oil ignites but does not sustain a flame. A good lubricating oil should have a flash point of at least 200 degrees Celsius. Another “temperature” property is the pour point: it is the minimum temperature at which an oil will move. The cloud point is the temperature at which it begins to seem hazy or foggy. The thermal stability property of a lubricant is the capacity of lubricants to withstand breakdown at high temperatures. For example, sludge can be caused by a lack of heat stability. The fire point: it is the level of temperature at which oil ignites and maintains a flame while the oxidation stability property is the capacity of a lubricant to withstand the chemical reaction with oxygen. Increased viscosity and the development of sludge deposits are possible outcomes. Additionally, metal catalysts, heat, and light can hasten oxidation.

The bulk of surface materials in the industry that can come into contact with one another (such bearings, seals, and gears) are lubricated with specific oils to decrease wear and friction. Numerous studies on the tribological properties of lubricants based on nanoparticles have been published. These investigations demonstrate how the geometry and concentration of the nanoparticles in the lubricant have a significant impact on the wear and friction phenomena that can occur in any mechanical system [31]. A few tenths of one percent by weight of nanoparticles, or even less, could be used to enhance the system's tribological characteristics. In low load situations, friction reduction is primarily attributed to the bearing-like behaviour of nanoparticles, which roll between the contact surfaces while maintaining their shape. In conditions of high load, nanoparticles are formed and deposit a coating on the crests of surface roughness, which might diminish direct contact between the asperities and lessen wear. It can be said that abrasive resistance of polymers depends on particle size. The addition of nanoscale fillers has led to surprising results. A very good number of filler particles are stable, and when they are bigger than the abrasive particles, they increase the composite's resistance to abrasion. Elimination of filler particles, and reduction of filler size leads to a decrease in the abrasion resistance. This is not the case on the nanoscale. For instance, adding nanoscale $CaCO_3$ as an additive reduced material loss from abrasion by a factor of 2 even with only 3 weight percent of filler nanoparticles. It also concurrently lowers the friction coefficient and improves wear resistance [11]. The friction coefficient, which is determined by dry sliding on steel, monotonically decreases as the weight % of fillers rises. In order to reduce friction and limit power loss, lubricants aid to minimize wear in contacting surfaces. The addition of nanoparticles to base oil will improve a certain lubricating oil property, such as boosting load bearing capacity, improving friction and wear resistance, etc. Numerous issues with conventional lubricants that contain phosphorus and sulphur can be resolved by nano-lubrication. When suspended in a lubricant, nanoparticles have the ability to pass through small gaps that exists between abrasive surfaces in contact, and results in change in the tribological performance of the contacting surfaces. As a result, nanoparticles provide an alternate method of lubricating by bringing third body entities into the contact directly. Although balanced formulations have yet to be created, nanomaterials offer the potential to improve several lubricant characteristics [32]. Nano particles such as TiO_2/CuO have been discovered to improve the lubricating properties of lithium grease according to [33] these nano particles improved the wear resistance of lithium grease and decreased its coefficient of friction. For roughly the same amount of TiO_2 and CuO, titanium oxide significantly reduced the coefficient of friction between contact moving surfaces by about 40% and CuO reduced the coefficient of friction by about 60% in comparison to lithium grease without additives

2.2.7 Application of Lubrication in Gears

The power losses in gears consist of contributions from friction, lubrication, and gear windage, according to a study by [34] on the impact of lubrication on gear performance. Even while working at high temperatures, ester gear oil and grease increase efficiency; yet, thermal effect must be ignored. A lubricant with increased viscosity performs better in terms of anti-wear and energy conservation. The efficiency of the gearbox is generally higher with spray lubrication than dip lubrication. Friction and power loss are dramatically increased by when there is lack of lubrication. According to research from [34], higher viscosity lubricants and anti-wear and extreme-pressure oil additives extend the life of gear surface strain. Lack of lubrication exacerbates thermal effects, resulting in significant wear damage and scuffing. Unless the jet velocity is low, jet lubrication provides a longer fatigue life than dip lubrication. According to sliding-rolling conditions, the lubricating fluid flow may cause fatigue cracks to propagate. Failures caused by oil degradation can appear as white etching or dark etching zones. Gear lubricants with the proper greater viscosity were found to be able to reduce vibration and noise [34]. Oscillations in rattling can be brought on by a spike in lubricant temperature that reduces oil viscosity. Furthermore, ignoring lubricant damping can result in an overestimation of rattle, which implies that damping lessens rattling vibrations.

2.2.8 Application of Lubrication in the Aviation Industry

Lubricants are used to lessen friction and wear. High-quality aviation lubricants are needed for the rust and corrosion protection that they may provide for seldom used aircraft [35]. Unused aircraft are more likely to get corrosion and rust, among other problems that might result due to in-activity. The easier it is to properly and efficiently lubricate and maintain an airplane, the more frequently and regularly it is flown. Aviation oil eliminates build-ups of varnish, grunge, and sludge in the oil pan of an airplane. However, a clean ring belt region and improved combustion control also result from lubricants that keep the airplane engine running smoothly. When piston rings can move freely, the engine operates more effectively, has better ring seal, uses less oil, and creates less exhaust fumes. The movement of the rings within the grooves is restricted by a dirty ring belt, which prevents them from sealing, as a result, there may be pressure created between the ring face and cylinder wall, which could result in wear [36]. Oil is used more frequently to cool air-cooled aviation engines than water-cooled automobile engines. About 40% of the engine's cooling capability is normally provided by automotive oil. In engines used in airplanes, a bigger portion of the engine's heat must be transferred through the oil. Oil acts as a heat-transfer medium, that is it removes heat from moving parts as it passes through the crankcase and oil coolers, continuously cooling the engine's bearings and piston rings. Aviation oil also serves as a seal between the cylinder walls and the rings, as well as helping to seal the gasketed parts and the synthetic seals for the crankshaft [35]. Oil helps to maintain a seal as it spreads around certain areas. In order to ensure that the seal's materials are suitable and that the seal lasts as long as possible, aviation oil must be of a formulation or a mix. Among the most crucial aspects of aviation oil are its lubricating qualities. A viscous and strong oil coating between parts in motion is necessary for proper lubrication in order to minimize wear and friction. An aviation engine's outer boundary, in the area above the cylinders, has boundary or mixed film lubrication. The top cylinder is the hardest part of the engine to lubricate because the oil rings scrape much of the oil coating from the walls of the cylinder before it gets there. To safeguard the engine at startup, lubricant must still be present in the upper cylinder. In addition, after a month of inactivity of an engine, several lifters have been loaded to their maximum spring pressure and pushed up against cam faces [35]. It takes some time for oil to once again reach all of those surfaces once the engine is running. Therefore, at such essential boundary locations, you require good boundary or mixed film strength. In the cam and crank journal sections, oil film retention is less important during start-up. An airplane engine has a continual lubricating coating between any parts that might rub against one another when everything is working properly. It would take a very long time for a component to wear out due to the minuscule wear that the lubricant flow itself may cause. The combination of viscosity and velocity is needed to keep the oil where it should be between moving parts. In an aircraft engine, oil viscosity matters more than in an automobile engine. According to [35], the dependence on the viscometrics (viscosity properties) of the oil increases with the amount of additives present. Without additional additives, the lubricating potential of a base oil may be restricted. In order to avoid pre-ignition or detonation in aircraft engines, additives used in automotive or diesel truck engine lubricants, such as ash-bearing detergents and anti-wear zinc-dithiophosphate, cannot be utilized in aviation oil.

The viscosity index is a crucial factor in viscosity measurement. The viscosity index is an arbitrary numbering system. Lower values indicate that an oil's viscosity changes more as the temperature rises, whereas higher numbers indicate that it changes less. The viscosity index of single grade oils normally ranges from 90 to 110. Multigrade oils that have a viscosity index of 150 or higher are better able to withstand drastic temperature changes and maintain their viscosity properties. The viscosity index of some automatic transmission oil can reach 200 due to its extreme multigrading. Applications including automatic transmission fluid, aviation oil, power steering fluid, hydraulic fluids, and gear oil frequently use multi-grade oils. Base oils can have their viscosity index increased by adding viscosity modifiers, commonly referred to as viscosity index enhancers. The viscosity index of aviation oils can be changed using a variety of polymers. Oil formulators can choose the viscosity modifiers with the best performance and price attributes because they come in a variety of molecular weights

2.3 Cutting and Grinding

For a metal removal process such as machining, a leftover cutting face will be seen on the surface after a cutting tool has cut a workpiece. The residual size of a workpiece is influenced by the feed rate, edge radius, main/auxiliary deflection angle, and tooltip arc radius. By changing the feed rate and angle while the part is being machined, the deformation and cutting area of the part can be reduced. Another effective method to reduce surface roughness and stop plastic deformation is to increase the cutting tool's rake angle [37]. In order to reduce plastic deformation and stop the growth of tool burr and scale, the equipment chosen for the cutting operation should also be in accordance with the properties of the material.
Grinding is a method for performing fine machining. The degree of hardness and speed of abrasive grains is extremely high. It is possible to achieve surfaces with high machining precision [38]. Because of the benefits of grinding, the temperature in this particular machining process can reach quite high temperatures, deepening the plastic deformation, which causes the remaining chips from the milling process to be small. The majority of the fragments are extruded during the grinding process. During the plastic deformation process, the face of the work piece will have a relatively high temperature leading to a reduction in plastic deformation, which will afterwards cause the pieces to acquire a light surface roughness. The feed rate and cutting speed also play an important role in the finishing of a product using the wrong feed rate and cutting speed can damage your cutting tool or your work piece. Reduced feed rate results in a smaller residual region at the top of the machined surface, which lowers the average roughness value. Cutting temperature rises as cutting speed rises [37]. When the cutting speed is 20-25 m/min and the cutting temperature is roughly 300°C, the average roughness value increases because the friction between the cutting tool and the face of the workpiece as well as the length of the chip is high.

2.3.2 Good surface finish: An Overview on Machining Operations

When machining the appropriate cutting parameters should be used while performing machining operations in order to have good surface finish. Cutting plastic materials quickly, reducing the feed rate, utilizing a high-efficiency cutting fluid, enhancing the process system stiffness, enhancing the kinematic precision of the machine tools etc. are various parameters to consider. Choosing the tool's geometric parameters is very important before starting any machining process; adjusting the radius of the arc in the tooltip to reduce the angle of contact between the workpiece and the tip, minimizes surface abrasion and facilitates cutting [37]. Tools made of fine-grained cemented carbide should be used and suitable material for the tool that has low affinity for the workpiece should be chosen in order to reduce the amount of auxiliary blade wear. To reduce the amount of friction between the tool and the workpiece, the tool edge needs to be sharpened, cutting fluid should be added while performing machining operations in order to have a smooth cutting action, and appropriately heat-treated workpiece materials with good toughness should be used to enable high plastic deformation and reduce machine tool vibration.
Machining technology is essential when precision cutting is required. A procedure that is irrational or eratic may have an effect on the production's efficiency and processing quality.

For many precision-machined objects, finishing is required after rough machining. A wide range of raw materials are available for use in the construction of mechanical equipment parts. The choice of cutting and machine tools used in the processing is intimately related to the roughness and hardness of the workpiece because different raw materials have varying densities [9]. Heat should be applied to the workpiece to increase its hardness and prevent plastic deformation of its face. In cast iron for example, due to its weak tensile strength, the graphite particle size in cast iron causes issues while machining and should be reduced. Element such as sulphur, lead, etc. should be present in the steel which makes it easier to cut also, alloying elements should contain a uniform and fine distribution of carbides.

2.3.3 Surface Finish

Only by smoothing or finishing the surface can one reduce or limit the roughness of a surface. First, the idea of smoothness needs to be understood in order to obtain the surface finish. A surface that isn't raked, lump- or hole-free, is smooth. A surface is said to be smooth if it has a (unique) tangent plane at each point and no singular points. When a finely polished plate is placed on top of another polished surface, the top plate will sink until the two polished surfaces are in close contact, this is because there are no ridges or cracks between the two surfaces, which would reduce the opposing frictional force if they were to come into contact while sliding. A suitable surface finish will improve a finished product's appearance and increase its durability. Therefore, the primary winner is the end user. Additionally, a number of surface finishing techniques help manufacturers during the manufacturing process. For instance, brushing the surface prior to painting enhances metal adhesion. As a result, getting a high-quality finish is easier. According to [39], finishing is the last stage of component manufacturing and demands the highest level of form, accuracy, and surface integrity. The process of fine finishing involves adding functionality to the workpiece's surface in order to improve its quality attributes. They are several benefits to surface finish which are; increase in corrosion resistance, makes painting and other coatings adhere well, increases surface electrical conductivity, increases toughness and wear resistance while lessening the effects of friction and improves the aesthetics of the workpiece. There are several finishing processes which will be reviewed below

2.3.4 *Coating, Electroplating and Electropolishing*

In powder coating, the metal component is first electrostatically coated with dry powder before being heated at high temperatures to "melt" the powder flakes and fuse them to the metal surface. Furniture, automobiles, agricultural equipment, electrical equipment, sporting goods, and many more things employ the powder coating technique (Kazanas & Lowell, 2003). A liquid paint or coating substance can be applied in a number of ways, as the name implies, including dipping, brushing, anodizing, galvanizing and spraying. Electroplating is the process of coating an object with another material. Each of the several electroplating procedures makes use of electricity to coat metals by passing an electric current through a solution. In contrast to the electrolyte, which is a solution containing the metal ions that are being added. When electrical current is applied, the material functions as a cathode. This causes the ions that are deposited on the treated surface to be pulled to it [41]. This process has several advantages, including improved aesthetics, reduced surface friction, increased durability, and higher corrosion resistance. It is possible to treat almost any metal using this technique, however zinc, copper, nickel, gold, silver, and other metals are the most frequently utilized ones. Electropolishing and electroplating are similar because they both involve electricity and chemical reactions. In contrast to electroplating, which adds ions to the surface being treated, electropolishing removes ions from the surface being treated. Electropolishing is widely used to deburr, lower the average surface roughness, and provide an even, smooth, and clean surface devoid of flaws. Metals like stainless steel, aluminum, copper, titanium, nickel, and copper alloys are frequently subjected to electropolishing.

2.3.5 Sanding, Lapping and Grinding

These surface finishing tasks are still frequently performed by hand, using only a few simple tools and equipment in the hands of highly qualified workers. Recent advancements in automation have decreased the demand for human labor and the need of these primitive and obsolete methods and so, there are better methods and machinery for the alternative to this process. These operations use a variety of machining techniques referred to as abrasive machining to either remove a layer from the surface or reshape it. Whether they are dry or wet, defects on the metal's surface are removed with this technique (using oils, water, or other liquids). Aluminum, cast iron, carbon steels, brass, stainless steels and aluminum are among the metals that frequently need to be machined using abrasive techniques [23]. In order to achieve fine finishes and great precision, lapping is widely used to make optical lenses, bearings, gauges, and other things.

Conclusion

In-conclusion, tribology plays an important role in reducing wear. There are different methods of reducing wear and the methods reviewed in this paper are: the use of lubrication, wear resistant materials, nanotechnology and smoothing of surfaces. Additives play an important role in determining the efficiency of a lubricant, different types of wear resistant materials have their area of application and there are different methods of smoothing surfaces which have their merits and demerits. In the case of nano-technology; the application of nanotechnology in lubricants improves the mechanical characteristics of that lubricants, but it is important to note that nano-particles chemical composition is a parameter to consider in the reduction and improving of anti-wear performance, whereas the geometry of nanoparticles is mostly important for friction reduction. The application of tribology in reducing wear can be observed in the aviation industry; were oil (lubricants) is preferably used in reducing wear compared to other methods; Aviation oil eliminates build-ups of varnish, grunge, and sludge in the oil pan of an aircraft, serve as a seal between the cylinder and ring of the engine and removes a bigger portion of the engine's heat, just to state a few. Therefore, the selection of a suitable method for reducing wear is based on the area of application.

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