Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-21
Properties and Mode of Wear

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and we have talked about the introduction related aspect of the surface engineering and the various mechanisms and the modes of the wear which leads to the loss of material from the functional surfaces. Now we will try to see that if you have to develop the wear resistance surfaces, so that the longer life of the tribological components can be achieved.

For that purpose we need to select some of the materials which can be applied using suitable techniques onto the surfaces which are being considered for improvement and therefore the choice of the suitable material for improving the tribological life of the component becomes critical and this kind of choice is normally made in light of the application and for a given application the kind of conditions which will be experienced by the metal during the surface.

So, we know that for the different surface conditions the different material removal mechanisms will be working onto the surfaces. So we need consider what is the operation mechanism involved in removal of the material under given set of the conditions. So that we can select suitable material having the required properties, so that those material removal mechanisms can be reduced. So, that the rate of material loss from the functional surfaces can be reduced in order to enhance the tribological life of the component.

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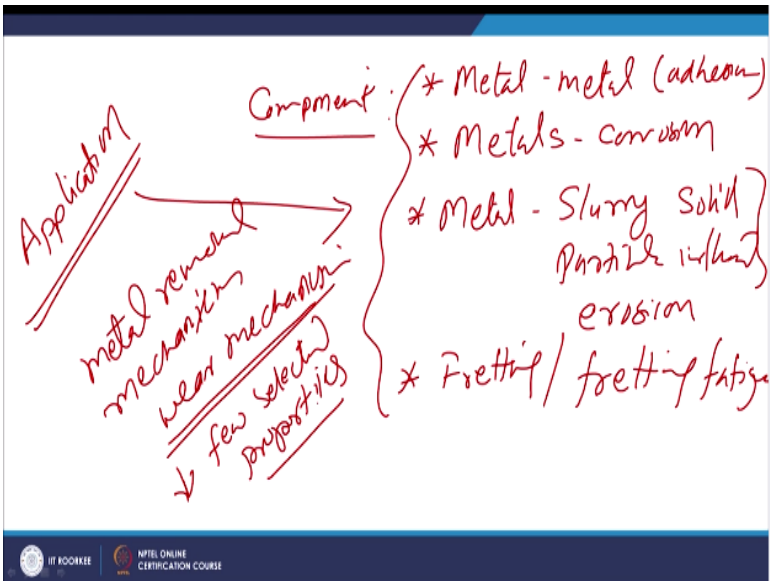

So, what is the first step is in the selection of the material for improving the tribological life is the consideration of the application for which the material is to be selected or for which the surface engineering surface is to be engineered. So application is important means we should consider service conditions for given applications like there will be relative movement having the metal to metal contact like in piston and cylinder or the carriage is moving over the light lath guide ways.

Or there is metal handling the liquid metal liquid or the liquid metal or any other medium which is causing the corrosion of the component. So, here it will be adhesion and in the second case when the metals are interacting with other molten metals or the medium which can cause corrosion or when the metals are interacting with the slurry having the solid particle suspended in the fluid through which is passing over the metal system.

So this is the condition which will be causing the erosion which is this kind of the loss of material is observed in case of the hydro turbines or the pumps which are used likewise like there is a loose fitting between the 2 mating components having the relative motion during the service causing the material loss will be causing the fretting or fretting fatigue under the dynamic loading conditions fretting fatigue.

So, variety of the applications where the metals are used and each one will be experiencing the different kind of conditions, different mode of the material mode or mechanism of the material removal. So based on the application certain material removal mechanisms which will be working and in light of the operational metal removal mechanisms which we can say as wear mechanism. Now we need to consider how to retard it cannot be stop but we can reduce the rate of material removal by any of these wear mechanisms.

So that component offers the longer life of the component, so in order to reduce the rate of wear under the given wear mechanism we need to ensure that material is having few selected properties. So that it can really retard or reduce the rate at which material loss is taking place.

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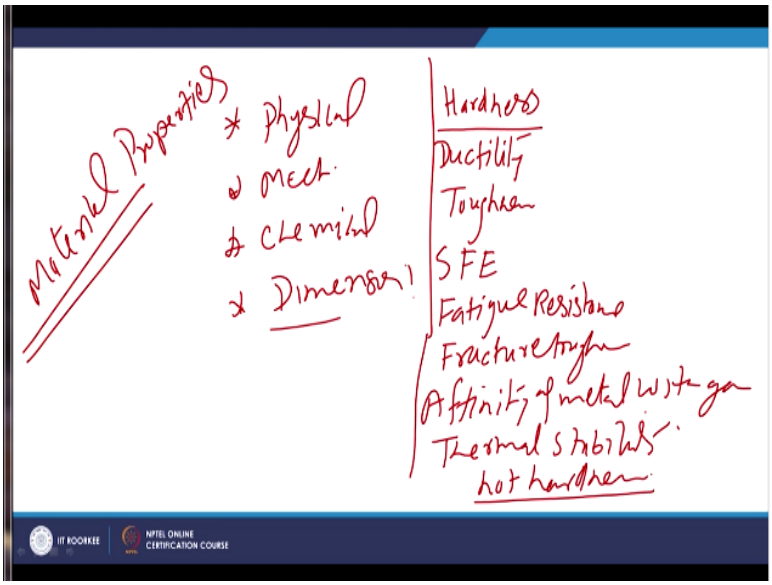

So, what will be those material properties which will be reducing the wear under the reducing the wear by a given wear mechanism that we need to see. So first of all we will understand what are material properties especially with regard to the metals which will be experiencing the wear like adhesive wear, abrasive wear, erosive wear, corrosive wear or cavitation, erosion etc.

So, the properties which are of the importance or in general they are the physical properties, mechanical properties, chemical properties and the dimensional properties. These are the novel properties which are of the great importance governing the material removal or the rate of material loss by the various operational mechanisms and if we just club all these group of the

properties then some of the properties which I can mention here will be of the great significance with regard to the material removal mechanisms are like hardness.

Then we have the ductility, then there is toughness, then there is stacking fault energy, then fatigue resistance, then fracture toughness, then affinity of the metal with the gases, affinity of a given metal with the gases like oxygen, nitrogen, steam if it is present nearby and the 1 of the more important property is the thermal stability which we can say in terms of the that hot hardness how rapidly material looses it is hardness at high temperature governs this.

So, now each of these properties needs to be understood to see how they will be affecting the behaviour of the material when it is subjected to the various kinds of the wear conditions.

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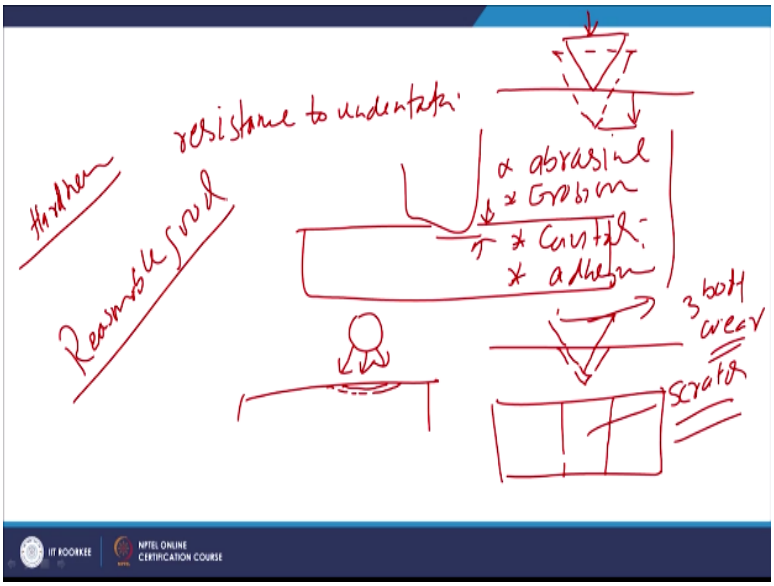

So, let us understand hardness first hardness basically indicates the resistance to indentation what is meaning of this the surface when it is applied with the pointed load like this. Normally for checking the hardness we use the standard edentate indenter and extended loads are applied. So, when extended load is applied through indenter it will definitely be penetrating into the surface of the work piece up to surf and depths.

So, greater is the depth of penetration, so this is the depth by which penetrate there has indenter has penetrated onto the surface of the work piece, greater is the depth of indentation lower will

be the hardness. So and this kind of the indentation can be formed by various operational mechanisms like hard particle is being pressed over the surface of the work piece, so it will be indenting by some depth.

So, under the abrasive wear conditions, under the erosion conditions, under the cavitation conditions and even under the adhesive wear conditions this depth of indentation due to the hard particles which are being pressed onto the surface becomes crucial with regard to the volume of the material which is being removed. Because if this is the depth up to which indenter or the hard particle has penetrated on the surface.

Then relative movements subsequent relative movement of the hard particle will be forming scratch and that is scratch on the surface will appear in form of this group. So, such kind of the abrasive group or scratch formation will be leading to the removal of the material by abrasion or under the adhesive wear conditions it will be in form of the 3 body abrasive mark or 3 body abrasive wear kind of situation.

Similarly under the cavitation conditions when a bubble busts, busting of the bubble develops the pressure and these pressure heat the surface. So, it will be causing the surface layer deformation, if the material is hard then it will not be deforming up to the greater depth and in that case the chances for nucleation of the crack under the cavitation conditions will be reduced and that is why it is important to have the reasonably reasonable good hardness not very high hardness.

But reasonably good hardness is important for cavitation, for adhesive wear even for the erosive wear definitely extremely high hardness helps in the abrasive wear conditions but in other conditions very high hardness may cause the increasing wear rate. So, for abrasions certainly high hardness is important but for other modes of the wear like erosion, cavitation and adhesion reasonably good level of hardness is required.

Otherwise because the 2 high hardness compromises with the toughness and which in turn facilitates the material removal through other modes of the wear through the fast crack nucleation and the growth of faster growth of crack. So, reasonably good means low hardness is

like 20hv and high hardness very high hardness is like 1400hv reasonably good hardness like 400 to 700hv.

So having the hardness in this range is the good one which can really resist the minor stress conditions which are being created either by the abrasive marks at this will be reducing the kind of indentation also. So the damage onto the surface will be reduced is the surface hardness is good there are various methods of measuring the hardness like there is a rockwell hardness test where we can use A scale, B scale, C scale.

A scale is used for extremely hard materials, then somewhat less hard material, C scale is used and very somewhat lower hardness material. So highest and then lowest and medium hardness, these are the scales which are used, so steel ball is used for B scale and diamond cone is used for the C scale.

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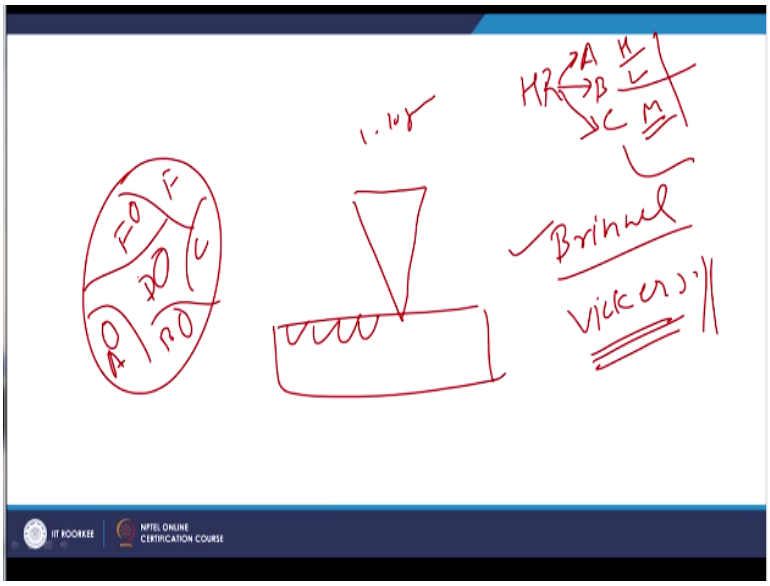

Likewise Brinnel hardness is also used for low hardness metals then Vickers hardness is the another method which is used it is available in both variants like macro hardness and micro hardness. In case of the micro hardness the indenter size is very small and the load is also in grams like 1 gram, 10 gram etc., while in other cases the load magnitude is very high like 100kg or 150kg for HRC.

So and for the Brinnel hardness is also high, so for the micro hardness test methods are used for measuring the hardness of the individual micro constituents like say all most of the metals are made of the various constituents like this metal in the magnified view if we can A, B, C, D, E and F and if you are interested in checking the hardness and each of the constituents because each will have different composition, different crystal structure.

So, the different physical properties, the different mechanical properties in terms of hardness, so through the micro hardness we can check the micro hardness of each of the constituents easily or the so that hardness of each of the constituent is identified to see what are the tough or ductile phases present and what are the hard and brittle phases present in given material.

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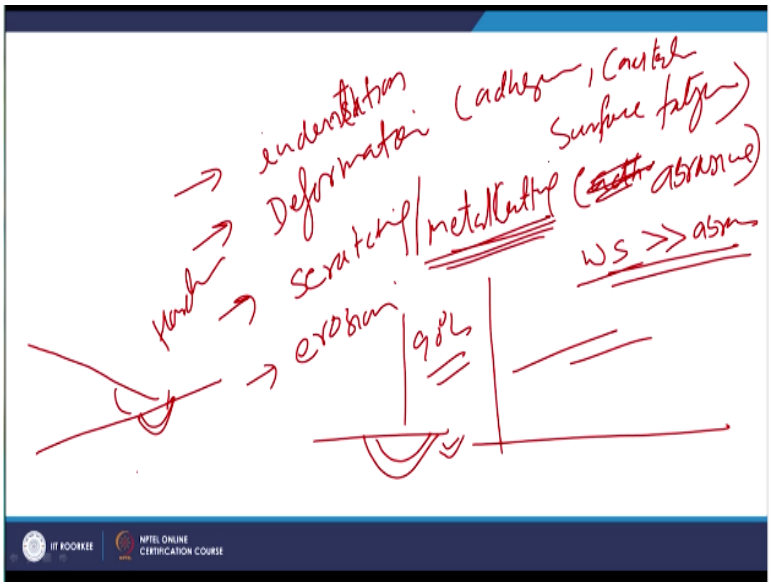

So, this is a about the hardness and what are the things which are influenced by the hardness, why hardness is important because it resists the indentation this is 1. It resist the surface layer deformation, so this is especially important under the adhesive wear conditions, cavitation conditions and surface fatigue conditions, too high surface layer deformation will be leading to the increased metallic intimacy.

And since the indentation is affected, so it will be affecting the scratching tendency and metal cutting tendency like under abrasive wear conditions metal one of the metal one of the mechanics miss the metal cutting if the metal is very soft then removal takes place by the metal

cutting. So, under the abrasive wear conditions the metal cutting plays a big role, so often if the material is of low hardness then it will be facilitating the metal cutting and higher removal of the higher rate of the material removal under the abrasive wear conditions.

And it is also important to consider the hardness when we are choosing the counter surface, it is not good to have the counter surface of the matching hardness values it is always good that if that the mating components are having the different hardness. So and similarly the hardness of the hardness is also important especially with regard to the abrasive wear conditions when the abrasive wear conditions or when the abrasive hardness is for greater than the surface of the workpiece.

Then abrasive hardness does not affect but when the hardness of the server B surface work piece surface is greater than the or close to the hardness of the abrasive, then wear rate is significantly reduce. So, choice of the work piece material or the kind of the surface which is to be generated if it is having the hardness close to that of the abrasives hardness, then certainly it will be reducing the wear.

But if it can make the material brittle also, erosive wear is also affected because of these erosion is affected especially when the particles are impinging the surface at low angle material removal takes place by abrasion which is in significantly influenced by the hardness value while in case of the high angle impingement it is the brittleness that governs the material removal and under the severe conditions at high angle.

Because at 90 degree it causes the maximum metal removal rate by the erosive wear mechanism. So, it is preferred that hardness is somewhat lower when the impingement is taking place at 90 degree, while the hardness is high when the impingement is taking place at low angle. So, these are the some of the ways by which hardness affects of the material from the functional surfaces.

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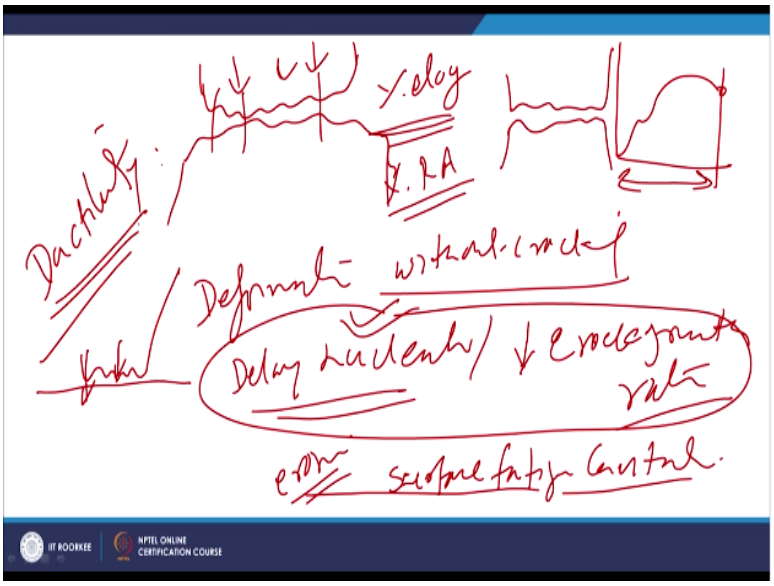

Ductility is the another property, we know the ductility about the extent of to which a metal can be elongated prior to the fracture. So, it is about the percentage it is measured in number of ways percentage elongation until the fracture in the tensile diagram like say this is the strain, so the strain indicates at up to the fracture. So, the extent of elongation which is possible before fracture indicates the percentage elongation.

And another way is the percentage reduction in area that is also an another measure of the ductility, so what is the importance of this because if the material is having the high ductility it can be deformed means deformation is possible deformation without cracking, this is the good site is the material is ductile, it will facilitate the deformation without cracking, this is 1.

And because of this it will delay the nucleation and if the crack is already being developed then it will reduce the crack growth rate. So, crack growth rate is reduced if the material is ductile and it also delays the crack nucleation. So, those metals having the good ductility in combination with the good strength they are certainly good from the crack nucleation and it is growth point of view.

Because all these both these are delayed, so the under the wear conditions like surface fatigue cavitation and erosive wear the ductility really plays a good role because in these wear mechanisms the nucleation of the crack followed by their growth eventually leading to the

removal of the material in form of fine chips, all that is delete if the material is having the good ductility at the same time if the material is having peaks and valleys at the surfaces.

So and the because of the high ductility of the metal these peaks, valleys, peaks and valleys will be collapsing under the actual stress conditions during the service and collapse these peaks and valleys at the surface due to the ductility it will be leading to the closer intimacy between the metals from the 2 sides without development of crack. If the metal is having the very limited ductility then it will not deform rather it will break or get fractured.

So and material will be removed in form of fine pieces this is one aspect and if the material is really hard and brittle of the low ductility. Then it will be causing the indentation onto the surface of the soft metal. So this such kind of the hard peaks present on the surface of the hard material they will be causing the indentation onto the softer surfaces, if the material is having low ductility. So, good ductility will delay the surface, crack nucleation in it is growth.

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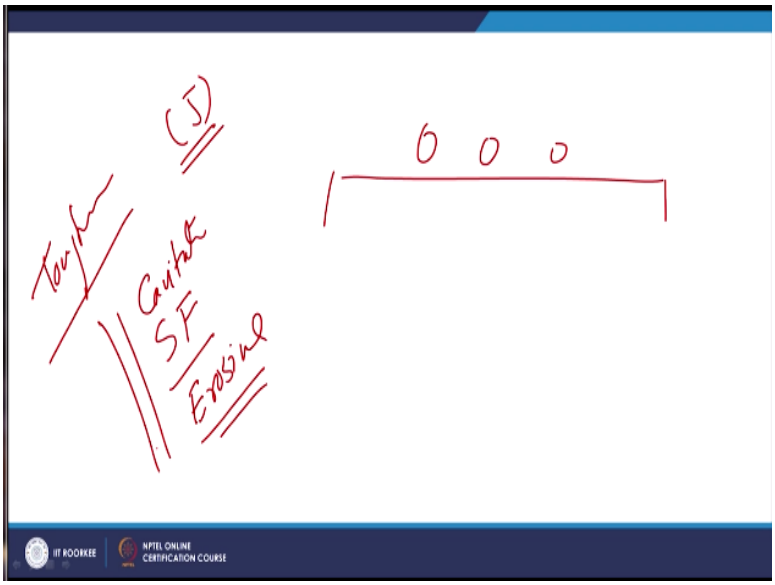

Toughness basically indicates the amount of the energy absorbed under the impact conditions, so which is normally measured in terms of the joule, if the material is having higher toughness it will be offering the greater resistance to the fracture under the impact condition. So impact conditions are observed under what conditions, so those metals which are having the higher

toughness they will be offering good resistance to the removal of material under the cavitation conditions.

Because there is continuous impact of the continuous bubbles are busting continuously and pressure waves are being applied onto the surface of the material and therefore if the material is high is of the higher toughness then it will require lot of energy for the formation of the cracks and the growth of cracks subsequently will be leading to the formation of the particle. So, the good toughness materials will be offering the greater resistance to the cavitation, same as true for the surface fatigue wear and erosive wear where particles are impacting.

So, all those conditions wear conditions where there is impact good toughness materials will be offering the good resistance to the removal of the material. So because it will be governing the crack nucleation and growth solid particle erosion, cavitation and surface fatigue. These are the 3 conditions for which good fatigue resistance will certainly help in resisting the rate at which material will be removed or reducing the material removal from the surfaces.

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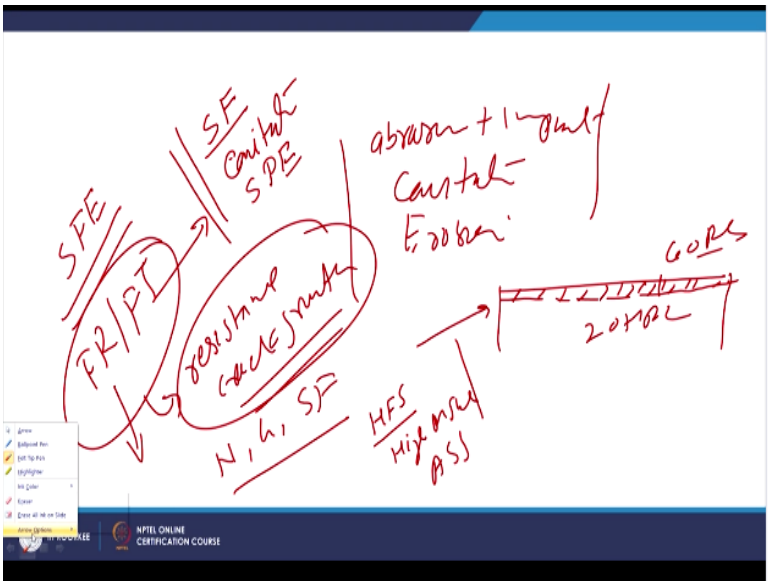

Now, the stacking fault energy is the another one which is important, so all those surface conditions like abrasion coupled with the impact or cavitation or erosion where solid particles are impacting onto the surface, in the all these conditions whenever impact happens the surface

layers get deformed and if the metal is having low stacking fault energy surface layers will get work hardened.

And work hardening means materials in hardness of the material will increase and it will resist the wear effectively. So, the metals like had field steel or high manganese steel such kind of the metals show low stacking fault energy even austenitic stainless steel these show the low stacking fault energy and show good work hardening tendency under the impact conditions and once the material surface is hardened means hardness is increased from the low value like 20HRC is increased to like say 60 HRC or 50 HRC due to the impact during the service.

So, it will be enhancing the resistance to the removal of the material by these wear mechanisms then fatigue resistance and fracture toughness both are important. Fatigue resistance and fracture toughness both are these properties which will be showing the resistance to crack growth which eventually causes the removal of the material, fatigue resistance about the resistance for the fatigue and under the dynamic load conditions where in first the nucleation then growth.

And then certain fracture of the component takes place well the fracture toughness takes indicates the resistance it will offer for nucleation and then growth of crack. So, wherever such kind of situations happen the good fatigue resistance and fracture toughness will be offering good resistance to the removal of the material such kind of conditions exist in surface fatigue, cavitation and solid particle erosion.

These are the conditions were really fatigue resistance and fracture toughness play a good role because in all these cases the crack nucleation and this growth followed by the collisions will be leading to the removal of the material in form of fine chip. So, both these properties are of the importance affinity to the atmospheric gases is the another important property affinity to the atmospheric gases.

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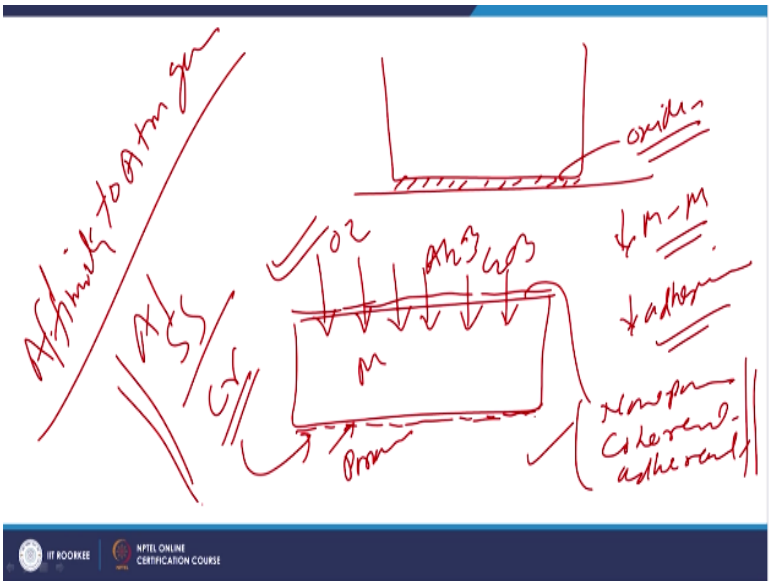

Since most of the metals will be working under the ambient condition however there are specialised conditions also. So, like if the 2 metals are interacting under the ambient conditions, so metals as soon as they interact the surface is because of the frictional heat in and presence of the atmospheric gases they get oxidised. So, oxides are present metal oxides are present at the interacting surfaces at the interface.

So these oxides will be reducing the metal to metal contact and thereby they will be reducing the adhesive wear. So this is good from the adhesive wear point of view, on the other hand those metals which are expose to the ambient conditions and if they form such kind of oxides like Al2O3 or Cr2O3 these are the oxides which are non porous coherent and adherent, they remain attached with the surface of the workpiece.

So, these features facilitate the features in the oxides restrict the access of oxygen with the metal, so further oxidation is reduced and so they are the corrosion of them metal for the corrosion of the metal is reduced, if the metal is having these properties. On the other hand like iron oxide metal having the non porous, non stacking, non metal is metal oxides are porous and they are not coherent, they are adherent, so they will get removed easily.

So, the removal of such kind of oxides will be leading to the exposure of the fresh metal surface for further interaction with the atmospheric gases and which in turn will further promote the

wear of the material due to interaction with the ambient conditions, so in this case the corrosion resistance will be less, the rate at will material loss from the functional surfaces will be more as compare to the another case where coherent, stable, non porous, oxides and adherent oxides are formed onto the surface.

Like in stainless steel, like in chromium and aluminium kind of the components. So, here I will summarise this presentation, in this presentation basically I have talked about that how to choose the suitable material in light of the applications and service conditions because for choosing a material for a better tribological life it is important that we understand the tribological conditions which will be experienced by the metal.

So, in light of that only we can select suitable material, so what are the properties that we need to consider and how can they affect the different types of the wears that is what I have to try to explain with the help of different properties and their possible relations with the different modes of the wear, thank you for your attention.