Wear Mechanisms

Prof: Dr.Harish Hirani

Department of Mechanical Engineering

Indian Institute of Technology Delhi

Module: 03

Lecture: 08

Wear Mechanisms

Welcome, to lecture eighth of video course on tribology. Today's 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.

(Refer Slide Time: 00:55)

Some Guidelines based on Adhesive Wear

- For longer service life or reliability of devices/machines, wear behavior must be in mild regime.
  - Choose Dissimilar metals.
  - Under constraint of identical metals, choose the maximum hardness, so no further work hardening is possible.
- If severe wear behavior cannot be avoided, such as in ore processing or earth moving equipment, routine maintenance is essential
- Many plastics undergo a transition from mild to severe wear as a function of sliding speed (that increase temp.) or combination of sliding and contact pressure.

First let us see 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 guideline says that, if you are really aiming for longer service life or reliability of machine, always aim 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 lesser then one micron. That we are talking about the micro level, of course, we talk about the micro-components or nano-components and wear rate also. Particle size will decrease in that same order. To do that what is the suggestion that comes at

dissimilar material. Choose always dissimilar material which has 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 and fracture occurs like in ceramics, but, further hardening is not 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 of a cement industry. We know the particles will be there, will be some velocity and there will be wear surface or high temperature.

In this situation, we need to think about the routine maintenance with the increase of 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 have 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 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 depending on the myth strategy we are going to opt.

We have one case study on roller bearings, which will be covered in my next lecture, where we will see by rotation of the outer ring, we can 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 also operational side that will affect life of component. And the last guidelines say that try to load component below their transition limit.

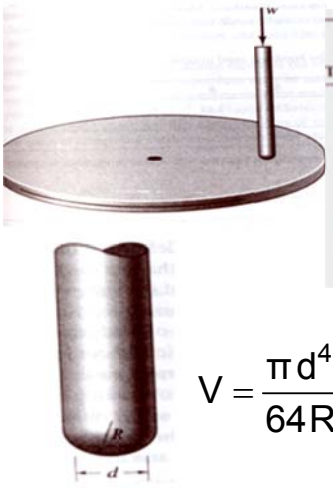
The transition limit comes from the load point of wear. Beyond certain load there will be a jump in wear rate which was shown in previous lecture in the slide. While the case we are talking about the temperature low polymers or plastic or elastomer we change their behaviour

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, try to avoid 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.

(Refer Slide Time: 06: 12)

Example: To find the best material for a dry journal bearing few tests were conducted on pin on disk machines. Disk material remained AISI 1040 steel. While pin materials were: A (225), B (30), C (50), D (70), and E (100). Find the best material for following experimental results.



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

$$V = \frac{\pi d^4}{64R}$$

Observation: Maximum d = 20.mm. Minimum d= 8.81.

To give some expose to the experimental data, let us take one example and in 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 of 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. Those tests were conducted on a pin on a disc machine commonly used machine.

Disc material which is generally stronger does not wear very fast is 1040 steel and while pin material: we have selected five materials. Material A is having hardness 225. Material B has a hardness 30, material C 50 BHN, D 70 BHN 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. 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 4^{th}, 5th and 6th is a 100 Newton, 7th 200, 8^{th} 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 be perform at the interface between the interface of pin and disc.

In the 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 that is 8 hours operation. The last one was for the 4 hours operation. What we gain as an output? Output comes as a wear scar. This also is 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 come 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 some sort of transition domain.

We have 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 radius does not show that, but, large d need to be smaller than radius r or radius of hemisphere.

We take that approximation, but, we can find out the wear volume. Whereas we are assuming this surface is smoother and portion below this line whole portion not been removed as may be, it has been transferred to the disc or the lose particles 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, 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.

(Refer Slide Time: 12:52)

$$\text{Wear volume, } V = k_1 W L/3H = \pi d^4/64R$$

$$\text{Sliding distance, } L = \text{test duration} * \text{sliding speed}$$

$$k_1 WL/3H = \pi d^4/64R$$

$$\text{or, } k_{12345} = \frac{d^4.H}{\text{time} * \text{speed} * \text{load}}$$

Test	Material		Sliding speed of disk, rpm	Contact force, N	Test duration, min	Wear scar, mm	K_{12345}
1	A	225	30	100	350	9.70	1.8971
2	A		30	200	100	8.81	2.259
3	A		60	200	60	16.01	20.5312
4	B	30	30	100	480	12.63	0.5301
5	B	50	60	100	480	15.27	0.5664
6	C		60	100	480	15.89	1.1068
7	D	70	60	200	480	20.83	2.2879
8	E	100	60	100	240	13.02	0.9978

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 is 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

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 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 and large same even though there is some change or slight change when we use a bicker hardness or rock well hardness, but, by large will remain same.

Whatever be the constant or multiplication factor that can be accounted as a part of constant itself. Then, 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 approximately 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. It 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, there 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 have not changed load from 100 to 200, but, we are keeping it same as 100. So, is speed increased and speed is 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 what will be the severe, then we need to perform more number of experiments.

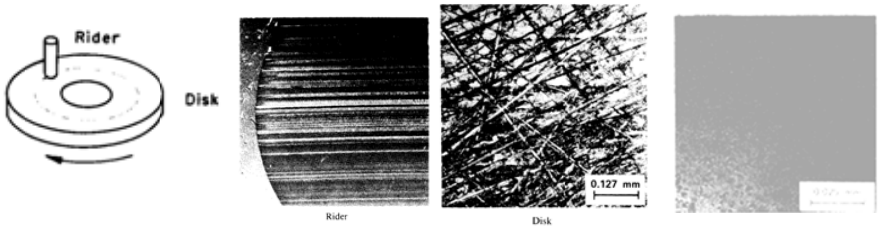
Reason being is more statistical parameter and we need to perform at least three to four experiments to adjust something. However, with the present results we can conclude that material B is a better option compared to all other or we say that material B is the best among 5 materials. This is just a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

(Refer Slide Time: 18:08)

Mild Wear

Mild Adhesive Wear: Small wear fragments (0.01 to 1 μm). Mostly metal oxides

- Low contact pressure (below transition limit) and sliding velocity. Formation of black powdered oxide.
- At higher velocities. More oxidation replenishes losses due to break-away of oxide fragment as wear debris.
- At higher loads, a hard surface layer (most likely martensite) is formed on carbon-steel surfaces because of high flash temperatures, followed by rapid quenching as heat is conducted into underlying bulk



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 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 is why the contact pressure is low and it is always 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 illustrate 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 speed is increasing there will be increase in the temperature. So, if there is increase in the temperature, there will be more chemical or reactivity. If there is more chemical or reactivity, then there is 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 below 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 heat treatment is happening on its own. That is 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.

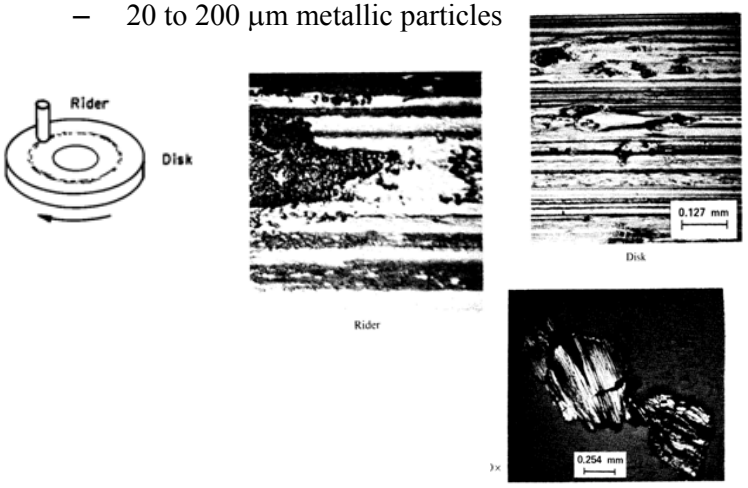
If, you see the cross section of the pin which initially was in a previous slide, I say that will be more flat surface. It does not come to the flat surface there are some scratches. You can see there are scratches, but, of course, this scratch values are generally lesser than 1 micron and this is surface of disc. Even though we know the disc is a rigid and 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.

(Refer Slide Time: 23:39)

Severe Wear

Severe Adhesive Wear : If load increases, the oxide film cracks off, exposing fresh metal which welds and wear rate may increase several hundred fold.

- 20 to 200 μm metallic particles



And, this last is not very clear. Picture shows 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 again material will be exposed in the surface which is transferring the load.

It gives more opportunity for adhesive wear, more and formation of cold junctions. And if we introduce friction force, tangential force, wear rate will be very high. That is 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 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 about the mild wear the 1 micron or we were talking 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 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 it can be on a severe wear side or it can be on a mild wear side depending on the situation.

If it is getting a natural powder of the wear 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 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 if I see the surface wear out on the rider we are able to find out there is major portion 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. As severe wear component will not sustain 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 complete failure of the machine and so on.

And see here the particle size are showing the size greater than 254 microns sized 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 dimension will reduce and will get a greater wear rate.

(Refer Slide Time: 28:00)

Seizure

- "to bind" or "fasten together".



➢ Causes:
  - Poor heat dissipation
  - Poor lubrication or improper lubricant.
  - Smaller Clearance.
  - Installation error (Excessive load).



Observation: Excessive loading & heating govern the Seizure phenomenon.



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 seizure is to bind or to fasten together. In 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 an adhesion bond or completely joining process, the welling process. And if it happens bearing is not going to operate its not going to show it is 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 cages and they are equally spaced. That is why we are getting equally spaced patches on outer surface of inner ring.

If the material was attached to the surface and some 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. Wear! What are the causes for this? We say that there are number of possibilities. Heat generation in 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 have not designed a system from dissipation capabilities; however, there is another chance that lubrication was not proper.

System was designed keeping in mind that lubrication 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 a 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 be not manufactured properly, the trolleys are changed. You want to keep a trolley between two components may be say as a clearance weight has 20 microns, but, due to the improper manufacturing it turns out to be only 5 microns.

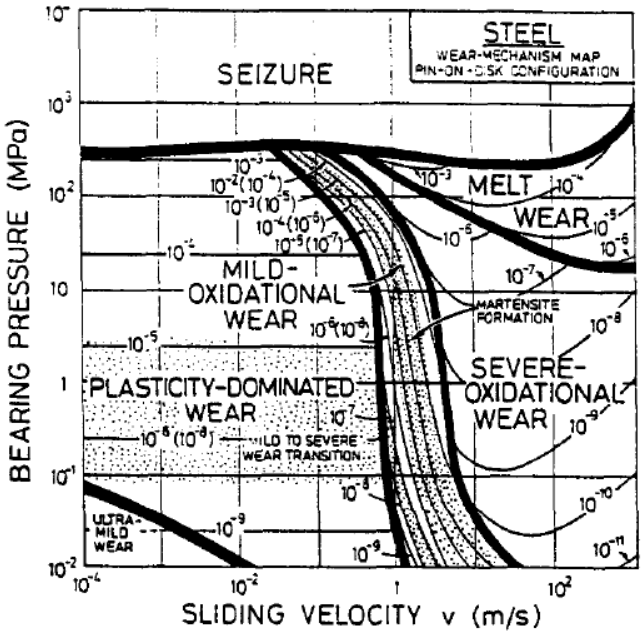
So, there is a huge difference between twenty micron clearance weight and twenty microns clearance weight that will cause excessive temperature, high friction and subsequent the high temperature and that lead to the seizure. This is one of the most common errors or one of the most common causes of failure 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 there will be excessive load at 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. What we say by observation is the excessive loading and heat that governs the seizure phenomenon or excessive adhesive phenomenon.

(Refer Slide Time: 33:41)

Wear Map

Sum of all the wear mechanisms



We have one slide on the wear map. It is a rigorous topic because it is very extensive topic on 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 constant need to be 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 much 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 computer's hard disc we coat for the ultra mild pair. This shows that initially the wear is 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 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.

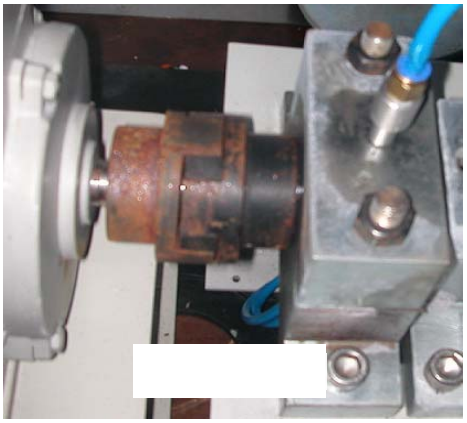
Plastic deformation is here, where as the high temperature the flow ability material will be there. So, it will act as a melting metal. Again high velocity and high pressure together will finally, cause a seizure of component. So, if we have kind of wear map we can choose which material will give good 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 that compo life matching with our desired life? If it does not the desire life or is not 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 depending on the situation, we can design system accordingly.

(Refer Slide Time: 40:16)

Corrosive Wear

Chemical reaction + Mechanical action =
Corrosive wear

Corroding medium: chemical reagent, reactive lubricant or even air.





So, that was the 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 a corrosive wear. Interesting thing this wear is caused by chemical reactions. Starting point is 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 its 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 sort of chemical or sulphuric acid or acid which is formed after the reaction may be 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 oxide layer on the surface.

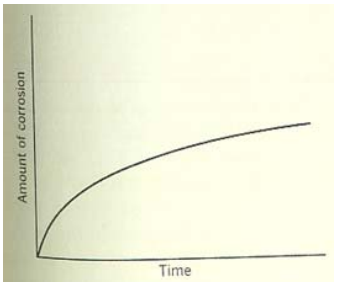
What we can figure out is that the dimension of this brown layer is slightly larger than parent or initial dimension of the coupling, it swallows it increases in dimension. And there is this layer also. If I rub this coupling with a finger I will be getting red oxide or iron oxide on my finger and fingering 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 on its own unless there is some sort of vibration or some other mechanism.

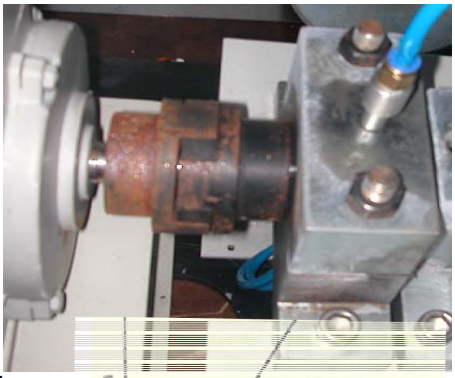
So, vibration itself is a mechanical action which is going to cause detachment or removal of this layer because of that, this layer is brittle in the nature and is porous in nature. We can say this is iron oxide we rub this surface will be getting this oxide on a rubbing surface. There are couple of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

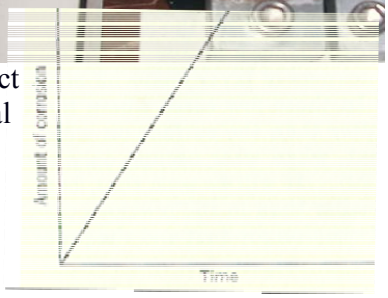
And in the interface there was some sort of moisture or some water in grease or oil. That has caused this kind of corrosion. Quite possible if the temperature increases, wear rate of the corrosion will increase. And then in that case we will find out some deep impression on the inner surface. However, 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 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 occurs in wear of engine bearing where the engine oil gets acidic and when oil itself is 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.

(Refer Slide Time: 45:26)







- Stages
  1. Sliding surfaces chemically interact with environment (humid/industrial vapor/Acid)
  2. a reaction product (like oxide, chlorides, copper sulphide)
  3. Wearing away of reaction product film.

NOTE: Particles of reaction product may act as abrasive.

Interesting that about the corrosive wear is that the passivation, 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 about the amount of corrosion is not a corrosion rate, it is cumulative. It is a summation from the zero time. This has initially some slope and this slope is continuously changing and getting corrosion and finally, it will reach to the steady state condition and is getting passivity in its stop on 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. Then 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 over 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 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 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 not? 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.

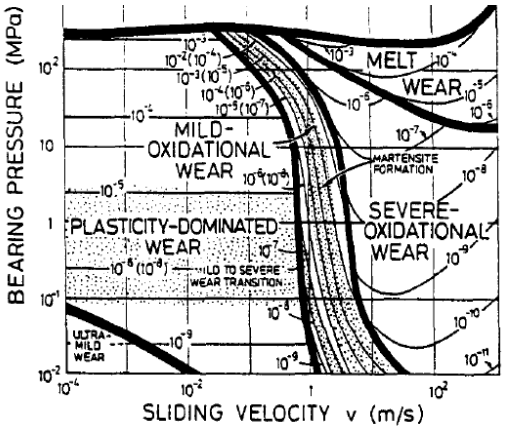
(Refer Slide Time: 49:02)

Observation related Corrosive Wear

Thin corrosive layers play protective role.

- Growth in thickness becomes liable for brittle fracture. Soft debris!!
- High temperatures enhance surface energy, thereby increase thickness.

- EP additives are designed based on CWM.



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 on 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 is it needs 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 to 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 sheared.

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. 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 misnomer 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 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 on 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 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.

(Refer Slide Time: 53:51)

$$V_e = K\, A(\alpha)\; i(v)\, M$$

$$i(v) = (\text{particle_vel})^n$$

$$n = 2 \text{ to } 2.5 \quad \text{for metals}$$

$$n = 2.5 \text{ to } 3 \quad \text{for ceramics}$$

$$M = (\text{particle_size})^3$$

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 is where the definition comes we say that erosive wear is 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 be there to avoid this wear. That is why we need to understand the mechanism. Same thing happens 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 most often we keep 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 at which particle is going to hit the surface. We know from the momentum point of view that this angle will decide how much energy is getting transformed from the particle to the solid surface. So, impacting angle is important to us.

And the last is 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 we are assuming is 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 is strongly going to out fact impact wear or the amount of the wear. While impacting angle depends on 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 constant. We can say this constant indicates after how long this particle will be detached?

Function an 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. also Thanks.