Chapter 1
Introduction of Automotive Tribology

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Abstract Tribology is existed at the interface of two materials which are in relative motion and this causes friction at the interface. Due to friction, heat is generated between two meting surfaces which causes wear on surfaces either one or both the materials. To reduce friction and wear at interface, a lubricant is supplied. This lubricant may be either solid lubricant such as graphite, graphene etc. or liquid lubricant such as base oil, mineral oil etc. or semisolid lubricant such as grease. In this chapter, the detailed description of friction, wear and lubrication is given. Furthermore, a number of examples are also presented where tribology is very important such as bearings, gears, engines, orthopaedic joints and micro-machines. At last, the brief introduction of important applications are also discussed along with brief prescription about book chapters.

Keywords Friction · Wear · Lubrication · Automobile · Bearing · Gears etc.

1.1 Introduction

The word "Tribology" has been taken from the Greek word "Tribos" which means "rubbing" or to rub and suffix "Ology" means "the study of". Thus, tribology means "the study of rubbing of two materials" (Duncan 1997). Therefore, Tribology is existed at the interface of two materials which are in relative motion and this causes friction at the interface. Due to friction, heat is generated between two meting surfaces which causes wear on surfaces either one or both the materials. To reduce friction

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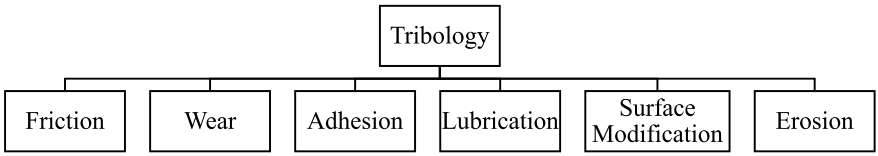
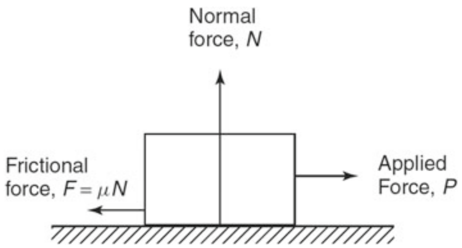


Fig. 1.1 Different aspects of tribology

Fig. 1.2 Schematic representation of friction



and wear at interface, a lubricant is supplied. Tribology involves the study and the applications of the principles of friction, wear, lubrication and surface modification which is diagrammatically shown in Fig. 1.1.

1.1.1 Friction

The resistance force experienced in relative motion of solid surfaces, fluid layers, and/or material elements sliding against each other is known as friction which is shown in Fig. 1.2. There are two types of friction, dry friction and fluid film friction (Rabinowicz 1995). When there are two solid surfaces sliding against each other and energy is entirely dissipated between the surfaces then it is known as dry friction. This dry friction is again subdivided into two parts; static friction and kinetic friction.

1.1.2 Wear

The degradation of material or removal of material is known as wear. Wear occurs due to the friction between two surfaces. There are different types of wear which is shown in Fig. 1.3.

When a hard material rubs against a soft or hard material in direct contact than abrasion wear occurs. It may also happen that hard particles are present at the interface as contamination or as "third body". The third body is defined as the wear debris or oxidized particles that is trapped at the interface (Williams 2005).

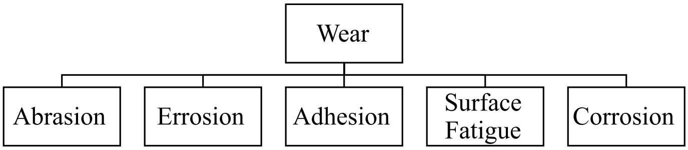


Fig. 1.3 Classification of wear processes

When a small solid or liquid particle impacts a solid surface, deformation may take place on the solid surface. If such impacts are repeated over and over again with continuous impact of particles, there will be removal of the material locally. This mechanism of wear is known as erosive wear.

When the surfaces are soft and plastically deforming than adhesive wear occurs. Large adhesive forces between materials lead to plastic deformation and material removal in the form of highly deformed flakes. Very large adhesive forces can also lead to what is known as cold welding at localized contact points. The cold-welded part can also tear-off the material locally. The best example of adhesion is joining of slip gauges. They are joined because of applied pressure through hands.

Surface fatigue occurs because of repeated forces applied on the surfaces. Due to which cracks are propagated on subsurface which further grows and generated the wear debris on surface.

Corrosion is widely occurs in hydro turbines. This occurs because of the moisture present in surrounding and universe.

1.1.3 Lubrication

To overcome the effect of friction and wear at interface, the lubrication is provided. It is either in the form of solid lubricant such as graphite, graphene etc. or liquid lubricant such as base oil, mineral oil etc. or semisolid lubricant such as grease. The basic principle of lubricants are control friction, control wear, control interfacial temperature, control corrosion, remove contaminants, form a seal (grease) etc. (Stribeck 1902). The performance of a lubricant depends on its chemical, physical and rheological properties. It also depends on the external parameters imposed such as contact pressure, relative speed, and temperature. Based on the nature of the fluid film formation, different lubrication regimes are defined and they are, Boundary lubrication, Mixed Lubrication, Elasto-hydrodynamic lubrication and Hydrodynamic Lubrication (Dowson 1993). These lubrication regime are shown in Fig. 1.4.

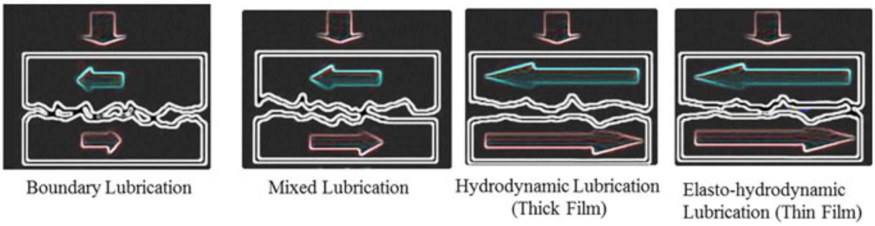


Fig. 1.4 Different regimes of lubrication

1.1.4 Factors Which Affect the Tribological Performance

There are various factors which affect the tribological performance of any system (Briscoe and Sinha 2002; Spikes 2001; Rathaur et al. 2018). These factors are shown in the Fig. 1.5.

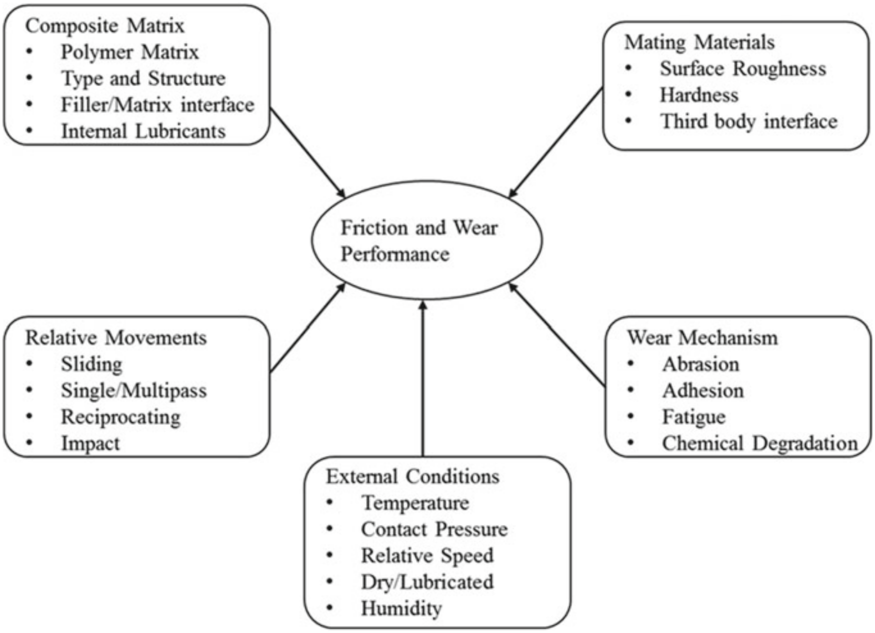


Fig. 1.5 Factors influenced the tribological performance of any system

1.1.5 Application of Tribology

It is very important to note that the tribological performance of any system, whether nano, micro or macro-scale, depends upon a large member of external parameters and important among them are temperature, contact pressure and relative speed. A number of examples, where tribology is very important. These are different kinds of bearings, gears, engines, orthopaedic joints and micro-machines etc. Among all these applications, tribological issues in automobile is discussed briefly in this chapter and detailed development in further chapters.

In automobile, there are various parts which are in a relative motion when vehicle moves. Among all parts, engine is most important part in automobile. This is also known as heart of automobile (Taylor 1998). The engine consists piston and piston ring, piston cylinder, connecting rod, gudgeon pin and cam-follower assembly. The lubrication is very important in all parts of engines. Now a days, customer satisfaction and environmental protection are very important factors in governing the development of automotive technology. There are various components present in automobile which affect the efficiency of engine largely such as bearing, piston ring, valve train and crank shaft etc. The researchers had tried various methods such as surface texturing, surface coating, modification in lubricant etc. for improving the efficiency of engine. The efficiency of any engine is largely affected by friction. The percentage of various friction losses with respect to engine components have been shown in Fig. 1.6. Therefore, in further sections, the various types of energy losses are described in brief.

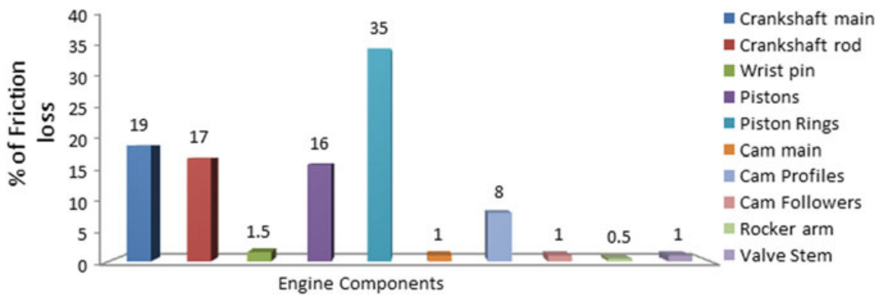


Fig. 1.6 Friction losses with respect to engine components (Taylor 1998; Nakasa 1995; Akiyama et al. 1987)

1.1.5.1 Energy Losses in a Vehicle

Engine Losses

The internal combustion engines (ICE) are very incompetent in converting the chemical energy of fuels into mechanical energy by movement of piston from top dead centre to bottom dead centre. Because of this movement, the friction occurs at interface which generates the frictional heat. In one survey, it is reported that approximately 62% of the fuel's energy is vanished in the ICE. For reduction of these losses, the advanced engine technologies are adopted. These are variable valve timing and lift, turbocharging, direct fuel injection, and cylinder deactivation. In addition, diesels are ~30 to 35% more competent than gasoline engines. This is because of the development in technologies and fuels which makes diesel vehicle more attractive.

Accessories

There are various types of accessories used in automobile such as air conditioning, power steering, windshield wipers, and other accessories. These accessories are used around 2% energy generated from the engine. Therefore, the improvement in fuel economy around 1% may be attainable with more efficient alternator systems and power steering pumps.

Driveline Losses

There are other losses of energy around 5% due to the transmission and other parts of the driveline. For reducing these losses in driveline various technologies developed which are automated manual transmission and continuously variable transmission.

Aerodynamic Drag

Drag is directly related to shape of the vehicle. Around 2–3% of energy is lost as aerodynamic drag in automobiles. The drag is significantly reduced by using smoother vehicle, but further reductions of 20–30% are possible.

Rolling Resistance

For forward movement of tier, a force is required which is known as rolling resistance force, which is directly proportional to the weight of the load supported by the tire. There are various technologies developed nowadays to overcome the rolling resistance such as improvement in deigns of shoulder and tier thread as well as improvement in materials which is used in the tire belt and traction surfaces. For passenger cars, the fuel efficiency is increased by 1% by reducing of rolling resistance by 5–7%. However, the balancing in these improvements are required against traction, durability, and noise.

Overcoming Inertia; Braking Losses

For moving forward a vehicle, it is required to overcome the vehicle's inertia, which is directly related to its weight. This is carried out by using drivetrains which provides the enough energy. If the vehicle weight is less than less energy is required for moving a vehicle. This can be achieved by using lightweight materials and lighter-weight technologies (e.g., automated manual transmissions weigh less than conventional automatics).

1.1.5.2 Energy Losses in Engine

More than 60% of losses in an automobile occur in the engine. These losses are exhaust gas losses (23.40%), in-cylinder heat losses (20.50%), and friction losses (7.70%), after cooler (7.30%) etc. Due to these losses, currently from an engine only 40% net power can be extracted. The net power is in engine can be improved by 10% by reducing exhaust gas losses, in-cylinder heat losses and frictional losses. Friction losses contribute to around 8% of total energy loss in an engine. The major subsystems of engine contributing to mechanical friction in an automobile engine are piston and ring pack, bearing and crank shaft system and auxiliary valve drives.

1.1.5.3 Systems in Engine Causing Friction

Figure 1.7 shows the stribeck curve of different components in engine and the lubrication regime they undergo during operation.

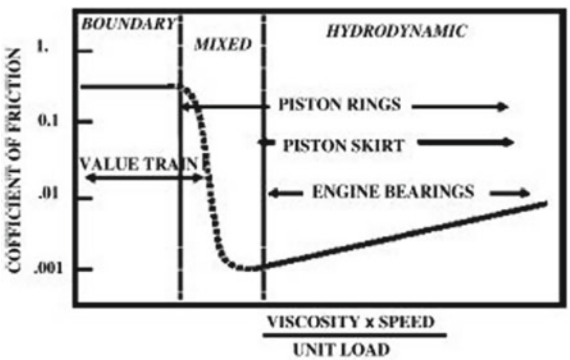


Fig. 1.7 Different engine parts and corresponding lubrication regime (Tung and McMillan 2004)

Piston Assembly System

The piston assembly system consists of piston, piston rings, piston pin, connecting rods and bearings. There are three main friction and lubrication groups contributing to friction in piston assembly system: piston skirt sliding up and down against liner, ring pack reciprocating against liner, and bearings in connecting rod and wrist pins.

The piston ring is one of the most intricate tribological elements in an engine which subjected to large variations in load, temperature, velocity and lubricant accessibility. Early studies show that the hydrodynamic lubrication theory is applicable to the interface of piston assembly and cylinder liner throughout most of the piston middle stroke. However, when the piston motion ceases near top dead centre (TDC) or bottom dead centre (BDC) of the stroke, the piston velocity is not adequate to establish a hydrodynamic lubrication action. Lubricating films become very thin and contact between the surface asperities on the ring and the liner will support part of the piston ring restoring force. Therefore, wear on the cylinder liner surface may occur in the vicinity of TDC and BDC. Severe surface wear could affect the liner-ring sealing performance and result in excessive gas blow-by and fuel consumption.

The Crankshaft and Connecting-Rod Bearing Systems

The main bearings in crank shaft, connecting rod and piston pin, connecting rod and crank shaft interface are falls in the category of journal bearing lubrication. Most of the friction in crank shaft originate from the main bearings supporting crank shaft in its rotational motion. Lubrication regime in main bearings is primarily hydrodynamic. Oil is supplied to the bearing surfaces through oil feeds along the crank shaft.

If the bearings are adequately lubricated, wear on bearing will be lower after an initial stage of running in period. However, shaft misalignment or particulate contamination of the lubricant supply can lead to excessive wear. Corrosion is also reported as an additional failure mechanism.

Valve Train System

This system consists of a series of mechanical parts that are used to control the intake and exhaust valves. The lubrication in valve train system ranges from hydrodynamic to boundary lubrication. Most of the friction in valve train system is contributed by camshaft bearings, cam/cam follower interface, rocker arm pivot/shaft and linear oscillatory components such as valves, guides, valve lifter, valve seal etc. The cam-follower interface is mostly under boundary lubrication, where the role of chemical reactions in thin films is vital. The action of lubricant additives especially extreme pressure additives is very important in this interface. Also, surface interactions takes place in cam and follower, thus surface topography of these parts is a critical parameter.

1.1.5.4 Lubricants

Engine runs smoothly if correct engine oil is chosen. The lubricant creates a thin film between two mating surfaces of automobile which prevent them from rubbing against each other and becoming worn or damaged. Oil also prevents corrosion, cools the engine and helps to keep the engine clean and protected.

Generally, 80% base oil and 20% additives were presented in engine oil. These additives include anti-wear additives, antioxidants, dispersants and detergents that keep the engine clean, and viscosity index improvers that ensure the oil maintains an optimum viscosity throughout the engine's operating temperature range. The base oil carries these additives to where they are needed, and provides vital cooling to engine components, by drawing away heat. Base oils can be either mineral or synthetic, and engine oils can contain all mineral base oil, all synthetic base oil, or a mixture of the two. Engine oils containing a mixture are typically described as part-synthetic.

Causes of Lubricant Degradation

The life of lubricant is finite in operation. After that, the degradation of lubricant is started or sometimes it becomes contaminated which indicates the lubricant change. There are various factors which are responsible in degradation of oil in an engine. Among all factors, the most common factors are oxidation, thermal breakdown of the lubricant oil, micro-dieseling, additive depletion and contamination. The brief description of the factors are given below:

Oxidation:

In this process the oil molecules reacts with oxygen molecule. Due to which the viscosity of lubricant is increased, causes the formation of sludge and sediment. It is also responsible for chemical depletion and breakdown. After starting of oxidation, the increment in acid number is started. In addition, rust and corrosion in the equipment is because of oxidation of lubricant.

Thermal Stability:

The thermal stability of lubricant is inversely proposal to the temperature means an increase in temperature of lubricant will result in a decrease in thermal stability. In research, it has been shown that, if the oil operating temperature is increased by 10 °C than the rate of the oil oxidation is doubled. This statement stated that the life of the oil is halved. This situation is not quite as calamitous because it reflect that the oils naturally have quite a long life time. Temperature is only a significant issue if it reaches above 65 °C. The mostly lubricants which are used in high temperature for certain period of time, blended with additives which prevents the oxidation in lube oil.

Additives:

The performance additives are twenty or more chemicals that is combined with the base stock to improve or impart different properties. Most of the additives are sacrificial in nature which means that they get used up during the lifetime of the oil. But, when the oil is using for lubricate a machinery components, the additives present inside the lube oil start depletion. Which causes wear at the interface of meting surfaces. This indicates the change of lube oil inside the machinery.

Furthermore, the rate of degradation of lubricant is widely influenced by contamination such as soot, water, air, etc. Because of depletion, wear occurs at the meeting parts which contains the fine metal particles. The fine particles start the catalyst process which start sparks and speeds up the degradation process of lubricant. Air and water also provides the source of oxygen. This oxygen is reacts with the oil, causes the oxidation of the lubricant. Because of this reason, the oil analysis sometimes can be helpful in monitoring your lubricant's contamination levels.

The present monograph provides the current and emerging research in the field of automobile which is very useful for readers in enhancing their knowledge in the various dimensions of research. The present book is summarized some of the novel materials, lubrication and surface morphology used for automotive application into three different sections.

1. New Materials for Automotive Applications
2. New Lubricants for Automotive Applications
3. Surface Morphologies for Automotive Applications.

The editors sincerely hope that the present monograph gives the comprehensive study of current trends adopted by automobile sectors in the development of new technologies and materials for reduction of friction and wear because the customer satisfaction and environmental protection are very important factors in governing the development of automotive technology. Furthermore, the present monograph is intended for all level of students (UG, PG as well as Doctorate), research scientist and industry persons.

References

Akiyama K, Manunaga K, Kado K, Yoshioka T (1987) Cylinder wear mechanism in an EGR equipped diesel engine and wear protection by engine oil. SAE paper 872158

Briscoe BJ, Sinha SK (2002) Wear of polymers. Proc Inst Mech Eng Part J: J Eng Tribol 216:401–413

Dowson D (1993) Piston assemblies; background and lubrication analysis. In: Taylor CM (ed) Engine tribology. Tribology series, vol 26. Elsevier, Amsterdam, pp 213–240 (Chap. 9)

Duncan D (1997) History of tribology, 2nd edn. Professional Engineering Publishing. ISBN 1-86058-070-X

Nakasa M (1995) Engine friction overview. In: Proceedings of International Tribology Conference, Yokohama, Japan

Rabinowicz E (1995) Friction and wear of materials. Wiley, New York. ISBN 10: 0471830844

Rathaur AS, Katiyar JK, Patel VK, Bhaumik S, Sharma AK (2018) A comparative study of tribological and mechanical properties of composite polymer coatings on bearing steel. Int J Surf Sci Eng 12(5/6):379–401

Spikes H (2001) Tribology research in the twenty-first century. Tribol Int 34:789–799

Stribeck R (1902) Die wesentlichen Eigenschaften der Gleit- und Rollenlager (Characteristics of plain and roller bearings). Zeit des VDI 46

Taylor CM (1998) Automobile engine tribology—design considerations for efficiency and durability. Wear 221(1):1–8

Tung SC, McMillan ML (2004) Automotive tribology overview of current advances and challenges for the future. Tribol Int 37:517–536

Williams JA (2005) Wear and wear particles—some fundamentals. Tribol Int 38(10):863–870