UNIT-2: "WEAR & TYPES OF WEAR"

Lecture by

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Instructional Objectives

After studying this unit, you should be able to understand:

- Classification of Wear,
- Theories of adhesive, abrasive, surface fatigue and corrosives wear, erosive, cavitation and fretting wear.

Wear

INTRODUCTION

- ❖ Wear is defined as the undesirable but inevitable removal of material from the rubbing surfaces.
- ❖ Though the removal of material from the surface is small, it leads to a reduction in operating efficiency.
- ❖ The more frequent replacement or repair of worn components and overhauling of the machinery may cost enormously in terms of labour, machine down-time and energy in the manufacture of spares.
- ❖ The term wear is used to describe the progressive deterioration of the surface with loss of shape often accompanied by loss of weight and the creation of debris. Through, at the outset wear appears to be simple, the actual process of removal of material is very complex.
- ❖ This is because of a large number of factors which influence wear.

Wear (Cont..)

INTRODUCTION

❖ The major factors influencing wear are given below:

- Variable connected with metallurgy.
  - ✓ Hardness.
  - ✓ Toughness.
  - ✓ Constitution and structure.
  - ✓ Chemical composition.
- Variables connected with service.
  - ✓ Contacting materials.
  - ✓ Pressure.
  - ✓ Speed.
  - ✓ Temperature.
- Other contributing factors.
  - ✓ Lubrication.
  - ✓ Corrosion.

Wear (Cont..)

INTRODUCTION

- Wear is a process of gradual removal of a material from surfaces of solids subject to contact and sliding.
- Damages of contact surfaces are results of wear.
- They can have various patterns (abrasion, fatigue, ploughing, corrugation, erosion and cavitation).
- The results of abrasive wear are identified as irreversible changes in body contours and as evolutions of gaps between contacting solids.
- The wear depth can be estimated with the aid of wear laws.

Wear (Cont..)

INTRODUCTION

- Further, the wear which occurs in practice is usually a combination of one or more elementary forms.
- Hence, no single empirical relations connecting wear with the operating parameters such as load, speed and material constants for all situations is available.
- In fact the search for such a single relation is somewhat meaningless since several quite distinct phenomena are lumped in a single word Wear.

Wear (Cont..)

INTRODUCTION

- Therefore, to combat wear, it is essential to understand the mechanism of the various elementary forms of wear given below.
  - ✓ Adhesive.
  - ✓ Abrasive.
  - ✓ Surface fatigue.
  - ✓ Corrosive.
- Through the knowledge of elementary forms of wear it is easy to understand the special forms of wear such as:
  - ✓ Oxidative.
  - ✓ Fretting.
  - ✓ Erosion.
  - ✓ Cavitation.

Wear (Cont..)

INTRODUCTION

- Survey carried out on wear encountered in industry has revealed the following contributions:
  - ✓ Abrasive 50%
  - ✓ Adhesive 15%
  - ✓ Erosive 8%
  - ✓ Fretting 8%
  - ✓ Chemical 5%
- There are many situations in which wear can change from one type to another. Adhesive wear may be responsible for generating hard wear debris which then leads to abrasive wear. Two types of wear may operate concurrently; eg: abrasive wear and chemical wear operate together in marine diesel engine cylinder liners.

Wear: Basic Concept

- Wear is damage to a solid surface generally involving progressive loss of material, due to relative motion between that surface and a contacting substance or substances.
- This includes topography without loss of materials, as well as the more usual case of material removal.
- The wear processes common in machines in which one surface slid or rolls against another, either with or without the presence of deliberately applied lubricant and the more specialized types of wear which occur when the surface is abraded by hard particles moving across it, or is eroded by solid particles or liquid drops striking it or by the collapse of cavitation bubbles in a liquid.
- The difficulties involved in fully describing and then in formulating models for, the behaviour of a wearing surface are not just associated with the extreme local conditions.

Wear: Basic Concept (Cont..)

- The problem is much more complex than that, for at least three more reasons.
- First, the process of wear itself changes the composition and properties of the surfaces and near surface regions; the material which separates two sliding surfaces can be treated as distinct ‘third- body’ with its own evolutionary history and properties and these properties will often change during the life time of the system.
- Second, the removal or displacement of material during wear leads to change in surface topology.
- Third, the mechanism by which wear occurs are often complex and can involve a mixture of mechanical and chemical processes; for example, in the unlubricated sliding of two steel surfaces, material may be removed by mechanical means after oxidation, while under conditions of boundary lubrication the source of wear is often the mechanical removal of the products of chemical reaction between the steel surface and the lubricant additives.

Classification of Wear Mechanism

- Mechanism of wear are the succession of events whereby atoms, products of chemical conversion, fragments, et al., are induced to leave the system (perhaps after some circulation) and are identified in a manner that embodies or immediately suggests solutions.
- These solutions may include choice of materials, choice of lubricants, choice of contact condition, choice of the manner of operation of the mechanical system, etc.
- The classification of wear parameters, along with descriptive terms of the wear mechanisms, is shown in Table.

Classification of Wear Mechanism

Class	Parameter						
Friction type	Rolling	Rolling–sliding	Sliding	Fretting	Impact		
Contact shape	Sphere/ sphere	Cylinder/ cylinder	Flat/ flat	Sphere/ flat	Cylinder/ flat	Punch/ Flat	
Contact pressure level	Elastic	Elasto-plastic	Plastic				
Sliding speed or loading speed	Low	Medium	High				
Flash temperature	Low	Medium	High				
Mating contact material	Same	Harder	Softer	Compatible	Incompatible		
Environment	Vacuum	Gas	Liquid	Slurry			
Contact cycle	Low (single)	Medium	High				
Contact distance	Short	Medium	Long				
Phase of wear	Solid	Liquid	Gas	Atom	Ion		
Structure of wear particle	Original	Mechanically mixed	Tribochemically formed				
Freedom of wear particle	Free	Trapped	Embedded	Agglomerated			
Unit size of wear	mm scale	µm scale	nm scale				
Elemental physics and chemistry in wear	Physical adsorption, chemical adsorption, tribochemical activation and tribofilm formation, oxidation and delamination, oxidation and dissolution, oxidation and gas formation, phase transition, recrystallization, crack nucleation and propagation, adhesive transfer and retransfer						
Elemental system dynamics related to wear	Vertical vibration	Horizontal vibration	Self-excited vibration	Harmonic vibration	Stick-slip motion		
Dominant wear process	Fracture (ductile or brittle)	Plastic flow	Melt flow	Dissolution	Oxidation	Evaporation	
Wear mode	Abrasive	Adhesive	Flow	Fatigue	Corrosive	Melt	Diffusive
Wear type	Mechanical	Chemical	Thermal				

Classification of Wear Mechanism

- Wear processes can be usefully classified into three broad groups:
  - ✓ Wear by hard particles or liquids.
  - ✓ Wear by sliding and rolling contact.
  - ✓ Chemically assisted wear.
- A brief introduction to the most common wear mechanisms in these categories are:
- ***Wear By Hard Particles or Liquids.***
  - ✓ Well-known wear processes which fall into this category include abrasion, adhesion, corrosion, solid and liquid droplet erosion and cavitation erosion. Collectively, these account for nearly 80 % of all wear-related costs in industry.

Classification of Wear Mechanism

❖ ***Abrasive Wear***

- ✓ This is the form of wear which occurs when a rough hard surface, or a soft surface containing hard particles, slides on a softer surface, and ploughs a series of grooves in it.
- ✓ The material from the grooves is displaced in the form of wear particles, generally loose ones.
- ✓ Abrasive wear can also take place whenever hard foreign particles such as metal grit, metallic oxides, and dust and grit from the environment, are present between the metal and then tear off the metallic particles.
- ✓ The former type is called two body abrasion and the latter three body abrasion (Fig. a and Fig. b).

Classification of Wear Mechanism

- ***Abrasive Wear***

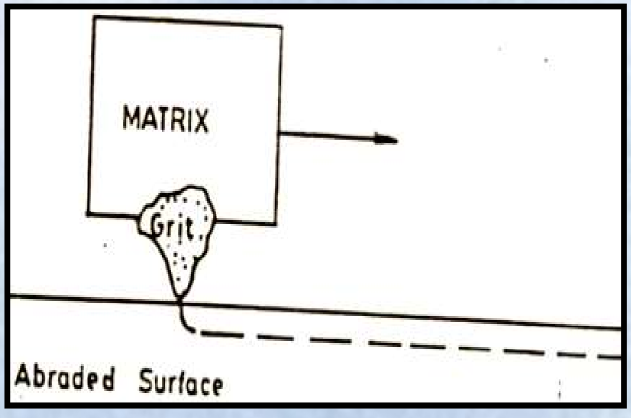

Figure a: Schematic View of 2-Body Abrasive Wear Mechanism .

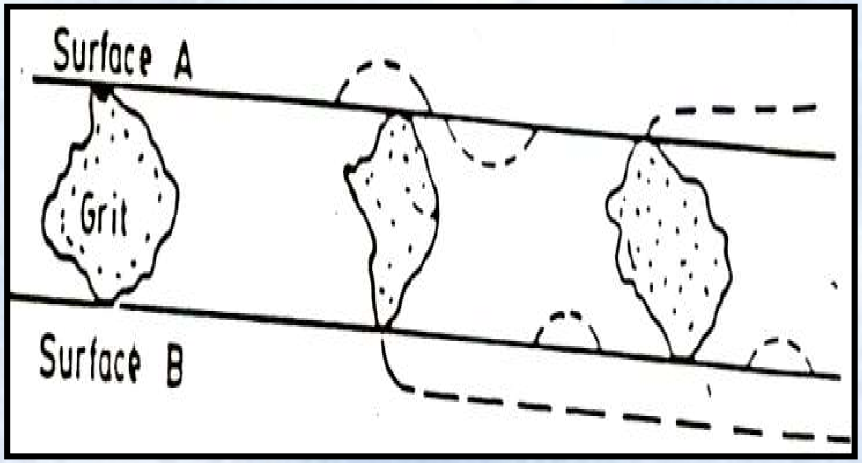

Figure b Schematic View of 3-Body Abrasive Wear Mechanism .

- Depending on the severity, abrasive wear is classified into gouging, grinding and scratching abrasion.
- Abrasive wear is one of the most common types of wear encountered in engineering practice, and it is probably the highest single cause of wear in many machine applications.

Classification of Wear Mechanism

- ❖ ***Adhesive Wear***
- ✓ This is the form of wear which occurs when two smooth bodies are slid over each other, and fragments are pulled off one surface to adhere to the other (Fig.).
- ✓ Later, these fragments may come off the surface on which they are formed and be transformed back to the original surface, or else form loose wear particles.

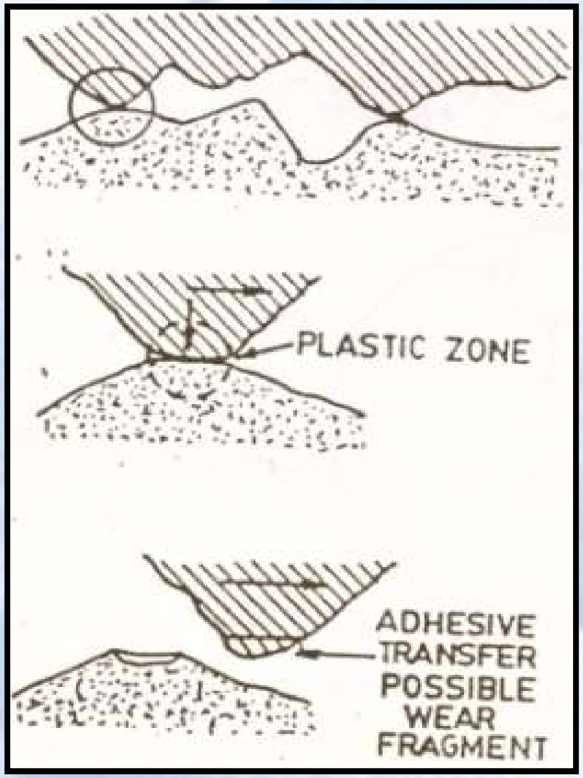

Figure 1.27 Schematic View of Adhesive Wear Mechanism [11].

Classification of Wear Mechanism

❖ ***Adhesive Wear***

- ✓ Depending on the severity of action adhesive wear is further classified as galling, scuffing, scoring, and seizing wear.
- ✓ This is probably the most basic type of wear.
- ✓ It is caused by a shearing action of microwelds formed between the surface asperities that actually carry the load between two mating surfaces.
- ✓ In turn, film failure is caused by high temperatures, pressures, and sliding velocities.

Classification of Wear Mechanism

❖ ***Corrosive Wear***

- ✓ This form of wear occurs when sliding takes place in a corrosive environment.
- ✓ In the absence of sliding, the products of the corrosion would form a film on the surfaces, which would tend to slow down or even arrest the corrosion, but the sliding action wears the film away, so that the corrosive attack can continue (Fig.).
- ✓ It is not easy to find a good illustration of corrosive wear, but an example of it is the IC engine cylinder surface wear.

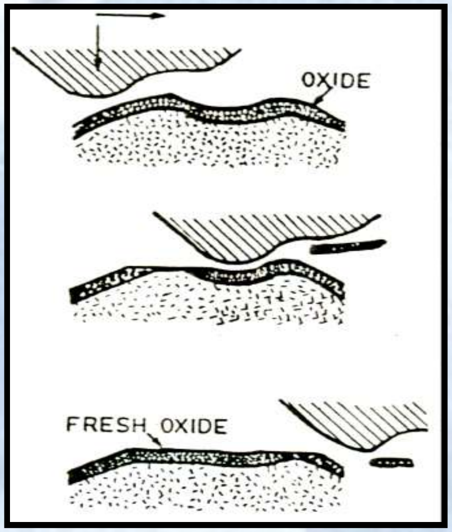

Figure: Schematic View of Oxidative Wear Mechanism .

Classification of Wear Mechanism

❖ ***Surface Fatigue Wear***

✓ This form of wear is observed during repeated sliding or rolling over a track. The repeated loading and unloading cycles to which the materials are exposed may induce the formation of surface or subsurface crack, which eventually will result in the break-up of the surface with the formation of large fragments, large pits in the surface (Fig.).

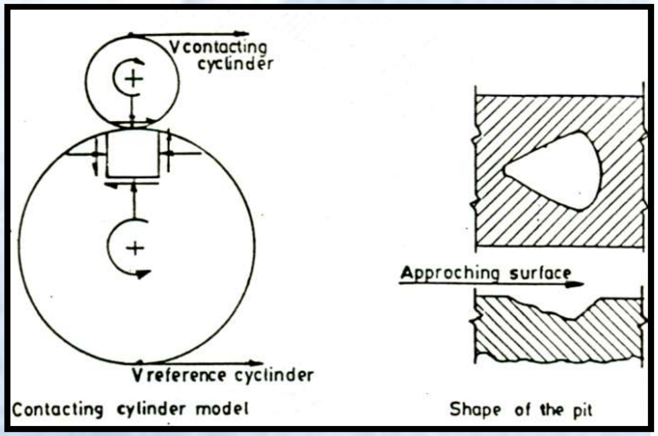

Figure: Schematic View of Surface Fatigue Wear Mechanism .

✓ This form of wear is also known as pitting, pitting corrosion, spalling and cause crushing. It is normally encountered in a pair of gears, ball and a race or cam and the follower.

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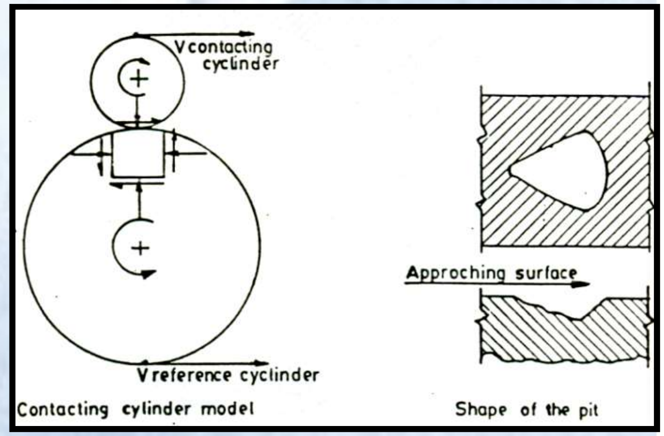

Figure: Schematic View of Surface Fatigue Wear Mechanism .

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Classification of Wear Mechanism

- ***Surface Fatigue Wear***
- ✓ The surface fatigue wear is further classified into two groups.
- ✓ Incipient pitting which is taking place when two virgin surfaces make the repeated sliding contacting.
- ✓ This may continue till the surfaces bed-in and will not progress thereafter.
- ✓ Destructive pitting sets in if the corrective action associated with the incipient pitting at the beginning of operation is insufficient to halt the pit formation.
- ✓ This is characterized as being progressive and leads to disintegration of the surface.

Classification of Wear Mechanism

❖ ***Special Forms Of Wear***

These are either another form of the basic types of wear arising out of changed situation or combination of the basic types of wear. Among these oxidation fretting, erosion and cavitation are the predominant types of wear encountered in Engineering field.

➢ ***Oxidative Wear***

✓ This is another form of adhesive wear.

✓ Metallic surfaces exposed to any atmosphere bearing oxygen will get oxidized and thin oxide film will be formed on the surface.

✓ This oxide film diminishes the adhesive wear and result in mild wear. However, during sliding it gets ruptured if not adherent to the surface and results in wear debris predominantly oxide in nature.

Classification of Wear Mechanism

- ***Special Forms Of Wear***
  - ***Fretting Wear***

- This type of wear is also known by several names viz. Frottage, fretting corrosion, false brinelling, wear oxidation, friction oxidation and chafing fatigue.
- It is a combination of adhesive, corrosive and abrasive wear.
- This form of wear arises when contacting surfaces undergo oscillatory tangential displacement of small amplitude.
- A typical example would be a splined out of line shaft coupling, in which the steel teeth undergo one small tangential to and fro movement per shaft revolution.

Classification of Wear Mechanism

- ***Special Forms Of Wear***
  - ***Fretting Wear***

- ✓ This type of partial movements also occurs in press-fitted assemblies.
- ✓ Damage may vary from discolouration of the mating surfaces to the wearing away of 1.5mm of material.
- ✓ In addition, the surface may show the formation of a great deal of corroded material or may have a heavily galled appearance with little oxide.
- ✓ It is presumed that the oscillatory motion breaks down any natural protective film on the surface, causing the metal to adhere and break away at each oscillation.
- ✓ Fretting damage is found in automobile front wheel bearings, kingpins, rocker arms, variable pitch propellers, landing wheels, cam followers in textile machinery, and electrical contacts.

Classification of Wear Mechanism

❖ ***Special Forms Of Wear***

➢ ***Fretting Wear***

✓ Then the debris may be converted into an abrasive oxide which causes the severe damage (Fig.).

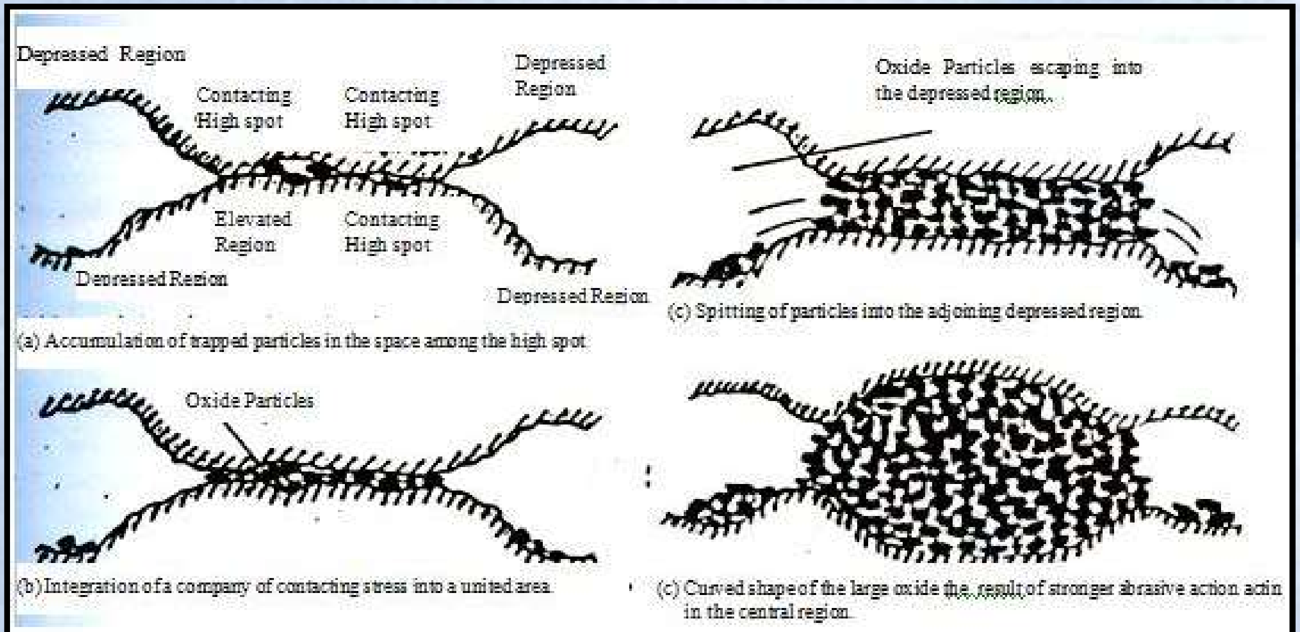

Figure: Schematic View of Fretting Wear Mechanism.

Classification of Wear Mechanism

- ***Special Forms Of Wear***
  - ***Erosion***

- ✓ The damage produced by sharp particles impinging on an object is closely analogous to that produced by abrasion.
- ✓ The main difference is that in erosion the surface roughness produced may become relatively greater, because an impinging particle may readily remove material from a low point on the surface (Fig.).

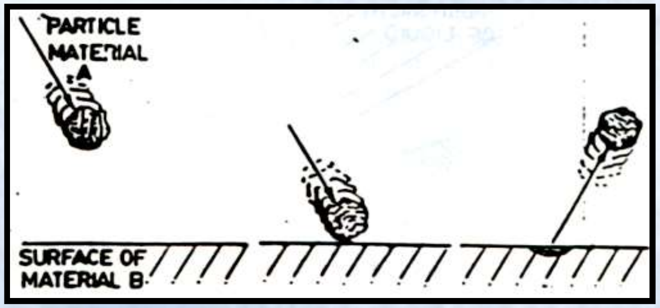

Figure: Schematic View of Fretting Wear Mechanism.

Classification of Wear Mechanism

- ❖ ***Special Forms Of Wear***
  - ➢ ***Cavitation***

✓ This is a process of surface damage and material removal caused by a liquid or gas without the presence of a second surface. In industrial practice the most common type of erosion is cavitation erosion (Fig.).

✓ It occurs in propeller blades, diesel engine cylinder liners, turbines and pumps. Cavitation is caused by high relative motions between the metal and the liquid.

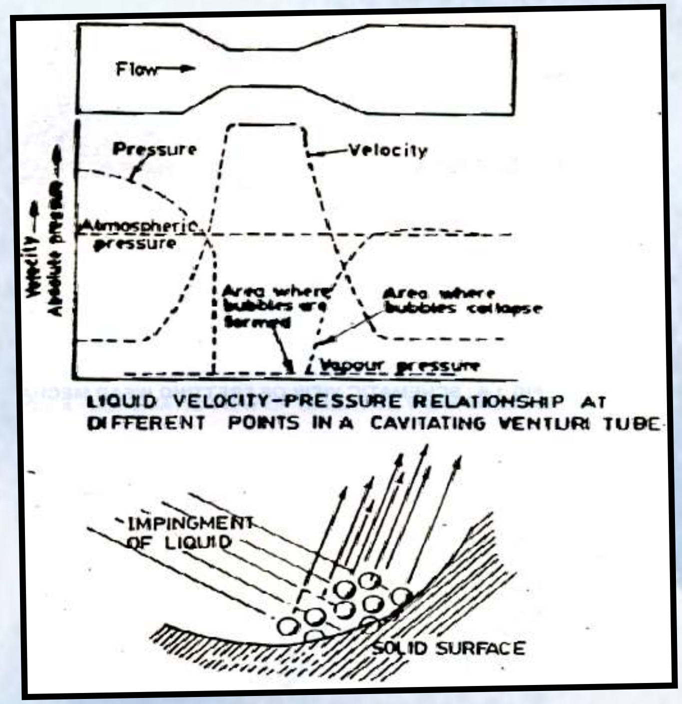

Figure: Schematic View of Cavitation Wear Mechanism.

Classification of Wear Mechanism

- ***Special Forms Of Wear***
  - ***Cavitation (Cont...)***
- ✓ At such motions, the local pressure on the liquid is reduced, the liquid temperature reaches the boiling point, and the cavities of the vapour are formed. When the pressure returns to normal, implosion occurs and the cavity collapses.
- ✓ This produces high impact forces on the metal, causing work- hardening, fatigue, and formation of cavitation pits.
- ✓ This action is purely mechanical, but often it exists in the presence of galvanic corrosion.

Classification of Wear Mechanism

❖ ***Wear By Sliding and Rolling Contact***

➢ ***Sliding Wear***

✓ Sliding wear is due to two solid surfaces sliding over each other under some applied load. In most engineering applications, such as plain bearings or bushings, the surfaces are lubricated in which case any wear that occurs is termed lubricated wear.

✓ Sliding wear is often also called adhesive wear, which is somewhat misleading since adhesion between the sliding surfaces represents but one aspect of sliding wear.

✓ Nevertheless, adhesion is evident in the well-known phenomena of scuffing and galling, which occur under conditions of high applied loads and/or poor lubrication.

Classification of Wear Mechanism

❖ ***Wear By Sliding and Rolling Contact***

➢ ***Sliding Wear (Cont...)***

✓ A characteristic feature of the sliding wear of metals is the occurrence of transitions in the rate of material loss as a function of sliding speed, applied load, and ambient temperature.

✓ In the mild (oxidational) wear regime, the sliding metals are separated by thin oxide films and direct metallic contact occurs only occasionally.

✓ Wear rates are low and the debris formed by the wear process is typically finely divided and consists of a mixture of metallic oxides.

✓ Mild wear is generally associated with the low loads and sliding speeds, although a severe form of oxidational wear can occur at high speeds and low loads where high interfacial temperatures result in rapid oxide film growth.

Classification of Wear Mechanism

❖ ***Wear By Sliding and Rolling Contact***

➢ ***Sliding Wear (Cont...)***

✓ With increasing loads and speeds, transitions occurs from mild to severe wear as a result of a change in the nature of the contact.

✓ The severe wear regime is characterised by penetration of the oxide films and direct metallic contact.

✓ Friction stresses tend to be high as a result of adhesion between the sliding metals and metallic wear debris is formed by material transfer and/or subsurface cracking and delamination.

✓ The wear rates experienced in the severe wear regime are two to three orders of magnitude higher than in the mild wear regime and are unacceptable in engineering applications.

Classification of Wear Mechanism

- ***Wear By Sliding and Rolling Contact***
- ***Rolling Contact Wear***
- ✓ Rolling contact wear occurs as a result of the repeated application of mechanical stresses to the surface of one body rolling on another body.
- ✓ It is most commonly found in components such as rolling element bearings and gears and is characterised by pitting due to surface fatigue.
- ✓ For this reason, the wear process is also often called rolling contact fatigue.
- ✓ The fatigue process is exacerbated by sliding (slip) which often accompanies the rolling motion, particularly in gears, and applies additional friction stresses on the surfaces.
- ✓ It is therefore important to ensure adequate lubrication of rolling systems in order to minimise the influence of slip.

Classification of Wear Mechanism

❖ ***Wear By Sliding and Rolling Contact***

➢ ***Chemically Assisted Wear***

✓ Chemically assisted wear refers to material damage which is caused by the combined influence of wear and environmental attack (corrosion).

✓ It is widely encountered in industrial systems such as slurry handling equipment and power generation plant.

✓ The rate of material loss associated with chemically assisted wear is often considerably higher than the sum of the material loss rates due to wear and corrosion alone (i.e. these mechanisms act synergistically).

✓ This is not unexpected since wear can accelerate corrosion by removing protective oxide films and exposing fresh, reactive metal surfaces.

✓ A special case of chemically assisted wear is fretting wear or fretting corrosion which is caused by small amplitude oscillations of contacting surfaces which are normally at rest.

Laws of wear

- **ARCHARD'S LAW OF ABRASIVE WEAR**
- Friction and wear depend as much on sliding conditions (the normal pressure and the sliding velocity) as on properties of materials concerned.
- The normal pressure and the sliding action are necessary for wear, i.e. mechanical wear is a result of the mechanical action.
- Therefore, the wear process depends first of all on the rubbing process.
- The earliest contributions to the wear constitutive equations were made by Holm (1946).
- Holm established a relationship for the volume of the material removed by wear (W) in the sliding distance (s) and related it to the true area of contact.

Laws of wear

❖ **ARCHARD'S LAW OF ABRASIVE WEAR**

✓ Archard (1953) formulated the wear equation of the form: the volume of the material removed (W) is directly proportional to the sliding distance (s), the normal pressure (pn) and the dimensionless wear coefficient (k), and inversely proportional to the hardness of the surface being worn away (H), i.e.,

$$W = k\frac{p_n s}{H}$$

✓ Nowadays, it is generally recognized that wear is related to the wear coefficient, the pressure and the sliding distance.

✓ Pin-on-disc test experiments can be used to determine how wear is acted by the pressure and the sliding distance.

Role of wear debris in modifying friction and wear

- ✓ The friction phenomenon is very sensitive to changes of sliding conditions.
- ✓ Experimental studies demonstrate that wear particles entrapped between sliding surfaces can affect frictional and wear behaviour very signicantly.
- ✓ The presence of the debris implies modifications of the friction coefficient and the wear rate, see Kuwahara and Masumoto (1980).
- ✓ Circulation of wear particles is reflected by the friction coefficient, which increases when the particles are accumulated and decreases when the particles are removed from the sliding interface.
- ✓ According to Suh and Sin (1980), the kinetic coefficient of friction for metals is in the neighbourhood of 0.1 to 0.2 (but mostly in the range of 0.12 to 0.17) regardless of materials tested, i.e. gold on gold, steel on steel, brass on steel, etc.

Role of wear debris in modifying friction and wear

- ✓ Wear particles entrapped between sliding surfaces affect frictional behaviour increasing the friction coefficient to 0.5-0.7.
- ✓ Variations in the friction coefficient show evolution of the amount of debris in the contact; a stability of the friction coefficient indicates a constant amount of debris in the contact interface.
- ✓ In some experiment study, a steady value of the friction coefficient was reached when the number of newly formed wear particles was equal to the number of particles leaving the contact interface (= 0.28 initial value, = 0.63 steady value).
- ✓ The steady-state wear rate may be larger for some sliding conditions where wear particles cannot be removed from the contact and act as abrasive particles.

Role of wear debris in modifying friction and wear

- ✓ There is a number of reports in the literature that spherical and cylindrical wear particles roll over each other with resulting low friction.
- ✓ It has also been reported that, as a result of the roll formation, the coefficient of friction undergoes transition to lower values by a factor of three, and the wear decreases by several orders of magnitude.
- ✓ The coefficient of friction in the presence of rolls usually ranges from 0.1 to 0.4 (Zanoria et al., 1995).
- ✓ It has been suggested that cylindrical debris can act as miniature roller bearings or "solid lubricants", so that sliding friction can be reduced.

END OF UNIT

Thank You