Wear Mechanisms

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Lecture: 08

Wear Mechanisms

Welcome, to lecture eighth of video course on tribology. Today is topic is wear mechanisms. We started wear topic two lectures previous to this, started with abrasive wear then adhesive wear and will be continuing today adhesive wear two slides on adhesive wear. And in addition to that will be covering corrosive wear and erosive wear.

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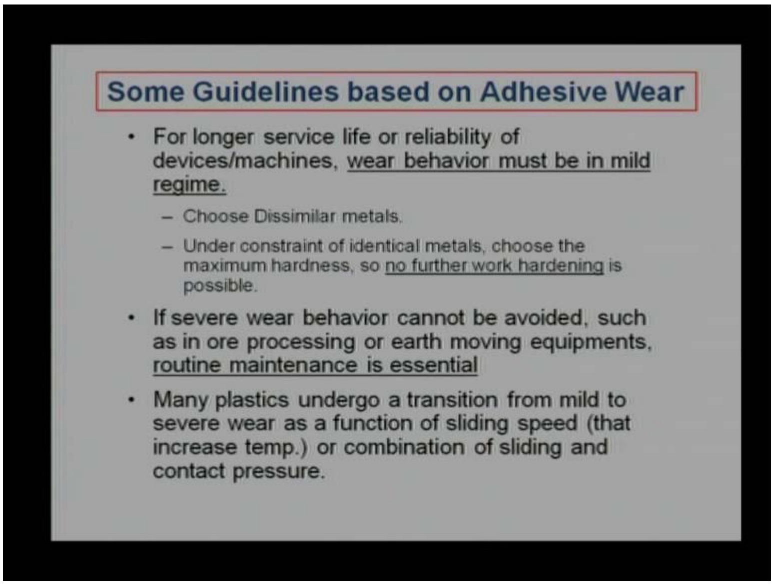

First (( )) some guidelines or some observation, which we gain through adhesive wear mechanisms. If we follow these guidelines, we will be serving to the nation will be able to save the cost and in hand servicing increase the life of components. So, first guidelines say that for a longer service life or reliability. If you are really aiming for longer service life or reliability of machine always aims for the mild regime wear.

In this case mild regime means wear particles which are coming out of material or surfaces need to be much smaller than size (( )) then one micron. That the we are talking about the micro level, of course, we talk about the micro component or nano components and wear rate also particle size will decrease in that same order. To do that what is the suggestion? is comes at dissimilar material. Choose always dissimilar material with have a lesser adhesion capabilities. So, wear rate will be lesser compared to similar materials and; however, one says that choose high hardness. Of course, hardness does not mean that they go to very high hardness where the brittle fracture occurs on like in ceramics, but, hardness we are further work hardening is not possible.

To that level we reached to a level where the further no work hardening is possible that kind of hardness is sufficient to reduce a wear or to bring the components in mild wear domain. If we follow this I am sure that component life will increase. In addition to that there are two other guidelines we say severe wear behaviour cannot be avoided. If we know that severe wear cannot be avoided application is like that like a cement industry. We know the particles will be there will be some velocity and there will wear the surface or high temperature.

In this situation, we need to think about the routine maintenance with increase the life of components. Here I can quote one good example of the roller bearings, say large size roller bearings. Where the inner ring, outer ring rollers and cage everything is separate that assemble at the time of application. Interestingly, outer ring is subjected to localized stress concentration or we say that applied load will be very or the very low area or almost micron size area.

There will be localized wear and there is no relative motion or relative velocity compared to the absolute frame. In that situation what we can do? We can rotate that outer ring by few degrees after few hours of operation. And u say if you bring some maintenance strategy we rotate outer ring we can increase the life of component or life of the outer ring by four times or five times or six times depends on the myth strategy we are going to opt.

We have one cases ready which on roller bearings result which will be covered in a next lecture .Where we will show by rotation of the outer ring ,we are able to save life or increase the bearing life by four times. So, where ever the severe wear is there we should use some maintenance strategy, some additional aspect not only the mechanism side.

But, operational side that will end as a life of component. And the last guidelines say that try to load component below in their transition limit.

The transition limit will know the transition limit comes from the load point of wear. Beyond certain load there will be jumped in wear rate which was shown in previous lecture when on slide. While in case we are talking about the temperature low polymers or plastic or (( )) we change their behaviour with the temperature. Of course, all the material changes the behaviour with temperature. But, polymers are most sensitive compared to metals compared to ceramics.

We are emphasizing on the plastic in this case. So, that try to avoid the try to think that it should not reach to the transition limit or beyond transition limit. Try to keep it in mild domain keep it in low transition temperature low transition load in this case.

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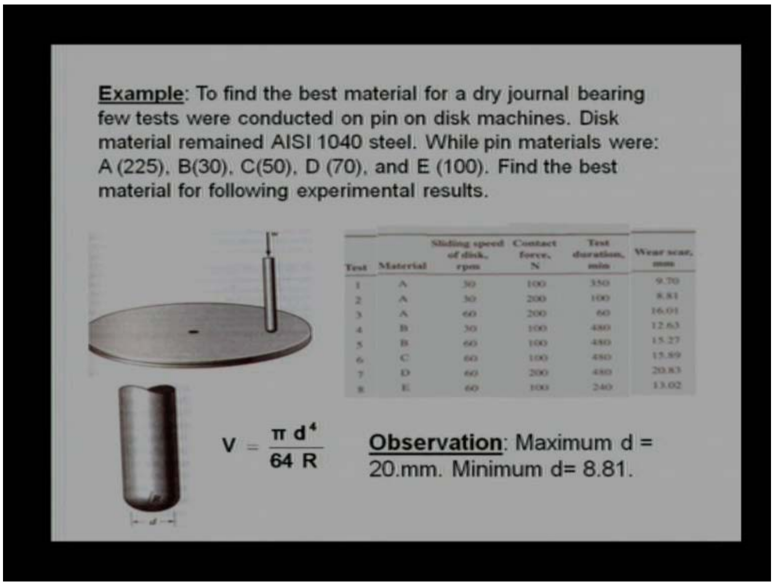

Test	Material	Sliding speed of disk, rpm	Contact force, N	Test duration, min	Wear scar, mm
1	A	30	100	350	9.70
2	A	30	200	100	8.81
3	A	60	200	60	16.01
4	B	30	100	480	12.63
5	B	60	100	480	15.27
6	C	60	100	480	15.89
7	D	60	200	480	20.83
8	E	60	100	240	13.02

To give some expose to the experimental data, let us take one example and this example. What we are aiming? Find the best material for dry journal bearing. We are assuming there is no lubrication or there is a lubrication that is by material its own. We are not providing a third substance. There are only two substance material one and material two. We are not providing any additional third substance from them. So, for dry journal bearing few tests were conducted then there is a those test will conduct on a pin on a disc machine commonly used machine.

Disc material which is generally stronger does not wear on very fast is 1040 steel and while pin material, we have selected five materials. Material A is having hardness (( )) hardness is 225. Material B has a hardness 30, material C 50 bhn, D 70 (( )) and E has a 100. So, there are five materials and some experiments were conducted on that. We are saying that again find the best material based on the following experimental results. And these are the experimental results; we say that we have performed three experiments on the material A, two experiments on the material B. 1, 1 each on C, D and E material. You can see the parameters which were selected as a input parameter.

In first test rpm was selected as 30 rpm, rotationally speed of disc as 30 rpm and applied load contact load is 100 Newton.As kinetic of this pin on disc machine is shown over here. You can see this is the pin, a smaller size compared to the disc and disc material is steel. This pin can be material A, material B, material C, material D, material E anyone of this. And apply load w is wearing in this following order.

So, that for first case is a 100 Newton, for second and third is a 200 Newton, for 4th, 5th and 6th is a 100 Newton, 7th 200, 8th 100. It does not show any order as such. These tests were performed orbitally and in addition to that there is a column which shows, what is the time duration of experiments which you will perform at the interface between the interface of pin and disc?

In first case we operated almost for the 6 hours, second 100 minutes, third almost one hour similarly, fourth, fifth, sixth, seventh they were operated for 480 minutes is 8 hours operation. The last one for the 4 hours operation. What we gain as a output? Output comes as a the wear scar. This also shown on this pin, the wear scar which is generated as a hemispherical pin. After removal of this portion lower portion this pin will be flat at that portion and if we expose this pin for slightly more time slowly that d will continuously increase otherwise also shown over here.

When the minutes we are operating the material A for 350 minutes, wear scar is almost 9.7. When we are operating at the 100 wear scar is 8.81 is reduction. However load has been increased two times. So, increase in the load and decrease in the time both factor will work and finally, results comes as 8.85. In third case we are increasing the speed to the two times from 30 to 60 rpm and keeping the contact load the same, but, duration is decreased. In this case wear scar is increased and this indicates clearly there is a some sort of transition domain.

We are increased the rotationally speed, we have increased the load and it is jumping in some transition regime or is crossing the transition is going to the mild wear to severe wear. So, this kind of experiments helps us to find out whether the mild wear or severe wear is dominating. Similarly, there are other experiments what we find minimum value of the d is around 8.81 and maximum value of the d is 20.83 m. Keep in mind that this d is smaller than its cache does not show that, but, (( )) large d need to be smaller than radius r or radius of hemisphere.

We take that with approximation, but, we can find out that the wear volume. Whereas we are assuming this surface is smoother and portion below this line whole portion not been removed as may be in has been transferred to the disc or the lose particle depends. This wear volume can be figured out or can be determined using this relation. This has a unit of mm cube or metre cube.

If we use this relation and we try to find out what will be the wear constant. Because, in this case speed is varying time is varying load is varying and if you are able to figure out what will be the wear constant. That will tell us whether pin whatever the material we are choosing it is suitable or not. So, in this case what the slide concludes that maximum d or maximum scar which is 20.83 and minimum is 8.85.

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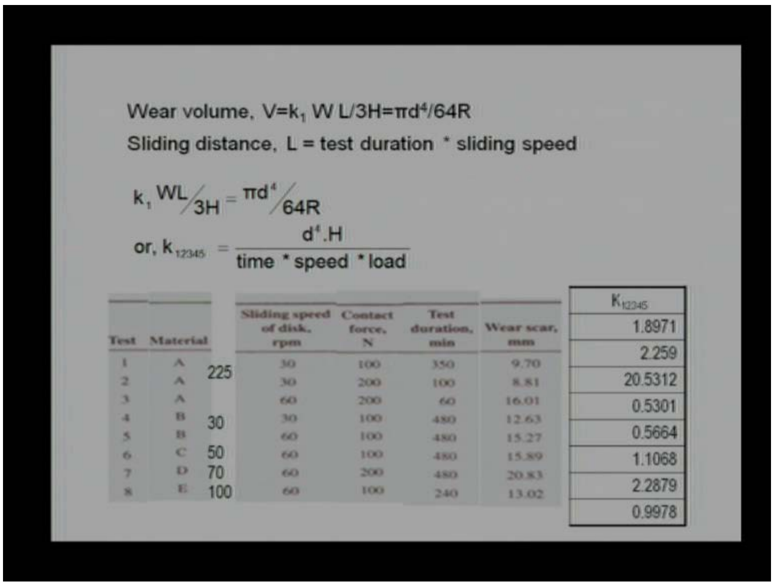

Now, we use the formula what we have derived earlier for adhesive wear. Say that v is equal to total volume and in this case total volume is also given in terms of sliding distance. Once we calculate this total volume we need to find out what was the sliding distance. On that sliding distance itself can be determined wears on the sliding speed and total time taken for the test or test duration. So, l will be known to us, w is known to us, w l hardness is known to us.

In this case d, we have measured from experiments and r may be unknown to us can be assumed, but, when we equalize this expression r can be removed or we can take that has a one constant. So, by equating these two expressions we are getting this relation. Now here r is unknown to us and pie is constant, 3 is constant. So, I am assuming that instead of k 1, I will assume a new constant k 12345 as some expression. It depends on the wear depth or wear scar depth or is length and in this case with (( )) at time speed and load.

As we are just going to compare absolute value of k does not mean much to us. It is only the comparative value which we need to find. So, in that case that why we are avoiding using substituting the value of r. We do that and in addition we are not expressing h in terms of Newton per metre square. Here we are giving itself in a term of a brinell hardness. Constant will be by a large same even though there is a some change or slight change when we use a viqor hardness or rockwell hardness, but, by a large will remain same.

Whatever the constant or multiplication factor, that can be accounted as a part of constant itself. That, why we are expressing unit as it is? This a wear constant it may not be dimensionally stay in this because we are expressing in terms of brinell hardness. So, what we are getting from this relation, this is already given .We are substituting this value and what we get from this equation is something like this constant k 12345 is 1.8971 or maybe say aproximal one 1.9 for test one.

It is increased for test two. So, this clearly says there is a transition. It is not remaining constant from 1.9 to 2.3 is increased from 1.9 to 2.3 there is substantial change; however, for third test there it comes around 20.5 a substantial jaw. That means, when this component was working in a mild domain initially and has reached to the transition domain and finally, it is in severe domain or regime is severe in this case. However, when we see the material B which has a relative low hardness what we are getting wear cost under the 0.53 and 0.56. This may be under slight numerical calculation or substitutions. So, we may be some experimental errors. So, this can be relaxed we say that this material has a consistent performance.

Even though it was working from one condition 30rpm second condition 600 and we are not changed from load from 100 to 200, but, we are it is keeping same as 100. So, is speed increased and is speed his not affecting this material. Similarly, for some other material we are getting these results. However, I can say these results are not sufficient results to conclude which material will be good. Thus if you want to see the transition domain you want to operate it as severe domain or you want to see the what will be the severe then we need to perform more number of experiments.

Reason being is more statistical parameter and we need to perform at least three to four experiments to adjust something. However, with the present results we can conclude that material B is a better option compared to all other or we say that material B is the best among 5 materials. This is just example hypothetical example, how to proceed? How to check? Which material will be good? Material will be preferable material? However, for conclusion for definite conclusion we need to perform number of experiments. With the topic will be dull when we start lecture on measurements. Now what we could just from the previous slide is that there is a mild wear and there is severe wear.

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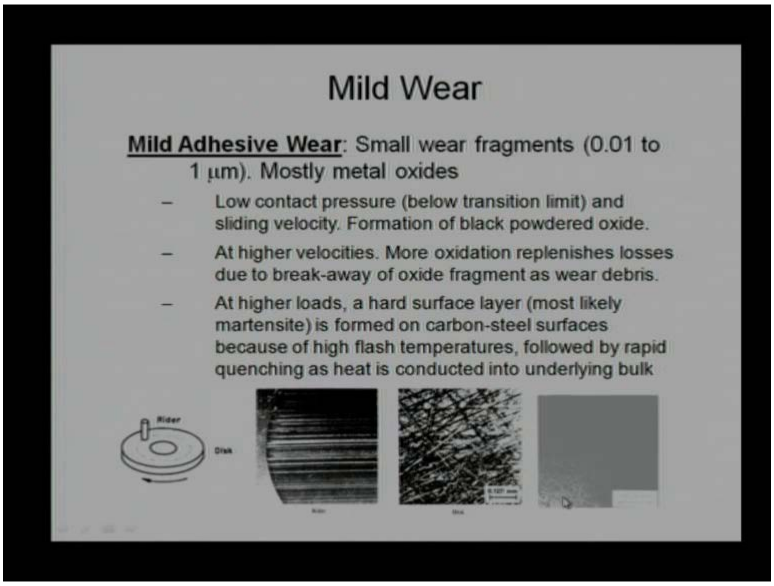

And we this slide shows few points on the mild wear. We say that in mild wear we are getting small wear fragments. Small in the sense the dimension of the particle is much smaller than the dimension of component. Again another point comes there is mostly this particles are metal oxides. They are not pure metal material which get oxidised that is coming out. Another word to reduce the friction, we allow exposer or material to the environment. So, that can form some oxide, reduce the shear strength of the interface reduce the friction coefficient.

In that case, we are saying that also leads to the initial wear, where the wear is mild domain or maybe say ultra mild also. When the wear particle size is almost 10 and a metre, we do not count that as a wear. It is a ultra mild wear. However, it comes roughly 1 micron and out of 1 micron wall size, we know the major part will be the oxide. So, material removal rate as such is not very dominant. So, that is tolerable, if you are trying to design some component for the five years, seven years this kind of mild domain will work very well. Now what are the characteristics?

We are saying that applying low pressure or apply load is relatively low that why the contact pressure is low and it is always a below transition limit. It is not even touching the transition limit. Whenever we open particularly in ferrous related component we can find out some black colour, black powder or black colour powder, mostly the iron oxide which will come out. Because iron has a natural tendency to form oxides in environment. So, to signify or to lustrate the mild wear we can give generally example of the iron or steel which are most commonly used materials.

They form some oxide layers on top of their surface and that is slowly bearing out and mild wear. However, if we increase the speed sliding speed is increased sliding distance is increasing that will lead to higher wear rate. But, interesting thing is that if the sliding is the speed is increasing there will be increase in the temperature. So, if there is increase in the temperature, there will be more chemical reactivating. If there is more chemical reactivating, then there is a more formation of the oxide layer.

So, removal of oxide layer and formation of oxide layer will be a dynamic process. So, wear rate will not be enhanced as such from material point of view, but, from oxide point of view yes. It does not matter much to yes. If it remains blows certain limit we can go ahead with higher speed till it reaches towards melting point or temperature which is going to change the microstructure of the surface or which is harmful for the overall system design. Now another possibility is there if you apply a high load material is getting changed when they are getting higher hardness and that in open air or in environment if is getting quenched, heat rapid that is also fine for us.

We are increasing the load which is increasing the temperature and it is getting cooled. So, the self heat treatment is happening its own. That also fine for us all three domains or all three conditions are favourable from a component design point of view. So, we can recommend this compared to the severe wear. There is a semi sketch shown pin and disc machine sketch here we are using the word rider instead of the pin and there is a small very thin line showing the mild wear. That signifies the mild wear.

If, you see the cross section of the pin which initially has a previous slide I say that will be a more flat surface. It does not come to the flat surface there are some scratches. You can see there are scratches, but, of course, this scratch values are generally lesser than 1 micron and this a surface of disc. Even though we know the disc is a rigid on stronger on having higher hardness, but, still has a micron level it get scratches. So, may be that when we do pin on disc machine experiments we should replace afters we say may be couple of thousand hours if the disc is damaged.

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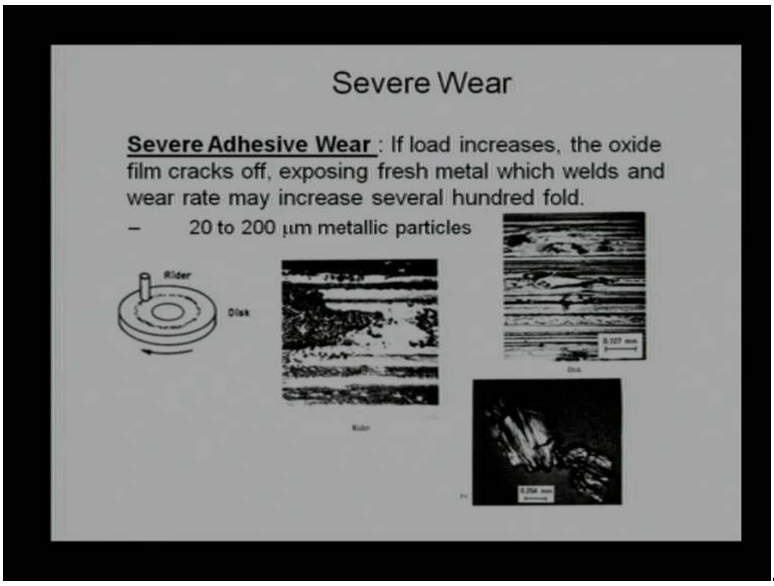

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And, this last is not very clear picture shows particles smaller size particles. They are generally very smaller in size may be I say order of 1 micron or lesser than that. Now coming from shifting from mild wear to the severe wear, what are the characteristics of severe wear? In this case we are saying that the load is increased, it is weakening the oxide layer. Or we say that load is increased and the surface is rough the asperities will penetrate in the surface will tear away the oxide layer and virgin material and assign material will be exposed in the surface which is transferring the load.

It gives more opportunity for adhesive wear, more and more cold junction formation. And if we introduce friction force tangential force wear rate will be very high. That why we say that cold junction formation and wear rate will increase by several hundred folds. Resending oxide layer is lost lubricant layer is lost, coefficient of friction is going to increase, wear rate is going to increase and particle which will come out. From this mechanism will turn out to be more like a size in the range of 20 to 200 micron equation terms.

We were talking in the mild wear about the 1 micron or we were taking about the 20 micron plus in the severe wear then the result in between them what happened to 2 micron what happen to 5 micron what happen to 10 micron? We generally keep them these particles size and transition domain. We cannot conclude that this is severe wear or is a mild wear. If it continues for some time we can it can be as a severe wear side or it can on a mild wear side depend on the situation.

If it is getting a natural powder of the wear out wearing out if the debris acting as a lubricant layer as a solid lubricant it will turn out to be mild wear domain or otherwise either particle size are continuously growing in a size it will be severe wear. So, we are keeping one to twenty micron size in transition domain just to characterize the similar way the way we have done in previous slide.

We are showing the pin and the disc machine sketch. Here you are able to see a thicker or wider line wider circle in the case there is a high wear rate. And I f I see the surface wear out surface on the rider we are able to find out yeah there is major (( )) which is been removed from the surface and there is a fragmentation. It is a very irregular surface and same thing if material is lost from the surface quite possible is deposited from the (()) disc.

We can see the very irregular surface here and this scale is only 127 micron, but, we are able to see in some cases this wear scars are even greater than 127 microns. But, (( )) as severe wear component will not sustain for longer and we need to replace that component. If we won and stop operation of machine otherwise sudden failure of the one component will damage because when the other component by transferring their load to their other components and there will be severe wear or (( )) failure of the machine and so on.

And see here the particle size particle size are showing in the size greater than 254 microns (( )) particles will be like that and average will be turning to be between 20 to 200 microns. Few particles are even exceeding 200 micron size. We keep removing more than 200 micron size particles from the surface. Naturally component dimensional will reduce and will get a value (( )) rate.

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Now, last slide or line is severe comes as a big bang we say that is a seizure as a seizure occurs whenever there is a high temperature or very high load. If I see the definition in dictionary what we find that is seizure is to bind or to fasten together. Another word this kind of bonding within roller and ring happens this is inner ring applied for roller bearing and the roller. You can see there is a adhesion bond or completely joining process the welling process. And if it happens bearing is not going to operate its not going to show its function it is going to be more like a solid element.

There will not be any relative motion. So, we need to shut down the machine. And we need to completely replace the bearing we need to apply force to even separate this roller from the ring.

This is ultimate is a final mode of a dissever mode. Here there is another example shown the inner ring in two half a bearing in the ring of bearing rollers. You can see there are material been plugged out of the inner ring. There are patches and parallel patches; that means, these rollers were spaced otherwise we should get continuous layer of this material remover, but, you know rollers are generally kept in a cages and they are equally spaced. That why we are getting equally spaced patches on outer surface of inner ring.

If the material was attached to the surface and some was force was applied to remove and after removal rollers also looks like this. They have lost the material reduction in dimension and cannot be reused. Unless they are reconditioned recoated one wear (( )) wear. What are the causes for this? We say that there are number of possibilities. Heat generation is higher coefficient of friction is high heat generation is high. As system does not have a capability to desperate that heat to transfer that heat to the environment. If it does not have that capacity what will happen there will be a continuous increase in the temperature.

Initially we may say that 40 degrees centigrade at the room temperature after all started operation it will reach to 50 then 60 70 80 90 100 and there is no limit. It may reach to the 700 800 and if it happens then surely material will start flowing and the welding process will occur. That will be hot welding in this case; that means, we have not designed a system properly. We are not designed a system from dissipation capabilities; however, there is another chance that lubrication was not proper.

System was designed keeping in a mind that lubrication will work or lubricant will work, lubrication mechanism will be active, but, may be because of the power supply or pump failure lubricant was not delivered to the bearing surfaces or tribal surfaces. In that case what will happen there will be jump from low coefficient of friction to high coefficient of friction? We say in lubricated case we kept the coefficient of friction of 0.05 and lubricant is stopped getting delivered at the interface coefficient of friction increase to 0.3, 0.4, 0.5, 0.6. Actually there is a substantial change in heat generation may be six times to twelve times and system which was designed with the low heat dissipation capability will not be able to tolerate that high coefficient of friction.

In that case extreme adhesion will occur seizure of component will occur. Similar thing happens also with the smaller clearance. If the clearance is not done properly or the two components are not designed properly or may be designed properly, but, may ne not manufactured properly, the trolleys were changed. You want to keep a trolleys between two components may be say as a clearance weight has 20 microns, but, due to the improper manufacturing we turn out to be only 5 microns.

So, there is a huge difference between twenty micron clearance weight and twenty microns clearance weight that will cause excessive temperature high friction and subsequent the high temperature and that lead to the seizure. This is one of the most common errors or one of the most common causes of failure or we call it as installation error.

The components are not installed properly the assemblies are not fitted properly. If there is a miss alignment and if there is a miss alignment there will be excessive load at the one side. Excessive load high stress concentration at that point will increase coefficient of friction significantly and that will lead to a high temperature which finally, stops the operation by seizure right. What we say observation is the excessive loading and heat which govern the seizure phenomenon or excessive adhesive phenomenon.

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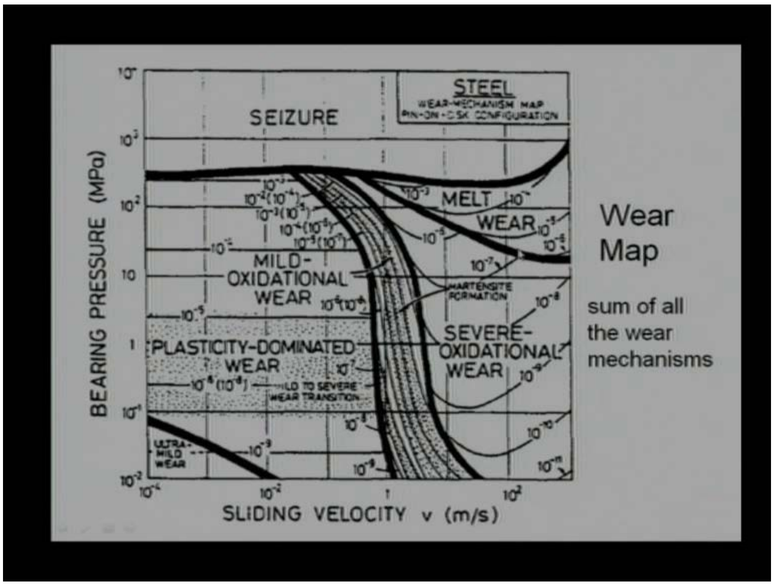

We have one slide on the wear map is a rigorous topic because it is a very extensive topic wear maps. People have done lot of work and only drawback about the wear map is it needs to be for one particular material pair. It cannot be a journalised one.

It has a number of merits this wear map has a two axis we are saying the x axis is the velocity axis metre per second y axis is unit pressure axis and expressed in mega Pascal. And this wear map shows that kind of wear happening at the interface. It does not separate abrasion wear adhesive wear at the individual level, but, it shows overall wear performance. That is why the orchard equation is satisfactory by a large abrasive wear equation and adhesive wear equations were treated in similar manner.

There was a constant and that need to constant need to determined and based on that constant we can plot results. Otherwise in both the equation load was common. w was expressed load was expressed for w hardness were expressed by h distance h soft hardness material hardness or the softer material and sliding distance. Only the constant which was in abrasive wear was a much higher value compared to adhesive wear.

And this wear map represents only their constant a combination of abrasive adhesive fretting forty corrosive altogether, but, this gives as a general idea how wear behaviour will change. Think about this lower domain where as some boundaries the thick colour thick black colour thin line thin black colour lines. This shows that this complete boundary will have almost same wear rate. They can be figured out by using the equations and where in domain we are saying that ultra mild wear always recommended. It does not cause must cost to us.

Component will survive by years and years and years. So, ultra mild wear should be recommended mostly for the micron industries or particularly the computers (( )) we coat for the ultra mild pair. This shows that initially the wear is in infused for the elastic deformation, but, if the pressure is increased we have certain limit there will be plastic deformation also. Then compare wear rate wear is to somewhere 10:09 or wear coefficient is 10:09 which means after 10:09 seconds, the asperity will tear away or adhesive junction will tear away. With cause of fragment or will produce the particle. As the pressure is increased plastic plasticity comes in to picture wear rate is also increasing may be say by three times three orders.

If we further increase pressure then, it is coming oxidational wear from ultra mild wear to the mild on slightly having mild. We can say medium wear mild oxididational wear held still material component metal component will be lesser than oxidation component. Here the wear rates are 10:05, 10:04, and the coefficient of friction is 10:04. If I compare this 10:10:04 with the 10:09 in a component which is under this operating condition will see 10: 05 times more life. Or we say hundred thousand times more life compared to the component which is operating in this domain.

If we keep on increasing the pressure we have reached to the final seizure; that means, load has increased significally that may be because of some failure of the pump which is stopped lubricating some lubricant supply or may have caused because of the improper installation or some bearing failure which has tilted the shaft and cause the failure of the complete machine.

It was related to the pressure. Now if we continuously increase speed or sliding speed you can see the wear rate as low as 10:11. Here there are some sort of low sharing happens because of the hydrodynamic action. With increase in the velocity we are able to get some sort of levitation on hydrodynamic film or aerodynamic films. So, that will reduce the wear constant may be 10:09 to 10:11 and second thing is that there is a more possibility of high oxidation. Oxide component is increasing compared to the metallic component, but, in between there is a transition domain where the particle size may range between 2 to 20 microns. High velocity and high pressure may cause a melting of material that called a melt wear again.

Plastic deformation is here, where as the high temperature the flow ability material will be there. So, it will act as a melting metal. Again high velocity and high pressure together will finally, cause a seizure of component. So, if we have kind of wear map we can choose which material will give good results. We know loading condition if we know operating speed and we know which material we are using we can figure out what will be the overall life of that component. Is it is that compo life is matching with our desired life? If it does not desire life or is not a as per our hints we can change material. We can change the condition, we can change velocity, we can change load, we can transfer load from one component to other. We can bring two components depends on the situation we can design system accordingly.

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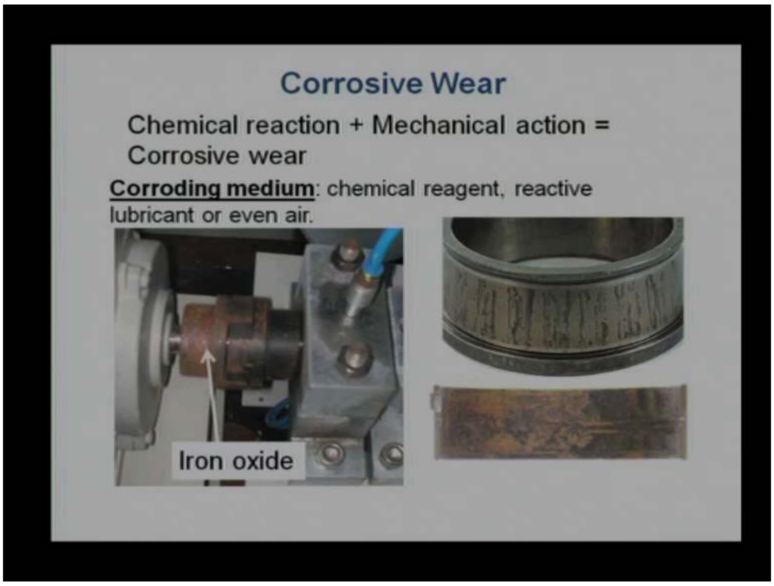

So, that was last slide on adhesive wear of course, a last slide adhesion involves a abrasion plus corrosion plus ferric. But, that was related to adhesive wear, now we are coming with the next mechanism that corrosion or is a corrosive wear. Interesting thing this wear is caused by a chemical reactions. Starting point is a chemical nature. So, that chemical reaction plus mechanical action makes corrosive wear. If chemical action is missing only mechanical action we cannot see corrosive wear. If chemical reaction is here, but, there is no mechanical action we can say that there is a corrosive wear.

It is a combination and what are the corroding media? It can manage them it can be lubricant also. Lubricant is getting acidic using his basic characters where it will act as a corrosive media. Here which has a moisture content it can act as a corrosive media and some kind of sort of chemical or sulphuric acid or acid which is formed after the reaction may be say sulphur dioxide gas was released from one chemical action reacted with the water got formed a sulphuric acid. And that sulphuric acid is acting with metal shows there is corrosion.

What are the problems with this corrosion? problem is chemical action? To illustrate that we have taken example of one coupling. As job coupling connecting motor with a shaft and there is some magnetic bearing support. I took this example, because I found in lab there is some brown colour coming on the coupling initially it was completely black. The brownish colour generally comes because of iron oxide and we know very well the couplings made of the steel will be subjected to the atmospheric reactions and some sort of oxide layer will be formed on the surface. So, there is a brown layer oxide layer on the surface.

What we can figure out that the dimension of this brown layer is slightly larger than parent or initial dimension of the coupling, it swallows it increase in dimension. And there is this layer also (( )). If I rub this coupling with a finger I will be getting red oxide or iron oxide on my finger and fingering this way that is we are doing some sort of mechanic collection on that. If, you do not do that this layer will not be separated its own unless there is some sort of vibration some other mechanism.

So, vibration itself is a mechanical action which is going to cause detachment or removal of this layer because of that has this layer is a brittle in the nature and is a porous in nature. We can say this is iron oxide we rub this surface will be getting this oxide on a rubbing surface. There are couple of other examples. You can see this is inner ring of the one the roller bearing and this ring has some oxide layer or we say that some sort of marks on the surface these are the roller marks.

And in the interface there was some sort of moisture or some water in grease in oil. That has caused this kind of corrosion. Quite possible if the temperature increase, where rate of the corrosion will increase. And then in that case we will be to find out the some deep impression on the inner surface. However, if the corrosion is under limit in ultra mild domain reason. Then we will not be able to lose much there will be marks, but, without change much change in the dimension (( )) tolerable, but, many times if the corrosive rate increases because of the temperature because of excessive friction or because of the excessive load.

Then that is turning to be avoided turning to be stopped. This is occurs in wear of engine bearing where the engine oil get acidic and when oil itself a lubricating oil is acid is coming completely in contact with the bearing surface. Naturally there will be excessive of corrosion wear and bearing need to be replaced in the situation. Whereas the corrosion plus rubbing will change dimension of bearing, and the dimension of bearing change occurs then we need to replace it.

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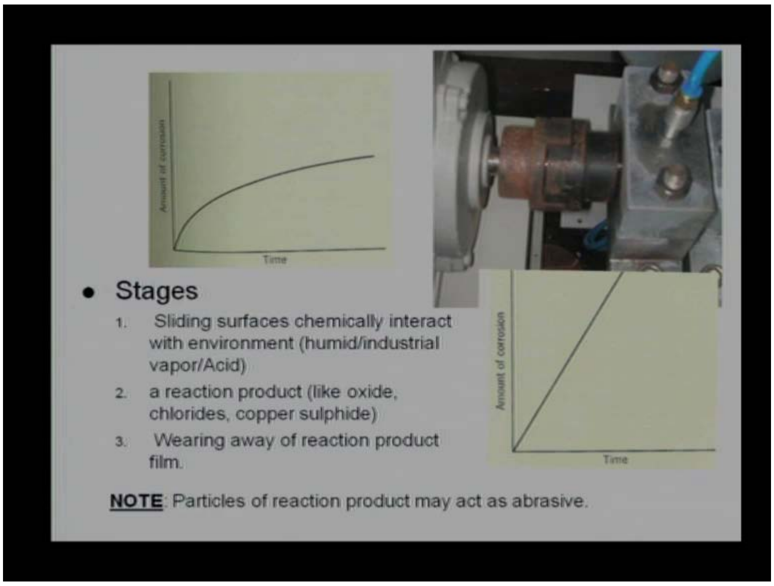

Interesting that about the corrosive wear is that the pasivation, that wear rate will continuously decrease. Thus see this figure we say that there is a time x axis and amount of the corrosion. We are talking amount of corrosion is not a corrosion rate, it is a cumulative. It is a summation from the zero time. This come has initially some slope and this slope is continuously changing its getting corrosion and finally, it will reach to the steady state condition and is getting passivity in its stop its own.

We do not have to do anything. The same thing over here if I rub this surface again corrosion will happen. But, if I do not rub keep as it is nothing is going to increase. When it corrosive layer will not increase beyond certain limit unless excessive vibration is lost from that surface or removes from the surface. Of course, as the layer grows layer is already brittle and porous strength of the layer will continuously decrease or we say that strength of this layer will be a function of thickness.

With increase in the thickness the strength is going to decrease. We need to be careful about that it should not happen that layer is continuously increasing and generating number of particles from that. So, few points from this we say that it goes in three stages. Sliding surface for chemical interact with the environment. It can be humid or it can be acid or any industrial vapour or steam.

Reaction product is formed like iron oxide chlorides or copper sulphide in presence of different chemical like chemicals. If mechanical action is introduced then there will be wearing a way of reaction product film. This oxide film will be removed sulphide film will be removed. If there is a mechanic collection is ending if they are loosely attached if the thickness is beyond certain limit beyond critical limit.

If that happens we can say that instead of following this curve we need to follow this curve. For the time corrosion rate is increasing continuously or we say that corrosion rate is constant. But, cumulative factor of the corrosion is continuously increasing is reaching to the mono dynamically increasing reaching the maximum value whichever is allowed to us. So, if there is a mechanical action this curve will be followed. If there is no mechanical action this curve will be followed.

There will be corrosion, but, no wear. While in this case there will be corrosion plus wear and wear is going to pass more corrosion. Now one point to be noted is that these particles which are getting removed from the surface or an oxide may act as abrasive material. And finally, cause the damage of the material due to the abrasive wear. As I mentioned in last lecture or previous lecture that abrasive wear failures are the maximum wear occur due to the abrasive wear or the maximum. Interestingly adhesive wear also leads to the abrasive wear; corrosive wear also leads to the abrasive wear or final destiny the same.

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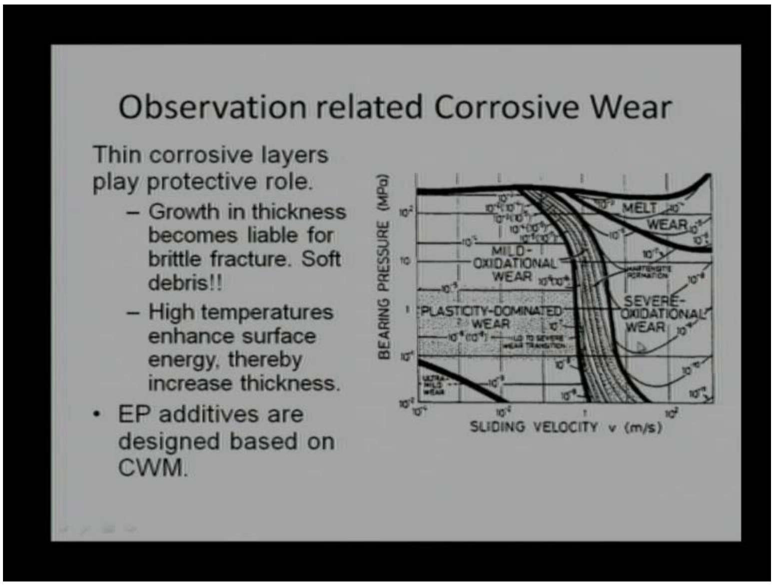

But, illustration mechanism or initial mechanisms are different. Some observation related to the corrosion, I am saying that the thin corrosive layer may act as a protection.

Interestingly we know if material is a virgin is innocent no oxide layer on top of the surface it will show very high coefficient of friction, high adhesion, high wear rate. But, if there is a thin layer may be say order of 10 micron then it will be attached firmly or weakly depends to the surface. But, it will act as a friction reduction mechanism or is other component or material which reduces the friction and subsequently reduce the wear rate. So, one way if I understand corrosion mechanism I can utilise it as lubricant layer or I can say I can utilise corrosive wear mechanism to lubricate the surface.

But problem it need to be controlled. If it goes out of control then thickness will grow and is a brittle material or oxides are brittle if the thickness is continuously increasing strength will keep on decreasing. And there will be detachment from the surface and if there is detachment from the surface this porous layer will get converted in number of particles. And that will initiate abrasive wear which is not desirable. However, many times we say that the layer itself is a soft material layer, even after getting this loss from the parent surface, it will get in a number of small particles, but, softer in nature which can be easily shared.

So, this soft material porous layer will act as lubricant layer even after getting detachment from the surface, but, there is only little material which behaves like that. Is another point has come that at the high temperature we know the surface activity will continuously increase. If there is increase in the surface activity more and more formation of oxide layer will occur. And if it is not continuously removed and removed from interface itself then, it may cause high wear rate.

One interesting thing is that we use additives in lubricant and one kind of the additives is extreme pressure additive. Extreme pressure itself is a miss normal it should be extreme temperature additives. What happens to these additives when the temperature is increased beyond certain limit? They turn out to be active and then they react with the surface, but, in controllable fashion. Will make a layer, may be say 5 micron to 10 micron on the surface and that will act as lubricant layer.

In another word E P additives can be used for the higher temperature application. When we are operating machine components from the 200 to 300 to 400 degree centigrade in the range somewhere in 2 to 400 degrees centigrade E P additives are going to help us. Typical example is the wear lubricants we use E P additives in wear lubricants. We know the bulk temperature may be even eighty degree to hundred degrees centigrade, but, at the interface this temperature may go much higher than that. It may reach to two hundred fifty degree centigrade and ordinary lubricant will not work there it will not protect the surface. So, E P additives which make which corrode the surface I am using the word corrosion. E P additives really corrode the surface, but, we are happy they are acting as a sacrificial layer. There is a layer formation and layer removal after certain duration after certain cycles, but, it will corrode damages the surface, but, that damage is acceptable to us.

Because, it is going to help it is going to reduce the coefficient of friction and is going to reduce subsequent wear. If we do not use the E P additives there will be scuffing, it will be adhesion or extra extreme adhesion and wear will stop working. There will not be any relative motion between the wear surfaces. So, we required E P additives in those situations which are fruitful to us. So, this same thing which is said E P additives are required to enhance activity of the lubricant and react to the surface. That is helpful and is what shown in this case the thickness is continuously increasing under the pressure wear is also increasing. There will be more and more wear rate.

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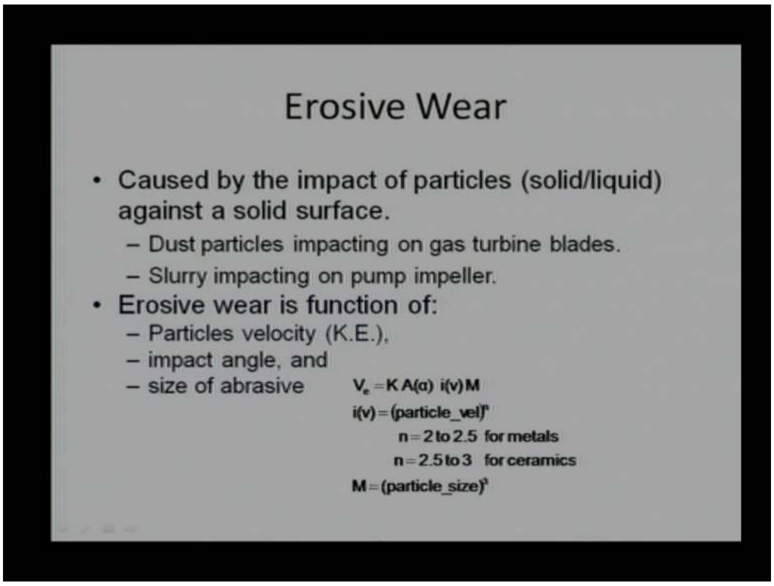

Now, we will come to the erosive wear. Interesting this wear occurs with the solid particle as well as the liquid particle the liquid particle can erode the solid surface. That was the definition comes we say that erosive wear caused by the impact of the particles.

Particles may be solid may be liquid, but, one definite thing is that they need to have velocity; they need to have kinetic energy. If there is no kinetic energy with the particles it will not cause any erosion. If I am able to divert the particles and bring the velocity to zero to zero kinetic energy, there will not be any wear rate at least from erosive wear mechanism point of view. There are couple of examples which are very common. So, that when helicopter passes through the dust or the some height may be say 1 kilometre to 2 kilometres high where there is too much dust.

Then what will happen in that case dust particle will impact on gas turbine blades and cause erosive wear. Suitable design need to there to avoid this wear. That, why we need to understand the mechanism? same thing happen if there is a slurry pump is used and we know the slurry has particles and there will be some velocity some kinetic energy will be given they will impact in the impeller and they may damage the surface.

That is why the most often we use keeps changing the impeller after certain operating hours. We can say the erosive wear is a function of particle velocity because we know the kinetic energy depends on particle and it is a strong tendency. It depends on the impact angle the angle which had which particle is going to hit the surface we know from the momentum point of view that this angle will decide how much is energy is getting transformed from the particle to the solid surface. So, impacting angle is important to us.

And the last says what the size of particle is? Is this the low size or a high size? We know size is related to mass and mass is related to kinetic energy. So, overall mechanism is related to kinetic energy particle velocity related to kinetic energy, but, we say that strong dependence because it comes a v square when the mass has we are assuming the spherical particle then there is three power third comes with the d cube particle size will be proportional to the d and then volume will be proportional to d cube.

So, again there is a severity. There is a strong dependency of the particle size. We say that particle size as well as velocity they are strongly going to out fact impact wear or the amount of the wear. While impacting angle depends which material we are using that will affect the impact wear or erosive wear.

This equation generally given v is a wear rate there is a some constant. We can say imparticle constant or some (( )) how many after how long this particle will be detached?

Function a alpha which is a function of impact angle, function I which is a function of velocity and mass which is a function of particle size. We will be detailing this; we will be discussing this in detail in our next lecture. We will continue the erosive wear in next lecture. Thanks.