Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-20
Surface Damage: Diffusive Wear and Evaluation of Surface Damage

Hello, I welcome you all in this presentation related with the fundamentals of surface engineering and we are talking about the various types of the wear mechanisms. So far we have talked about 4, 5 types of the wear mechanisms like adhesive wear, abrasive wear, erosive wear then cavitation erosion and corrosive wear and melting wear. In this presentation basically I will talk about the 2 aspects 1 is the diffusive wear.

And another is about how to characterise or access the extent of damage which is taking place onto the surface subjected to the wear mechanisms various types of the wears, so starting with the diffusive wear.

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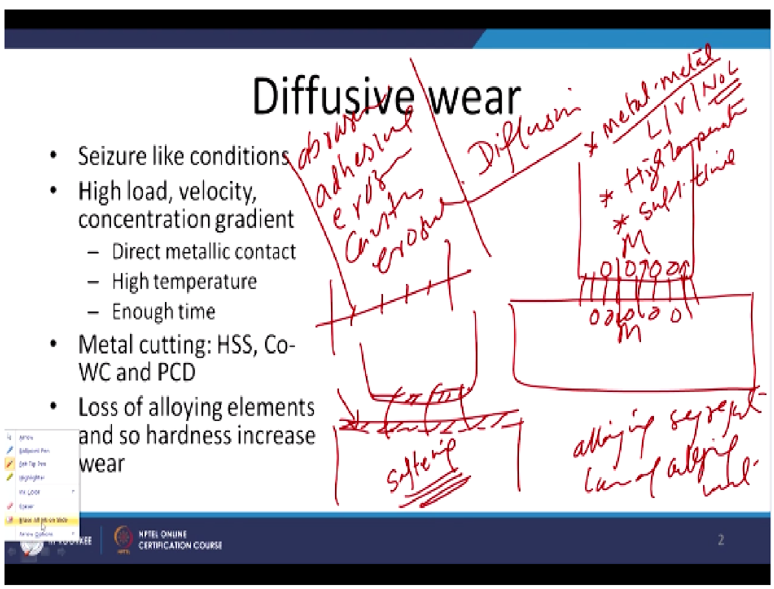

We know that in case of the diffusive wear the diffusion is the basic mechanism. So for the diffusion what is important that the components which are interacting must be in direct metal to metal contact for diffusion to take place. This is the requirement because diffusion, basically diffusion means diffusion of atoms from 1 side to another and for movement or diffusion of atoms from 1 side to another it is necessary that there is a direct metallic intimacy between the 2.

So, this is one requirement that there has to be direct metal to metal contact and this can happen when the load is high enough, velocity is high enough and say the failure of the lubricant. So, there is nothing to keep them separate, so basically seizure like conditions lead to the no lubrications, seizure like conditions lead to this situation, so this is one aspect where that metal to metal contact is needed.

Another aspect which is important for the diffusion is sufficiently high temperature. So, that diffusion coefficient is good enough for the movement of the atoms diffusion of atoms from one side to another. So, high enough temperature is required and then not just the good metal to metal contact and high temperature will be enough but there has to be sufficient time for movement of the atoms from one side to another to have a significant effect on the alloying segregation or loss of alloying elements during the diffusion.

So, due to the diffusion, so diffusion will be responsible for loss of material especially when the interacting surfaces are experiencing the diffusion in such a way either there is a loss of alloying elements or segregation of some of kind of the alloying elements near the surface layers. So the such kind of the losses are segregation leading to the degradation in near surface layer properties 1 or both the sides. So, if the loss is taking place from this thin layer then it maybe leading to the loss of hardness, loss of strength causing the softening.

And softened metal surface will learn will to resist the wear effectively whatever kind of the wear it is say in all forms of the wear like adhesive wear, erosive wear, cavitation, erosion in all these forms of the wear abrasion, the hardness is very important and if due to the loss of alloying element there is loss of hardness of the material surface layers then it will be more prone to the loss of material by all these normally observed wear mechanisms.

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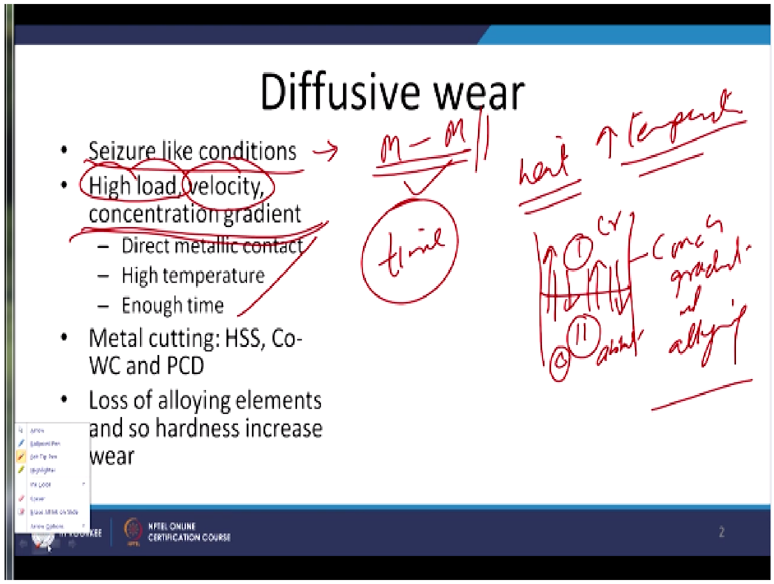

So, if we see here under the seizure like conditions, under the adhesive wear conditions means during the adhesive wear under seizure like conditions of course there is direct metal to metal contact situation. And this is facilitated by the high velocity, high load and this is the another driving force which is required high velocity and high force will generate the heat, sufficient heat and heat localisation, so the rise in temperature will be caused by these conditions.

So, we have both situations which are favourable like metal to metal contact due to the high load and rise in temperature due to the high frictional heat generation. Now another important thing is time, so if the sliding is taking place at a too fast speed then time will be less for diffusion to take place. But there at the same time there has to be driving force for diffusion to take place like if the there are 2 metals direct in contact A means metal 1 and metal 2.

The diffusion across the interface will happen only if there is a concentration gradient of alloying elements. If there is variation in alloying elements like chromium is present large quantity in 1 side and here it is absent then certainly there is a large driving force for movement of chromium atoms from one side to another. Similarly if the carbon is more in this side or less on the other side then carbon will be diffusing from the component 2 to the component 1 side.

So, there has to be enough concentration gradient for the diffusion to take place, so that the loss of alloying element or the segregation of alloying element can take place. So, these are the 3 conditions which are required for diffusion to facilitate the diffusion.

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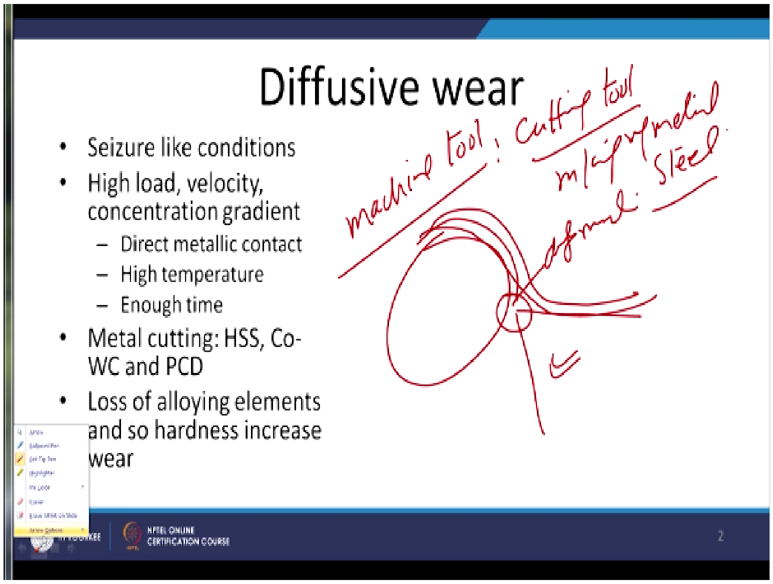

Now we will see there is a typical engineering component which is called machine tool where in machine tool the cutting tools used for machining of metals like steel, cast iron etc., so this is a tool during the machining applies the force onto the work piece. So, by sheering extend material is removed and so because of the application of the forces the deformation is involved in the cutting zone, chips are formed.

So, material is removed in form of the small chips which will be moving over the phase of the tool. So, basically during the metal cutting tool works onto the work piece tool onto the work piece and causes the machining to remove the material in form of fine chips.

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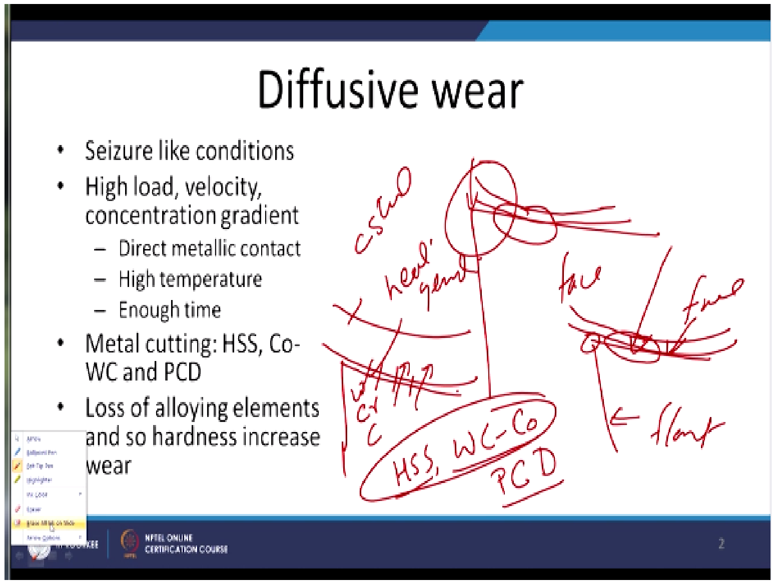

So, whenever the tool acts onto the work piece, the forces are generated, the forces will be acting near the cutting edge. At the same time the chips which are coming out of the workpiece in form of small pieces of the metals or continuous chips which are coming out they will be moving over the phase of the tool. So, due to the involvement of lot of energy in machining part of energy is converted into heat, that heat causes rise in temperature.

And maximum rise in temperature takes place in the region close to the cutting edge. If this is the phase of the tool and this is the flank of the tool, this is the cutting edge. So maximum temperature rise is observed somewhere little bit away from the cutting edge and this is the location where the chips will be sliding under pressure over the phase of the tool. So since the chips of the steel which may have mild steel, structurally steel or any particular alloy steel which will be flowing or moving over the phase of the tool.

They will have definitely different composition than the tool material, tool materials are mostly high speed steel or tungsten carbide, cobalt tools or like say those which are used for non ferrous materials like poly crystalline diamond. So, in case of the steels these 2 are simple carbon steels these 2 kind of the metals are commonly used, so means this will be having higher chromium, tungsten and carbon concentration in the tool.

And if it is the simple carbon steel which is having the controlled content of the carbon only in the iron. So, the chips which are moving over the phase of the tool at a high speed under pressure they will be causing the heat generation as well as the presence of the metallic contact between the chip and the phase of the tool, all the chips will be consciously moving. But in presence of the concentration gradient higher gradient on the alloying element on the tool side has compare to the chip side.

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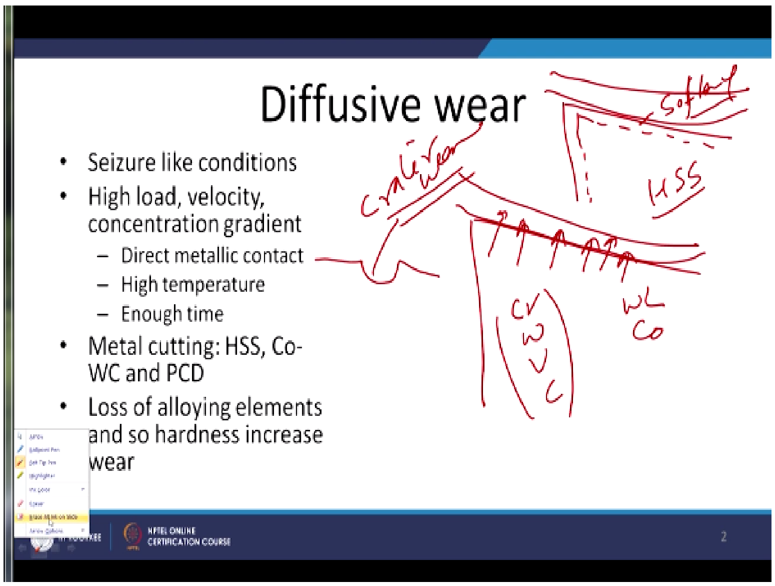

This leads to the situation where the loss of the alloying elements from the phase of the tool to the chips starts. So, the tool is having the higher concentration of the alloying element in form of like tungsten carbide, cobalt or chromium, tungsten, vanadium, carbon etc. and since the temperature is high direct metal t metal contact exist and contact is continuous. So, there is continuous tendency for the loss of these alloying elements to the chip through the diffusion.

And if continuous diffusion of these elements means these elements diffusing out continuously towards the chip and which will be moving continuously and will be disposed of finally in form of the waste material which cannot be used for any useful purpose. So, such kind of the loss alloying element from the phase of the tool leads to the depletion of chromium, tungsten, vanadium, carbon from the typical high speed steel tool.

Similarly loss of carbon from the tungsten carbide, tungsten from the tungsten carbide at cobalt. So, these losses will be leading to the softening of the phase of the tool and softened phase of the tool when the chips are rubbing the phase of the tool under pressure. So it will be causing softening of the tool phase will be leading to the increased loss of the material from the phase and what we may get that on the phase near the cutting edge, we may get some kind of the depression which will appear in form of the crater wear.

So, basically crater wear is attributed to the loss of the material from the phase of the tool due to the loss of alloying element from the phase and these alloying elements are loss to the chips which are continuously in contact with the phase of the tool.

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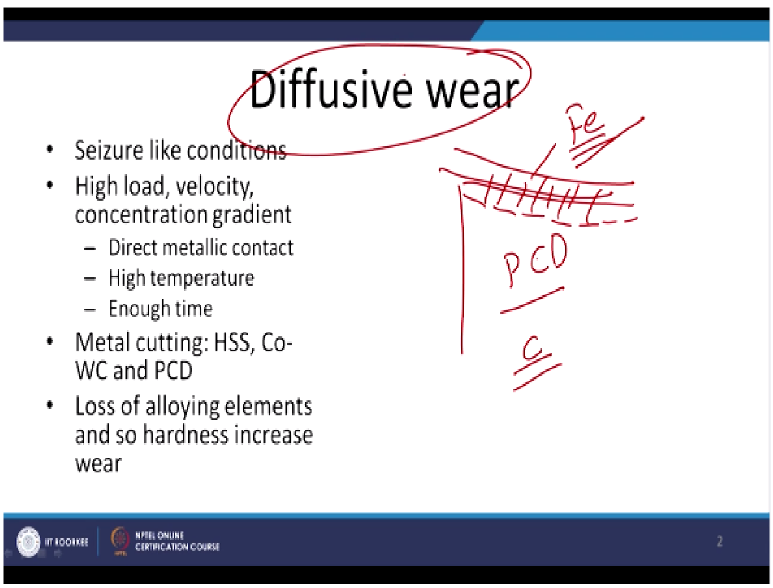

The similar kind of the damage and degradation is observed if the polycrystalline diamond is used for machining of the steel. Since in steel iron is dominating and iron is having very good affinity with the carbon, so in polycrystalline diamond which is a form of the carbon only. So, the carbon at a higher temperature starts getting diffuse out through the iron, so this leads to the again damage to the diamond tool bits in form of the loss of hardness.

And so during the machining of the steel polycrystalline diamond looses it is hardness due to the loss of carbon and therefore polycrystalline diamonds are not used for machining of the steels. But for non ferrous metals and the glasses can be machined effectively using this. But still the mechanism of the damage here is again the diffusive wear because loss of the carbon in case of the PCD will be taking place to the iron and which in turn will be adversely effecting to the properties of the tool which is required for effective performance.

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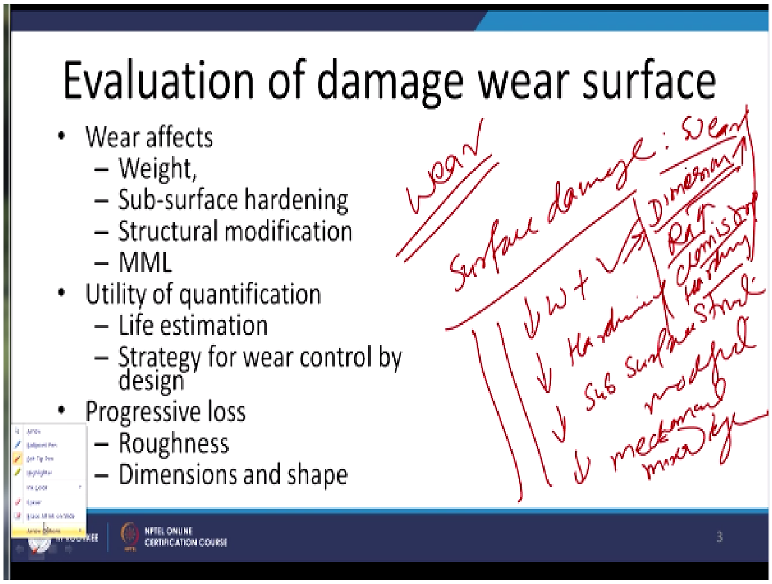

Now whenever we put any component in use we normally say that there is continuous wear and tear in the component. So, whenever a wear is taking place any component how to check the extent of damage which is taking place onto the worn out component. So, to check the surface damage on the component subjected to the wear what we should see.

Basically whenever wear takes place will notice that there is reduction in weight of the component. And the surfaces are getting hardened because of work hardening, so work hardening of the surface and near surface layer is taking place, will also notice that near surface structure is getting modified. So, sub surface structure is damaged basically refined modified so we can look for that also.

And even when the surface wear is taking place will find that especially under adhesive wear conditions near surface one mechanically mixed layer is formed, which will be governing the actual surface properties of the material. So, whenever there is wear of any form will notice that there is a loss of weight and whenever there is loss of weight will notice that there is loss of dimensions, there is a loss of surface roughness is increasing.

So, there is a chemistry modification chemical composition is modified or mechanical properties in terms of the hardness is getting modified. So, we should actually look for these variations whenever component is subjected to the wear. So, the damage to the wear surface damage to the surface being subjected to the wear can be checked through the variations in dimensions, roughness and chemistry hardness, structural modifications etc.

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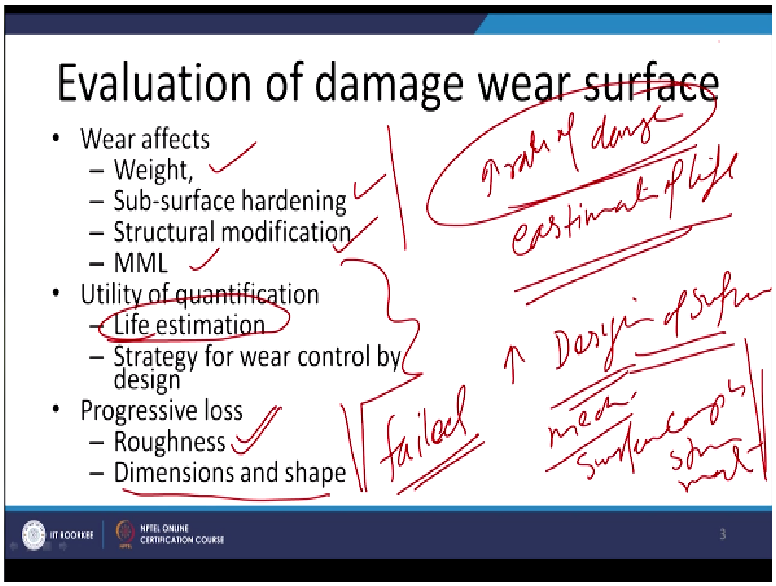

So, here this is what we say that weight, sub-surface hardening, structural modification, mechanical layer formation takes place whenever wear is taking place and this continuous progressive loss of the material during the wear causes the increased surface roughness or modified dimension in geometry of the component. And when these things happen beyond acceptable level will say that component has failed and we need the repair or a replacement of the component.

But what is the use of studying the wear surface damage actually through the study of the surface damage will be able to see what is the rate of damage, which is taking place. So, that we can quantify the we can estimate the life, so this is 1 aspect, estimation of life of the product is possible, if we can really quantify the rate at which damage is taking place. And if we know that what are the operational mechanisms through which damage is taking place and what is it is rate, we can design the surfaces more effectively.

So, designing of surfaces more effectively in such a way that it has a required combination of mechanical properties, it has required surface composition, structure required material. So, all these will be able to deliver the required set of the properties, so that the rate of surface damage of the material can be reduced and the life of the component can be enhanced. So, that is the purpose of a designing a surface or designing of a surface engineering of a component.

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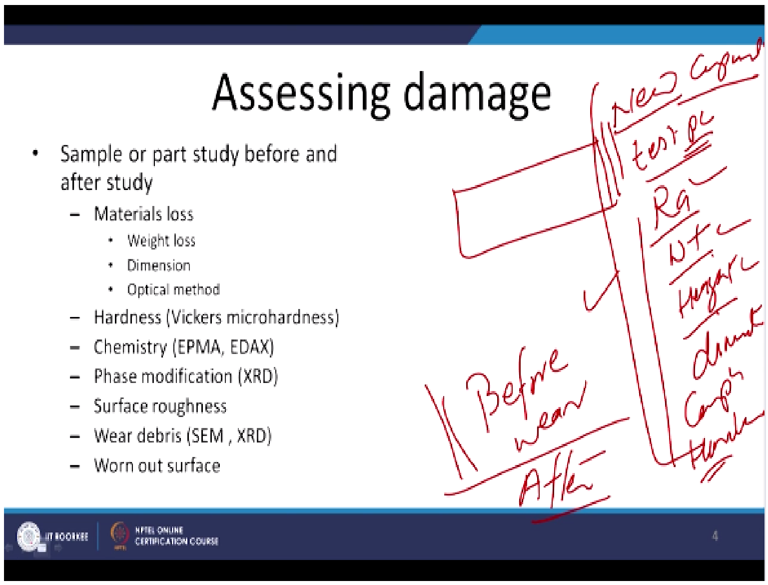

So, what are the techniques which are used to assess the extent of damage which is taking place, the simplest method is to see what was the component before test likes what were the dimensions of the new component, new component or new test piece. So, what are the features of the new test piece, it maybe in form of the roughness, it maybe in terms of the weight, it maybe in terms of the height or the dimension particular dimension of the component, it can be the diameter of the component which is being considered, it maybe chemistry, it maybe surface hardness of the component.

So, what are the features of, what are characteristics of the new component or the test piece. So, new component means before wear, what are the properties and after the component is subjected to the wear what are the properties, what are the changes in these properties are taking place, that is what we have to assess to see the kind of damage is taking place. So, these are the various parameters which can be used for the assessment of the kind of damage or extent of damage which is taking place in the component being subjected to the surface damage by different operational mechanisms.

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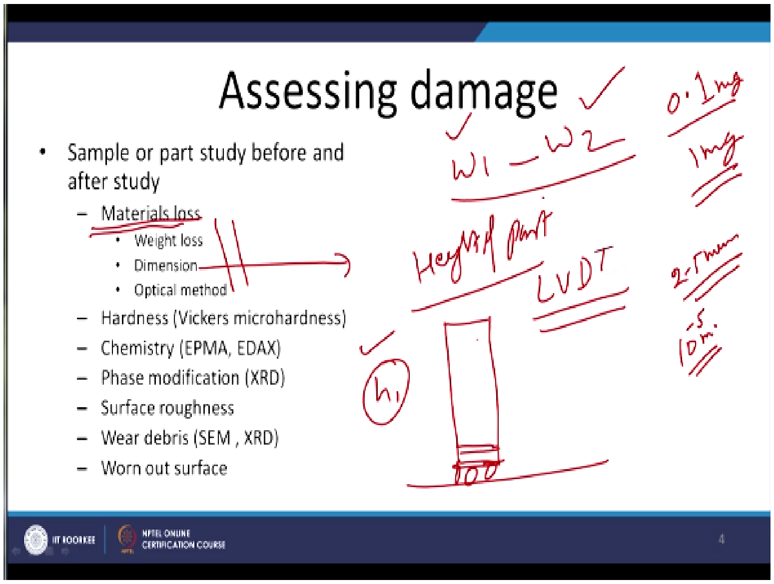

So, these are like material loss, if we have to measure the loss of the material from the component subjected to the wear or any particular kind of the damage then we can use these 3 methods for measuring the extent of the material loss taking place. So, what we will do initial weight of the component and final weight of the component will be taken and depending upon the operational wear mechanism we normally use the weighing balance accurate up to 0.1mg for the adhesive wear test.

And for abrasive wear where wear magnitude is too high it can be 1mg least count of the weighing balance which is normally used. So for the weight loss method we simply measure the weight of the component before test and after the test or before service and after the service. Similarly in case of the dimension based method we measure the height of the part or the test piece before the test and after the test like typically LVDT is commonly used mechanism or the device which is used for measuring the reduction in height which is taking place.

And normally say like 2 to 5mm reduction can be measured during the adhesive or abrasive wear test and these kind of the test method means this kind of the test method for checking the dimensional laws will be accurate up to 10 to the power -5 meter. So, but the height base methods are not that accurate because if any wear particle like this is the height of the sample in the beginning.

And during the test it is given some reading with regard to the height and after the test there will be gradual loss of the height. So, of course there will be reduction in height of the component but sometimes if some wear debris particle is left then it will be giving the errorless result regarding the height of the component.

So, it is always good to measure the surface damage in terms of the weight loss rather than the loss of the dimensions or the loss of height. Although otherwise it will be required to measure the lost dimensions at number of locations to air average out the extent of damage which is taking place if the dimensional loss of dimension is being used as a measure of the kind of damage which is taking place for the in a given material due to the abrasion, erosion or wear surface mechanism.

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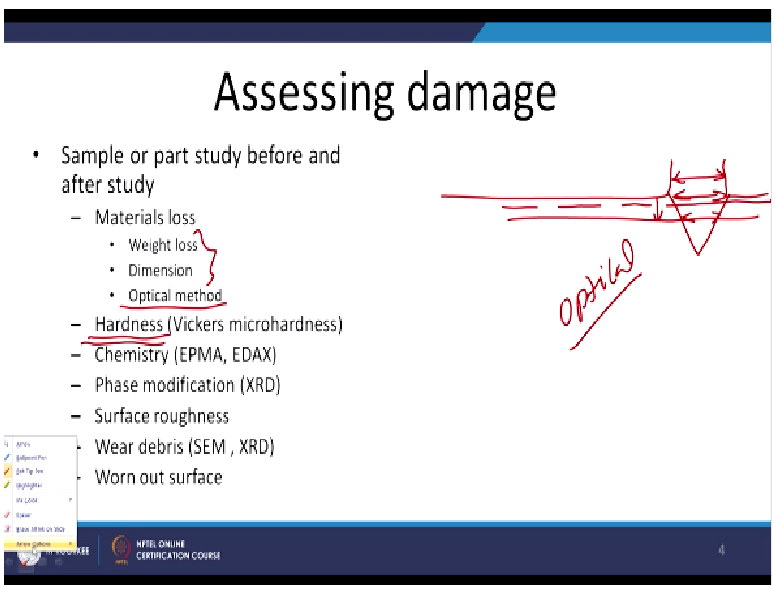

Sometimes we are not able to measure neither the dimension nor the weight if the component is very bulky, very rigid still if you want to measure the kind of surface damage which is taking place due to the surface degradation mechanisms. Then we use 1 optical method, so in that method like this is the surface, so what we will do make 1 indentation and say this is in the beginning and we will measure the this length of the indentation at the top.

So, as there is gradual loss of the material from the surface this length will keep on decreasing. So, increasing loss, decreasing this length of the conical hole or cavity which is created intentionally in the beginning for measuring the loss of the material which is taking place, this is basically optical method where we make 1 indentation and then we will keep on checking the length of the diameter of this impression or indentation left at the top surface.

So, that it can be used for the back calculation purpose for the extent of the damage or extent of loss of material from the functional surface is taking place.

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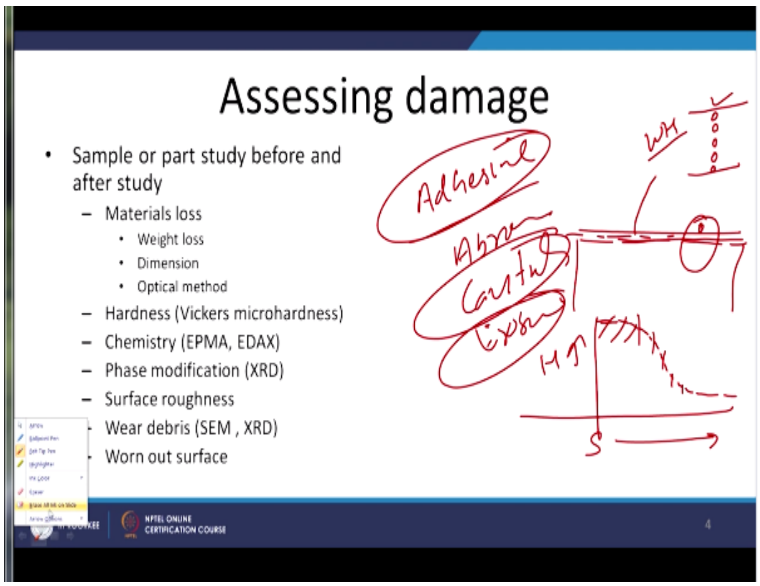

Now the hardness test is another method which shows the kind of damage which is taking place. In this case what we do since in most of the wear mechanisms like adhesion, abrasion, cavitation, erosion where some kind of the stresses will be acting at the surface. So, these stresses cause near surface layer deformation, these near surface layer deformation will be causing the work hardening.

So, work hardening will be increasing the surface hardness, so the extent of surface hardening has taken place that is what we can easily check through the micro hardness measurement, increasing from this surface I mean increasing depth from the surface. So, what we do in magnified if we see this location then this is the surface will measure the hardness at different locations, increasing at increasing depth from the surface.

And this is the surface and increasing depth is on the x-axis, so what we will get basically hardness on the y-axis what it will show that there is higher hardness at the surface and then hardness is decreasing as we go deeper and deeper below the surface. So, what it will suggest that near surface layer up to this extent there has been significant increase in hardness because of the work hardening.

And there after extent of work hardening is reducing and further regions which are further below they are unaffected by the extent of surface damage uses taking place, adhesive wear cavitation in case of the adhesive wear and the cavitation wear. And erosive wear this kind of hardening is very commonly observed. So, this can also be used to assess the kind of damage onto the surface is taking place.

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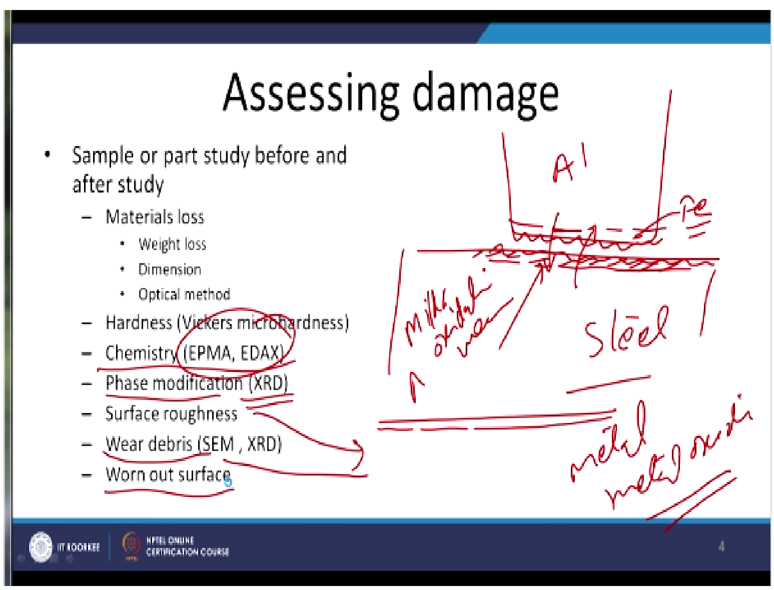

Like under the adhesive wear conditions will notice that chemistry, surface chemistry modification also takes place like this is 1 metal say aluminium and the counter surface is steel. So, during the adhesive wear near surface layer deformation will be taking place their oxidation will also be taking place and during the interaction under the metal to metal conditions during the adhesive wear there will be continuous transfer of elements from one side to another.

And this will be leading to the situation where both surfaces will have the elements from both the sides like this side will have the oxides of the aluminium well other side will have the oxides of the iron, this is called transfer and back transfer of the elements involved in both the sides. And therefore there is a change in chemistry of the surface layers especially during the adhesive wear to confirm this kind of the transfer and back transfer of elements from 1 side to another.

We can perform test like EPMA and EDAX analysis these are the characterisation techniques about which will be talking in detail subsequently. At the surface layer will also see that these oxides are being from so XRD analysis can be use to confirm the presence of these oxides and if these oxides are present at the surface it will suggest the presence of the mild oxidative wear.

Because in mild oxidative wear both the metals which are involved they will get oxidised removal of these oxides will be the responsible for wear but their presence at the surface will be confirmed by the XRD analysis during the phase analysis which will indicate that mild oxidative wear was responsible for loss of the material from the functional surfaces. Similarly the surface roughness can also be measured using the different surface roughness test methods.

And abrasive wear test, erosive wear test sorry abrasive wear and erosive wear will be causing more surface roughness as compare to the adhesive wear. So, depending upon the wear mechanisms which involved this kind of roughness which will be produced that will be different and we can quantify the extent of damage which is taking place on the surface with regard to the surface roughness can be quantified metallic debris.

As I have said is produced during the severe metallic wear and mild oxides, during the mild oxidative wear, during the adhesive wear test are produced by are produced means mild oxidative wear produces the mostly metal oxides. So, the presence of the metallic particles are the metallic oxides that is what can be confirmed through the XRD analysis and scanning electron microscopic study of the wear debris. Similarly the worn out surfaces can also be studied using scanning electron microscopy to see the kind of damage which is taking place onto the surface.

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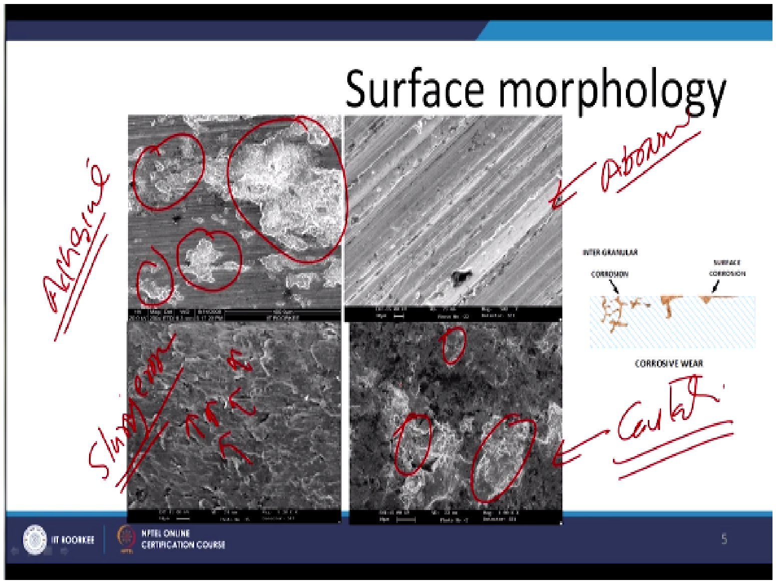

For example these are 4 scanning electron micrographs of the 4 different surfaces created by the different surface wear mechanisms like this is for the adhesive wear. Adhesive wear as I have said mild oxidative wear adhesive wear through mild oxidative wear mechanism causes the lot surface oxidation which we can see in form of these white oxides and patches, while abrasive wear will be causing the indentation and then formation of the deep scratches.

So, this corresponds to the abrasive wear, while slurry erosion will be causing in slurry erosion wears like say scent particles impacting onto the surface of the metal causing the deformation in particular directions. So, basically the pits cracks and the material elongated in the direction of the impact of the wear causing erosive hard particle that will be damaging the material surface in particular way.

And this is the cavitation wear, in case of the cavitation wear will see lot of pits, cracks and cavities are generated onto the surface. So, surface morphologies will differ significantly when the different types of the surface damage mechanisms work on to the metallic component and this also can be studied using the electron microscope. Now here I will summarise presentation, basically in this presentation I have talked about the diffusive mechanism.

And the different approaches which can be use to characterise to quantify the kind of surface damage which is taking place means during the different types of the wear mechanisms, thank you for your attention.