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Tribology Mechanism Analysis of the Effect of Manufacturing Processes and Metallurgy on the Wear Behavior of Materials

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Abstract: *wear is a continuous and undesirable drop in the surfaces of the involved parts, resulting in a relative motion between them. In conventional conditions, wear is a result of the concentration of excessive tension between the two contact nodes, which is achieved by vertical and tangential forces (friction). In general, the type of relative motion determines the wear process, while the wear mechanisms depend on the energy interactions and the material between the components of the tribosystem. The purpose of this paper is to The tribology mechanism analysis of the effect of manufacturing processes and metallurgy on the wear behavior of materials. In this regard, the concept of tribology, the goals of tribology and tribocism were examined. In the next part, the wear factors and other parts of the process and mechanisms of the 7th wear (Abrasive Wear, Adhesive Wear, and Sheet wear, Tribo Chemical Wear, Fretting Wear, Surface Fatigue Wear and Erosive Wear) were analyzed. In this regard, the library method and the snapping tool were used. In a general summary of wear and tribology systems, the result was obtained that the nine factors; time, speed, velocity and slip; temperature; forces between components; applied load; surface geometry; surface quality and surface finish; Physical, thermal and chemical properties of the lubricant used to reduce friction; the material of the parts under wear; mechanical, thermal, chemical and metallurgy; environmental conditions; useful parameters affecting the wear mechanism, the severity of its degradation, and the strength and resistive force.*

Keywords: *Production Processes, Metallurgy, Wear Material Behavior, Tribology Concept.*

INTRODUCTION

Surface engineering is an economical way to produce equipment and components with required surface properties such as wear and corrosion resistance. Since many destructive phenomena such as corrosion wear friction and heat on the surface of the components occur, surface protection is a significant and important technology. In brief, surface engineering involves the use of traditional or new thermal technology or other surface operations, such as a variety of cladding methods on sensitive materials and components of engineering to achieve a composite material with properties, which is absent in any of the constituent parts of the brain or surface of the piece alone (Lin et al., 2014).

The emergence of new surface technologies for the first time provided this an exceptional opportunity for engineers to place parts made of non-ferrous alloys and even non-metallic alloys under surface operation (BK and Das, 1994). Thus, the scope of application of surface engineering has expanded, not only iron alloys, but also non-metallic alloys, and even non-metallic materials and polymers, are required (Wei Zhanga, 2012). there are different methods for improving the surface properties of parts under wear by cladding a material with high wear and corrosion properties on the desired component, including Thermal Spray, Physical Vapor Deposition Techniques (PVD) and Chemical vapor deposition (CVD) Thermochemistry Cladding, and even soldering, etc. Among these various Cladding techniques, due to the availability of the required equipment and lower costs, and the ease of use for mass production, as well as the quality of the cladding produced to create the layer resistant to wear and corrosion is one of the best choices. Coverage applications are common in various industries such as automotive, aerospace, electronics, oil and gas chemistry and petrochemicals (Pasanga et al., 2013).

The purpose of this paper is to analyze the mechanism of tribology of the impact of production processes and metallurgy on the wear behavior of materials.

Tribology

Tribology has been derived from the Greek word Tribos, meaning "rubbing". Tribology is the science and technology of surfaces in contact with each other that have relative motion. In this way, tribology evaluates the phenomena associated with friction, lubrication and wear of engineering levels to provide an accurate understanding of surface interactions and suggestions for improving the performance levels under practical conditions (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy").

Tribology and surface science are a multidisciplinary science whose phenomena relate to various branches of engineering, such as mechanics, materials and basic sciences such as physics and mathematics. In material engineering, the effect of microscopic structure on wear behavior is of particular importance. Due to the fact that the microscopic structure is not exactly related to the chemical composition, and with thermomechanical and thermal operations, a wide range of structures can be found in the materials, as a result of tribology research, it mainly examines the effects of manufacturing and metallurgy processes on the wear behavior of materials. The wear causes the surface to degrade, and gradually removes the material surface, eliminates the dimensional accuracy of the parts, and increases vibrations and reduces the work efficiency of the piece, and ultimately the parts lose their applicability (Hutchings, 1992).

The frictional force is one of the main factors in the creation of wear and, in contrast to lubrication and the reduction of friction coefficient, is one of the contributing factors to this phenomenon. The wear phenomenon has been challenging at the beginning in mechanical devices, and engineers have used various techniques such as lubricants, or types of bearings and hinges to counteract this phenomenon.

1. Objectives of the tribology

The most important trilogy objectives are to control the amount of friction and wear to increase the life span of the components, increase the efficiency of engines and devices, energy storage and improve safety.

2. Triobesystem

- Triobesystem is an engineering system in which wear occurs.
- Wear is not a material property, but depends on the components of the triobesystem.

Components that are involved in a triobesystem has been shown in figure (1)

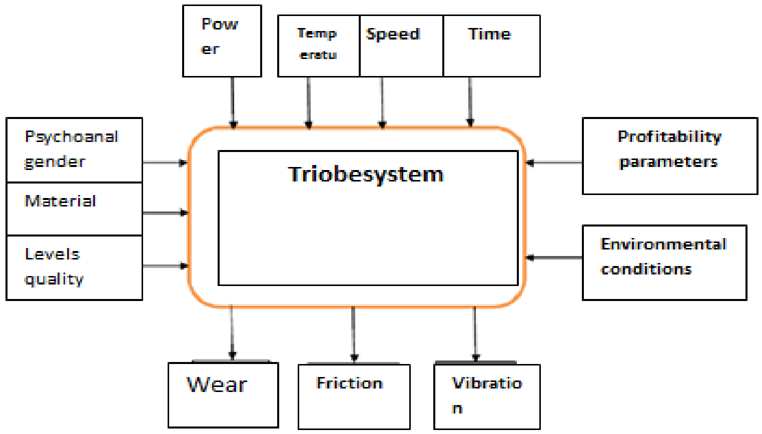

Figure 1: effective components in a triobesystem (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy")

Effective factors in wear

In a general summary of wear and tribology systems, it is concluded that the nine factors affect the wear mechanism, the severity of its degradation, and the amount of force and resistivity.

1) Time
2) Speed, speed rolling and sliding
3) Temperature
4) Existing forces between parts, the amount of load applied
5) Geometry of the surface, the quality of construction and payment of surfaces
6) Physical, thermal and chemical properties of lubricants used to reduce friction
7) Generated parts under wear Mechanical, thermal, chemical and metallurgy properties
8) Environmental conditions
9) Profitability parameters

The sum of the effective parameters in wear, along with their effects on wear, is called triobesystem. The effects of these factors are as follows in the set of system components.

- Noise
- Vibrations
- The deterrent force or friction force
- Wear and degradation after it occurs on parts

Friction

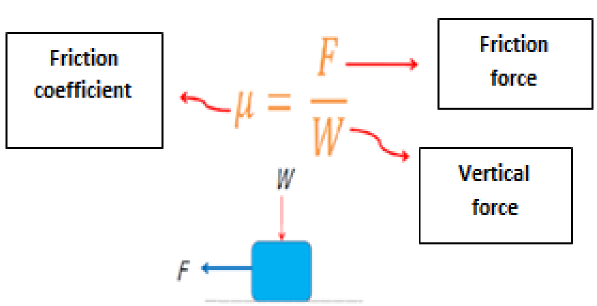

Figure 2: Friction coefficient calculation method

The size of the frictional force results from two main factors: the vertical force and the actual surface. So the size of the friction force is independent of the contact surface.

In steels, metal oxides such as FeO, Fe2O3 and Fe3O4 on the surface of the contact often reduce the adhesion forces of the surfaces and provide lubricant properties. The lubricating properties of Fe2O3 are higher than the other two oxides. Also, the study of sliding friction in crystalline materials shows that materials with a Hcp crystal structure are less friction than fcc and bcc. Graphite is also a lubricant with a very low friction due to the presence of a hexagonal structure in this material. Friction and wear rates have a direct relationship with each other, and should reduce friction coefficient to reduce wear rates. The lubricants generally fall into three categories of liquid lubricants, such as oils, liquid lubricants such as greases and solid lubricants such as graphite. The most important advantages of solid lubricants are sustainability versus increasing temperature and resistance in chemical active environments. Therefore, in industries with difficult working conditions that do not allow the use of other lubricants, such as the aerospace industry, solid lubrication mechanisms are used (Mehta, Masood and Song, 2004).

Wear on lubricated surfaces

Despite the reduction in wear when lubricants are used, there is always a wear phenomenon in this case. Lubrication with four hydrostatic mechanisms, hydrodynamics, elastomer hydrodynamics and boundary lubrication are performed by liquid lubricants, which are often seen in contact with axle bearings. This classification has been done based on the conditions of delivery of the lubricant to the desired location and lubrication conditions at the beginning of the lubrication system. Hydrostatic lubrication is like hydrodynamic lubrication with thick lubricant layer and the difference between these two mechanisms is that, in a hydrostatic lubricant, the lubricant layer performs the separation of the surfaces by fluid pressure, and this pressure must be provided by the pressure pump. The elastic hydrodynamic lubrication is a combination of the elastic deformation of surfaces and the formation of a layer of oil by the hydrodynamic mechanism. The borderline lubrication is that lubrication is performed by the grease. In this case, the buckling points of the two surfaces are in contact with each other, but the remaining surfaces are separated from each other by the presence of a thin, soft, and semi-solid layer of grease.

The following figure shows three different types of placement of the lubricant layer between the surfaces.

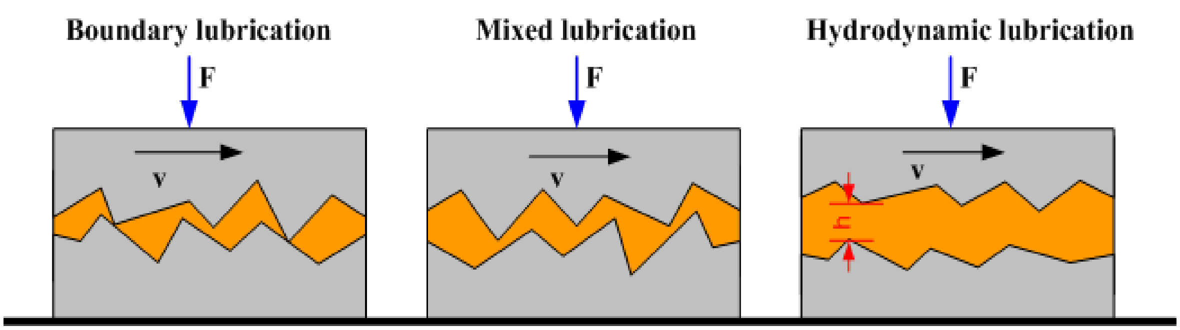

Figure 3: (Types of placement of the lubricant layer to 3 full face layers, thin layer, lubricant layer and boundary layer (Mellor and Brian, 2006)

Wear between non-lubricating surfaces

A type of wear that has not been used with any intermediate lubricant is found less among industrial components and equipment, because it is often used between the levels of at least one type of lubricant, even in the form of lubrication itself without the presence of a lubricant. Occasionally, in the absence of a complete lubricant, the presence of oxides on the surfaces or the presence of the atmosphere creates lubrication conditions. Only if the surfaces are in a complete vacuum and are cleaned by another factor such as electron beams, the absence of lubricants is possible (Mehta, Masood and Song, 2004).

Wear processes and mechanisms

Wear is a constant and undesirable drop in the surfaces of the involved parts, resulting in a relative movement between them. In conventional conditions, wear is a result of the concentration of excessive tension between the two contact nodes, which is achieved by vertical and tangential forces (friction). In general, the type of relative motion determines the wear process, while the wear mechanisms depend on the energy interactions and the material between the triobesystem components (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy").

A. Wear processes

1) Sliding
2) Rotation
3) Impact
4) Swinging
5) Erosion

B. Wear mechanisms

1) Abrasive Wear
2) Adhesive Wear
3) Layer sheet
4) Wear Tribochemical
5) Fretting Wear
6) Surface Fatigue Wear
7) Erosive Wear

1- Abrasive Wear

Abrasive Wear occurs when a rough surface is slippery in front of a softer surface, slipping into it and creating a series of grooves. The dust particles produced by the mechanism can be pulled. In this case, Abrasive Wear is a biaxial type. Abrasive Wear can also be created in different situations, for example, when abrasive particles in the interface between the two surfaces are in a slip condition and separates particles from both surfaces, Abrasive Wear in this face is called a three-body. Abrasive Wear is not a two-part body if the surface of the material slipping is harder, smooth and polished. Likewise, Abrasive Wear is not seen in three bodies when the abrasive particles are small and softer than the material being slipped. Therefore, it is possible to create situations in the slip system that does not occur at any rate that can be thought of as Abrasive Wear. According to the results of Abrasive Wear, the severity and weakness of Abrasive Wear depends on the hardness ratio of the abrasive material to the hard wearing surface. Research has shown that the surfaces are more resistant to Abrasive Wear, which has a hardness of more than half the abrasive hardness. Abrasive Wear resistance is usually attributed to the hardness of the surface and the part (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy").

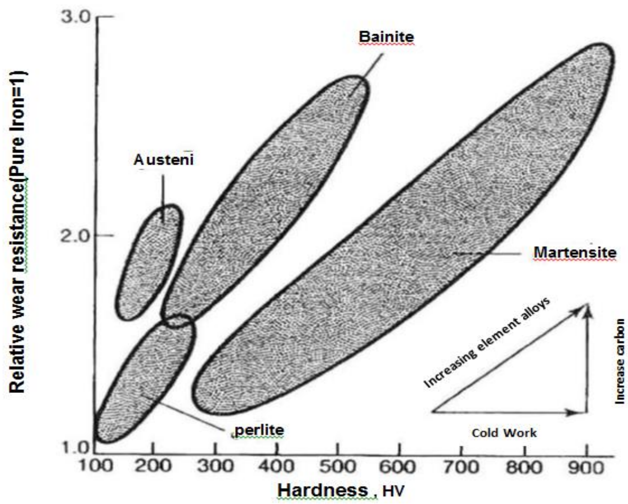

Figure 4: The Effect of Different Microstructures on the Resistance to Abrasive Wear of Two-body Steel against Abrasive Particles (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy")

The main mechanisms of Abrasive Wear are plastic deformation and fracture failure. This type of wear is carried out in two types of wear and a three-piece wear. Figure (5)

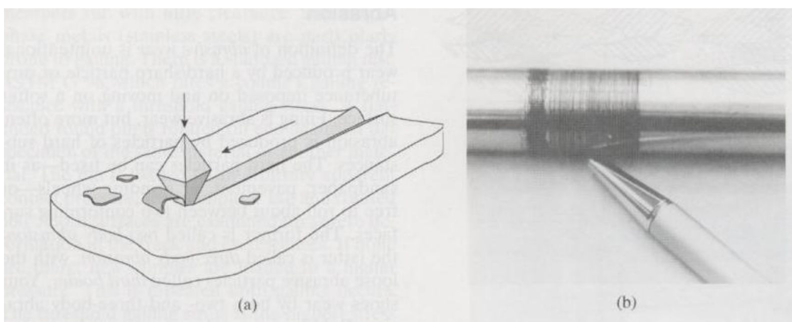

Figure 5: Abrasive Wear (a) and wear surface of the shaft due to the slip of the liner (b) (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy")

The dust particles produced by the mechanism can be trapped (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy").
In this case, Abrasive Wear is a two-body type (Figure 6)

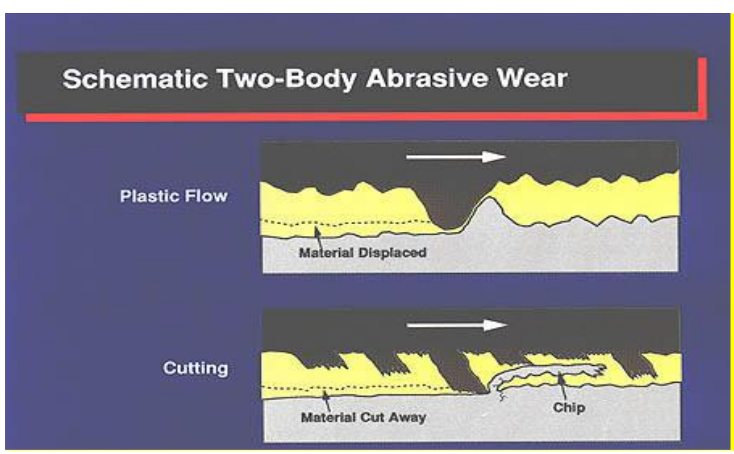

Figure 6: Schematic View of Abrasive Wear two-body (Hutchings, 1992)

Abrasive Wear can also be created in different situations, for example, when abrasive particles are located at the interface between two surfaces and slip away from both surfaces, In this case, Abrasive Wear is called three-body. Figure (7)

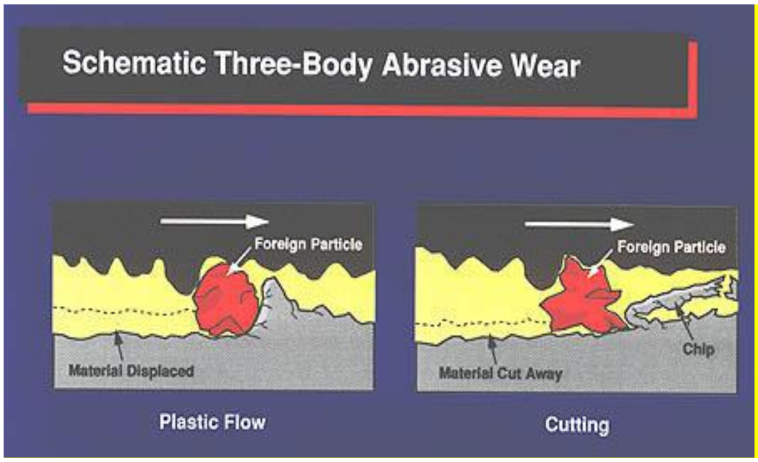

Figure 7: Schematic View of Three-Body Abrasive Wear (Hutchings, 1992)

Shatter wear resistance is generally expressed in terms of surface hardness. However, the effect of the hardness phenomenon or the hardness of the erosion surfaces should also be considered.

1-1- Abrasive Wear Mechanisms (Kumi, "Development and Evaluation of an Abrasive Wear Test Equipment"):

A) Micro Ploughing
B) Micro Cutting
C) Crack
D) Micro Fatigue

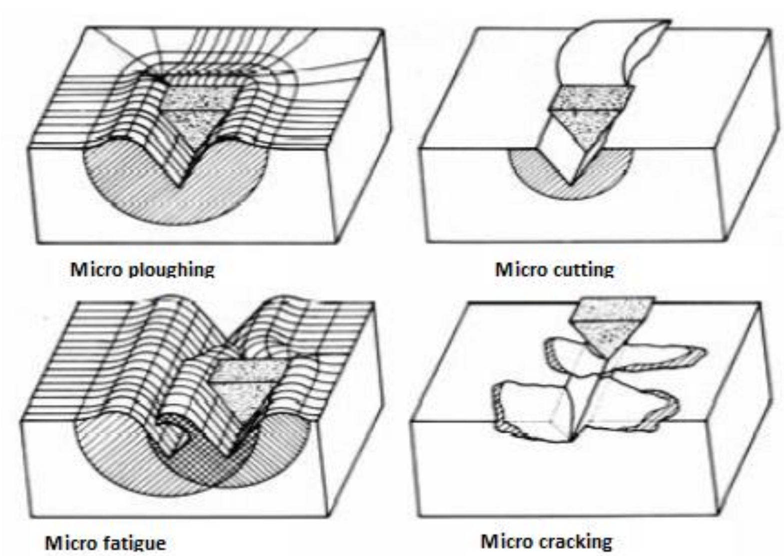

Figure 8: Schematic of Abrasive Wear Mechanisms (Kumi, "Development and Evaluation of an Abrasive Wear Test Equipment")

A) Micro Ploughing:

In this case, abrasion of the soft surfaces does not cause the pulling of material and only material is displaced on the surface and it is regularly accumulated as bumps on both sides of the groove and it usually forms a nose in front of the abrasive material. The mechanism is very similar to the ploughing of agricultural lands and the amount of material separated is less than the volume of the groove created usually due to the displacement of materials on the surface. The Micro Ploughing phenomenon is mainly considered on very soft surfaces. One of the important indicators of this mechanism is the appearance of strain in a relatively wide range around the surface grooves (Kumi, “Development and Evaluation of an Abrasive Wear Test Equipment”).

B) Micro Cutting:

In this case, cutting by the abrasive material causes a long wear particle. The transfer of the Micro Ploughing mechanism to the Micro Cutting occurs when the hardness of the material is increased compared to the previous one. The volume of separated particles is equal to the volume of the grooves created. The transfer of Micro Ploughing to Micro Cutting also depends on the contact angle of the abrasive material and the coefficient of friction (Kumi, “Development and Evaluation of an Abrasive Wear Test Equipment”).

C) Micro Cracking:

If the stiffness of slip surface increases, Abrasive Wear can be created under a micro cracking mechanism. In this case, the plastic deformation around the groove is negligible and the amount or volume of the wear particles is far greater than the volume of the grooves created on the surface. In this mechanism, the pulling of wear particles is due to the formation and crack propagation around the embedded grooves. By increasing the surface stiffness, wear mechanism is transmitted from micro cutting to the micro cracking (Kumi, “Development and Evaluation of an Abrasive Wear Test Equipment”).

D) Micro Fatigue:

The accumulated particles around the surface grooves are continuously displaced by abrasive materials, which can cause the Micro Fatigue phenomenon (Kumi, “Development and Evaluation of an Abrasive Wear Test Equipment”).

2- Adhesive Wear

The surfaces of the engineering parts produced by various processes are not completely smooth and have multiple heterogeneities. As a result, the involvement of engineered parts in the surface is taken place at several dispersed points and it causes a lot of stresses in these areas. This issue causes plastic deformation and topical connections on the surface. Adhesive Wear occurs when a topical slip between the two involved surfaces causes the rapture of connections and eventually the transfer of material from one surface to another. The rapture of joints occurs in the interface or in the more acute state in a depth from the joint part continuously. If the rupture is in the initial contact surface, the shear strength of the joint is less than the strength of both materials involved and the transfer of material is not taken place from one surface to another. But if the rupture occurs in the bottom layer, the shear strength of the joint is greater, in which case the material is transferred from one surface to another. Generally, changes in the surface layer can affect the type of rupture. Table (1) (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy").

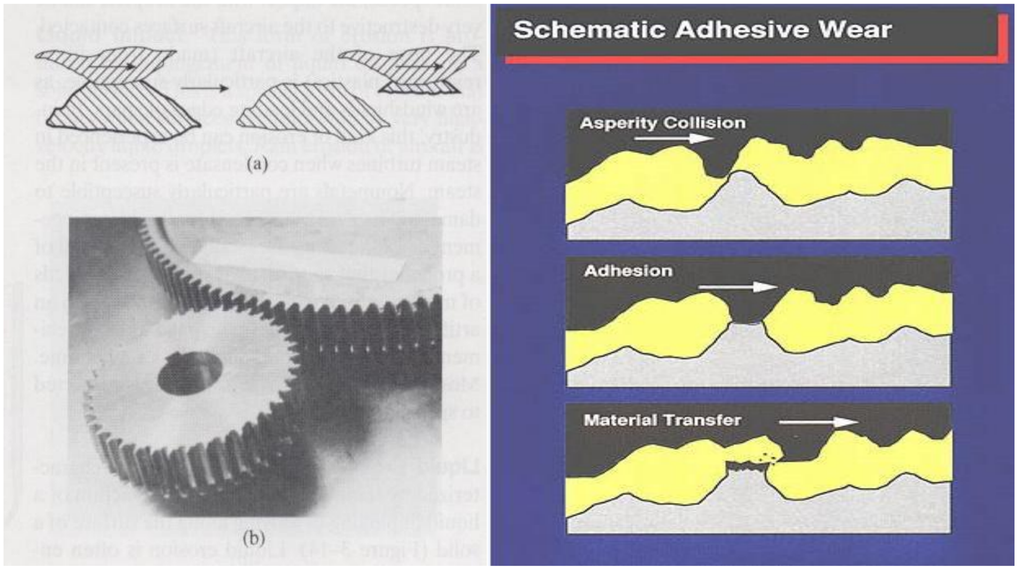

Figure 9: Schematic View of Adhesive Wear and Adhesive Wear of Two Rotors (Hutchings, 1992)

Table 1: changes in the surface layer and type of rapture related to it (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy")

Changes in surface layer	Type of rapture
Formation of additional vacancies, unsustainability of crystals in surface and flowing them	Rapture in interface
Formation of dislocations, hard work of friction surfaces	Rapture in depth
Formation of protective films with low stability	Rapture in interface
Increasing heat of contact part-soften	Rapture in interface

The map drawn from the amount of adhesion of the elements to each other Fig.(10) can be used to predict the adhesion of the wear surfaces of metals.

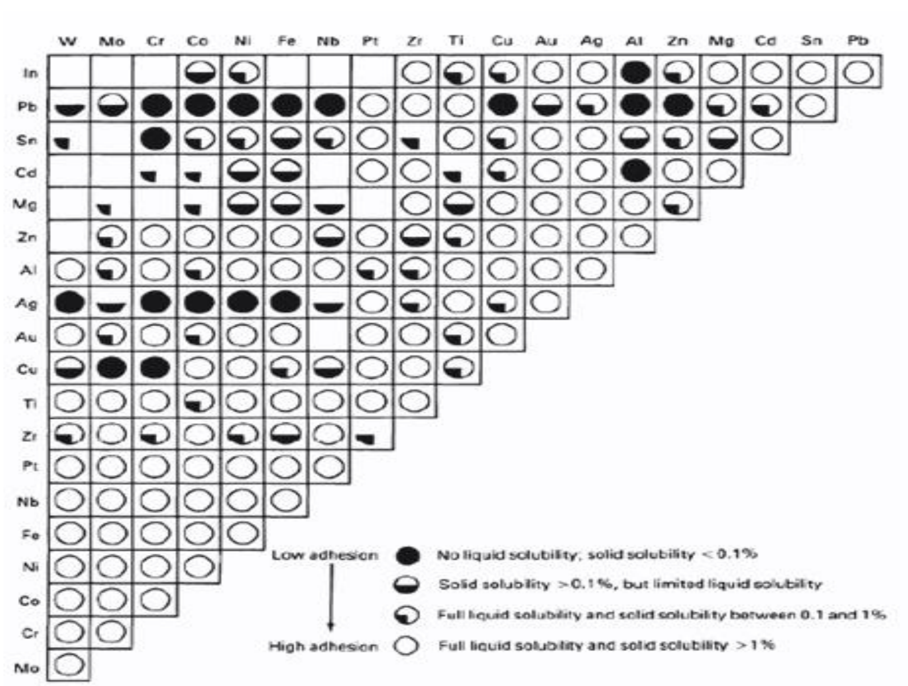

Figure 10: map of the adhesion of the elements together (Blau, 1992)

2.1 Adhesive Wear Mechanisms (Kumi, "Development and Evaluation of an Abrasive Wear Test Equipment"):
There are several mechanisms to justify the adhesion and the joint of surface heterogeneity:

A) Mechanical Interlocking:
Due to the local deformation, surface heterogeneities of relatively strong joints create between two surfaces.

B) Diffusion Theory:
The transition and intrusion of atoms in the interface of the surfaces involved causes strong joint.

C) Electronic Theory:
The electron transfer causes the formation of loaded layers on both sides of the interface and joint is taken place due to the effective electrostatic forces of the layers.

D) Adsorption Theory
The secondary intermolecular forces of the surfaces in full contact cause strong and bonding joints. The tendency to form bonding joints depends on the chemical and physical properties of the materials involved, the manner and amount of loading and surface properties such as contamination and roughness. Since the bonding force depends on the actual contact surface, resistance to plastic deformation depends on the shape of the crystalline structure, the number of slip systems and the defective energy of picking. The tendency to the cohesion from the crystal structure of the hcp increases to bcc and fcc.

3- Delamination Wear
In the Delamination Wear surface, the material is considered to be laminated that is separated from the surface by the process of wear in the triobesystem, like the isolation of the onion shell. According to lamination theory, shear plastic deformation, crack germination, and spreading it is created in a short depth of surface that finally it leads to the laminated separation of wear particles. Transferring material in this mechanism, unlike Adhesive Wear, does not occur due to the cohesion on the surface. This phenomenon is especially observed in low-speed back and forth motions (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy").

3.1 Theories presented for lamination

A) The theory of dislocation accumulation under the surface
B) The theory of the distribution of compressive stresses on the surface

A) the theory of dislocation accumulation under the surface
At the time of wear, the material near the surface does not have a high dislocation density, because the atomic layers on the surface are bonded only on one side so the material on surface and near the surface, relatively less hardworking is taken place on it. In the process of wear and by increasing slip distance, dislocations begin to accumulate in short distance from the surface. The factors of this accumulation can be structural heterogeneities. For example, stopping dislocations by secondary phases, sediment phases and carbides are factors that intensify this accumulation. With the accumulation of dislocations around hard particles, the ground around these heterogeneities will be deformed. Due to the discontinuity between the ground and the heterogeneity during plastic deformation, this deformation leads to the formation of cavity and crack around these particles. When the crack length reaches the critical level, the material between the crack and the surface is detached as a sheet-shape particle (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy").

B) The theory of the distribution of compressive stresses on the surface
According to this theory, when two slip surfaces are in contact with each other, due to repeated loading, the softer surface heterogeneities are easily deformed and some of them are fractured. By separating these

heterogeneities, the surface is relatively flat and, in this case, contact is not involved between the two-surface heterogeneities, but the harder surface heterogeneities merge in the softer surface and create grooves. Due to alternating loading of harder heterogeneities on a softer surface, plastic shear deformation is accumulated and points are drawn on the surface and under the surface. With the continuity of deformation and tension under the surface, cracks germinate under the surface. Crack germination is not possible on the surface and close to the surface, since in the contact area a high pressure stress exists as three-dimensional and prevents cracking germination. The continuation of this process leads to the expansion of the cracks; the cracks connect together and spread along the surface at a certain depth, which depends on the material properties and coefficient of friction. In certain and weak places, these cracks cut the surface from depth and wear particles appear as thin and long sheets (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy"). To avoid Delamination Wear, the materials used must be rigid and flexible (high toughness) and show a less frictional coefficient when contact (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy").

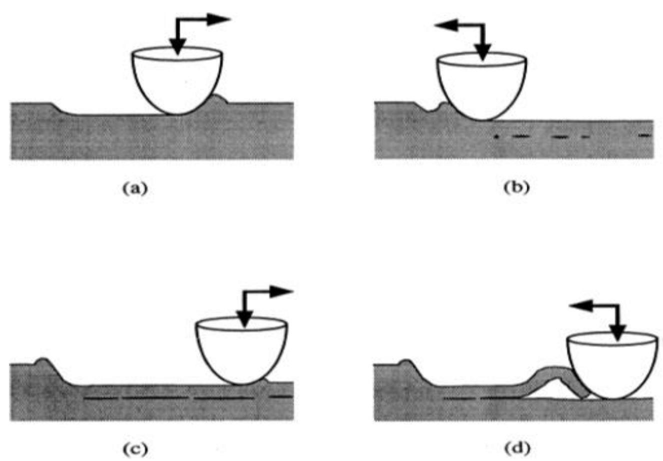

Figure 11: schematic of the occurrence of laminated wear (Kumi, “Development and Evaluation of an Abrasive Wear Test Equipment”)

a) Plastic deformation of surface
b) Crack germination in the layer below surface due to plastic deformation
c) Spreading crack from grains of crack caused by plastic deformation
d) Separating loose wear sheets

The following figure shows the lamination phenomenon due to Delamination Wear.

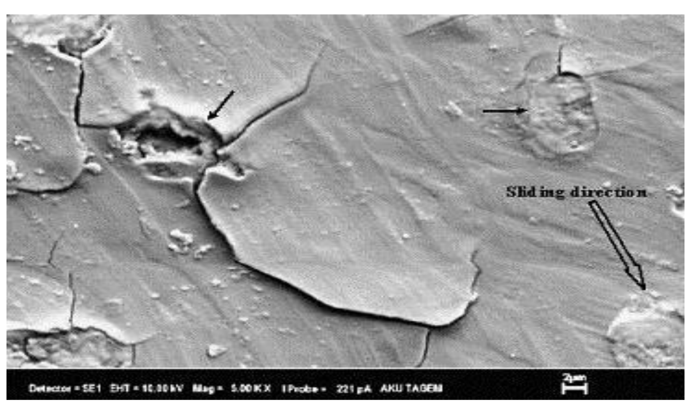

Figure 12: Scanning electron microscopy (SEM) from the Delamination Wear phenomenon (Blau, 1992)

4- Tribo Chemical Wear

Tribo Chemical Wear is the indicators of two contacting surfaces that react with the surrounding environment. The adjacent environment can be gas or liquid. The wear process continues with the formation of the reaction product layers and the continuous separation of the layers on the surface of the contact. In the presence of oxygen, these layers contain large amounts of oxides that are formed on the surface and then disintegrated in the form of wear particles.

4.1. Tribo Chemical Wear Mechanism

A) Metal contacts between the surface heterogeneities that lead to the separation of the metal due to cohesion. Micro metal wear particles may oxidize.
B) Chemical reaction of metals with the environment leads to the formation of protective surface layers that can reduce metal contact.
E) Cracking the protective layer of the surface due to high local pressure or microhardness results in the formation of non-metal wear particles. Metal or non-metal wear particles can act as abrasive particles and roughen the contact surfaces.
F) The subsequent formation of protective layers of surface leads to the smoother of surfaces.

Destruction and weight loss of surfaces are taken place by repeating these processes.

4.2 Important factors in tribochemical wear

Tribo Chemical Wear is strongly influenced by the kinetics of the formation of surface layers and their properties, which determines the resistance to detachment. These properties include: Flexibility, strength and cohesion to the substrate. Resistance to cracking the tribochemic layers increases by increasing the strength of the underlying material. The low wear occurs when the stiffness of the tribochemic layer is equal to the substrate. This also reduces the attacks of hard particles to the underlying layer. The amount of chemical activity to minimize wear depends on the severity of the slip, contact pressure, temperature, and surface quality. Harder layers of surface can reduce Tribo Chemical Wear. But on the other hand, Abrasive Wear increases. The risk of Abrasive Wear depends on the loading state and the properties of the surface layer, such as stiffness, torsion and adhesion to the substrate and the properties of the substrate material (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy"). In Fig. 13 you will see a schematic of Tribo Chemical Wear.

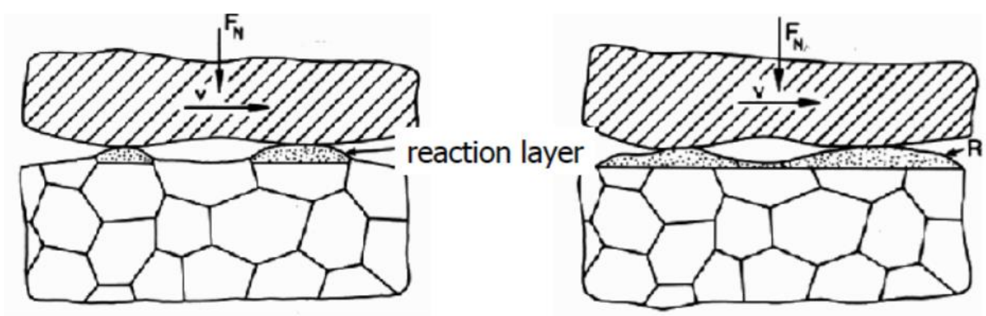

Figure 13: schematic of Tribo Chemical Wear (Blau, 1992)

5- Fretting Wear

This type of wear occurs when the two surfaces in contact are placed under low range swinging loads and slip through vibrational stresses created. The swinging range in operation is between 2 and 22 microns. This phenomenon is sometimes accompanied by corrosion and oxidation, but also it is found in non-oxidizing metals such as gold and platinum.

5.1 Fretting Wear Mechanism

A) Adhesion and producing metal wear particles (Adhesive Wear)
B) the creation of wear particles by chemical mechanical effect. In this step, the mechanical action causes the fracture of oxide films and the clean of surface and strain of metal, which, due to being active, in the next half-cycle, the presence of the atmosphere leads to the re-oxidation of the surface (Tribo Chemical Wear)
C) Uniform producing of wear particles by fatigue (Surface Fatigue Wear)
D) The oxide wear particles produced by the above processes play the role of abrasive powder and cause continuous abrasive wear of surface.

Each of the fretting wear steps is controlled by another major wear mechanism. As a result, several factors can affect fretting wear. Mechanical variables such as number of cycles, displacement range, applied force and frequency, and physical variables such as temperature, stiffness, and final finish of surface are among the factors of fretting Wear (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy"). In Fig. 14, the fretting wear schematic mechanism in the relative motion of a shaft and sleeve including it is displayed.
Motion with a low swinging range in this mechanism is created from various conditions such as irregularity, the presence of fine particles in lubricants, the presence of sediment particles, and so on, which ultimately can damage the inner surface of the sleeve.

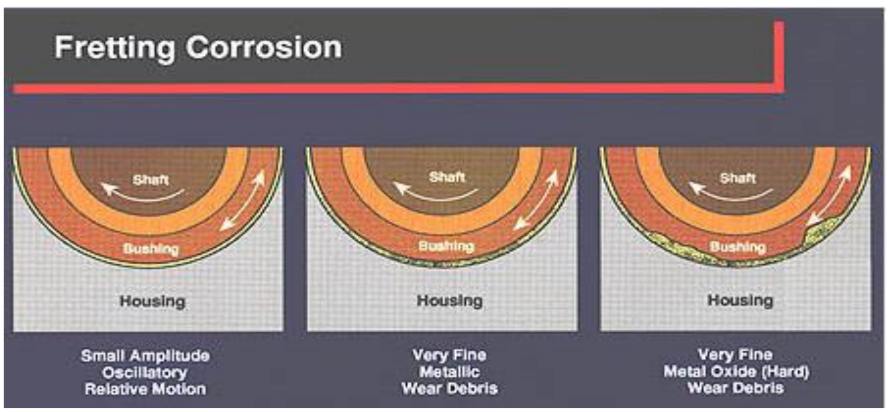

Figure 14: Schematic Mechanism of fretting Wear (Hutchings, 1992)

In Figure 15, the outer surface of a bearing damaged by the fretting Wear mechanism can be observed.

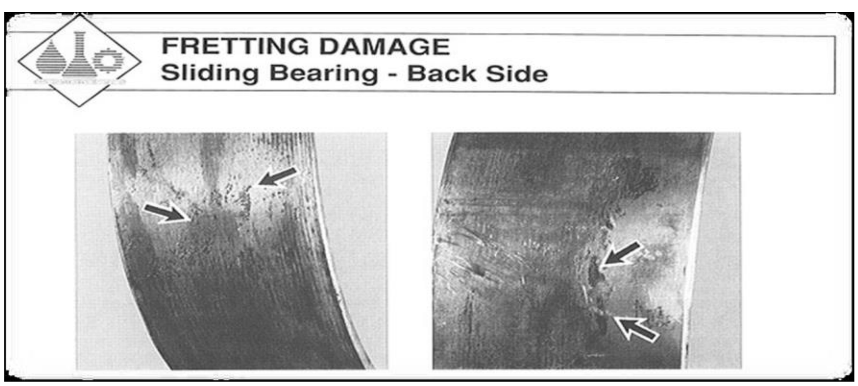

Figure 15: the damaged surface of a bearing due to fretting Wear (Hutchings, 1992)

6- Surface Fatigue Wear

In this type of wear surface, the material is weakened by cyclic or periodic loads, and after the formation of micro cracks and growth, part of the surface is separated. By applying repetitive loading on an object, after a certain cycle, loading of the surface part is susceptible to microscopic cracks, and these cracks continue to grow rapidly and eventually cause the pulling of a part of the surface (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy").

Figure (16), pulling of a part of the wheel surface due to the motion on the rail and the occurrence of a fatigue wear phenomenon can be observed.

Figure 16: wear of wheel fatigue due to motion on the rail (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy")

7- Erosive Wear

In some cases, wear is obtained from the collision of hard particles with the surface, which are either carried by a flow of gas or existed into the liquid. This type of wear is called erosion, and it is often defined as erosion of solid particles or erosion due to solid collision to differentiate between damages caused by high-pressure liquid or liquid droplets (Salehi and Afsharzadeh, "surface Metallurgy and Trilogy"). In Figure 17, a schematic of the Erosive Wear mechanism is considered. This process is very similar to the sandblasting process, during which the surface part is eroded due to fine particles' collision to the surface part.

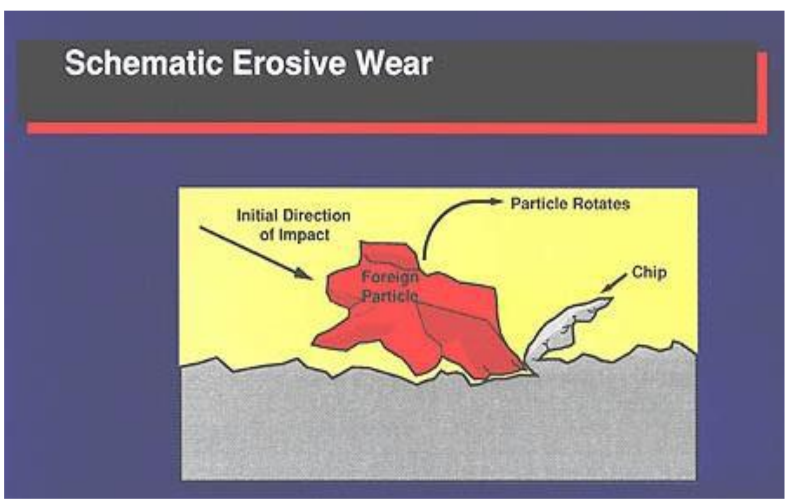

Figure 17: Schematic of Erosive Wear Mechanism (Hutchings, 1992)

7-1- Erosive Wear Factors

The wear rate in this mechanism depends on several factors, for example, the shape of the particles collided with the surface, stiffness, the impact velocity, and the angle of collision of particle with the surface. The angle of impact is one of the most important factors of Erosive Wear. For Ductile materials, the maximum of wear rate occurs when the angle of impact is approximately 32 degrees, while this angle is 92 degrees for non-ductile materials (Kumi, "Development and Evaluation of an Abrasive Wear Test Equipment").

Conclusion

Today, steels are considered as the most widely used metal in comparison to other types of metals due to unique properties. Due to the expansion of the use of thermally operational carbon steel as well as their different applications and the high thermal operation and economic efficiency of these types of steels, parts manufacturers are forced to use more these types of steels to produce various products.

Improving the wear properties in parts that are in contact with each other during work is an important step in increasing life of their function. For this purpose, different operations of alloying and various surface operations are used in different conditions and with various materials and equipment to improve the tribology properties depending on the type of part and type of function. Each of these operations has advantages and disadvantages, working time, complexity of operations and different costs. Therefore, finding a method that is accompanied by a significant improvement of resistance against wear, increasing the quality and strength of widely used and costly metals is very significant, so composite and Nano composite coatings with more effective tribology properties are considered in improving the properties of metals and non-metals.

The major problem with the use of steels in various industries is due to surface phenomena such as corrosion, wear, fatigue, etc., which imposes a significant cost on the economy of each country. Therefore, the study of tribology behaviors, types of mechanisms and causes of wear in surface parts is important in order to properly understanding the phenomena of wear.

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