Surface Engineering for Corrosion and Wear Resistance Application
Prof. Jyotsna Dutta Majumdar
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Kharagpur

Lecture – 10
Wear Part – II

Hello we are in the process of discussing the different modes and sub modes of Wear.

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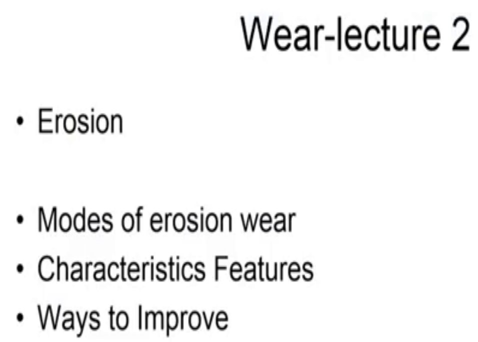

So, today we will discuss about the erosion and adhesive mode of wear. Now if you talk about the erosion wear this is nothing, but when the instead of solid particle solid part as the meeting surface we basically take fluid or maybe gaseous species as the meeting surface and where there is relative movement between the solid component and that of solid or gaseous species.

So, in this talk we will discuss about the erosive sub modes or different sub modes of erosive wear. The characteristics features of erosive wear as well as the ways to improve it.

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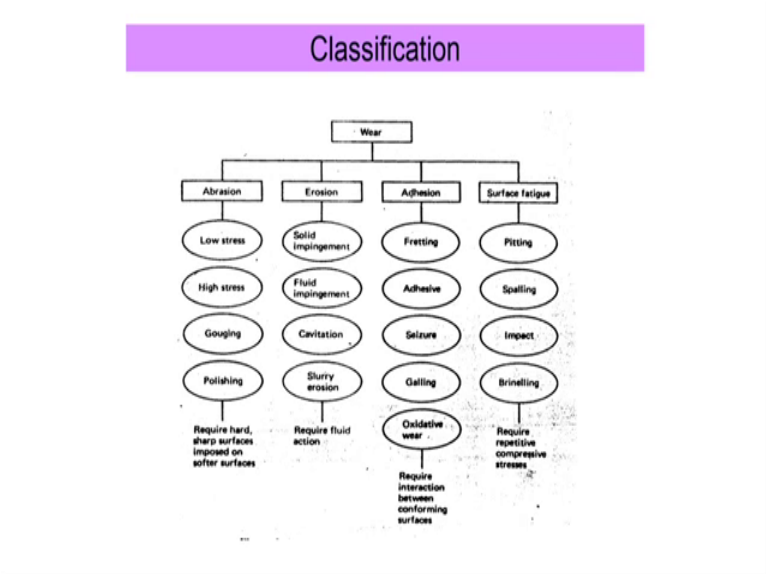

Now, if you talk about the different erosion phenomena again if you go to the classification we will see that erosion can be divided into 4 sub categories: one is solid impingement fluid impingement cavitation erosion and slurry erosion.

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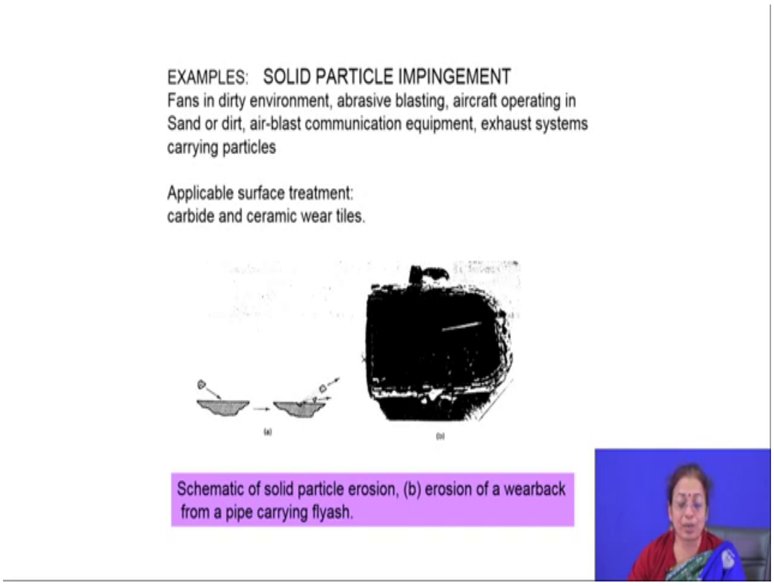

So, quickly go to the solid particle impingement, now if you just see the name from there itself you will get an idea about which kind of wear or which kind of material degradation takes place and the name is after which. Here if you see the different names the name names are after the environment the component is say see as well as some of the cases it is also the phenomena which is responsible for naming the particular process.

Now, if we talk about solid particle impingement and liquid particle impingement that is mainly after the name of the environment. After the environment which is interacting with the surface. So, solid particle impingement is a phenomena which occurs when the particles are dispersed in the gaseous species actually per small solid particles dispersed in the gaseous species they interact with the component and cause the wear to occur.

So, this is called solid particle impingement because of the fact that the environment is mostly gaseous and the impingement or solid particles occurs on the surface. Now, examples are like fans in dirty environment then abrasive blasting, aircraft operating in the sand or dirt then air blast communication equipment, exhaust systems carrying the particles. So, here if you see the mechanism by which the erosion occurs or the failure occurs.

It is nothing but high energy particles when interact with the surface there is the cutting action if the particles are highly regular and is very much soft and hard in nature. And if it is not and if the energy carried by the particles is high enough to cause the failure of the component by typical action of the by typical or may even the energy associated with the particles is higher than that of yield strength of the material then there is deformation and subsequently failure that deformation and subsequent subsurface crack formation and failure of the materials and then material gets away from the surface.

So, the mechanism may be anything like that depending on the softness of the particles, depending on the hardness of the particles, depending on the mass of the particle. Here basically you use the term energy in term instead of the instead of load because each particle carry each particle carries some energy which is equivalent to half m v square m is nothing, but the mass of particle and v is the velocity of the particle.

So, there when large numbers of particles they basically impinge on the surface of the component. Naturally lot of energies are carried by them; that energy basically can cause the deformation of the material from the surface and their subsurface failure and then failed component failed particles go out of the surface and there is loss of material from the surface.

So, each the each one of the examples as given here carries the same kind of failure because again particles they have interacted with the surface cause failure. If you see the surface or characteristics feature of the solid particle impingement you will find that there are presence of small-small pits and holes on the surfaces depending on the velocity of the particle, depending on the mass of the particle, depending on the size of the particle.

So, this is the characteristics features of the surface. So, erosion of a wear back from a pipe carrying flyers actually we will find lot of particles impinged on the surface and accordingly pits and holes are there. So, if you just quickly go through that abrasive applicable surface treatment, this is usually if you apply very thin hard layer on the surface by a typical hard facing operation physical vapor deposition or chemical vapor deposition process. You can get rid of or you can minimize the probability of the solid particle impingement.

Then another kind of impingement phenomena may be termed as liquid impingement process, which occurs when the component is in the flowing liquid especially in river or in sea when the like pipelines or maybe any kind of constructions which are there in the sea or inside this deep inside the sea or river or maybe is a typical sea, sea fall they are the kind of phenomena occurs they are termed as liquid particle impingement.

When liquid particle impingement the liquid particles the in a mass they basically impinge on the surface the similar to that of a solid particle. If solid particles are also there in the liquid they basically add up to the wear phenomena and while impinging they basically they deform the surface and also the cause of subsurface failure and the and they removal of the material from the surface.

So, this is called liquid particle impingement similar to that of solid particle impingement. But in liquid particle impingement depending on the composition of the liquid there may be also the phenomena of corrosion that is the liquid may interact with the surface and then form different other compounds which may be termed as chemical it by chemical interaction with the surface forms different compound which may be termed as a corrosion. So, if corrosive media is there in the liquid it adds up to the wear phenomena it increases the rate of wear further and you call it as erosion corrosion.

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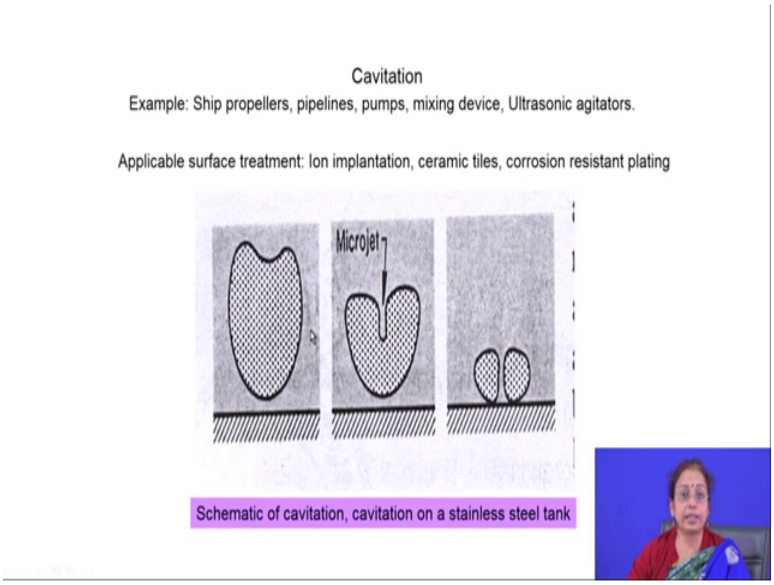

So, these are the two different types of corrosion.

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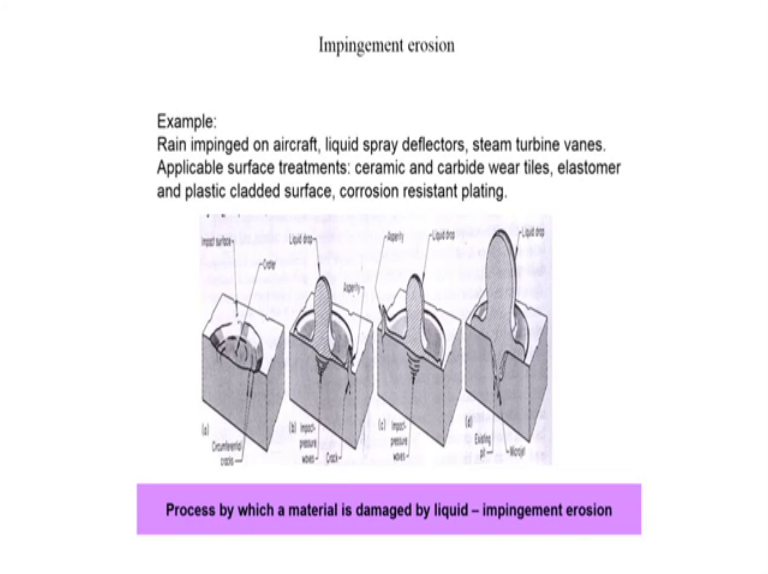

So, if you see the surface of the liquid impingement process you will find that the surface looks like there are deep holes on the surfaces are observed. And there are also sub surface crack formation and the failure depending on the sub surface failure the liquid particle may impingement and subsequently cause degradation of the material from the below surface region.

So, examples of the liquid impingement phenomena are rain impinged on aircraft, liquid spray deflectors, steam turbine vanes, these are the typical examples and surface treatments which may be applied to the prevent this kind of liquid impingement erosion there. Ceramic and carbide wear tiles, elastomers, plastic cladded surface, corrosion resistance plating because; whenever liquid comes into picture there is also corrosion phenomena which play important role which plays important role and cause the degradation of the component.

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So, after liquid impingement you will see that the surface looks like typical lot of pitting pits are there on the surface in addition to that there is also some directionality on the pitted surface. Because whenever there is slowing liquid which is interacting with the surface depending on the direction of the flow the component removal also will depend on. So, components or surface materials get removed in along certain direction depending on the direction of the flow of the component.

Now, 3rd type of erosion is Cavitation erosion. So, this is a special form of erosion which usually observed in the liquid media because especially in natural liquid media like in ponds or maybe in sea or in river when the component is there, or when the structure is there, you will find that in those large that liquid media there is always fluctuation in temperature and pressure.

So, somewhere you will find that some species how depending on the temperature and the pressure of that environment. The gaseous species which represent in the environment, they also have different different form. So, usually in all big media lot of gaseous species are there and those gaseous species sometimes they are in the form of soluble form sometimes they are not in the form of soluble and also their solubility changes as a function of temperature and pressure.

So, when the there is any high pressure very high temperature there is solution on the other hand when the pressure decreases or when they at the temperature decreases then they just from the bubble. So, when you see these all liquid media you will find that natural liquid media like pond or sea or maybe the river, there are a lot of gaseous bubbles present in the environment. So, those gaseous bubbles when this see the solid surface they get blast rate.

So, when they blast actually; so naturally what happens that there is again drop in pressure in the blast rate region. So, because of drop and pressure in the blast rate region lot of liquid from the surrounding zone basically close end and they cause the again erosion process at a much rapid rate. So, that is called cavitation erosion. So, that particular cavitation erosion occurs in such a first rate that the material degradation occurs if very quickly and if you see the surface is lot of cavity formation on the surface.

Because the cavitation erosion phenomena is associated with formation of large cavities on the surface, and that mechanism if you just quickly go through mechanism of the cavitation erosion is nothing but again large deformation of the surface sub surface crack formation and failure. And, if corrosive media is there in the environment then corrosion adds up to the particular degradation further. So, they rate of corrosive I mean corrosion cavitation or cavitation corrosion is much faster than that of cavitation erosion.

So, typical examples are in ship propellers, pipelines, pumps, mixing devices and ultrasonic agitators. And if you are interested to get rid of this kind of cavitation erosion phenomena, you have to apply the surface treatment like ion implantation, ceramic tiles, corrosion resistant plating these all technique you have to applied or these all to first precautionary measures you have to take in order to reduce the cavitation erosion phenomena.

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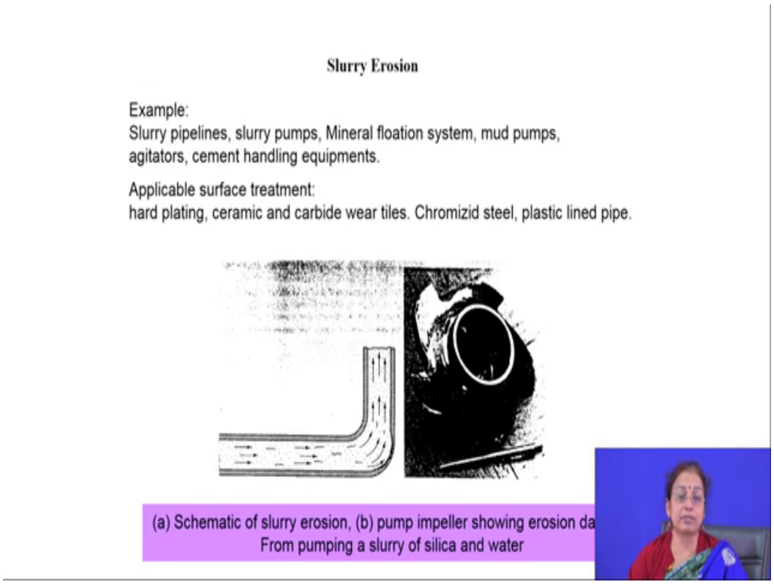

Another kind of erosion is a slurry erosion in slurry erosion this term slurry refers to the presence of the solid particles in liquid when the volume fraction or mass fraction of solid exceeds 10 percent.

So, whenever there is very large amount of solid particles present in the liquid media, you call it a slurry this is a kind of viscous media. So, when the slurry flows through the pipeline specially this kind of wear occurs in pipelines. So, whenever the slurry flows naturally those all solid particles they basically interact or impinge over the surface of the typical pipe or solid component to a large extent and they cause failure of the material by the mechanical interaction. So, slurry erosion usually occurs in pipeline pumps mineral flotation system, mud pumps, agitators, cement handling equipment.

So, those all equipments the slurry erosion is a commonly observed kind of wear. So, applicable surface treatments are hard plating, ceramic and carbide wear tiles, chromizid plating plastic lining pipelines. these all precautionary measures are taken in order to minimize the probability of this slurry erosion.

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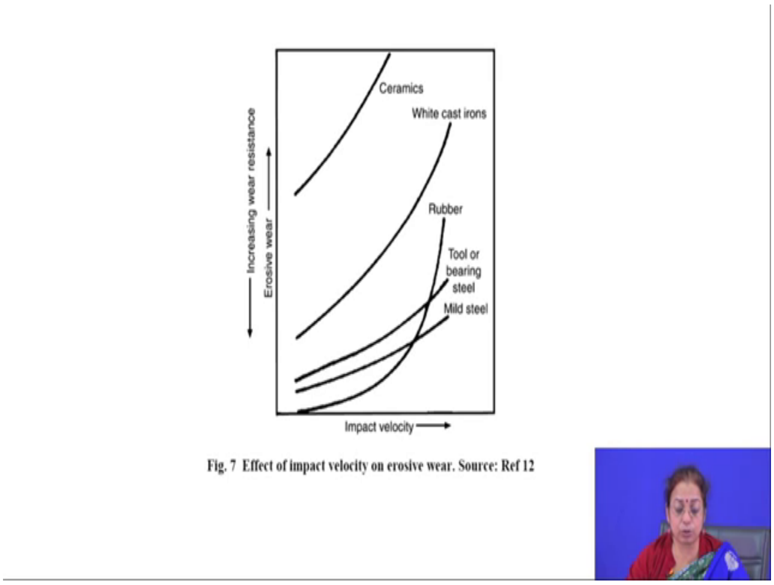

Fig. 7 Effect of impact velocity on erosive wear. Source: Ref 12

Now, if you quickly go through the different parameters which influenced the erosion phenomena they are temperature of the media, they are the velocity of the media, they are mass of the particles which are present in the media. And these are the or and also the environmental environment species composition like; whether it is chemical react to it chemically reactive or non reactive chemical reactivity of the media.

So, these are the 4 parameters which determine the rate of the cavitation or any kind of erosion wear. And so, if you just quickly go through the kinetics as a function of the impact velocity you will find that impact velocity as it increases the erosive wear also increases. And, if you quickly go through the behaviour of different materials to erosive wear you will find that ceramic particles is having lowest erosive wear it highest erosive wear it as compared to that of steel or tool steel bearing or rubber is having lowest erosion rate.

On the other hand they are having the highest wear rate. So, wear and erosion cannot be correlated because ceramic particles are highly brittle in nature. So, they are eroded to a large extent. So, when they are solid in nature, but when they are coating when they are used as coating naturally their performance changes because there may be thin layer and the material itself is very much tough in nature.

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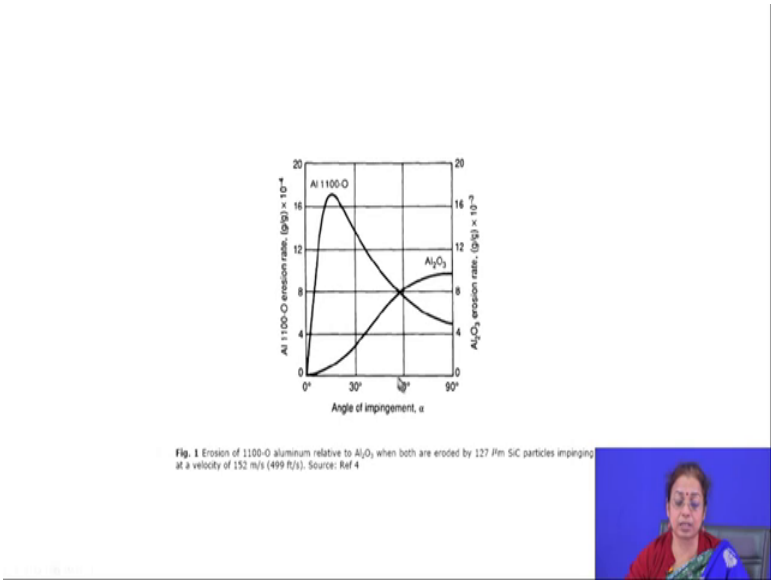

Angle of impingement also plays very important role in determining the kinetics of solid particle impingement. So, this is the case where angle of impingement is plotted as a function of erosion rate is plotted as a function of angle of impingement, we find that for solid bulk metallic material the maximum erosion occurs at an angle of impingement of 15 degree or so. On the other hand in case of ceramic materials maximum erosion occurs at an angle of impingement of 90 degree. This is because of the reason that in different materials erosion mechanism is different; in case of metallic material the erosion mechanism is mainly by cutting mechanism.

So, as the angle of impingement is lower much force or much much energy or mass softness basically plays important role to cause the to have maximum impingement on the surface and which leads to material removal. On the other hand if it is ceramic material if it falls perpendicular to the surface naturally maximum amount of load is borne by the particles and you will find that maximum amount of wear occurs on the surface.

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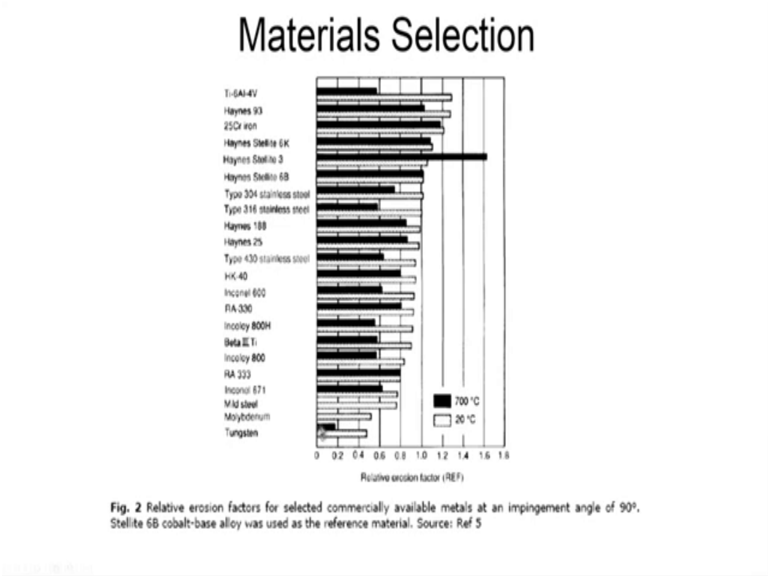

Fig. 2 Relative erosion factors for selected commercially available metals at an impingement angle of 90°. Stellite 6B cobalt-base alloy was used as the reference material. Source: Ref 5

So, whenever you are interested to select the materials you have to be materials for erosion resistance application you have to know the erosion behaviour of different materials. So, erosion behavior of the different materials they are sequentially arranged here and basically you will find that at different temperature so you find that as you go on increasing the temperature you will find that relative erosion factor. Relative erosion factor is nothing, but it is a erosion rate between the erosion rate erosion ratio of the fewer material and that of the standard material which is the hardest in nature.

You will find that tungsten is having lowest relative erosion factor and which temperature basically it decreases further. So, you can understand that sometimes temperature is having positive influence; sometimes temperature is having negative influence on increasing the erosion rate. In some of the metallic materials if you see about see you will find that relative erosion factor actually increase decreases in all cases, but except the case for stay light it increases.

So, relative erosion rate is actually it gives you kind of impression on the selection of the material lower is the relative erosion factor naturally higher is the stability of the material in that environment and you should choose the environment you should choose the material accordingly.

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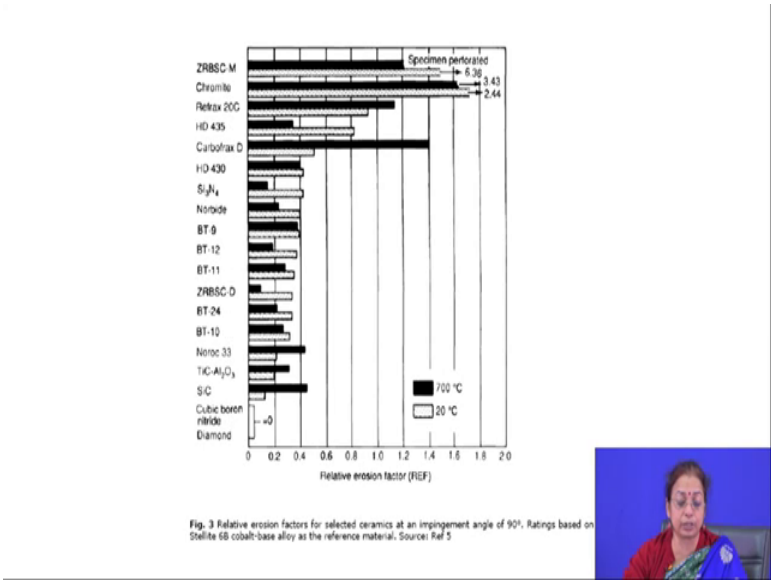

Again the relative erosion factor is shown as a function of temperature for different materials for ceramic material; you will find that cubic boron nitride is having very low relative erosion factor and then silicon carbide and then titanium carbide and finally, chromate.

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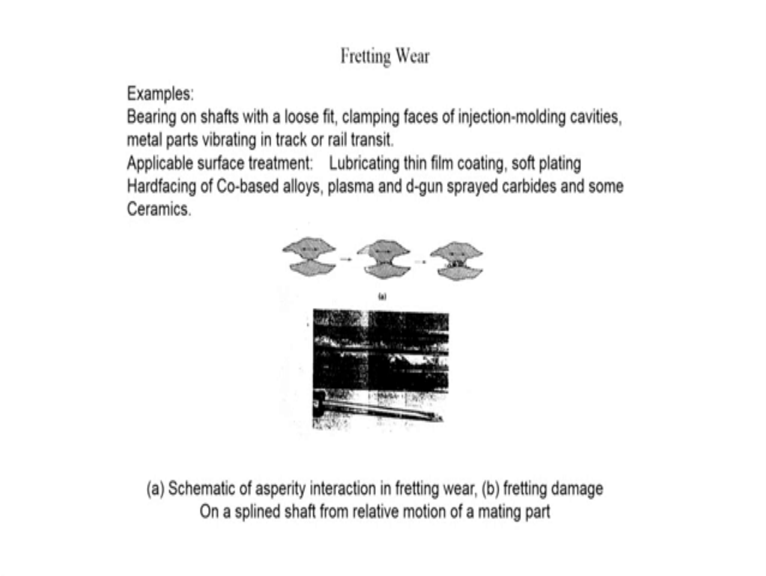

So, this particular ceramic materials behaviour is very important because many cases for reducing the probability of the or maybe minimizing the erosion wear. Erosive erosion process actually to minimize the failure due to erosion you basically apply a thin or thick hard face layer on the surface, for which you have to choose the proper material. And usually ceramic materials are used as the material for coating or a heart facing in order to reduce the probability or failure of the materials by the erosion.

Now coming to the next type of wear that is a adhesive wear you have to be again you have to come across the another kind of combinations, where metal to metal combinations very important role. So, this term adhesion refers to the initiation process by adhesive bonding. So, in a adhesive wear if you just quickly go through the different types of adhesive wear or different-different modes of sub modes of adhesive wear you will find that, they are again 5 different sub modes by which the adhesive wear proceeds.

One is fretting wear, simple adhesive wear, seizuring, then galling, and then oxidative wear. These are 5 different modes are a adhesive wear proceeds. So, this is called simple adhesive when there is no other mechanism play important role. But only the action adhesive action between the 2 surfaces plays important role.

So, for example, copper moving over copper, aluminum moving over aluminum or steel moving over steel where it is simple adhesive based wear phenomena; where the adhesive interaction between the 2 surfaces play important role to cause the adhesion. So if you just quickly think of the material failure by adhesion usually in addition the hardness difference is minimum actually when the or the probability of adhesive failure increases when the similar materials are moving over each other instead of dissimilar material.

Their hardness difference will also should be minimum as minimum as possible. And there lower is the surface energy differences the higher is the probability of the adhesive failure or adhesive wear phenomena to occur.

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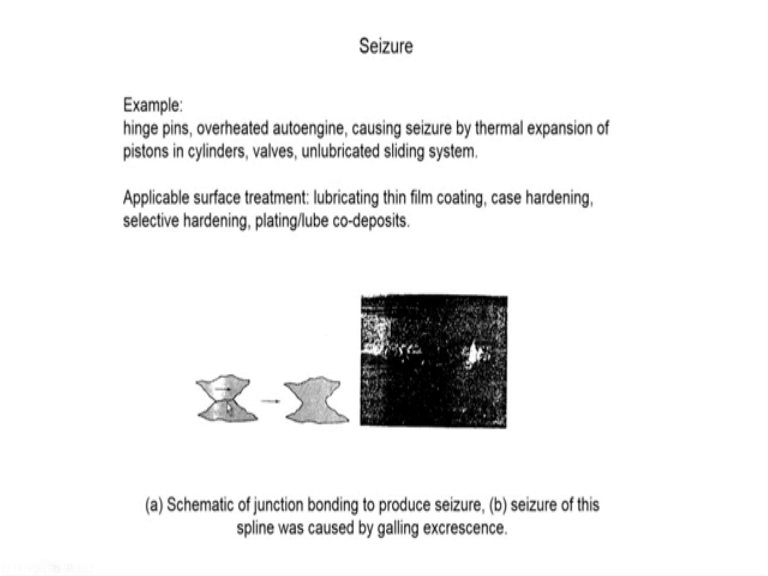

So, in simple adhesive wear phenomena the where initiates by the adhesive warning and then depending on the hardness of the individual surfaces you will find that the failure occurs.

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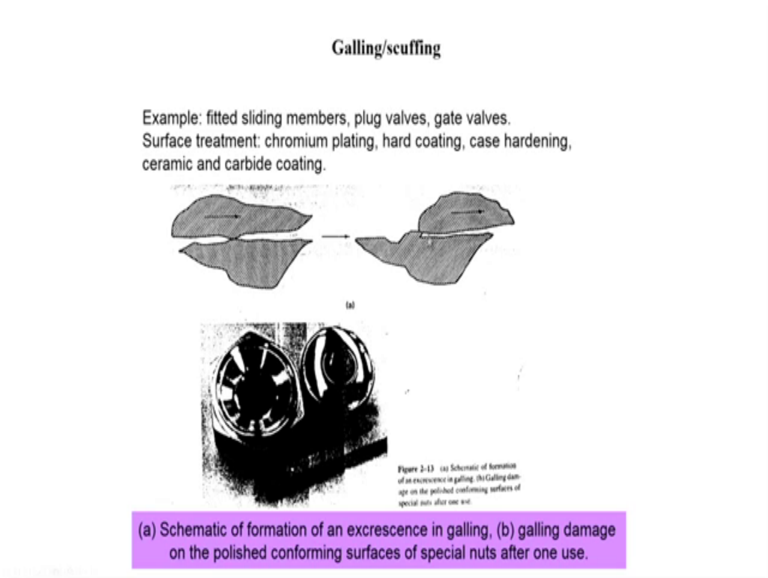

So, initially the there is adhesive bonding formation and after adhesive bonding forms then there is actually. Because of the sliding motion there is a large amount of force which is applied at the interface, and the softer the made there is removal of the material from the softer of the combinations. And that particular materials, which is removed because of the hardness differences that actually creates lot of roughness on the surface and subsequently the wear rate actually increases.

So, in case of adhesive wear, the main mechanism by which or mean way by which people basically combat the adhesive wear, is by the process of lubrication. So, if you apply a very thin layer of lubricants, you basically reduce the probability of the interaction between the 2 surfaces and by that process you reduce the probability of adhesive wear as well. So, another kind of adhesive were is a fretting wear; fretting wear is a kind of free to adhesive wear were apart from the linear motion there is also fretting motion between the 2 surfaces. So, fretting motion is nothing, but a kind of oscillatory vertical movement between the 2 surfaces of very low magnitude.

So, when the fretting motion is there between the 2 surfaces naturally there is the rate of removal of the material also increases. So, fretting motion actually they aggravates or increases the kinetics of the adhesive wear; increases the rate of the removal of the material. So, typical examples are; bearings on shafts with a loose fit, clamping faces of injection molding cavities, metal parts vibrating internet trucks or rail transits. And applicable surface treatments are; lubricating thin film coating, soft plating hard facing of cobalt based alloy, plasma and d gun sprayed carbides ceramics coating, these are the typical way by which you can compared the probability of the fretting wear.

So, in fretting wear initially the mechanism is natural naturally by adhesive bond formation and then when there is oscillatory motion naturally there is micro fatigue phenomena so as a result of which there is soft surface crack formation. And then the removal of the material because of the crack propagation and then subsequently the removed material they get accumulated at the interfacial region. So, in all adhesive wear based phenomena; adhesive wear based all in all adhesive wear actually the mechanism of wear changes from 2 body to 3 body at a later stage of wear.

And the kinetics of wear is very much dependent on the kind of the loose particles that are formed because of the adhesive interaction. Seizuring is a kind of wear where you will find that there is no loss of material because of wear, but there is a just joint formation adhesive joint formation between the 2 surfaces. So, this is another kind of wear where there is no loss of material, but there is d setting of the component you cannot use it further.

So, for example, hinge pins, overheated auto engines, causing seizure by thermal expansion of the pistons in cylinders, unlubricated sliding system. So here actually the when the components are having; very similar composition, very similar hardness, when temperature achieved in this particular or temperature experienced by the component is very high, then there is a adhesive joint formation. The adhesive joint is responsible for this seizuring action and as a result of which the component stops its movement.

So, usually you can get rid of this kind of a error by typically having the cooling operation continuously, and also applying lubricating thin film coating on the surface. Galling wear or scuffing wear is another kind of wear, where there is that flue of the material at the interaction point rather than removal of the material. So, when the one of the combinations is basically one among the combinations is basically duct highly ductile in nature.

In that case because of adhesive joint formation and subsequent interaction subsequent sharing force acting on the component and also sliding motion there is a flow of the material from the malleable or from the softer or maybe ductile material of the combinations; ductiler of the combinations. So, when there is flow of material usually there is d setting of the component and that d setting is responsible for that is for responsible for its action actually. So, it is chop seeds action.

So, whenever there is naturally the galling wear naturally you will find that the component does not serve in that environment and you have to get rid of the component you have to remove it completely and you have to change it with the other component. So, typical exams of the galling wear or the fitted sliding members the valve gate valves and usually you can get rid of this kind of wear by the application of very hard surfacing process like; chromium plating, hard coating, case hardening and also you can get rid of this kind of wear by continuous cooling operation. So, that temperature experience at the junction or at the adhesive joint is minimum.

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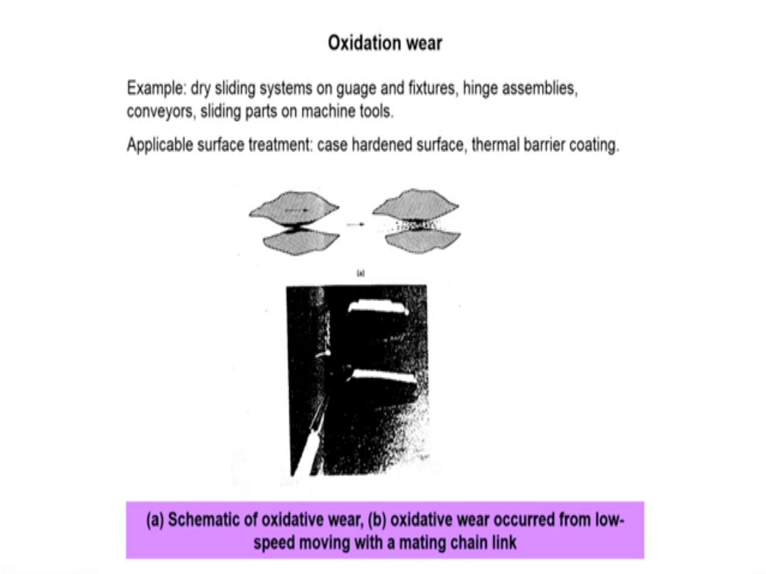

So, an oxidative wear is another kind of wear again the kind of a adhesive wear where there is oxygen in the environment. So, because of presence of oxygen there is oxide formation and when the oxide formation is there naturally one way it is beneficial because the component stops it is interaction there is an interaction between the solid particle solid materials. So, adhesive the probability of adhesive joint formation is minimized, but on the other hand as there is a relative motion usually if the oxides are highly loose and porous in nature the oxide gets removed and then suddenly after that the phase surfaces get exposed too.

So, whether it is oxidative wear or not, oxidative wear always acts negatively towards the wear failure because it always increases the kinetic software. But in adhesive wear the contribution of oxidation is minimum but adhesive wear it is maximum because of the fact that in abrasive wear the hardness difference pairs are important role. But in case of adhesive wear the joint formation is very important when there is adhesive joint formation that plays very important role it causing wear.

So, when there is oxidation process depending on the nature of the oxide layer that is forming it can contribute positively or negatively too; when the oxide is highly porous in nature it increases the kinetics of the wear. On the other hand when it is very much strong and protective in nature it reduces the probability of adhesive wear further.

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Finally it can be stated that in this particular in today's talk we discussed about erosive wear, different sub modes of erosive wear and also the typical different sub modes of adhesive wear in details. And, we will subsequently follow it up by discussing another kind of wear in the next lecture that is we will discuss about the fatigue wear or surface fatigue in details. And, then we will discuss about the ways by which you can prevent the different types of wear in practice and also examples of different wear failure.

Thank you very much.