Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations
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Lecture-14
Surface Damage: Adhesive Wear II

Hello I welcome you all in this presentation related with the subject fundamentals of surface engineering and we are talking about the mechanisms of the adhesive wear. In the previous presentation we have talked about the mild oxidative wear which primarily takes place under the low load, low sliding speed conditions. And where proper lubrication has been given but if the sliding conditions are very severe under the load is too high a speed is too high under the lubrication is poor.

Then it can lead to the very high rate of the material removal in form of the wear now we will see another extreme side of the sliding wear.

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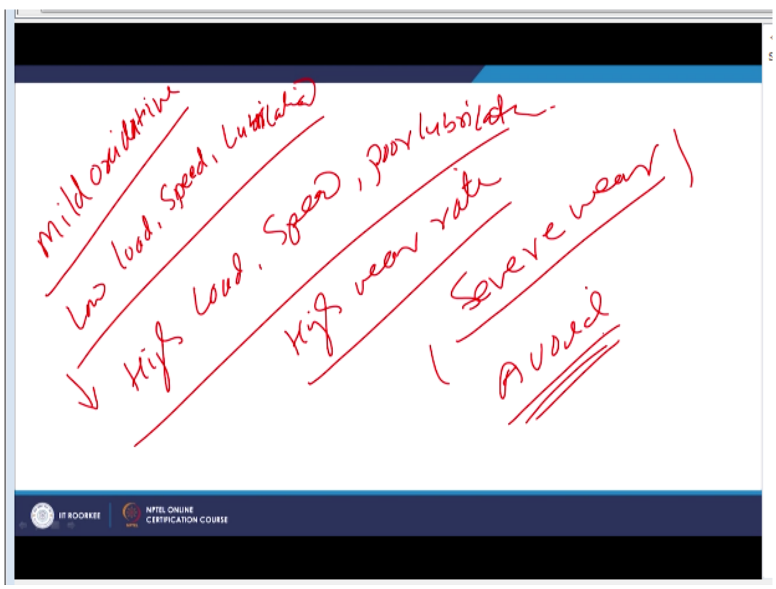

So, 1 was the mild oxidative wear where which takes place primarily under the low load, low sliding is speed and proper lubricated conditions. But if the conditions on the extreme side very high load, very high relative speed and very poor lubrication exist. Then it leads to the very high wear rate from the functional surfaces and that is termed as the severe wear. So, severe wear is something that we would like to avoid under the normal under the service conditions.

Because it causes very high rate of the removal of the material from the functional surfaces and that can damage performance of the component very badly.

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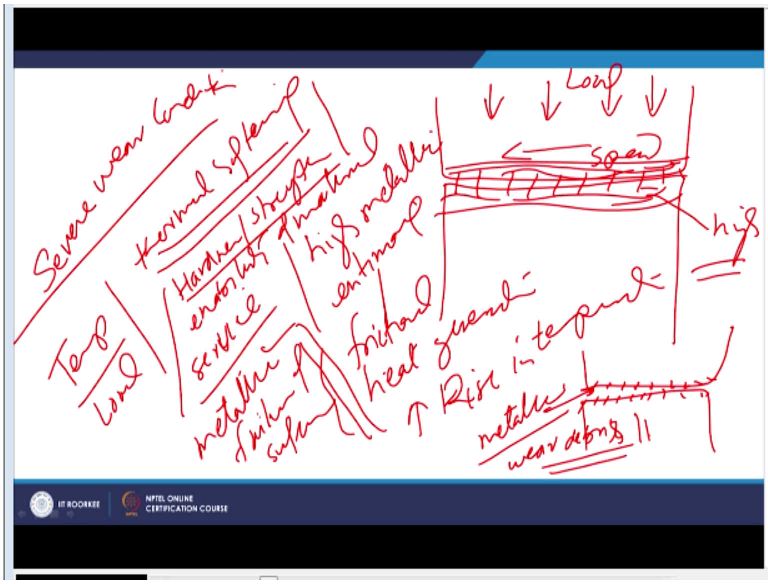

So, what are the overall things that happen under the severe wear conditions. So, if we see the 2 metallic systems which are direct in contact with each other under very high load and very high sliding speed conditions. Then the direct metal to metal contact between the 2 is very high so, high metallic intimacy exist under these conditions. And these conditions favor lot of the frictional heat generation.

So, high frictional heat generation leads to the significant rise in temperature of the functional surfaces. So, the temperature near the sliding interfaces increases to the high value and so, increase in temperature so, basically high temperature, high load due to the localization of the heat at high sliding speed leads to the thermal softening of the material present near the surface layers.

So, these layers gets softens significantly and because of thermal softening material it is looses it is hardness it is strength. So, these conditions lead to the inability of the material to take up the service load. So, material is not even to take the service load and therefore surfaces means metallic failure of the surfaces starts under these conditions. So, this is one situation where high load high sliding speed causes generation of the too much frictional heat.

And excessive heat localization causes significant rise in temperature which internally leads to the thermal softening weakening of the material in terms of the hardness and strength. And under these conditions under such conditions material looses itself, hardness and it is strength and ability to take up the service loads and under these conditions it leads to the metallic failure of the component.

So, instead of the typical surface layer oxidation and it is removal during this sliding which typically happens under the mild oxidative wear conditions. In this case the metallic failure takes place which occurs inform of very large size wear debris. So, basically large size wear metallic particles are removed in form of the wear debris.

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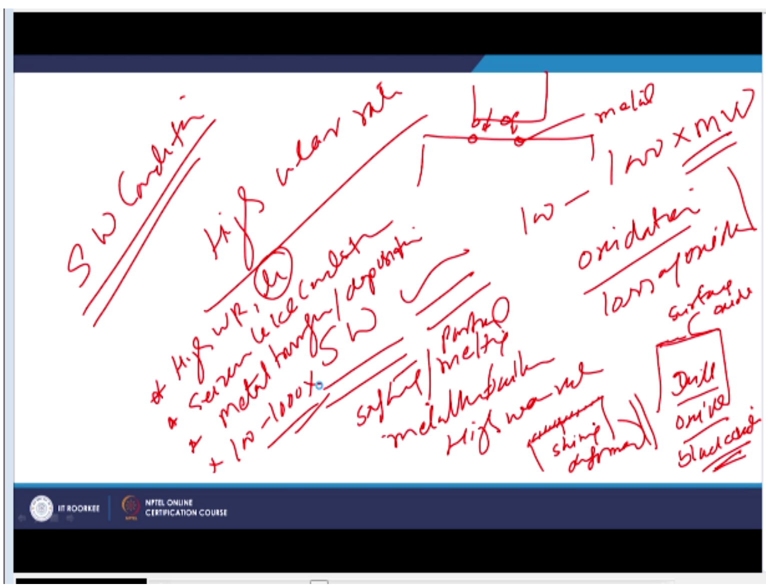

And these conditions under the severe wear these severe wear conditions leads to the high wear rate. So, wear rate if we compare severe wear is about like 100 to even 1000 times of the mild wear conditions. So, under the mild wear conditions the wear rate is very low as compared to the severe rate wear rate and in this case what we have basically oxidation and removal of the oxides.

And loss of oxides from the functional surfaces cause a loss of the material from the functional surfaces and causes the wear while in this case the softening of the material and sometimes the even partial melting weakening of the material causes the metallic failure and so, the high wear rate. So, if we see the 1 surface which is subjected to the mild oxidative wear will have the surface oxides present.

While in another case subjected to the severe wear it will have hugely plastically deformed surface. So, shining and deformed surface is typical feature of the severe wear while dull and oxide layer presence under the scanning electron microscope shows the mild oxidative wear conditions, further here black oxide is typical feature which is black oxide powder is the form in which wear debris is produced under the mild oxidative wear conditions. While large metallic particles are removed in form of the wear debris under the severe wear conditions.

So, whenever the severe wear conditions exist we may have the condition of the very high wear rate number 2 it is just like scissor like conditions. And metal transfer as well as deposition we may find the thermal softening and even partial melting may lead to the deposition of the some of the material from the softer and weaker material onto the harder and stronger material. So, this kind of condition leads to the deposition of the metal onto the counter surface or the harder surface.

So, this is the another feature which is observed and the friction is also high under these conditions and the wear rate is also significantly high like 100 to 1000 times of the mild oxidative wear conditions.

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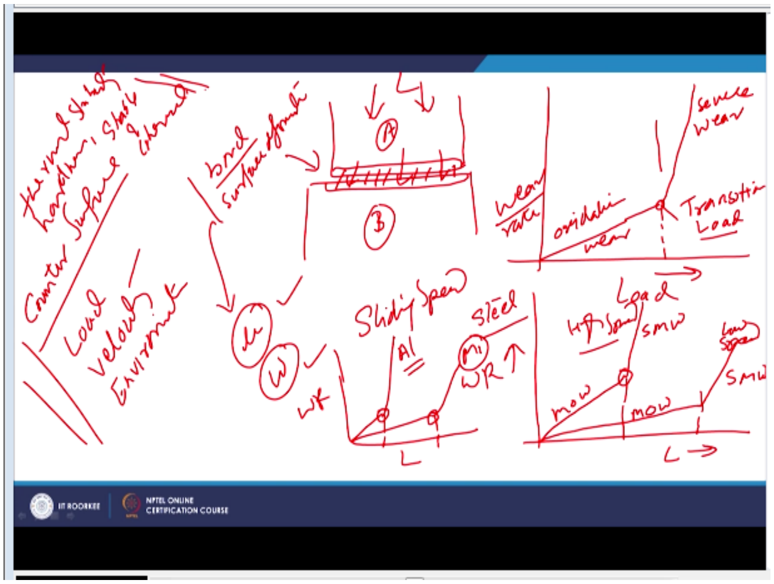

So, now what we will see that if we just notice the counter surface, role of counter surface, role of the load under which sliding is taking place load of the sliding speed and the environment in which the sliding is taking place. So, we will take up the load first, we know that if the load which is being transferred across the mating component through the interface like this.

The load is being transferred through this interface between the 2 components, so increase in load will bring the 2 components A and B closer. So, the intimacy metallic intimacy between the 2 components will be increasing and that will be increasing the bond formation. The surface layer deformation tendency and because of the excessive metallic intimacy this will be increasing the frictional force.

This will be increasing the wear of the material because greater is the area of the contact between the mating components through metal to metal contact. Then the greater will be the frictional force and greater will be the wear of the material and that is why and when the 1 type of the wear mechanism is involved generally the wear rate increases with the increase of the normal load which is being applied.

But after as, so this is 1 case where 1 type of the wear mechanism is involved like mild oxidative wear. So, wear rate increases gradually up to a limit of increase in the load. And once this limit is across then we may notice that the slow for the wear rate verses the normal load changes abruptly and this is the situation where there is a change in the wear mechanism which is where in like severe wear is taking place.

So, this severe wear this point where the transition from the mild oxidative wear to the severe wear is taking place which we can see from the change in slope of the curve between the wear rate and the normal load. This can be termed as the transition point where with regard to the load transition from mild to from the mild oxidative wear to the severe metallic wear is taking place.

So, this load at which this kind of transition from 1 big mechanism to the another takes place is termed as transition load. Now this transition load is found function of the number of parameters which maybe in terms of the sliding speed like if the sliding speed is a very low sliding speed then we may find a slope is going like this the load at which transition from mild oxidative wear to the severe metallic wear is taking place that is too high for the low speed conditions.

And if the speed is too high then we may find that wear rate is increasing at a higher rate and the transition is also taking place much earlier. So, the load at which this kind of the transition from mild oxidative wear to the severe metallic wear takes place is reduced at high sliding speed. So, this is one way with the change of the material as well as number of other factors, this kind of transition may happen in at different loads.

So, this load, this wear rate and if we see that for 1 material which is very good in terms of resistance to the severe wear. So, this is the transition load for material 1 and if we take another material this kind of the transition may take place at much lower loads. So, this may happen with the materials like steels and this may happen with the materials like aluminum.

So, depending upon the material the transition from the mild to oxidative wear can take place under the different the load conditions. And that in turn will be influenced by the number of factors. So, what is happening basically as I have said under the severe metallic wear conditions the rise in temperature is leading to the softening of the surface layers and thermal softening is weakening the material in terms of the hardness strength.

And ability to take up the load and so, if we see what is more important basically the thermal stability of the material resistance and hardness at elevated temperature and stable and coherence surface is stable and coherent surface even at high temperature material which is able to offer these features that will be offering the very good resistance to the transition from mild to oxidative wear.

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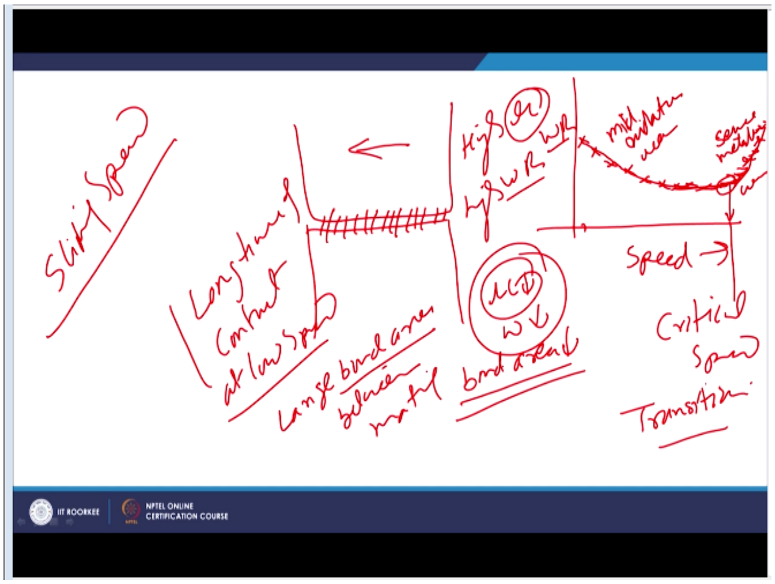

Now if we see another aspect related with this, then we have the sliding speed what we have seen that increase of normal load in general increases the wear rate. And this increase in wear rate is linear up to a limit and thereafter sudden increase in the wear rate takes place as soon as there is a change in the wear mechanism from the mild oxidative wear to the severe metallic wear.

So, if we consider again that the 2 mating components are under the sliding conditions means under the adhesive wear conditions, when the relative speed between the 2 is low. Then the time period for which contact exist at any region between the 2 sides that is too long. So, long time of contact exist when the relative speed between the 2 mating component is very low.

So, long time of the contact at low speed leads to the large bond area formation area between the mating component. So, at low speed since there is a lot of time for in mechanical interlocking, diffusion as well as the exchange of the electrons across the interface. So, the bonding between the 2 sides is good and that is why the contact the bond area between the 2 being formed at a low speed is more.

And therefore it results in the high friction as well as high wear rate and with the increase of a speed the time available for the exchange of electrons the time available for forming the bond between the 2 sides is very less. And that is why the bond area between the mating component is very small in size and small area of the bond the cold bond being formed under the adhesive wear conditions between the 2 sides.

If this area is small then it will be leading to the reduction in the friction and reduction in the wear. So, at high speed in general what we note is that if we see the wear rate verses the sliding speed relationship. Then at low speed since the contact period between the 2 sides is very is longer then what will be happening at high speed. And therefore at low speed bond area is more, wear is more, friction is high.

So, what will notice that with increase of a speed there is continues reduction in the wear rate then it becomes constant. Thereafter again starts increasing after certain speed like this, so initially increase of a speed there is a reduction in wear rate. And then wear rate becomes constant and then wear rate starts increasing. So, the initial phase up to which their initial phase where there is a reduction in the wear rate with the increase of the speed.

This is the portion where the bond area is decreasing due to the reduction in the bonding time between the 2 sets with the increase of the sliding speed. And this is the zone of the mild oxidative wear and the point above which wear rate is starts increasing with the increase of the speed. So here will be seeing the severe metallic wear and in this case the increase of speed is so high that frictional heat generation is starts to localize the heat.

And heat localization causes the rise in temperature, rise in temperature causes the thermal softening, thermal softening lowers their yield strength and the hardness which in turn makes the material enable to take up the service loads and that is why metallic failure starts beyond a certain critical speed. So, the speed at which this happens is known as the critical speed or the transition speed where the transition from mild to mild oxidative to the severe metallic wear takes place.

So, this is what is in general observed in those metal systems where adhesive wear primarily takes place through the oxidation and the loss of material from the functional surfaces takes place through the removal of the oxides. Now if we see the role of the different factors with the regard to the wear and friction. Then what will happen we have talked about the role of the load, we have talked about the role of the velocity.

Now we will see the role of the counter surface this is important now counter surface as per as counter surface is concerned. Here it is the hardness of the counter surface, the temperature of the counter surface and the material of the counter surface. Material like crystal structure composition and the micro structure of the counter surface. So, if like this 1 material and this is the another.

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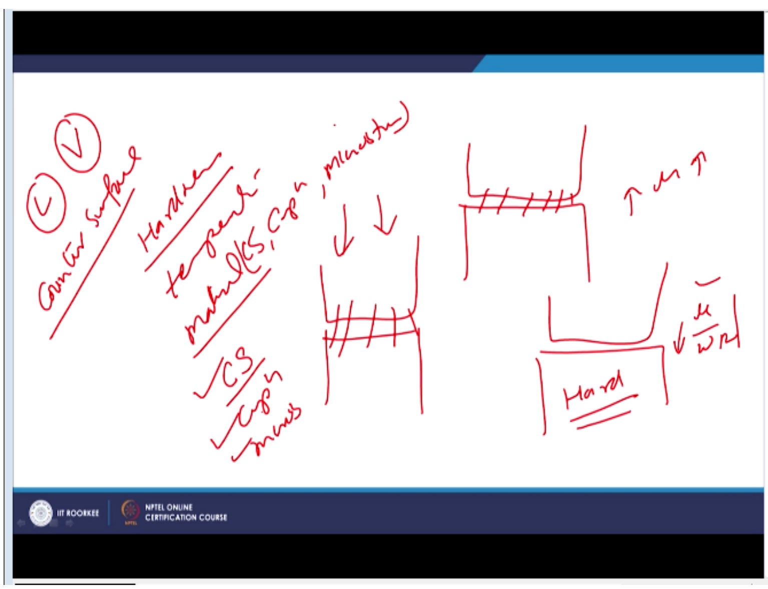

If both are of the same hardness then the bonding between the 2 is very good because of the collapse of the peaks and valleys from both the sides and forms the cold bonds very easily. And which in turn leads to the higher wear and higher friction. But if 1 is soft and another is hard, then just 1 side collapsing of the peaks and valleys will be taking place. So, the counter surface is hard then it will help in harder than the work piece material or another mating component.

Then it will be leading to the reduction in friction and reduction in the wear and that is why it is preferred that the 2 mating components are made of the different materials. The same is true for the counter surface material if the 2 if the 1 mating component and the counter surface component both are same crystal structure, same composition and same micro structure. Then the bonding between the 2 is extremely good and increased tendency to form the metallic bond.

And the cold bond between the 2 sides under the given service conditions leads to the higher friction and the higher wear rate. And that is why the mating components like the mating components are made of the different crystal structures, different compositions and the different micro structures. So, that this kind of tendency performing the bonds effectively at the interface can be reduced.

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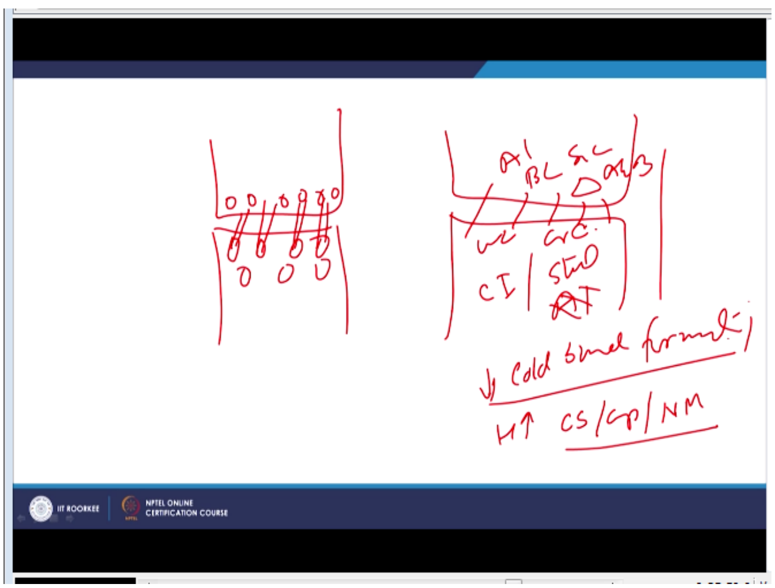

There is another aspect to this if there is one material like aluminum alloy and another material is also aluminum alloy then the wear rate will be very high. And if another material is like cast iron or if there is steel then the tendency to form the bond cold bond across the interface will be reduced and that in turn will be reducing the wear rate. There is another aspect what is that if 1 side is having lot of non-metallic constituents.

And this is the metallic one the exchange of the free electrons across the metal and non-metallic particles will be very limited and that is why the bond formation tendency will be reduced. So, if the 2 sides are having the reinforced non-metallic constituents in the metrics of the material like aluminum metrics is reinforced with the SiC or Al 2O3 or boron carbide. Similarly the cast iron or the steel is having some other tungsten carbide, chromium carbide other kind of the ceramic materials.

Then the free electron exchange is easily possible through the metallic metrics while the exchange of the free electrons through the metal and non-metals constituents will be difficult. Similarly the mechanical interlocking between the vey hard ceramic particles between the metallic and non-metallic will be difficult. So, these conditions actually will favor the reduction in the cold bond formation across the interface.

So, harder is the interface and the different crystal structure, different composition, different and the presence of such kind of the non-metallic constituents in the counter surface. Then these will be decreasing the tendency for the cold bond formation with the mating components and which in turn will be reducing the wear and friction tendency. Then there is another aspect that is about the temperature of the counter surface like the temperature of the counter surface against which one component is sliding.

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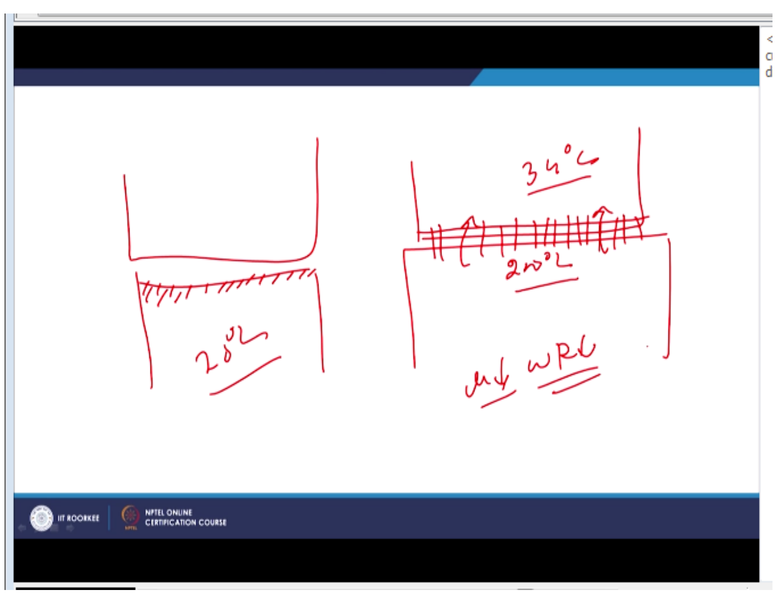

So, if the temperature of counter surface is like say 200 degree centigrade and the mating component is just at 34 degree centigrade. Then under such conditions the heat will be transferred across the interface and this will be leading to the softening of the 2 sides very easily and which will be promoting the formation of the cold bonds and metallic interlocking and the metallic intimacy between the 2 sides will be increased, when that counter surface temperature is high.

And under that condition the rate of material removal from the 2 sets will be high as compared the case, when the counter surface is maintained at lower temperature say 20 degree centigrade. So, the counter surface will remain is stable hard and will resist the tendency for the cold bond formation as compared to the conditions when the temperature was high.

So, it is always preferred that proper cooling arrangements are made so, that the counter surface means out of 2, 1 component is kept at lower temperature. So, that the metallic intimacy and interfacial bond formation tendency is reduced. And so, the friction can be reduced and wear rate also can be reduced, so that is about the effect of the counter surface.

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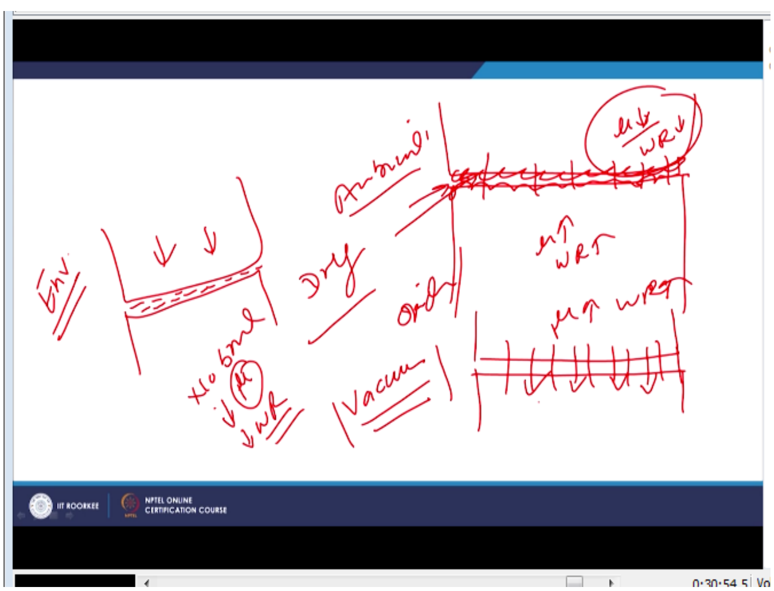

Now will be talking about the environment now the sliding between the mating components can occur in the different environments. These maybe direct metal to metal contact which is very dry, so direct metal to metal contact will have effective interfacial bond formations which will be leading to the high friction and high wear rate. But if that under the dry conditions if the interaction is taking place dry conditions means normal ambient condition under the ambient condition at least during due to the frictional heating.

Some oxides will formed at the interfaces of the 2 sides and this oxides will be reducing the metallic intimacy between the 2. And which in turn will help in reducing the metal to metal contact, so which in turn will help introducing the friction coefficient and the wear rate. On the other hand if the sliding performed in the vacuum, so in the vacuum there is nothing like impurity.

And the 2 sides will have direct access in terms of the metal to metal contact. So, friction will be high and wear rate will also be high. So the presence of oxides and oxygen and nitrogen in the environment will be forming their oxides and nitrides. These oxides and nitrides will be facilitating the reduction in direct metal to metal contact which in turn will be reducing the friction coefficient and the wear rate.

But if the sliding is taking place in presence of some lubrication like some kind of the medium is present, some lubricating medium is present between the 2. Then to ensure the metal to metal contact, these lubricant must be broken or made is unstable. So, that it is pushed out of the 2 component to have the direct metal to metal contact. So, of course the lubricant will remain between the mating components up to certain limit of the loading.

But if the loading is too high then it will be squeezed out from the interfaces and then the direct metal to metal contact will exist. So, under the normal conditions it is expected that lubricant is present between the mating component and it is able to separate the 2 components with respect to the direct metal to metal contact. And if there is no direct metallic intimacy then there is no bond formation.

And there is which in turn will be reducing the frictional force which in turn will also be reducing the wear rate. So, under the normal dry conditions normally it is the formation of oxides which reduces the metallic intimacy under the lubricated conditions. It is the presence of lubricant between the mating interfaces which reduces the metallic intimacy but under the vacuum an inert atmosphere.

Such kind of the oxidation and the presence of the impurities at the interfaces will be reduced and that in turn will be leading to the increased metallic intimacy. And so, which in turn will be increasing the higher wear rate of the material. Now, I will summarize this presentation. In this presentation basically I have talked about the transition from the mild to severe wear and the role of the load sliding speed and counter surface.

And environment related aspects the way by which it will be affecting the metallic intimacy, wear rate and the transition from mild to severe wear, thank you for your attention.