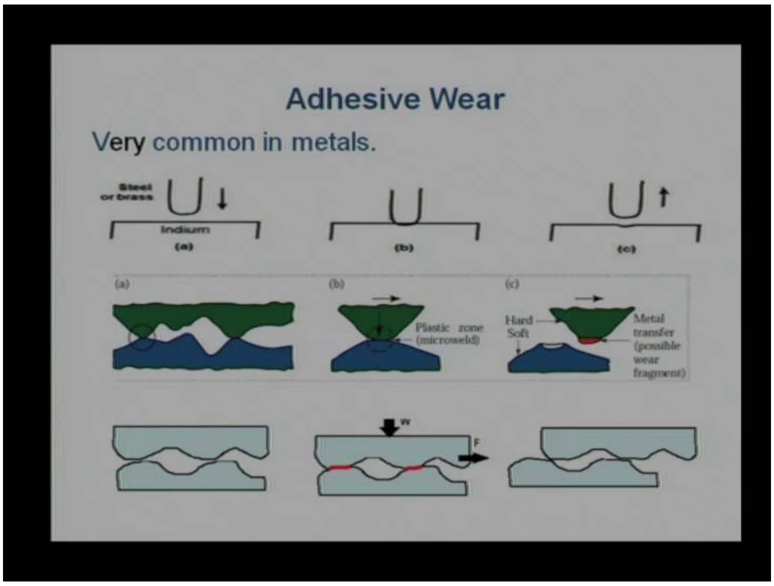
Tribology
Prof. Prof. Dr Harish Hirani
Department of Mechanical Engg
Indian Institute of Technology Delhi

Lecture No. #07
Adhesive Wear

Welcome to seventh lecture of video course on tribology. Today’s topic is adhesive wear. Last lecture we understood, wear mechanism related to abrasion, scratching or sometime we call as scaring. This adhesive wear is more related to the adhesion friction; we say that when two materials of (( )) for each other they make some bond. Remaining molecular bond is very strong, difficult to shear. If that happens, there will be (( )). We can reduce a strength of that molecular bond, then where it can be reduced. And generally understanding this topic helps us how to reduce shear strain of that bond.

(Refer Slide Time: 01:22)



Let us take a common example, which is a mostly coated in our books. You say that adhesive wear mostly a occurs in metals slightly lesser in ceramics. Any polymers load is a within limit, within transition limit then this kind of wear will not occur, but if the transition limit, whether some plastic deformation is possible? Then this kind of (( )). So, here in this diagram, three stages I showed one is a steel pin..

Many times, we can call as a steel rider and indium block or indium disk. If we praise steel pin with a some force, some normal force may be say w, it will try to indene in Indium something which is shown in figure b. If we retrack it back it will come up with the some sort of deposition on steels surface and some depth some removal or material from indium block.

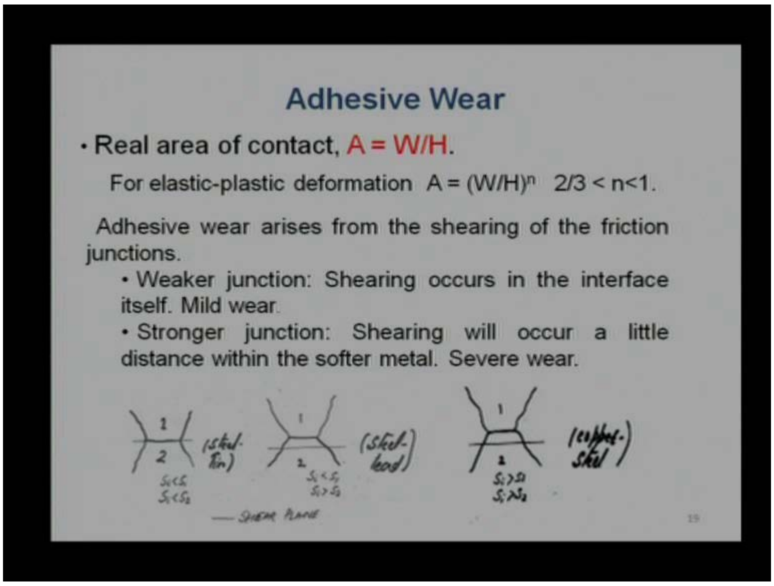
The Indium has a affinity towards the steel. It makes a bond it makes a molecular bond with the steel. Then indium strength is slightly lower bulky strain we say them (( )) force is lower. So, it leaves a fragment, transfer the fragment to the steels surface and same thing happen with the brass also. We try same thing with the brass pin indent in indium. It will give some sort of transformation of indium glass material. Let us take another situation..

See, we know all the surfaces all the molecular level are rough, they have some amplitude about the main value. And if load is applied, normal load is applied, there is a possibility of junction formation which was explained in detail in a fracture lecture. This reddish part is shown some area of contact. And we know this area of contact is much lesser than apparent area naturally almost a every (( )) will be undergoing plastic deformation to some extent limit up to the elastic limit if it can easily bend..

Now, if you provide some sort of a lubricant layer or there is a no chemical affinity of this matter metal one and metal two then, there is a possibility of easy shearing on that surface or breaking the bonds will be easier. There will not be much severe of course,; there all we were some fragment will be still getting torn away from the surface. So, there will be were what we call that as a mild wear mild adhesive wear. Take an example of c wave here c asperity coming in contact and going the plastic zone and what we call this as a micro weld.

Now, if we push it with the tangential force there is a possibility of junction growth and plucking out our material a blue color material on this red color is shown. There are general in the micro structure will be changed. It will not be as it is blue color. This surface is slightly hardened how is it affinity of this red portion is higher, chemical affinity towards the green metal is higher. So, metal will be getting transferred and this is a bigger (( )). We can say it is a severe wear and this on this slide I can say adhesive wears can be classified in mild wear and severe wear.

(Refer Slide Time: 05:50)



We will be studying this slightly lesser after sometime on when we come to the seven day slide of this of course,, of this lecture, but, let us quantify this wear mechanism or how the adhesive here of this. Whenever we want to quantify were like a wear volume or rate of wear, always is start with a real area of contact because of wear generally occurs at a area of contact. If there is no area of contact there will not be any wear..

If the two surfaces are completely separated by the lubricant layer, then there will not be any wear, but, if they are intimated the r super import or there is a some common area, one metal is connected in a other material. And there is a some sort of going junction which needs to be plugged out and need to be removed and need to be sheared. Then there is a possibility of wear.

So, to find out that area real area of contact we can use this equation. A simple equation is says a equal to w by H, where w is the normal load which (( )) defined that it is always normal load which matters it is not the dead wet, it is a normal load. It is divided by the hardness at which is the hardness of softer material whichever the weaker material; however, in this basic assumption is that there is a plastic deformation. That is why the H has been used h is the flow stress allows material to resist up to this material. If you increase pressure, normal pressure more than that then it will allow surface to (( )).

That is what the H is a flow stress and then this area a is equal to the w by h is valid only for plastic well or well made after the plastic deformation. Or we will know very well there will be all will some asperities very high height or low height. Not all the asperities will undergo plastic deformation. There will be contact at a elastic limits also and separating two surfaces other elastically will not be much problem. Effetely area of contact will reduce. If there is a plastic deformation naturally more idea will be in the contact. There is a deformation some flattening of surface more area of contact will be clear.

When we talk about the elastic plastic junction, when there is acid deformation as well as the plastic deformation, again say area can be modified using parameter n is lesser than 1, but, greater than 66 percent or greater than two by three. This is the modified area of contact. It will be established by number of researches go to the difficulty is there,how to find out the strength. It is very t d s and it will vary from one component to another component will vary from one situation to another situation..

Sometimes we have oxide layers sometime we do not have oxide layers. Sometime we have water presents sometime we do not have water presents. So, every time if I do some experiment I will be finding different relation for n and is uncertain parameter depends a number of variables. We can think about other option also. If I go with this kind of theory and what is a possibility weaker junction or a stronger junction? It is a more and more classic deformation junction will be stronger at one point more area of contact or in addition there is shear strength shear strength of a junction..

It is a possibility more area of contact, but, lesser share strength of the interphase. In that case friction force will be lesser and area contact even though larger, but, wear at will be lesser have a if shear strength of the junction is higher than rare it will be higher. So, whenever we talk about the modeling wear, it we need to account area contact as well as the share is strength. See is a possibility of weaker junction there is a possibility of stronger junction.

Sharing occurs at the interphase itself the shearing occurs the interphase. It is a mild way and if sharing occurs of the little distance within the one of the metal and one of the metal is the softer metal in this case then, it will be severe wear more and more material will be blocked out from the surface. So, we need to account area we need to account a strength. Interesting thing is that is very difficult to find out the shear strength of the interphase. Particularly, when a few asperities are plastically deformed and few are only elastically deformed.

We know very well to share plastic junction. We differ more force to share elastic junction we did not require much force. That means we need to count at the every asperity what will be the shearing strength straight (( )) is the highly statistical naturally. We need to find out some good relation which can avoid these many complexities. This may be good for the research who have when we want to concentrate only one machine component and try to do analysis of that machine component.

But, when talk about the generalization, when we talk about the theory, when we talk about the common equation, this equations when we have the this kind of variable will give more and more difficulties to demonstrate. What I explain in slide we are taking example of steel versus tin steel versus lead even steel and tin are in wear. Whether steel is subjected to some normal load again a surface one surface two and here there is a interphase shear strength also.

As here has been represented as a interphase shear strength s I s. One may be strength or shear strength of the steel and as to has a shearing strength of tin. What we are shearing in this case that s I is the lesser than s one s I is the lesser than s one s I is the lesser than s two. That means, interphase shear strength is lower compare to steel is a lower compare to ten either lowest among three. So, in this case we can assume there will be mild wear even in absence of lubricant. There will not be severe wear interphase is low shear strength taking another example of steel versus lead.

We know we have had a number of times a lead been deposited on the steel surface. Make a thin layer on a steel surface and use as a lubricant layer on that. This is because a good adhesion between the lead and the steel. However, when one component is made our steel and other component is made of the lead and they come in a contact. And then load condition subject it is sliding condition as well. Then there is a possibility of plugging out lead material more wear severe wear reason is.

Here the interphase shear strength is lesser than the steel, but, interphase shear strength is greater than lead when is interphase which is made will not be turn away will not be wear out in normal conditions. But, lead will be plugged out from the surface and that is going to (( )) surface. Rougher surface or steel surface will be rougher. Adhesion will lead to the abrasion and that will cause a catastrophic wear or it causes a z severe wear. This is another possibility.

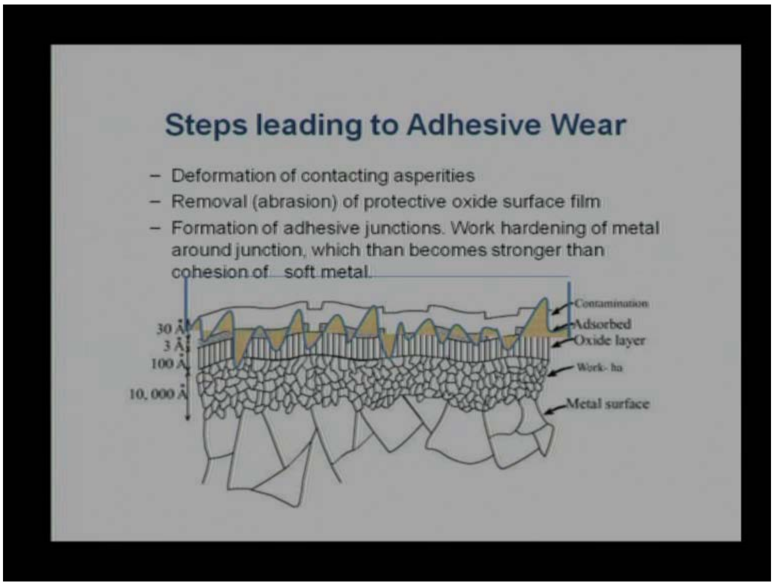
When we say that copper and steel are coming into the contact they have a good adhesion. We make a good strength at the bond. Interestingly, in this case is interphase shear strength is a greater than steel as well as interphase shear strength depends is a greater than shear strength of copper. So, we are looser at both the ends. Shear strength is a higher and it will be unpredictable for us whether steel surface is going to lose material or copper surfaces is going to lose material or it may be random.

Wherever the more asperities of the steel and are lesser higher high magnitude spread this as steel more continue a length naturally as asperity will be plugged out from the steel surface. If the asperity height is very high in a copper that move surface will be move or not. So, depends on surface depend on the shear strength of individual material and depends in the how the load is afraid with the one component is applied in some normal side also. So, the result enforce is a some at the angle at the interphase. It is not a along the interphase.

Then material wear will be high. That is why we say that we do not use the copper less steel as such without treatment. If your treating your increasing hardness we are trying to reduce the adhesion between a steel and copper than it can be used. However it cannot be used as a tribo pair as a slide wear. Reason being there is a high wear rate between a steel and copper when they make interphase. Interphase is much stronger than copper strength and in underphase the strength is a strong higher compare to the steel strength.

So, that is why we try to avoid this kind of fear or near otherwise we need to provide some lubricant. We know very well whenever there is a lubricant shearing strength of lubricant will be much much lower than interphase shear strength. Or we say that parent material shear strength and interphase which is made with the lubricant will be having less shear strength and it will be easily tear out and it will be we will not cause much wear is.

(Refer Slide Time: 16:30)

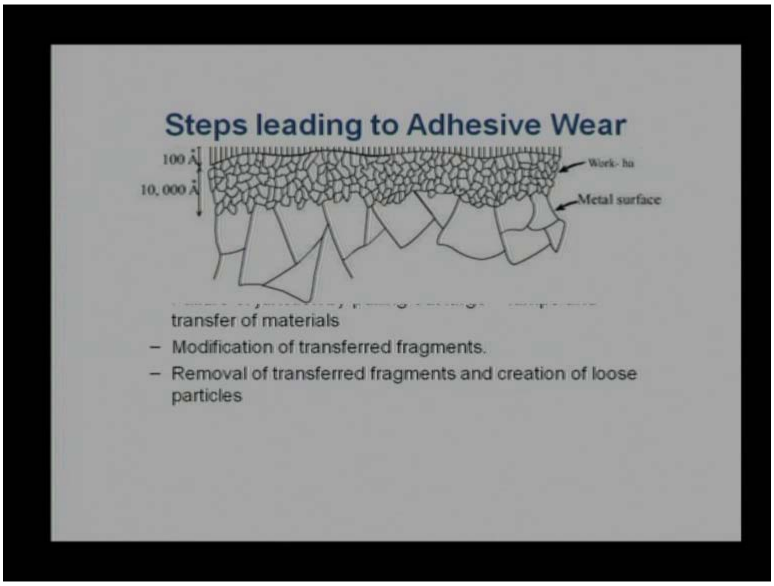


Interesting to see how adhesive wear progress; it will not be miss spontaneous there are some stages involve in adhesive wear. We can prevent or any (( )). See the first is the deformation of the contacting aspirities. Aspirities come into contact with material and deform the surface is something like this. I am assuming this is a one surface rough surface it is coming under load to the other surface. And other surface are the contamination layer at soft layer, oxide layer, work hardening layer and meta surface which was earlier shown in a friction lecture..

But, when the this rough surface comes in the contact in asperities surface which is a opposite to the this main surface because of that there will be some sort of penetration and removal of productive oxide layer. If the surface is stronger, penetration is here. There will be fracture of the oxide layer it will be fragmented and once it is fragmented it can be usual modes. So, if there is a removal of oxide layer then only the (( )) surface will be there always a original surface will be there pure metal will be there.

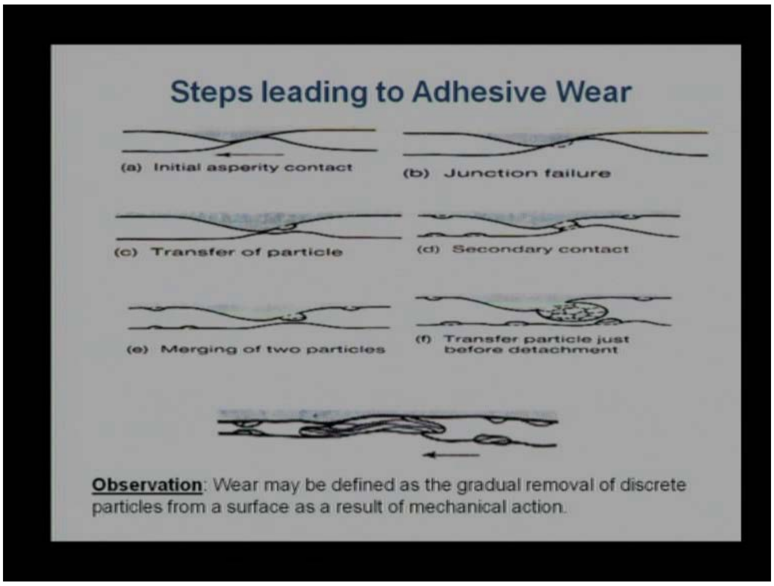
And you know very well pure metal will cost more adhesion compare to the oxide adhesion which will create a some more problem. See the formation will start once we remove the oxide layer. If there is a fracture removal of the oxide layer there is a possibility of adhesive junction which we have studied as an friction chapter. However, there is a possibility of work hardening of the metal which may increase strength, but if that layer is also removed then there is a more chance of where we can and check this something like this.

(Refer Slide Time: 18:41)



We say that most of the layers have been removed now. There is a only work harden layer is remaining and if there is a possibility of fracture of this layer or change in the properties which may bring some more (( )) and which removes the piece as it is from the surface. After removal there will be some loose pieces and there is a possibilities of more and more wear. We can demonstrate same with a one mechanism and gradual mechanism something like this.

(Refer Slide Time: 19:17)



You say that we say that lets take one surface coming in the contact with the other surface and this surface has a relative velocity. This surface is subjected to load in a the micro scales. Average surface is rough surface and contact is will occur on a asperities. For sake of simplicity we are showing only one asperity.

So, we can understand the phenomena how wise every surface will be having a normal (()) of asperities, but, for timing your assuming there are some n number of asperities and every asperity will behave more or less similar manner. Even though we know that is an approximation that is not a very good approximation, but, for understanding the mechanism understanding the physics this helps. So, when the surface is twist and is under load there is a chemical affinity of a material one towards chemical affinity or material two..

Then there is a possibility of penetration because of surface office as well as formation of the junction. And if it is a mood there is a possibility of very micron level size particle is plucked from one material to other material. That is why we are writing at a junction failure and plucking of one material to other material is something like this. When it moves this material has one small additional asperity and this additional asperity is the material asperity of the material two is not as a own asperity the material has been transferred from surface two to surface one, as I transferred as a adhesion..

Once it happens at one asperity similar behavior will occur a number of places. So, we can say there is a possibility of number of asperities additional asperities are adhesional per fuses on the material one. That is also possibility. In the material have relative same hardness or chemical affinity at other material also get some material from the surface one. So, just for completeness we are showing that both the surfaces have some putrescence some additional asperities when which over plucked from the other surfaces..

If it continues surface will get keep getting irregular surface either contact will reduce stress on the surface will increase and there is a possibility of junction growths. Initially there was a only one asperity smaller size asperities and than its getting more and more on that that. The area is continuously increasing. Not only area surface area, but, the height is also increasing. So, what we say that increase in a length of cantilever are unsupported surface. This is unsupported surface is continuously increasing then continuous increase and supported surface naturally there is a possibility of failure of that surface..

This is a maximum size asperity is grown up too much and not the even a small force can tear away this complete material can plug out or can remove from the surface one itself as a loose particle. That happens like that when it comes in the loose particle and there is a force on a surface one which is getting transferred on the surface two. Then this loose particle will get flatted it will be under compression and again the process will you start..

This is getting a third particle or third component in between which will have a different micro structure, will have a different hardness. You will have a different chemical affinity towards a material one and material two. So, this process continues. We start from adhesion there is a possibility of particle generation and bigger particle first and then it will be disintegrated in number of small particles. So, adhesion force or adhesive wear at the start and it may turn out to be abrasive here little stage..

If the hardness of this particle is much charger than parent materials it will cause abrasion wear. So, one wear mechanism is leading to other wear mechanism. So, we say that most of the failures are happening because of the abrasion. Abrasion percentage is much higher than adhesion percentage and adhesive wear comes on the second number analyst. Highest percentage failure is because of the aberration and second number is adhesion. However, if you see in a deeper side most of time is adhesion which is initiating the wear, but, what is the result, which is a identify the final that is caused with aberration..

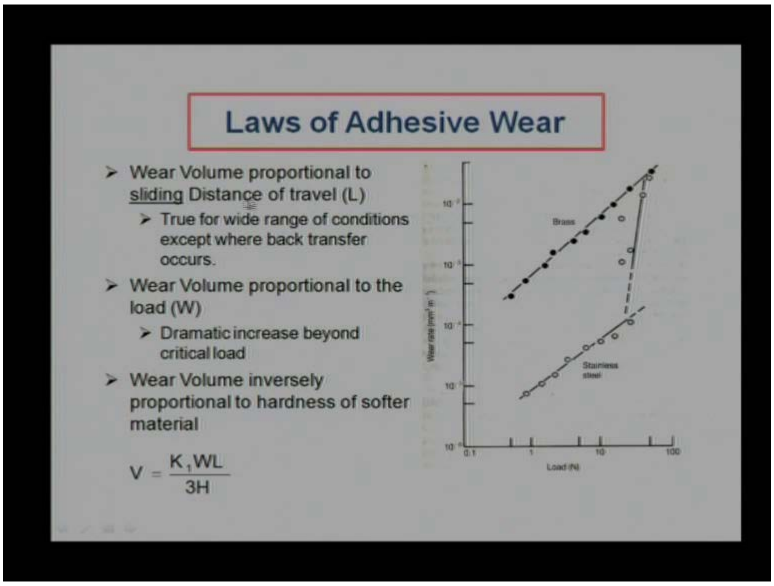
So, we cannot say an absolute sense that aberration is much more dominant compare to adhesion or more frequently occur in a compare to adhesion is a possibility adhesion is starts and finalized or come finally, to the aberration mode. So, there is a positive 50 percent I mean if that overall percentage between a adhesion and abrasion is 70 percent again. Assume that 35 percent goes to abrasion and 35 percent goes to adhesion, a micro level makes a nuisance generally starting with adhesion; tearing the junction generating the loose particles which leads to the abrasion.

In this case we can finalize or you can say conclude the slide you say that wear may be define as a gradual removal of the discreet particles and necessary the big particle need to reflect out. There is a possibility of small discreet particle size coming out of the surface as a result of the mechanical action. While we are trying the mechanical action, this whole process is the mechanic. It is not a chemical. One wear mechanism we know the corrosion wear which is the basically chemical nature, but, again the wear occurs the loss of the material will occur because of the mechanical action.

Generation of is generation of a layer which is a loose or having a lesser strength which can be easily fragmented is possible through the chemical action. But, removal of that layer from the surface is only possible through the mechanical action. It will not be the cursive layer this come is own. It needs to be cheer away it needs to have some mechanical work on there. That is why we say that wear may be defined as the gradual removal of the discreet material and the discreet particles from the surface as a result of mechanical action.

So, mechanical action is the new phase size on that. For every wear mechanical action need to be there that is why we need to reduce as for as possible to avoid wear at minimize the wear.

(Refer Slide Time: 26:27)



To quantify, we started with the quantification of the wear and we came to the first area of contact and on the shear strength. It was here like that difficult is very difficult to quantify as it is. From the physics point of view, people has started working on that and they did a number of experiments. We know the (( )) and (( )) gave the theory of adhesion junction growth and friction due to adhesion, but, later it was modified or converted by archer after doing number of experiments on a similar mechanism, but, he came to conclusion is that wear volume is generally proportional to sliding distance which is obvious..

We the contact surface travels more and more naturally wear particle removal of wear particle with more and more; however, exactly will be proportional or not we do not know, but it was completed by orchard at that generally it is a proportional to the slide in distance. More and more slide in distance more and more wear and that in same proportion; however, here is a some discussion on add we say that quite possible initially there is a more wear, but, later it will not being more wear.

So, you should not be say it that it is a always proportional to that. There is a possibility of changing one wear rate from one condition to other condition. We know there wear is a dynamic process changing from one condition to other condition is always there. So, from understanding point of view, we can say it is it depends on a distance on a travel and if we are able to do some experiments, we can still believe that the wear volume is proportional to n, but, there will be some constant that may give them some sort of probability of removal of material. So, we need constant along with this..

Seeking the conclusion which orchard gave after doing experiment uses at wear volume is proportional to load, which is also there because a friction force was initially treated are the proportional to the load. In that case similar way we are assuming the wear volume which is removed from the surface is proportional to the load right. There is a limit if it is subjected to plastic deformation if it is not subjected to plastic deformation than it will not be proportional to the load. It will be slightly lesser than that or effect of the load will not be that high there is a possibility of reduction in that.

So, if we use this law then we need a some relation or some constant along in that which can modify this depends on the area of contact. For time being we can assume this is proportional to w and finally, he give third interpretation you say the wear volume is inversely proportional to hardness of softer material which also comes from the friction side. Higher and higher hardness lesser and lesser will be adhesion and if there is a lesser and lesser adhesion there is a lesser and lesser wear volume..

From that angle also be angry, but again you were exactly inversely proportional you cannot compute on that there is a dependence. We say the wear volume depends on that wear volume depends on w wear, volume depends on a hardness h, but, with this 100 percent proportionality is there and not is a directly proportional or not. There is a possibility of some power loss some factor in.

That is why the finally, the wear equation which came from archard is given as a v is equal to k 1 w L divided by 3 H. Now here hardness of the software material L is a travel distance and w is a normal load, but there is a constant k 1. Quite possible constant k 1 is also accounting the factor w proportional do the directive proportional do the directly proportional should be there or not in also accounting the lunch hours and it is also defining with the relation or volume is inversely correctly inversely proportional to the inversely proportional to h or not..

This wear constant can be manipulated. We can do a number of experiments with assume these are the (( )) equation find a w find measure L and measure H. Listen that whatever the wear volume comes we can appropriately find k 1. If you do the thirty experiment or forty experiment statistical variation between k 1 for the k 1 can be measured easily or can be estimated easily this some estimate deviation; however, it has been interpreted also. This kind of wear equation is valid only for the linear profile..

Wherever there is a transition to the change in the load if there is a wear it suddenly increases this equation cannot be utilized just. Just thump immerse we are showing this crowd were the access are wear rate and the loot and we say the as a load is increasing there is a possibility of increase in a wear rate.

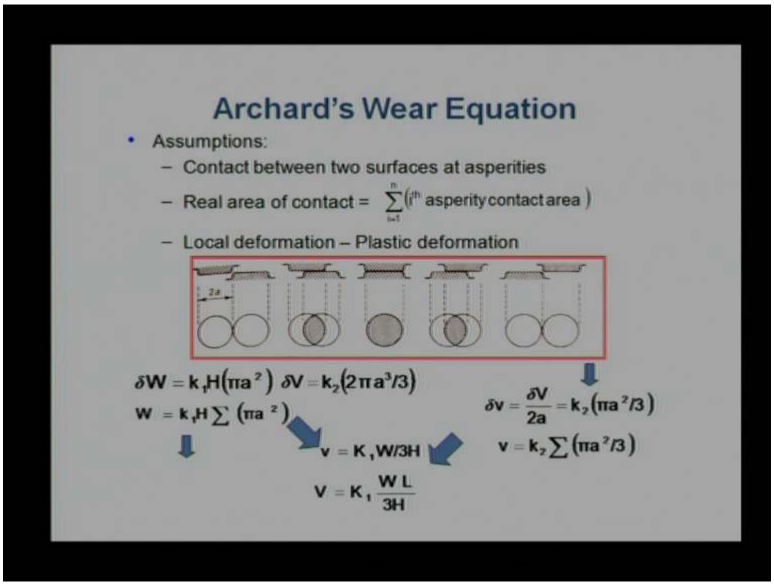
So, there is a proportionality which is shown in this case and number of data this data or experimental data on the (( )) equation. In that you can find there is some variation in that. So, in the statistical variation is here, but, if the variation is neglected. We assume the mean value you can save from this experiment here for stainless steel this is followed. Similarly, for the brass material that is also followed. This proportionality is followed. However, for steel or a stainless steel beyond certain load we are able to find out there is a sudden change in wear rate.

This sudden change in wear rate generally occurs because of the deformation or removal of the oxide layer. Assume that initially is a stainless steel has some sort of contamination layer and after certain load certain load is applied that layer is deformed, fractured and removed from the surface. Then there is a jump in the wear rate you can see the wear rate of the stainless steel is crossing the brass steel brass also brass material. In this case after sudden load the stainless steel will show worser performance compare to the brass material. There is a possibility of transition load and need to be incorporate or at least when we do number of experiment.

We should figure out what is the transition load and we should load the component below that load. Or we apply a normal load or load maximum load which we transferring from one surface to another surface and need to be lesser than a transition limit. Here the this equation shows that we are counting here only the plastic wear or with the plastic deformation and wear is causing after that; however, if we count elastic plastic domain together then this equation should be said modified.

You say that instead of w by h directly you should write w by h power n and n is a lesser than 1; however, there is a possibility here. There is a difficulty to find out n you know there is a one wear constant k 1 and if you introduce this one there will be two wear constant and figuring out the two wear constants. We require many more experiment and many fold experiments to get the real (( )). When we are working only the one pair or two pairs we can use this (( )) equation. We use input w l and h and figure out what will be the value of k 1 after doing number of experiments and reliably believing after that that experiment.

(Refer Slide Time: 34:40)



Now how what should has reached to this equation in to the number of experiment. Then he tries to give some sort of mathematical justification also assuming the asperities or a asperities are spherical in nature and under plastic deformation reflect it something like this. If there are two asperities if they see the cross section of the asperity is cycle; however, when I see the deformation deform surface is applied. So, the surface is getting flit after a deformation after plastic deformation and when the two surfaces are more related to each other.

When asperity is related moving relate to other initially the this is a angle of approach or start of sliding. When it crosses over there is area of contact, slowly slowly area of contact reaches to maximum value and after that again is reduced and comes to zero. This happens for a number of asperities and number will be parallel asperities. So, there will be area of contact and few asperities will be in contact and few asperities will not be in contact.

There is a some fraction of that; however, to come to the real relation, but, also assume initially that contact occurs only at the asperities. Without asperities there is no contact.

That is a true that is valid assumption and any severe root that real area of contact can be given by finding the area of contact of individual asperities and summing up all those areas. That is also valid is a justification is profit; however, only the problem with this equation was the plastic deformation.

Assume there is a plastic deformation and if we take that plastic deformation in the account, we can say that one asperity will bear some delta load that can be given by some constant k 1. We do not you are not 100 percent sure that there will be area of contact or complete area contact or what will be the area as such asperity in this case whether a will be really a or not. So, that pi a square and along with that there is a hardness whether complete asperities in contact or not and this constant is given as a proportional be constant in the scale. This is the area normal load which can be sustain or can be bearded by the asperities.

There is a possibility of wear of that asperity. So, that is given by delta volume delta another constant k 2 and this is the half of the volume the two pi a q divided by 3. There is a assuming the hemisphere of a will be removed or this area will be removed from the surface. This is the big assumption very you say that crewed assumption whole asperity will be removed in one go itself and the one surface is a travelling on other surface the whole asperity will be shared.

It is a very crewed evolution; however, that can be a accounted because he had accounted k 2 as a factor. If you assume the k 2 is much, much smaller then you can assume is only a friction of the area is been removed. There is not a 100 percent area if the k 2 is equal to 1 than all me the 100 percent. If I combine this pi a square is here pi a square is here, you can combine and we find out what will be the loads in terms of h and in terms of area. And when substitute it can get a relation v in this case small is a volume per unit to length and we are assuming a union length of contact is to a maximum which is coming into the contact area is 2 a.

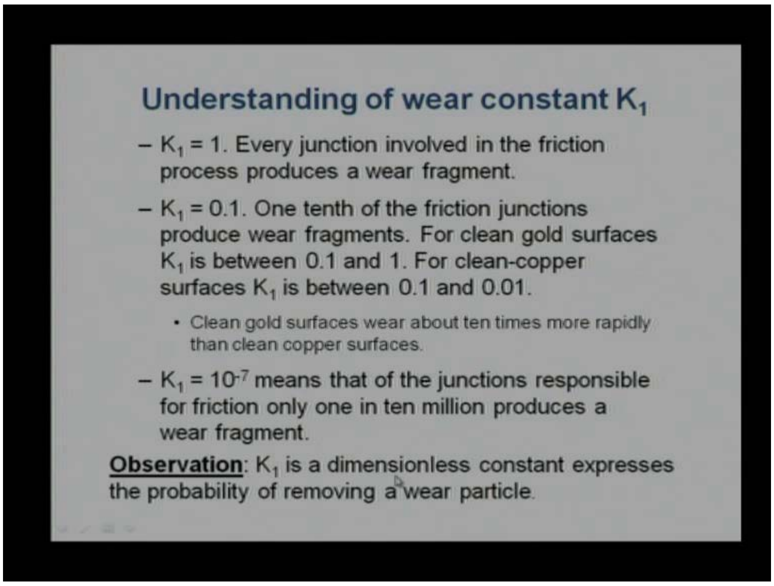
So, that is accounted here. Wear per unit length when we substitute from here pi a square in this equation. Here it is a v it is given a per unit length. That means, (( )) square constant k to pi a square divided by 3. So, this pi a square is common this five square is common and this both are summation. You do not have to account a number of asperities. It can be n it can be 2n can be 3n and n can be anything.

So, we is the easiest expression for us to remove pi a square which is uncertain for us to substitute this value. We come finally, it get v as a k 1 here k 1 itself is the ratio of k 1 divide to k 2. So, that is another constant. W is there and H is here and if you have account real sliding distance whether all asperities are coming to account and complete length travel to length is L that can be multiplied with the w to find out overall volume. That is an m q or centimeter q or meter q whichever you would have used.

So, there is a w normal load there is an L there is a h and there is a three is a factor which is directly coming from here. In many books we generally find out the k 1 by 3 itself is a factor. So, they write constant k were constant k as it is write were constant k into w into l divide by H. They do not count the 3 factor because that is a constant. You know the wear 3 itself is the constant. So, one constant divide by other constant will remain constant and that can be represented only with one constant that is possible..

So, wear equation can be given and this is a same equation what an archard gave interpreted from his own experiments. And an gave a three law of adhesive wear is proportional to the sliding distance. It is proportional to the normal load is inversely proportional to hardness. Increase sliding distance wear rate will increase you increase load. Wear rate will increase you increase hardness wear rate will decrease.

(Refer Slide Time: 40:43)



So, this is the same thing which archard gave initially and proved mathematically also; however, interesting thing is a we need to observe how one will change that will this will help us how to reduce the wear rate. Let us take 1st example when k 1 is equal to 1 that wear constant is equal to 1. What is the meaning of that every junction involved in a friction process or friction adhesion process is going to produce a wear fragment..

Whatever the junction is made that is going to get shear with some wear particle that is a smile slightly unrealistic. We know that even study case we will not be appoint that much story. If there is a fatigue case particle will sustain some cycles and it will be wear out after some cycle may be 10 cycle, 20 cycles, 100 cycles, 1000 cycles. So, this a highly unrealistic, but from understanding pi of you s k 1 is equal to 1. Means all as junction are going to tear away are going to generate wear particle..

If there are 1000 junction at any time, so, there will be thousand particle generated in one go. Next time at again will increase accordingly. If you reduce to tell appoint for another one tenth of earlier case, slightly there is possibilities of that see the one tenth of the friction junction produce a wear fragments. That is the case with a gold surface for the king gold surface they get attached. They make very strong bond. Coefficients of friction is very high and if you want to really tear it, some wear it comes up between point 1 to 1, but, more or less is related to point 1, point 2, point 3. There is a possibility of this..

We say that wear rate is high; however, in when you treat copper thin copper varieties slightly lesser than which are one tenth of gold itself which are the for clean copper, to this k 1 will be in a case of point 1 to point 0 y. Using copper is better than using gold you know the price of the gold is much higher than copper. So, it is always advisable if you have a chance better use the copper become a conductive. This requires some other properties are required user copper in that case and the confusion from this two sentence is the that clean gold surface wear out about ten times more rapidly than clean copper surfaces.

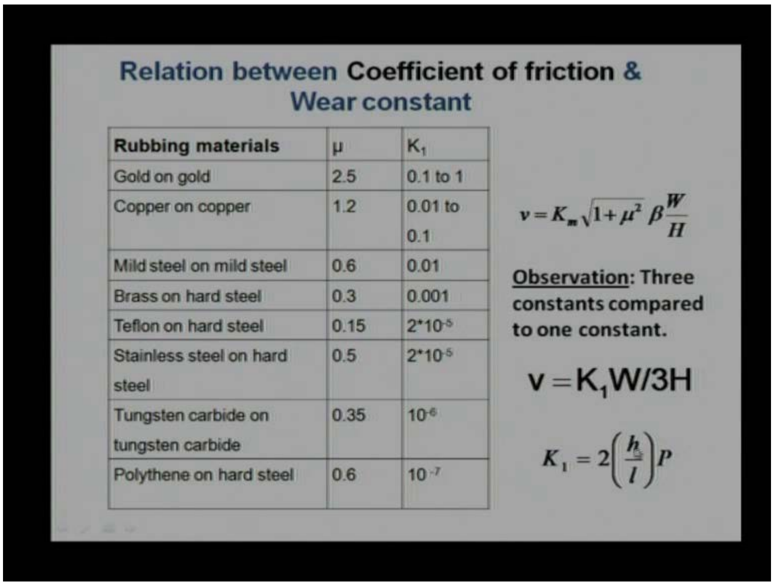
We are using the word clean we are assuming that there is a no contamination layer on that surface is an ascent. There is no additional material on that is a pure gold no oxide formation no lubricant layer nothing on that. It is a pure pure gold and pure pure copper. Over this is more realistic when we say the k 1 is (( )) to minus 7 and this is generally about aim of the design and aim over there. So, the 10 is to minus 10 means junctions responsible for friction. All in one tenth of the million produce of which are that is undergoing and now million cycles then only one wear particle is produce that is acceptable hours.

We know the materials will be subjected to the loose particles after number of cycles. And when a components are new initially there will be wear out the because of the bedding in time because of the asperities deformation or in surface is initially rough. If there is no much compatibility between this there is no conformity initially. Where it will be high, but, after that it leads to study state condition. There will be generation or loose particle, but, after certain cycles with this is what indicated over here generally after ten millions cycles.

The one particle is generated and can be lost from the surface which is more realistic for us and we can accept it right now, but we confirm to from this slide is that k 1 is a dimensionless constant. It does not have any damage. It does not have m or m q. It is a dimensionless in this case, but we have the way we have treated is the dimensional causes the constant and it can be given as a is the probability of removing the wear particle..

You are using very strong word probability over here, but, it appears that it shows a probability of the wear junction removal of the breakage of the junction with particle removing particles from the junctions or ticking out the particle or (( )) out of the particle and making it the loose particle. So, there is possibility here we can say the you can use the word the probability for k 1 is a probability of removing of their particle again. In this case when the overall expression we assume only asperity spherical asperity. We not assume any other asperity, but, there is possibility of other form of the asperities and then k 1 will be some will be slightly had an spherical is a possibility and then (( )) will be slightly hard.

(Refer Slide Time: 45:54)



This some we have (( )) adhesion friction on a friction to do adhesion process; we have given relation for the wear rate due to adhesion. So, there is a possibility of some relation between that coefficient of friction and wear constant. Some study to show that there is strong correlation and some history show there is a not much relation, they are not related at all. You say like gold or gold the coefficient of friction is roughly 2.0 to 3 while wear constant is a 0.1 to 1. If I reduce is coefficient of friction for some other surface is the copper and copper is from 2.5 to 1.2 wear rate is decreasing by ten times.

Here we are reduce the coefficient of friction by 2 times and were it is reduced by ten times. Now further 1.2 to 0.6 reduce wear rate 5 2 the 50 percent and you are able to reduce also wear rate to some extent, but, as this is given in a range we cannot say what is a range it may be from one to ten times reduce the wear further from 0.6 to 0.6. Here we find a big jump wear rate is reducing significantly again the 10 times 0.01 to 0.0001.

So, this more or less you say that if you reduce a wear coefficient sorry friction coefficient by one half wear rate is coming by one ten. That is a that is a advantage. We say that if are able to control a coefficient of friction we are able to control now wear constant also. So, here from 0.3 to 0.15 wear rate is reduced significantly there they say 2 into 10 is minus 5. Now there is a problem. We are reducing wear rate per 50 percent and this is reduced by 1 10 1 50 times the 150 (( )). And further increase in the coefficient of friction you had a tough 1 in steel is 0.51. Stainless steel and harder steel is a 0.5..

Using the wear rate coefficient is increased, but, wear rate remains same and these data show that there is no correlation between coefficient of friction and wear rate. While this data are indicating there is a correlation friction and wear constant. Same thing hear here in this case even the wear rate is coefficient of friction is increased from 0.5 from 0.6 still there is a reduction in wear rate. We are going on opposite direction in add increase in coefficient of friction, but we are increasing the coefficient of friction, but, we are reducing the wear rate.

So, there is a there are number of whether parameter which applying the role in this quite possible environment plays a role. When it has been done or in experimental performed in totality and (( )) we say that there is no definite relation for the wear and wear constant wear and friction or is like wear constant and friction surface; however, rho has given some relation. So, that sliding distance as wear volume per unit sliding this scent sliding. This end can be represented in this relation here..

Correctly proportional to w inversely proportional to hardness has been accepted as it is at the (( )); however, instead of wear constant 1 k 1 here does not we did k m square root of 1 plus mu square does the coefficient of the friction and there is a beta as a fraction. And this beta in the case what is (( )) thickness. How much area has been occupied by lubricant layer and how much area is the dry area.

So, beta basically represents the dry area. No lubricant layer it will be lesser than 1. In other word 1 minus beta times area is covered with the lubricant. So, shear strength will be negligible compared to shear strength is of asperities or interphase solid interphase. In addition he introduce the one plus mu square the coefficient of friction. As such is the we know the coefficient of friction may be 0.2, 0.3, 0.4 by make it a square it will turn out be 1.01..

It will not be not be very high value is not going to change much in magnitude, but, problem in this equation is that we are introducing when wear constant k m we are introducing coefficient of friction we are introducing the beta. So, they are three and notes and an archard equation there was only one unknown that is why the archard equation is the more popular.

Compare to the (( )) equation even though where is (( )) that is a modified archard equation, but, it is not to gain the much popular day. Reason behind is that it has a three constant and if the three constant cannot be given directly by theory need to be experimentally mass rate and complexities are going to increase. And we can say if I to do a same number of experiments this equation will be proffered because there is only one wear constant.

I require lazer number of experiment for that; however, the supported that the lubricant layer the things will change this same equation can be (( )). Archard equation also can be interpreted similar manner. You say the there is a more and more lubricant layer k 1 will keep on decreasing. So, it is not much problem for us. In my view using archard equation still is preferable compare to using modified adhesion wear theory equation or (( )) equation..

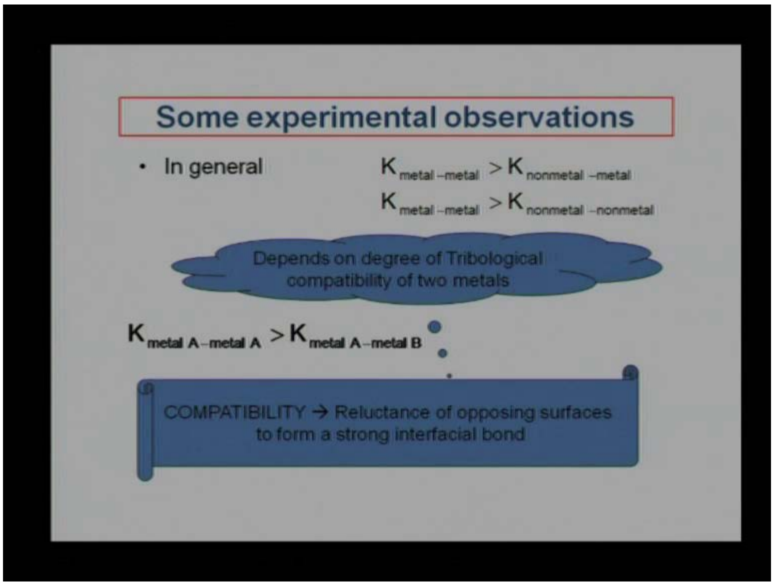
So, that it has a more number of unknowns this equation which has a lesser number of unknowns and whenever there is a lesser number of unknown we know that this equation cannot be relied as it is. We need to do some experiment to find out the results from that point of view I can use archard equation compare to (( )) equation.

There is another equation in a related to probability it has a archard express the k 1 is as such. The probability of the how many junctions are going to tear away or going to give a particles. So, and that relation is valid for the spherical asperities; some modification have come in, I mean propose by the research you say that institute of using the spherical. We can use any rectangular or any other dimension were the thickness of the asperities can be given s by h a d length of asperity can be given by l. Use this relation to quantify wear equation..

Or instead of writing directly k 1 as a constant write k 1 in this term. What is the probability of junction failure which produce a particle and what is the thickness of asperity and this in clearly indicate at the thickness is not very large (( )). Ratio is smaller the wear constant is will be released on and we say refer the surface wear constant will be larger. In this case h is greater than 10, the asperity hide is the much larger than is a expansion of or the length of the asperity. Actually wear constant will increased. So, this is the since to some extend accepted this kind of relation can be expected accepted as it is.

But, only the difficult is that how to find out h how to find out land and how to find out the probility. Even the we know that if we do number of experiments again h and l will keep coming in this. So, it can be used or can be interpreted as a qualitative manner not an complete quantitative manner because we required to find out h and l and a statistical distribution and based on that find out the what will be the wear rate. So, again (( )) used the use this equation if you are thinking about a one sort of condition one operating condition and you want to operate some machine component and want to test that this is good option.

(Refer Slide Time: 54:26)



Now some interpretation based on a experimental results. We can interpret something like this we say that if I am choosing metal one as a metal, one as a material, one as a material and metal two as a metal. Wear constant will be greater than if I choose material one as a non metal and material two as a metal. So, the is the by enlarge will be valid in other view in other word we choose nonmetal and metal combination. Compare to choosing metal combination from adhesion point option. We are not talking about the fracture point of view we are not talking about the strength point of view.

Here is the simple adhesion point of view because we know the matter has a more affinity towards the matter compare to metal and non metal. Similarly, the if and choose the metal and metal I will proof instead of that if I other requirements that satisfy I will choose nonmetal versus nonmetal that is going to give me lesser wear coefficient and lesser wear coefficient means a longer life or the component.

So, we can say third become a nature we can suggest that the option is that if your using the metal A versus metal A, they the similar microstructure having a similar material then neutrally they will have more affinity. They will make a stronger bond compare to metal A to metal B right. So, if I have options you say that I will prefer always versus nonmetal if all other constraints are satisfied.

Next option if I am not, this is the constant. One way another way will be going for the nonmetal and metal. If that is also constraint we have to use on the metal because of the some other restriction then I will prefer to choose metal A and metal B. They are two different metals. We will not choose the same material; however, it again there is a constraint then we need to have a some sort of factor. We need to say that they are work hard and so much and they lose their adhesion property or affinity in this case right..

So, you say that finally, the degree of whether wear rate high or low depends on compatibility of two metals and this compatibility means that how they are able to oppose your adhesion bond junction. If we are able to make a weak point at the interphase they are compatible with each other. There is a no complete bonding or form bonding than that kind of metals can be used always. We should not use that kind of material here. With this I am concluding my today’s lecture. Thanks for your attention. We will continue adhesive wear in our next lecture. Thank you.