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Study in Tribology Science and its Importance in Mechanical Engineering

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Abstract

Tribology is the science of interacting surfaces in relative motion, which makes it particularly important in mechanical engineering because so much energy is lost to friction in mechanical components.

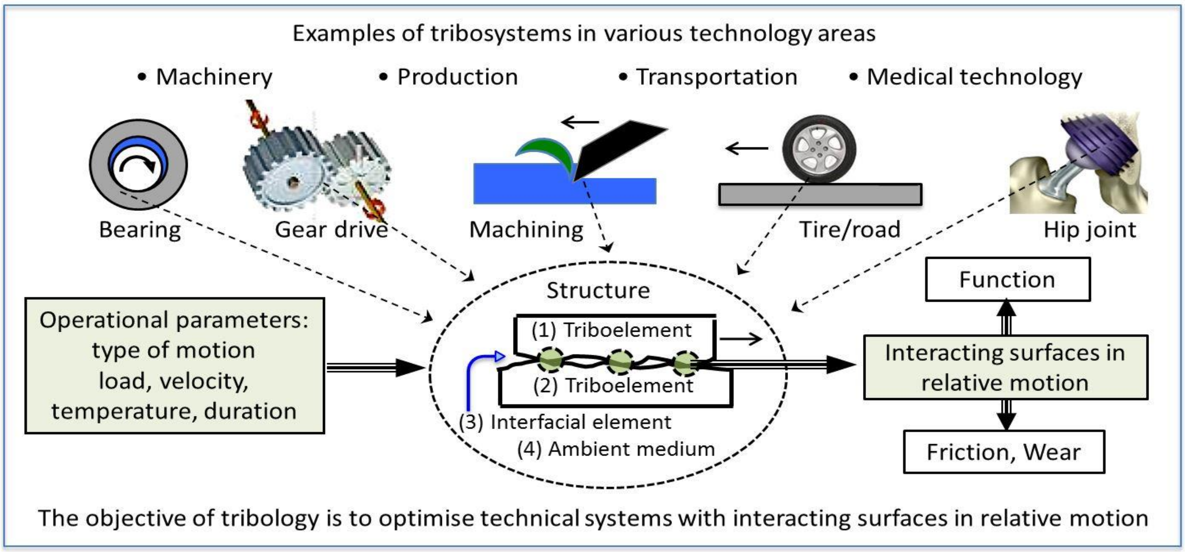
In this research, the study of tribology technology will be addressed in detail in mechanical engineering by introducing the technology and its development throughout history, as well as talking at length about its basic elements friction, wear and lubrication in addition to ways of test and measurement methods, some applications of tribology technology will be explained, also advanced research in this field will be discussed and finally we will be talk about future of tribology.

Keywords: Tribology, Friction, Wear, Lubrication, Test, Applications and Scope

1. Introduction

The name "tribology" comes from the Greek word "tribos" [τρίβοσ], which means "rubbing" or "to rub." It was first used in 1964, however the study of friction dates back to around 50,000 B.C., when people first began utilizing it to make fire. Lubrication techniques were employed by ancient Egyptian and Chinese civilizations to move massive stones that were used in their enormous structures. However, Leonardo da Vinci, the world's first tribologist, conducted the first systematic study of tribology between 1490 and 1500. He distinguished between sliding and rolling friction and concentrated on several types of friction. The study of wear, lubrication, and friction on interacting surfaces in relative motion is known as tribology science.

Traditionally, tribology research has concentrated on creating appropriate lubrication for machine components, particularly bearings. The majority of modern technology is also included in tribology, and it can have an impact on any procedure where one substance moves over another. The various tribology fundamentals friction, wear, and lubrication as well as their impacts and how lubrication might mitigate them, are explained in this article. Additionally, it will examine how to test tribology components and assess tribological behavior on tribometers. Numerous tribology applications will be discussed, along with a number of cutting-edge tribology science research projects. This paper will conclude by taking a look at the future of tribology.



Source: H. Czichos and M. Woydt: Introduction to Tribology and Tribological Parameters. ASM Handbook, Volume 18, Friction, Lubrication, and Wear Technology, 2017

Figure 1: Tribology Technology examples

2. Literature Review

We have derived the foundational principles of tribology in this study from extensive literature reviews and experimental observations. These principles not only enhance our understanding of friction, wear, and lubrication but also pave the way for innovative applications in various engineering fields(2,3,17,18,19,20,21). The references for tribological tests were obtained from relevant sources(5,16,18,19,20,21) . The applications of tribology have been cited from (1,9,10,11,13,15). Furthermore, discussions on advanced research within the field of tribology have been gathered from (4,6,7,8,12,14).

3. Fundamental Principles of Tribology

Some questions about the nature of wear and friction are asked at the beginning of this chapter. Despite the centuries-long search for the microscopic nature of friction, important discoveries on how the sliding process takes place on the atomic scale have been made recently. Coupled, scale-focused theoretical and experimental studies have given us unique domain-level insights into how various elements might influence the motion and energy-mediated structures of rubbing surfaces and the friction that goes along with them.

The ability of scientists to forecast friction, how different sliding-induced structural changes result in nano wear, how antiwear additives are activated and control tribochemical wear, and why certain material combinations wear more than others will all be improved with knowledge at the atomic level. Even with great progress, there are still many obstacles to overcome.

Understanding the relationship between friction performance seen over longer durations and atomic-scale processes in greater detail is a crucial component of future study. Lubrication is a significant area in tribology. For the development of novel materials and for the advancement of hard materials design expertise, it is crucial to comprehend how new infrastructures and processes affect lubrication and how dynamic lubrication may be controlled to promote efficiency and prevent damage.

3.1 Friction Mechanisms

The force that prevents two surfaces from moving together is called friction. A straightforward situation where the upper body (Body 1) slides against the lower body (Body 2) is shown in Figure 2. In this case, Body 1 is subject to a force FN that is perpendicular to the plane of contact. Another name for this force is the normal force. Conversely, the force that opposes motion and acts in the opposite direction of motion is called the friction force, or FF. The coefficient of friction is the ratio of the friction force to the normal force. Static, kinetic, and rolling friction are the three categories of friction. µs, µk, and µr stand for their respective friction coefficients, which often occur in the following order: µs,>µk,>µr.

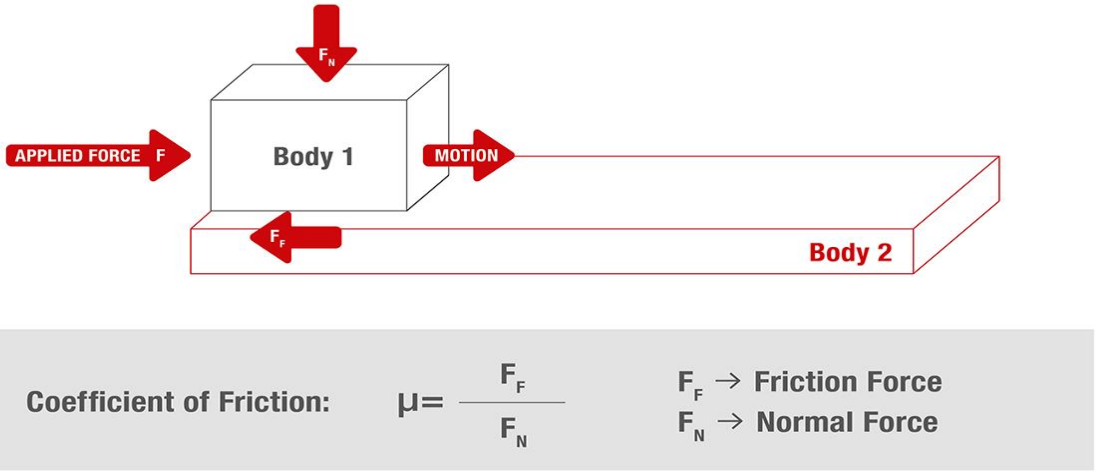


Figure 2: Friction mechanism

3.2 Wear Mechanisms

Wear is the gradual loss or displacement of material on a solid surface brought on by relative motion between the surface and a contacting substance or substances. Wear may or may not be desirable, depending on the various real-world application scenarios. For instance, wear could be advantageous in machining operations including polishing or grinding. In other situations, wear is quite undesirable since it shortens the lifespan of various components, results in surface fragmentation, and causes part failure.

- The different mechanical, physical, or chemical states of surfaces moving relative to one another characterize the wear process. Based on the most prevalent wear mechanisms, it is typical to categorize the many wear processes that are seen in practice into four main kinds. The main categories of wear are:
- Abrasive wear: wear brought on by hard particles or hard protuberances pressed up against and traveling along a solid surface.
- Adhesive wear: wear caused by localized bonding between contacting solid surfaces that results in material transfer between the two surfaces or loss from either surface.
- Fatigue wear, also known as fretting wear, is wear of a solid surface brought on by fracture resulting from tiny amplitude oscillatory motion.

corrosion is wear in which there is a substantial chemical or electrochemical reaction with the environment.

Wear parameters

Different parameters exist to help us quantitatively characterize various wear processes. The most common ones are:

- One wear metric that connects sliding wear data to operating parameters is the wear factor, sometimes referred to as specific wear rate. It is typically, though not always, described as the total wear volume divided by both the sliding distance and the normal force.
- Wear coefficient: a wear metric that connects tribology system characteristics to sliding wear measurements. It is typically, but not always, defined as the dimensionless coefficient k, as shown in the following equation: Wear volume is equal to k (load x sliding distance / softer material hardness).

Different wear mechanisms or rates in various diagram regions can also be represented by a wear map. Typically, the load (measured in force or contact pressure) and sliding velocity—possibly normalized to be non-dimensional—are the coordinate parameters of the graphic. An illustration of a wear map illustrating several wear regimes for steel sliding over steel in room temperature air is provided below.

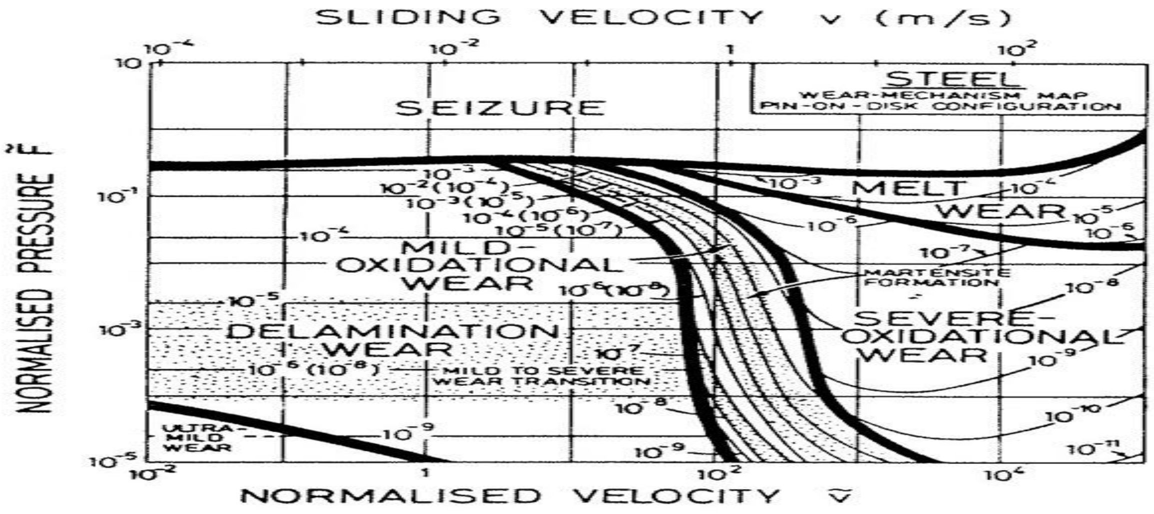


Figure 3: wear map showing different wear regimes for steel

3.3 Lubrication Mechanisms

The roughness of the surfaces of the majority of engineering materials can be measured using precise parameters like average roughness (Ra), root mean square roughness (RRMS), etc. The roughness peaks and valleys of two such surfaces interact when they begin to rub against one another, adding to the system's overall frictional resistance. By adding a medium at the contact interface, which should ideally keep the surfaces from making direct contact with one another, friction can be decreased. Most lubricants are either semisolids (greases) or liquids.

However, solid lubricants like graphite and molybdenum disulfide (MoS2) are also utilized in many applications. In severe situations, lubricants can also be gaseous, like air in air bearings.Lubricants are primarily used to lessen wear and friction between two mating surfaces. This is accomplished by creating a thin layer of lubricant that keeps the surfaces from making direct touch with one another. Lubricants serve as heat descriptors, cleaning agents, corrosion inhibitors, and other functions in addition to reducing friction and/or wear.

In certain situations, the system's frictional reaction can be used to gauge how effective a lubricant is. Usually, a tribometer—a measurement device—is used for this. The Stribeck curve, a technique employed by tribometers that will be frequently mentioned in the applications section, is a plot that illustrates the frictional properties of a liquid lubricant under conditions that typically fall into the boundary, mixed, and hydrodynamic regimes. The λ ratio—the ratio of film thickness to surface roughness—defines each regime.

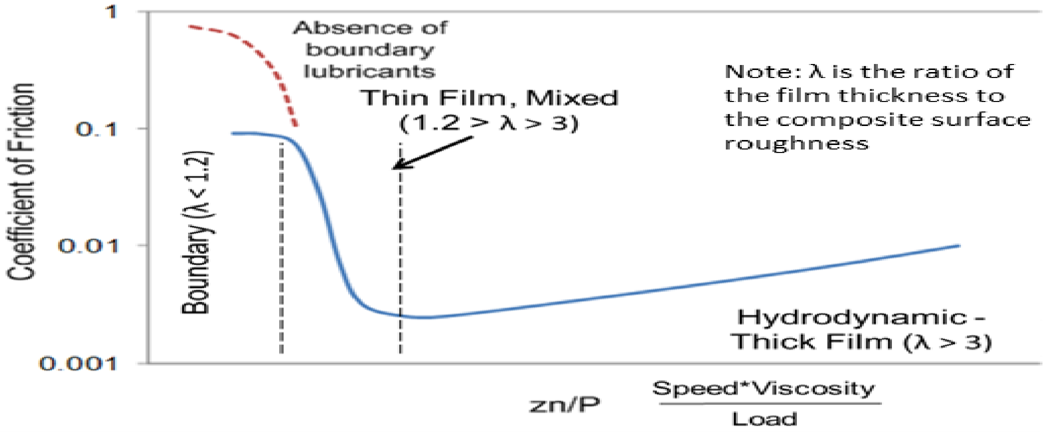


Figure 4: Lubrication mechanism\ the Stribeck curve

4 Tribological Testing

Tribological tests using tribometers must be as similar to a real-life system as possible because tribological qualities vary depending on the system. In tribology, the coefficients of wear and friction are the most significant parameters of importance. To be quantified, these parameters require a reference, such as temperature, contact pressure, velocity, time, or a combination of these. This section describes a few test procedures used to examine the system's wear and friction behavior.

4.1 Friction Test

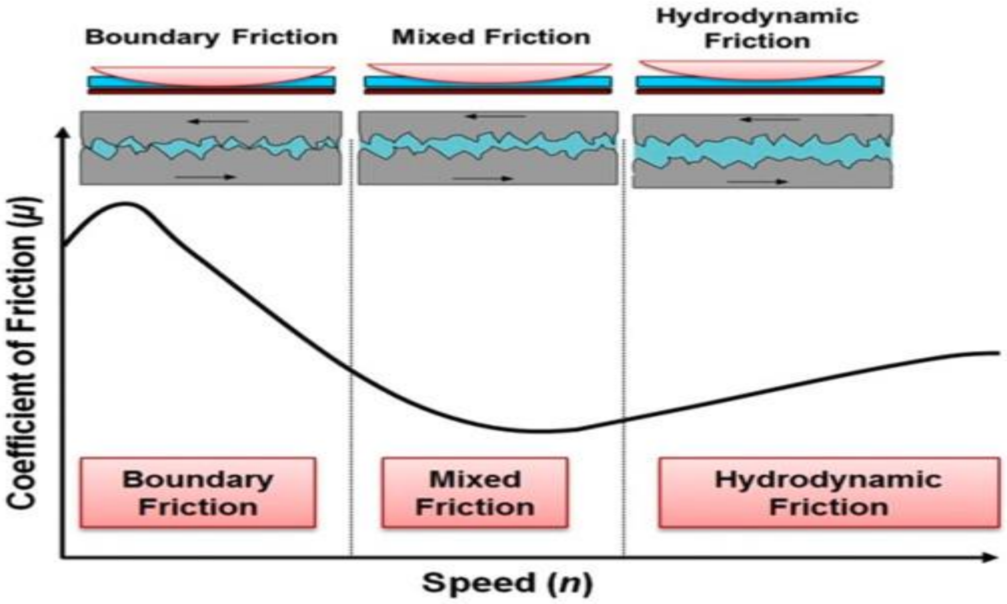


Figure 5: Stribeck curve depicting the coefficient of friction as a function of speed

Because the lubricant cannot entrain into the clearance between the two mating surfaces to form a load-bearing film, contact between surface asperities characterizes the boundary regime, which happens at the lowest speeds. The system has a high frictional resistance and is prone to wear because of the surfaces' direct contact and inadequate lubrication.

The system enters the mixed friction phase as the speed increases. A tiny quantity of lubricant enters the clearance as a result of the higher speed, just enough to keep the surfaces apart and reduce asperity contact. This results in less friction and a much-decreased likelihood of wear.

Lastly, asperity contact is prevented in the hydrodynamic regime, also known as the fluid friction regime, since enough lubricant is entrained into the contact to create a sizable load-bearing fluid layer. The thicker coating is the cause of the rise in frictional resistance. The lubricant's rheological characteristics predominate in this range.

4.2 Wear Test

By measuring the proper linear dimensions of the ball and disk specimens or by weighing them both before and after the test, the applicable ASTM standards calculate the amount of wear. The accompanying figure displays the typical ball-on-disk configuration along with the parameters needed to compute wear.

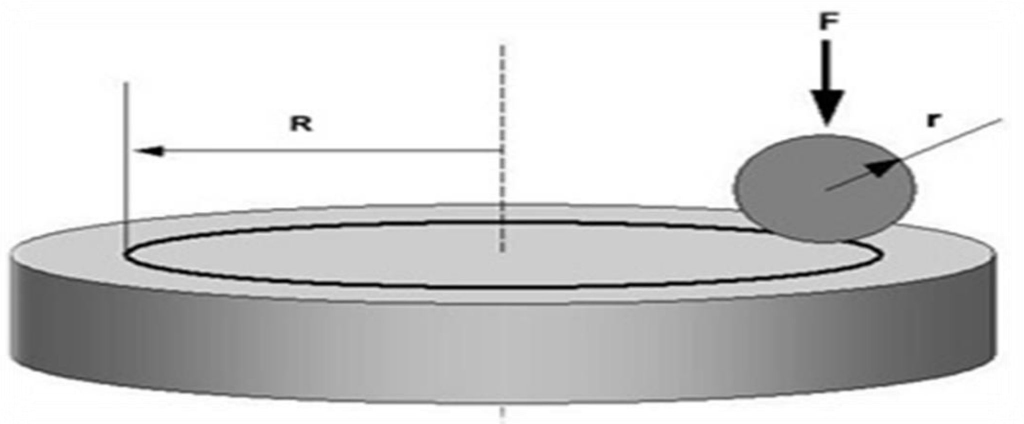


Figure 6: Typical ball-on-disk setup,

The following formula provides the disk's volume loss, assuming no appreciable ball or pin wear:

Vdisk = 2πR[r2sin−1(d/2r) −(d/4) (4r2−d2)1/2]

Where:

R = wear track radius

F= normal force applied

d = wear track width

r = ball radius

V_{disk} = disk wear volume

4.3 Other Test

Numerous different test profiles are utilized to describe the tribological behavior of systems in addition to the ones mentioned above. Temperature sweeps, normal force or contact pressure sweeps, and isothermal or isobaric tests in unidirectional or oscillatory mode are a few examples of these tests. Keeping the test conditions, including the samples or specimen, as similar to the real-life application as possible is the most crucial part of selecting the appropriate test procedure.

5. Applications of Tribology

Numerous industries are significantly impacted by tribology, which transforms their processes and improves overall performance. Here are few instances.

5.1 Automotive industry: In the automotive industry, where lubrication and friction are essential to engines, gearboxes, and braking systems, tribology is invaluable. Tribology advancements have produced long-lasting bearings, high-performance brake pads, and low-viscosity engine lubricants, which have increased safety, decreased emissions, and improved fuel economy.

5.2 Aerospace industry: Tribology is essential in aircraft applications where high pressures, temperatures, and speeds are present. For jet engines to operate smoothly at high altitudes and speeds and to avoid excessive wear, lubrication systems are crucial. Additionally, tribological research has helped create specific materials and coatings that guarantee dependable performance in demanding aerospace settings.

5.3 Energy sector: Tribology plays an important role in power generating and transmission systems. For example, effective lubrication methods and bearing systems are essential for wind turbines to maximize energy conversion and minimize maintenance expenses. In hydroelectric, nuclear, and thermal power plants, where enormous rotating equipment needs efficient lubrication and wear protection, tribology plays a crucial role.

5.4 Biomedical applications: There are further uses for tribology in the medical field. Tribological research helps prosthetic joints, like hip and knee implants, to reduce wear and guarantee smooth mobility. Tribological concepts are used in dentistry by orthodontic equipment and dental implants to improve patient comfort and lessen friction-related problems.

6. Advanced Research and Technologies in Tribology

In this section, we will discuss a variety of new and advanced research and technologies in tribology**.**

6.1 Nanotribology

At the forefront of scientific research is nanotribology. Nanotribology is an essential field of study for comprehending basic mechanisms and precisely regulating material interactions because materials display distinct characteristics and behaviors at microscopic levels that set them apart from their macroscopic counterparts. The development of nanoscale gadgets, advances in materials research, biomedical engineering, and environmental sustainability are just a few of the areas in which nanotribology is crucial. By exploring the complexities of nanotribological phenomena, scientists open the door to ground-breaking discoveries, enhanced technology, and long-term fixes that tackle today's problems and move us closer to a more robust and effective future.

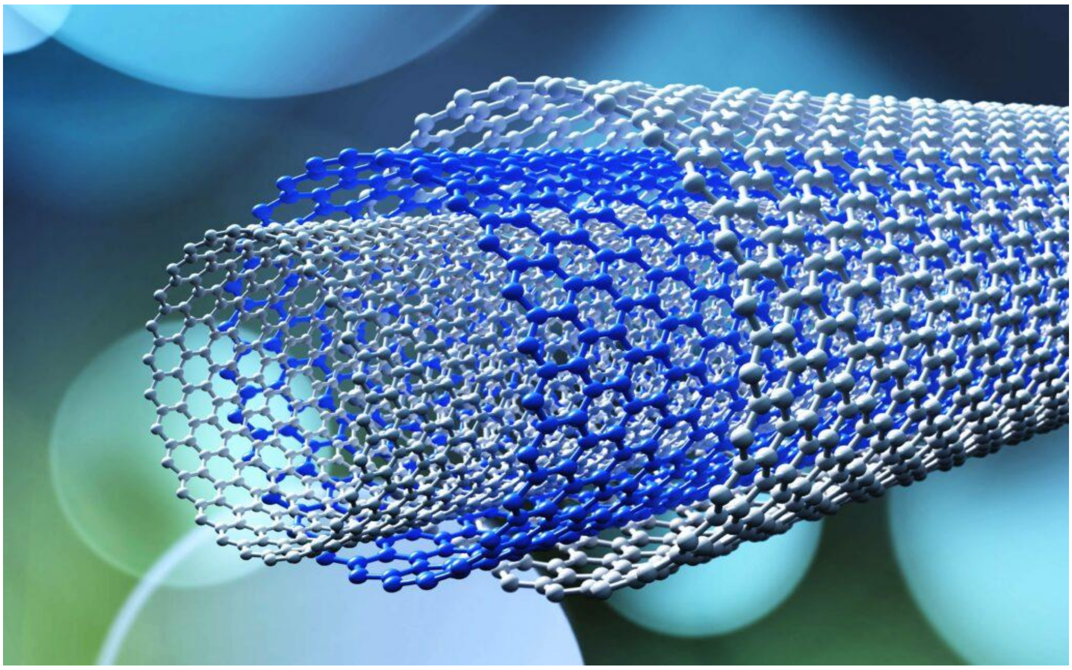


Figure 7: Nanotribology

6.2 Tribocorrosion

The science of surface changes brought about by the interplay of mechanical stress and chemical/electrochemical interactions between different components of a tribosystem exposed to a corrosive environment is known as tribocorrosion. In addition to friction, lubrication, wear, and tribologically stimulated chemical and electrochemical reactions, it integrates the mechanical and chemical interactions of the body, counterbody, interfacial medium, and environment. The several kinds of contact modes and schematic illustrations of tribological interactions involving concurrent mechanical and chemical effects are shown in Fig. 8.

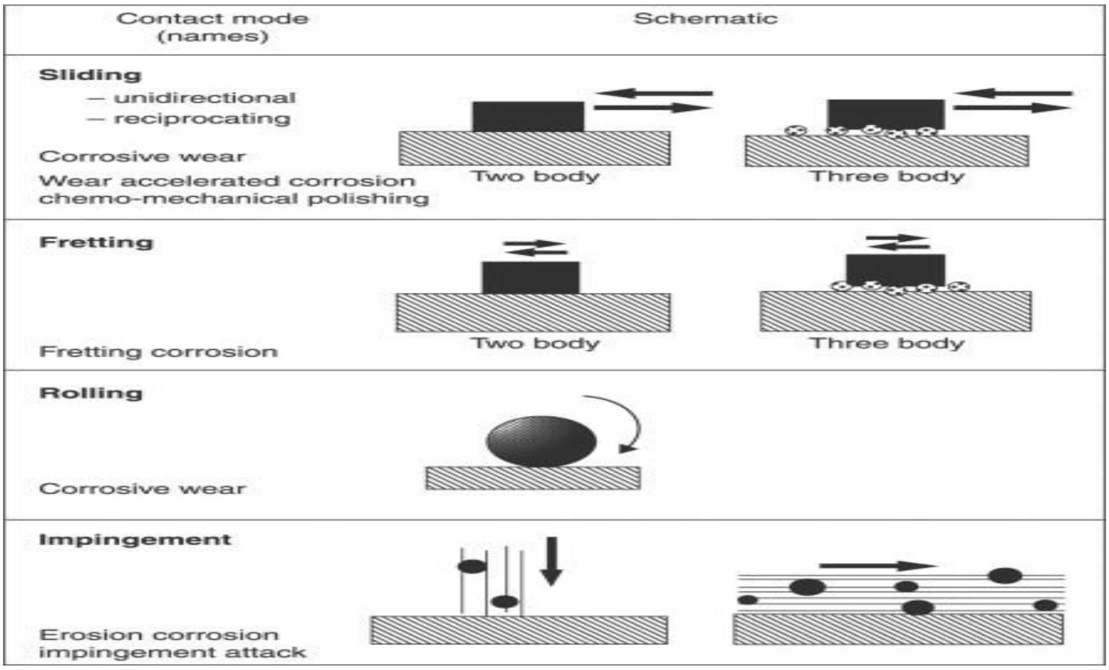


Figure 8: The various types of tribocorrosion contact modes

7. Future scope of Tribology

Tribology has been an essential component of mechanical advancement until recently. The importance of tribology will increase as the focus on innovation progressively shifts to nano and biotechnology. Sturdiness, which has not received enough attention in the past, will be a crucial factor used in industry in the twenty-first century.

Currently, contact mechanics and tribology are spreading to a wide range of new application areas that are at the forefront of global technological trends, including healthcare and biology micro- and nanotechnology. There have recently been several attempts to reach consensus on the state of tribology and accessible procedures after lengthy and controversial discussions. These initiatives, along with the rapid expansion into new areas of study like nanotechnology and life sciences, give cause to think that tribology will have a golden age in the years to come.

8. Conclusion

This article has described the principles of tribology, which is the study of wear, lubrication, and friction of interacting surfaces in relative motion, as well as methods for measuring them. In addition, a number of tribology applications have been defined, taking into account current research and the field's future potential.

Tribology, the study of wear, friction, and lubrication, is an important discipline that affects many facets of our life. By studying tribology, engineers and scientists may better understand how surfaces interact when moving, which helps them improve the durability, performance, and efficiency of machines in a variety of applications.

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