Video Course on Tribology

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Lecture No. # 09

Wear Mechanisms-2

Welcome to ninth lecture of course on tribology. In last lecture, we have discussed wear mechanism, we are continuing in this lecture, similar kind of wear mechanisms. We have covered abrasion, adhesion, corrosion and the last one slide we started with erosive wear. We are going to continue with the erosive wear in addition to that will be treating or will be learning additional to two mechanisms; one is a fatigue and other one is fretting. They have lot of similarity will be discussing those. This is last lecture slide, it is review we say that impact energy is required or kinetic energy is required to initiate erosive wear.

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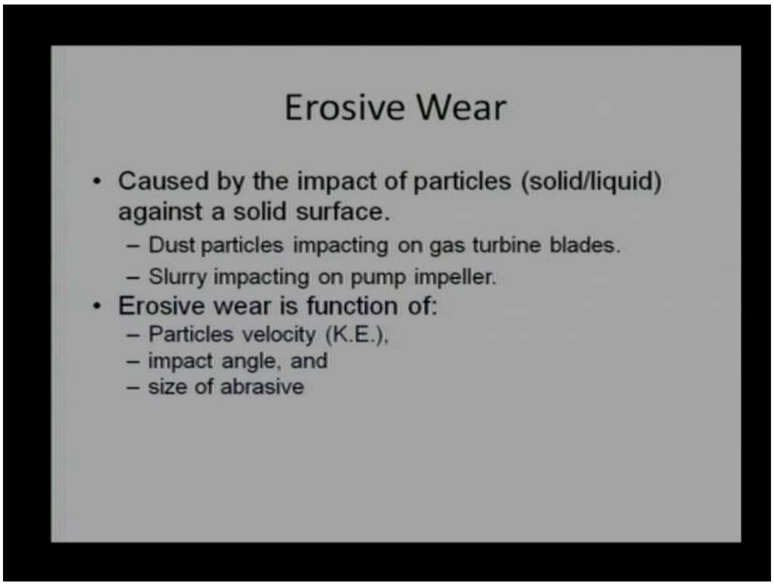

Particles either solid or liquid, they should come with some velocity impinge on solid surface; and impart some kinetic energy to the other surface; as this is the movement transfer, so angle of impact will be an important parameter. Similarly, is a related to kinetic energy, it will be mass of particles as well as velocity of particles will be related, that is why we gave this equation.

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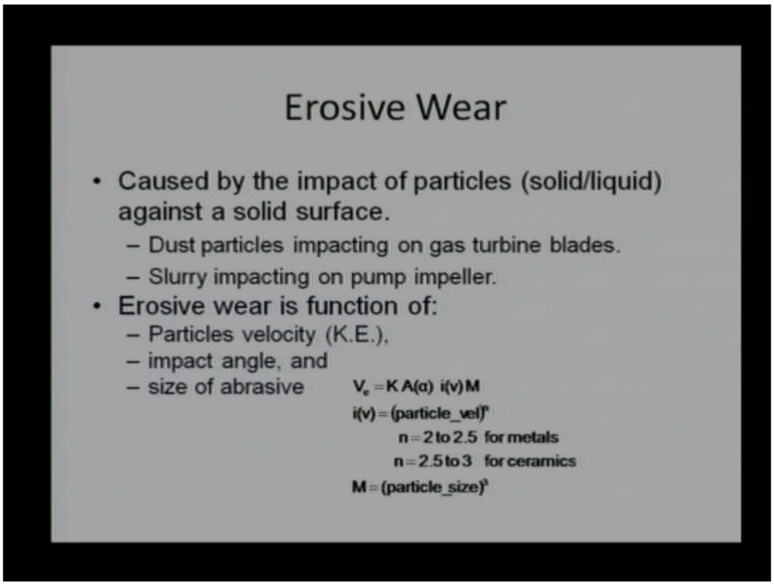

We say that, V e is a wear by erosion wear volume by erosion that is empirical constant; e as a function of alpha is an impingement angle, impact angle; I as a function of V is the velocity function and M as a function of particle size. Increasing the particle size will increase a wear rate; increasing the velocity will increase wear rate and impact angle will affect to one way another way depending the what kind of material we are using with material as tendency to observe the energy are it as hardness to resist the wear. So, it depends on this two properties wear rate will be decided.

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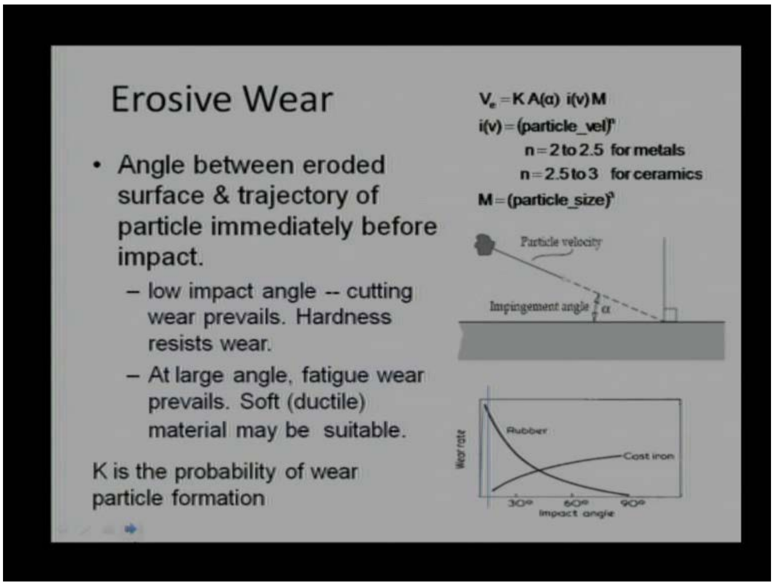

Now first let us define impact angle in an absolute manner, you see the impact angle not necessary particle coming from 10 meter away and we need to think about what is the angle of implementation but just before impacting what is the velocity? And what is the angle of impingement? Just before the impact in a solid surface that will affect the result. So we say that impact angle is angle between eroded surface, surface which is going to be rotate and trajectory the particle immediately before the impact. If impact angle alpha is initially very high or very low but its changing as a last moment then will be counting only last movement angle that will be alpha that is impingement angle that is impact angle. Both the things either are a low angle and medium or large angel characteristics will be different.

If particle is coming at the low angel, angle of inclination is lower all value of alpha is a lower like within the 5 degree, 10 degree, 15 degree then particle shape will also matron how is going and colliding with the surface. You know very well kinetic energy will not be transmitted that much as kinetic energy can be transmitted by 90 degree alpha or alpha equal to 90 degree but in this case the shape of particle will affect the wear rate. It will try to abrade the surface; it will try to cut the surface, it will work as a cutting tool so particle shape will matter in that case. To resist the wear; to reduce the wear rate hardness of the substance need to be higher or hardness of this component need to be higher. coming to other side if the angel of impingement; if angle of impact is higher side 75 degree, 85 degree or 90 degree all.

Then we required soft a material because most of the energy is getting transmitted to the substance or component. Softness is required about as mode toughness a material having more toughness will be important, which can observe the energy and most of the time is soft a material have more toughness abs energy observation capabilities, they can deform by observing the energy .wear rate will be reduced in that case compare to harder material which will fracture the surface itself.

So we have different treatment for low impact angle; we have different treatment for large impact angle and this diagram shows clear identity identifies clearly what is the role of impact angle, can see the impact angle is an x axis; wear rate is on y axis and 0, 30, 60, 90 degrees is been coated for cost iron which is harder material. As I am impact angle is increasing the wear rate is also increasing, because the cutting action it can resist for energy observe it cannot it done. So, that is what the cost iron at high impact angle should not be used.

Taking the example of soft a material that is rubber, elastomer which can have observed the energy. Initially the wear is very high, because they cannot be cut they have very lower resistance towards cutting, it can be simple cheeped away and layer can be simply separated but under compression they can resist much more force compare to this shear force that is why; the low impact angle, which impacts more sharing or cuts away the surface it is not require or we say that we should avoided wherever there is a the high impact angle more energy is getting transmitted and particle subjected more compressive load rubber material can be used. So, these are three example shows that what the importance of impact angle is and If we know characteristics of the particles, what is the impact angle we can choose proper material for that situation .This is what it shows that if impact angle is 0, if that angle is 0. I am talking absolute sense 0, than they will not be any wear rate that is why this initial curve does not show anything. It is not touching this surface impact angle is not coming in a contact at all.

So wear rate will be 0, it does not matter to us that we choose any any material that is a matter. Now is another concept on we said K is a empirical constant in this equation, if I go ahead with similar equation what was given by arguer again assume that K is of probability of wear particle formation. Wear particle formation means, the particle is getting this large it is getting removed from the surface what is the probability the K you can say in term. The K is the probability of that particle formation. So lesser the K better the results if you can reduce this K will it will provide very good results to us.

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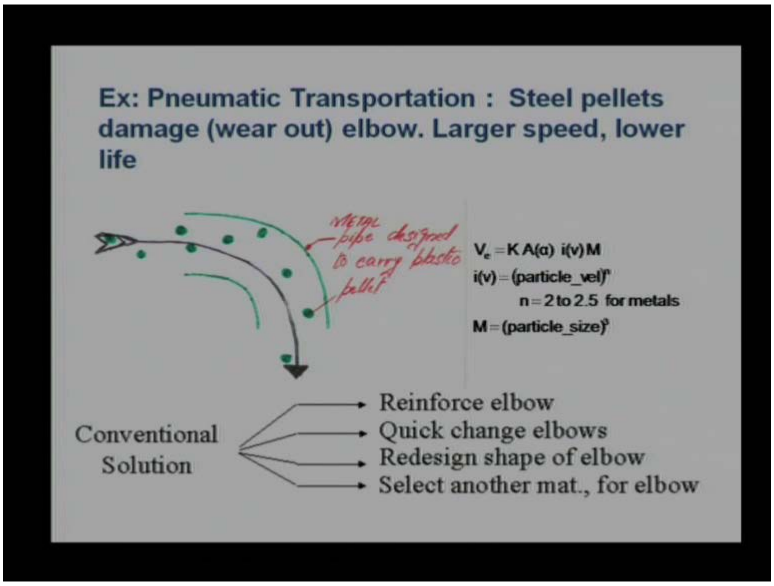

As, we are dealing with a wear and wear we know that is a system property it is not material property whenever you talk system property in the number of parameters will affect the results I can change the design; I can change the parameters or I change the material properties for getting good results. To illustrate the elastic one example is related to the pneumatic transportation. A pneumatic transportation means air or gas is being used as a carrier fluid to carry this pellet, the green colors we saw the pellet may be spherical in shape. The pneumatic curve, we say that gas is carried is from one end to other end and the major problems comes wherever there as a change in an angle. These particles are moving in a parallel pipe straight pipe they will follow straight path not much impact angle low impingement they will not be much wear rate of a surface or wherever there is an elbow or band comes than there is 90 degree change particle material need to be change in accordingly.

And we have heard in previous lecture of previous slide, we are discussed that if impact angle is high we should use soft material. This is a relative same thing; you say that initially may be some other material was used. Now, we are trying to use steel pellets in the same system is used for a steel pellets. A steel pellets having a literately more mass so if you push it will convert get more kinetic energy and will cause more wear rate of the pipe. In addition to that, we want to increase the speed of transportation it is not only wear changed the mass we are changing the density.

But we are changing the velocity also you want to go ahead with higher velocity and we know that kinetic is V is proportional to V square, sensitivity is increasing if you increase the velocity that may square effect is coming into picture so we need to think about which material will give the good result. As, I think from conversional point of view or a simple without much knowledge you can say we can rein force elbow rein force is may we can provide some sort of rubber padding inside the pipe; inside the elbow what will sustain impact or that can observe the impact. However the question comes will that be finding a good solution to us first thing is we need to change elbow. We need to coated is a is simple or is a easier, if it is easier without much cost than we should go ahead with that however we found that this is slightly difficult in addition to that not necessary all the particles are impinging at the 90 degree. There is a possibility the few particles impinging on the 5 degree few particle is image or impacting at the 15 degree few particle impacting at the twenty 5 degree depends.

With the number of particles and probably they may vary from 0 to 90 degree, main thing is that of course, mean value will be higher side will be may say 70 degree, 75 degree where still a particles ,which are getting impact ever impact in the rubber material at the lower angle. so rubber will be weaker and once it starts shearing; once it is start developing crack than it will cause failure, so again we need to replace that kind of elbow very frequently, that is why; we say that rein force may on the quick change in a elbow. May be initially it we were changing this elbow after thousand hours operation normally we can think about changing this elbow after 100 hours.

Assembly this is assembly will be appear problem in that case it will take more time; more material cost; more labor cost and shut down of the system for some time. Another option, we can think about the redesigning the shape of elbow instead of sharp 90 degree band, we can think about the changing the length on the longer side and very gradual curvature shape. we can gave whether the instead of 90 degree band, we have band often say 10 degree, 12 degree, 15 degree and under similar kind of rubber material can be used but we need redesign the system we need to have different kind of assembling because we are in quick increase the length of the pipe 90 degree sharp band pipe line may not be that high but when you go for the gradual strength the length of the pipe is going to be increased.

How we say the another one is a you choose totally a new elbow do not reinforce you change complete elbow material over the multi gray materials are may be use the rubber material with a some sort of hardening you fact, so that can do number of experiments on that and choose best material or after doing number of experiments which will suit completely for this kind of problem, I am using the word this all solutions are conversional it can be thought over easily but if we are understanding the wear mechanism properly. we know very well wear will take place of after sometime it is not spontaneous process, it is going to take few cycles few cycles may be 10 is to 3 cycles 10 is to 4 cycles and 5 cycles 10 is to 6 cycles can be utilize that as at advantages to or can we think from that angle and it is ok.

If this is a situation can I think about the temporary layer, which gets form and deformed and removed without causing any failure. Can I think about some layer self mate system self as a capability to make layer, remove layer and then form a new layer. So, without much damage may be some damage may be say 0.01 percent damages fine, if that is have gone we can think about a some layer and this is equation is given I can reduce K because i(v) is going to increase, M is going to increase.

Angle of impingement initially we show that the redesigning a cell shape of the elbow can be adjusted but if I do not want to do change in that a alpha will remain change I will is changing because of the input velocity is increasing; M is increasing; so both this increasing, that ware rate it is going to increase. If I want to reduce a wear rate, I have to play with a K that means, I have to reduce that value of K, the value can be reduced by reducing the number of particle which are impacting number of particles; which are impact in the pipe. If I can reduces probability from one to say 0.01. I may, can see in results. I can get same life of the components.

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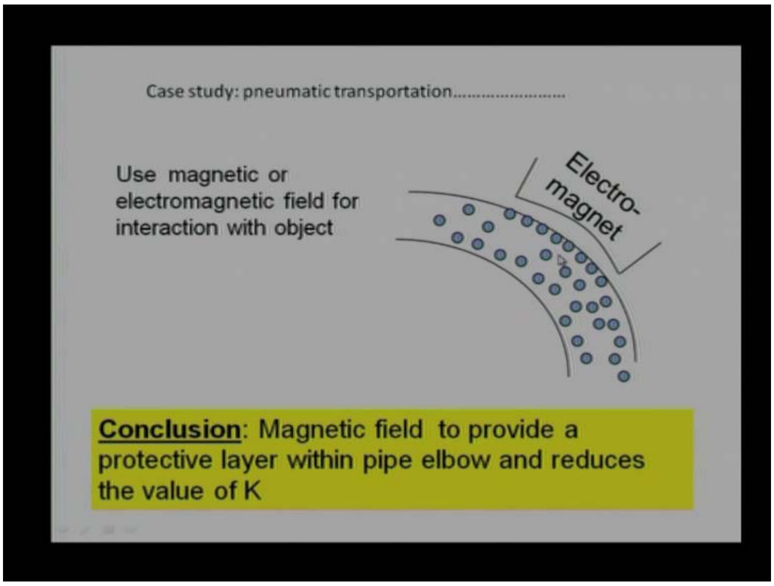

In that case, we can think form innovation point of view you can say that these are steel bonds and will get attracted to other magnet; can I think about the electro magnet attaching electro magnet on the pipe something like this there is a electro magnet very near to pipe whether this pipe is a magnetic or nonmagnetic there is does not much affect. The result because the magnetic field will vary if this nonmagnetic it is still electromagnetic can be used because we are thinking of the steel bonds. Interesting thing is that whenever we are using this kind of electromagnetic or all of steel particles will be coming near to the surface so, if I can control electromagnetic field provide just sufficient fields that one layer is formed not any other layer on that.

And what will happen there is a possibility particle comes impact one of the ball remove this ball because of the movement transfer and get attach to the surface. This will be continuous dynamic process one layer will be there always few particles will be removed; few pellets will be removed in every cycle and new particle will come and replace it so we are bringing almost negligible probability of impacting on the surface. Whatever the particle comes initially they will remaining and may be out of thousand particles or thousand pellets few may be 4, 5 or 10 will be removed.

So, we are coming down to very, very low probability this will be effective method to reduce the wear rate we are not change material we are just change the system design; we added few more fields instead of just mechanical field; we added a magnetic field to reduce the mechanical effect of the particles. So, this is a one way to deal with the problem, when we talk about the wear so if we understood the wear you can think of in board sense; we can come out of the box or we can think out of the box and get a good solution, much major solution; much more releasable solution ; much quicker solution.

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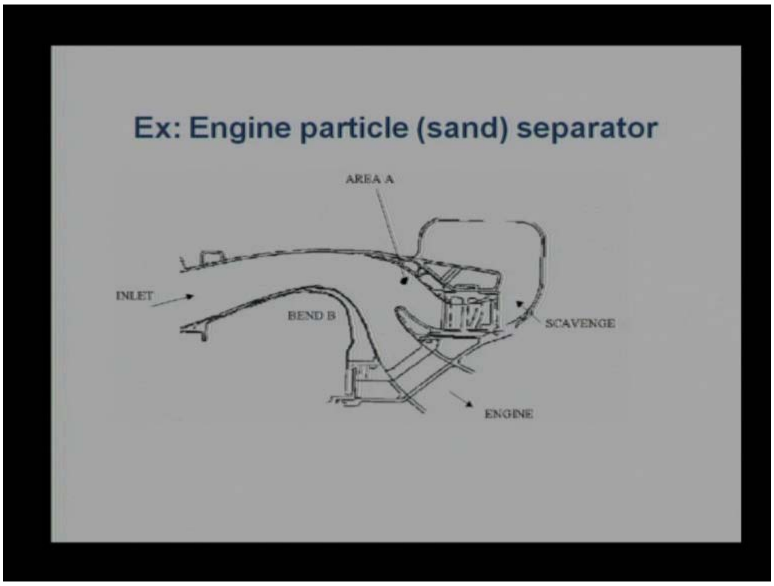

Let's take another problem, this is design of filter design may be say of aircraft engine or you may be say helicopter engine, which remain at the same height where the generally send concentration is very high in the air. what is the purpose of this design is that we want to suck the air, so that combustion can take place in engine, that means air is a sucked and supply to the engine or we know very well whenever the air is sucked, sand particles also will come along with that so we required one effective filter but we know very well if you use of filter you would here then, it will reduce the pressure that means we have to do separation we have to compares the gas and we are need extra system for high purpose. To avoid that kind of pressure loss generally they use this kind of design in the use of particle inertia, is a particles are coming with some velocity when it getting sucked and they will move in simply in the zone. Air, which can skip from that route can change is route because it has very low in inertia can come this side. The problem is that to increase the volumetric efficiency we require really very large volume, the volume of the air.

In addition, this is not full proving method still there is a possibility the few particles will come. If the particles are coming and hitting the engine cylinder or combustion chamber naturally, there will be a lot of problem in engine operation. It can fail any time. however there are system designs we use a redundant engines, so that even there is a one engine is failed, other engine parts are working or other cylinders are working properly that that redundant design is possible but can we reduce this wear rate might changing the system design there is a possibility.

We can think about changing in filter this is a factor one filter design. We are trying to scavenge the sand particles from this route and air through this route we can change the route there is another possibility. We can increase the volume of this dot so that more air can be shut and problem is that for any flying object lesser weight will be preferable. We required lesser driving force in that case, so minimization of weight will be one of the major constant minimization of the volume will be a major concentration. So, if I want to increase the volume of this that will not be acceptable because that is going to increase the volume; increase the weight and we require more driving power, which is a not very sound design.

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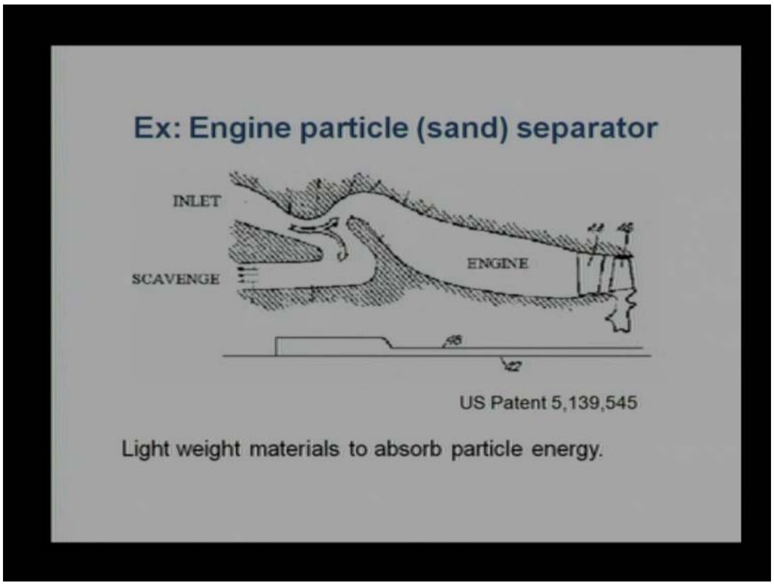

So, there is one pattern which was done in USA in 1995, when see there is an inlet change in design this inlet suck and we know the particle; we were trying to generating a hindrance.

So the particle come in impage on this and angle is almost 90 degree, after that there is a parallel particle change and direction is parallel to this. So, I can use this as the proper design a material of course, design is the already there we can choose proper material which as high impact angle. Air as a scare route also as there is change in curvature particle will not be able to claim that much, few particle which are claim and again come back it will not be having that much energy or we say may be having energy will be number of particle will reduce effectively and will be getting sound design. It has been proved that performance of this kind of design as improved engine life by 40 percent or reduces a wear rate by 40 percent which is substantial high.

You change a design and then get good result that really very good. you say that, we can think about this one material of light weight material if they not rubbers material suitable than we can think about some alternative material which can observe energy does not does not resist too much and you can see that kind of shape is more like finger shape which as a lot of flexibility. Particle comes in impacted is slightly flexible if anything system is flexible it will not around fast.

Unless this friction occurs on here this cross section will some if the friction occurs at this cross section that is fine but this can we say that will fatigue problem and we design some fatigue point of view if can design this system which as more than 10 is to 6 cycle, 10 is to 7 cycles, at 10 is to 9 cycles are depends on what kind of design we required or what is the life of the system. Many times when it comes back we can replace this material al.

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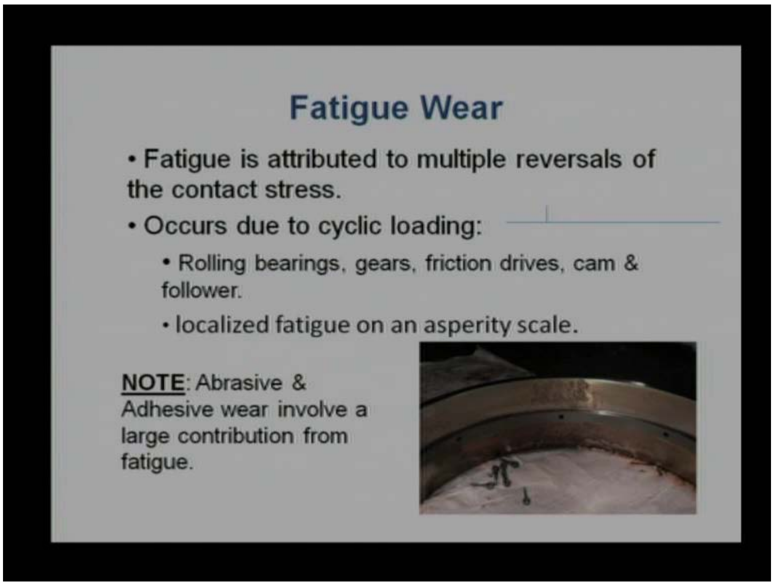

Now we are coming to the new mechanism, what we call fatigue wear mechanism even though I am using the word new mechanism but I should say that almost all wear mechanism or one way another way related to fatigue wear.

We started with abrasion, and then we brought probability into picture. Probability says that particles are not going to immediately dislodge from the surface. They will go under plastic and elastic deformation and after certain duration only they will come out the 0, that it will come sorry it will just this large will be removed from the surface. So fatigue one way another way is related to all mechanism it is related to adhesion also. we can give a formal definition: we say, that fatigue is attributed to multiple reversals of the contact stress that means particles are coming into contact solid surface are coming into contact and this stress is induce and relived also that is call why we are using word multiple reversals that is a load is applied and removed it is not constant load.

We can think about the asperities, continuously the particle when the surface is sliding asperity comes under load, bends and regain the shape. so loaded and unloaded that is the continuous stresses. we have number of examples related to the fatigue wear, we say that there is a common process if the common phenomena in a rolling bearings that was the rolling bearing have a definite life that is generally calculate based on the fatigue theory similarly, gets contact wear really governs a gear failure. We know very well gears failure can be predicted can be estimated by using two theories: one is Bending theory;

other is contact stress theory, Hertzan theory and 99.9 percent the failure occurs because of the contact stresses fatigue sorry bending does not cause much failure fatigue surface ban large is almost 3 to 4 in bending while contact stresses factor 30 not be 1.4, 1.5 all friction draws and came follower mechanism rolling action is rolling fatigue is governs for all wear mechanism but there is a other possibility that fatigue by sliding contact and that is more common at a localized one when we are talking about asperity level on a micro or atomic macron level or nano level atomic level.

Just to illustrate what I am trying to convey: Let's take, this is a well 9 is shown that is a surface layout I am talking about the front few of the surface and surface and surface is visible as a line and one asperities is there that show the irregular surface. Now if I apply a load on this asperity if I apply load on this asperity either it as to friction immediately with 99.9 percent will not happen it will change the shape, if the load is applied so as other substance other material or other component comes, passes this surface. When this passes this surface it gains the regains its position but what is there when it changing the position from the straight to the band position, it was subjected to this stresses the tensile stress and compressive stress. It is happening in number of times during sliding motion, number of times so truly this is a bending problem.

Now, I can deal as these as an abrasion or I can deal this as adhesion does not matter just see a micro level phenomenon is fatigue failure. This is one typical example, which was as you shown in first lecture can see the fits generated on an inner surface of outer ring separate entity and this is fatigue failure. We know if you see this kind of ring again brings in operation, there will be high irregular performance; lot of noise will be generated and this wear. At the end of this slides say that abrasive and adhesive wear involve a large contribution from the fatigue even though we are using word abrasion or adhesion But they are basically govern with fatigue.

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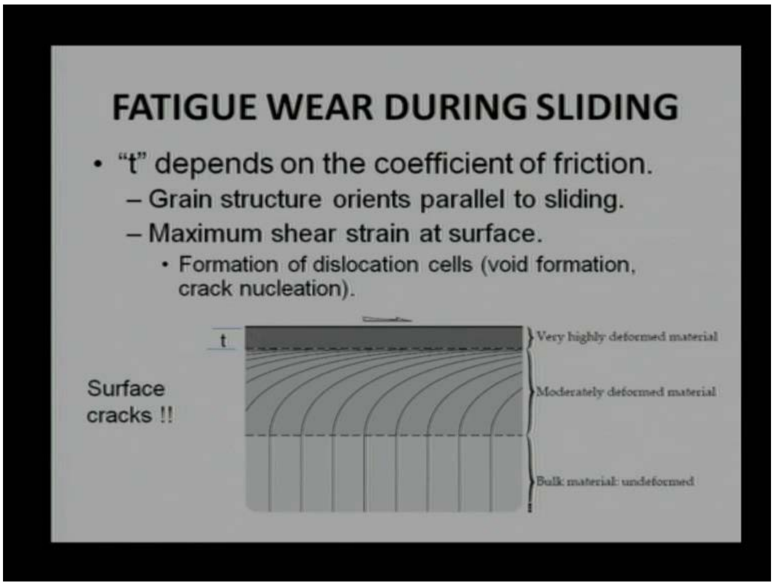

Just illustrate slightly in detail let's look at the this slide, this one figure it says that top layer at different color; second layer slightly different color and then parallel material. We are showing some sort of deformation lines that this line is a representing what is the kind of what kind of strain is developed in a surface we know if we try to move surface in a, we try to supply some sort of sliding force in this direction. Top layer will be sustaining maximum strength, then intermediately and then final layer final layer does not have nothing to sustain is a superficial phenomena.

So it will happen on the top surface and to some extent below that surface which is that that is why we say that this a top surface is very highly deform material. See the shear deformation on the material then modally deform and this is almost and deform to. now over all fatigue behavior will depend on the, t what is the thickness of t we are thinking many times this t is a outer layer when we talk about the bimetallic layer by your talk about the try metallic material with the three layers are there out we talk about the multi grid material with numbers of layers are there number of materials are bonded together to give the suitable performance**.**

Then this t really affects the results and we say that t majorly depends on coefficient of friction. The coefficient of friction is very high naturally we have to apply more and more sliding force, a more and more sliding force than, more and more grains will be deform in this direction they will reorient to a certain limit. In average the load is low or high maximum compare to, when we talk about the compression between three layers maximum is strain will be on the top surface. If we increase the load, then what will happen at the interface there will some sort of void formation which we have seen number of time when we talk about the rubber material, you banded you are able to see some sort of pose in rubber material. That is the void formation, if there is a wide formation that means there is no material.

Stress area is almost are the area which can sustain is stress is negligible, and that can be tear away easily, that layer can be cheeped away this bearing wherever there are many voids fraction will occur easily. that will remove the complete surface that is the reason when we say that t is smaller how the way talk in the bulk metallic material and top layer as a very small thickness; more bond than; lesser number of voids will be generated because of the more banding but thickness is more an a higher side then in the bonding will be slightly lesser and more and more voice will be generated. Delimitation that layer will be much easier that is why we need to design thickness properly or the surface which is an undergoing very high shear rate need to be design properly.

Sometime, we find the surface crack itself what we talk about the void generation and that will be more like sub surface but this a possibility of the surface cracks. Surface cracks we can think with simple manner roughness surface roughness itself as some asperities that is a going to create a problem and that is why shown over here.

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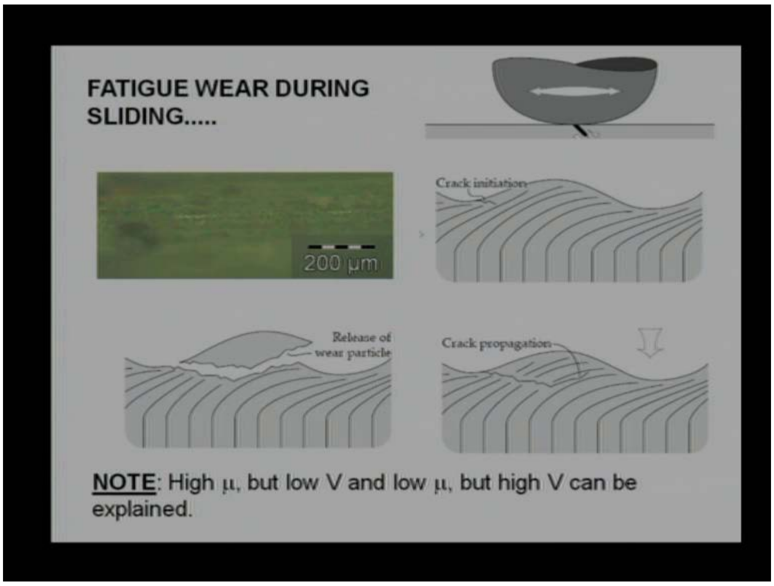

There is an asperity over here: if it is a residing motion goes keeps going on this depth is going to be in last; will be getting extended. Something is clearly shown in this sketch when we move this surface over this surface and there is a possibility of filing of material we know very well when we derive to derive in a moody road mud will get pile up in front of the tear same thing is happening over here. Material is getting pile up and this crack which will come directly in front of the load, then it will along it something like this when the elongation is keep going on and again and again the material comes of the force comes immediately when this surface.

It will turn out to be a delimitation removal of that particle from the surface. This one of the common phenomena happens in the gears. You can see gear pit over here, if your this kind of wear particle comes out may be order of few microns only. We are able to see the pit on the gear when wear there is a pit on the gear sliding will enhance pure rolling will reduced. There is a reduction in pure rolling increase in a sliding, that is going to cost further more and more tensile load or require more tensile load on the surface, more tensile load; more crack formations; more wear particle generation.

We can say when we understand this kind of mechanism. Now, we can explain one slide which we are seen I mean previous lecture or previous to previous lecture, where the high mu high coefficient of friction but low wear value was estimated for some material. On other hand low value of coefficient of friction but high wear rate was estimated. How as a low rate condition wear volume will be related to square root of one plus mu square that means this is directly related to the friction.

Increase in fatigue coefficient of friction means increase in wear rate. However, when we are talking about the fatigue and we are talking about fatigue mechanism. We can explain this is not 100 percent related for most of the material. Yes, we are related but not for very material.

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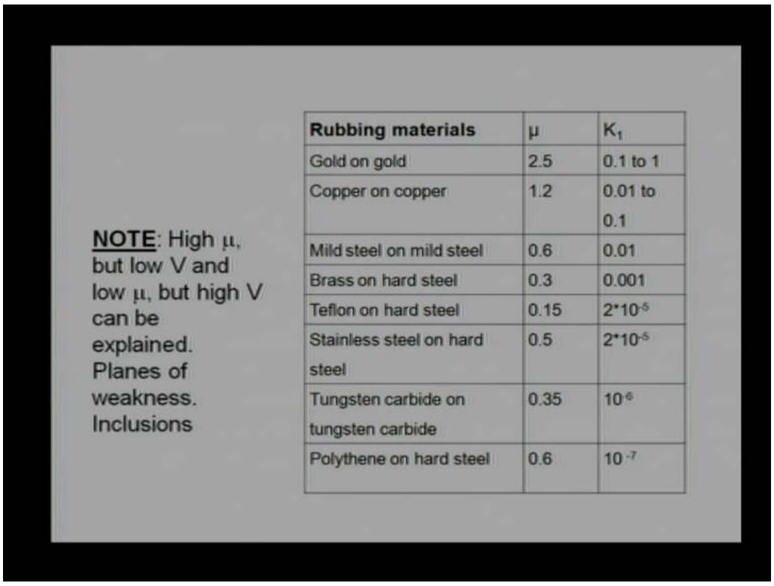

So, we as come back to that slide which we showed in a previous to previous lecture you say that in this case as a coefficient of friction is decreasing wear rate is decreasing but here coefficient of friction is increasing again but still a wear rate is decreasing. Now what are the reason quite possible, material combination which we are using they have some sort of wrinkles they have some sort of manufacturing defects. If they have manufacturing defer there a voids cracks will form a fraction surface or surface which can be easily fracture or delaminated from the material.

Even though they can show low coefficient of friction talk about carbine materials, when carbide is a rubbed about the steel coefficient of friction may be very, very low value but they have cracks they have voids when they are getting combined they make a surface which can be easily fraction that is why the wear it will be high even though coefficient of friction low but wear rate is high. Take another example of copper: talk about to 99. 9 percent pure copper no void no enclosure high coefficient of friction may be point 6 plus but wear rate will be low because fatigue will not be there are fatigue there is no crack generation or void so that material will not be run very fast.

So, those kinds of mechanism allow us to understand what the difference between coefficient of friction is and wear rate. we are not always related ;we are not always in harm with each other quite possible high wear coefficient of friction but low wear rate another hand low wear rate but high coefficient of friction. Understanding this kind of mechanism, help us to design better and better systems. What we are expect adding the this slide is the plane of weakness if material as a planes, which are weaker that means they are weaker than surfaces. Then, wear rate will be high or if there is inclusiveness in the material wear rate will be very high. Will discuss later about this when we cover one case in study in next lecture how inclusiveness can create more proper.

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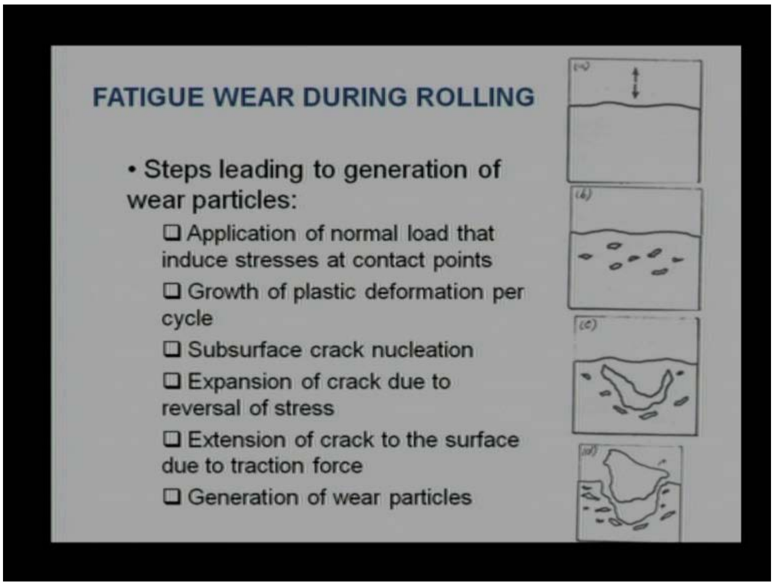

we discuss fatigue due the sliding or during slide motion, but there another fatigue which is more common that is what we call as fatigue wear during the rolling we know were well rolling induces very, very high concentrated stresses or we say that contact stresses are generally very high in rolling motion because area of contact is very, very low. so what are the possibilities. You say that this steps which are leading to the fatigue wear that is what we are applying a normal load that individual very high stress of the contact points. Blaming contact is stresses and bearing are almost 2 to 3 giga Pascal which is very difficult to imagine, we say either steel as only 560 mega Pascal as a strength, how can you sustain at 2 giga Pascal as a three times factor just 0.3 and still bearing can show number of cycles so that is the we contact stress are very different than the tensile is stresses.

And they need to be having a different kind of equation; different kind of behavior or different kind of treatment, when we try to solve problems. They are more over more or less compressive in nature that is why we use a material which are stronger in compression; competitive attention. ban large we have common thinking of steel to iron or ductile material they are similar they have similar behavior in compression intension but it does not happen with all the materials or when you work hard in the surface, it will have more compressive strength then the tensile strength and we want to bring the compression strength within a 3 giga Pascal plus. So that a results of a rubber to us.

Now, when we apply very high not very high normal load but if you apply normal load which induce high contact stress. There is a possibility of elastic and plastic deformation elastic deformation is not problem for us it will regain the ship that is the possibility of the plastic deformation some sort of depth in that. Once there is a d shape comes on the surface than problems, will start you say that after d shape or plastic deformation there will be some surface crack nucleation possibility, that d shape itself is generating nucleus or providing nucleus for the crack and one duals loading continues loading and unloading there is a possibility of expansion of the crack, subsequent to that extension and finally, generation of the wear particles.

I can show you all this image whatever we discuss on this slide using some pictures you say this lets take this in a surface is slightly irregular. We are talking about the loading and unloading reversal of the loading. So loading is a compression, when the load is reverse the it should come to the 0, what is the possibility of the rest the stresses. We are loading something in compression and believing in it quite possible a later direction, we know that the new factor later direction. There will be tensile stresses and that tensile stress can generate some sort of nucleus or some sort of voids in material if number of voids they come closure to each other. they will make a bigger void a larger side void.

And if it is loaded and unloaded continuously this void will extend up to the surface and the whole thing will come out that will generate a pit on the surface. So, rolling as well as sliding are generating the fits but with different kind of mechanisms. Here the later direction force met as large it deform the surface in compression but when the compression load is removed then it gets expanded; when it gets extension on that then we are getting tensely stresses on the perpendicular direction. what I am trying to say if I am loading this surface compression is increasing but when we are reliving it material as to relax it.

So that is why the stresses will be generating in perpendicular direction this direction and this direction that is what the crack is nucleated and expanding towards this direction. It does not come directly under the load it is going beyond this side and this side. That is happening because the later crack or a force or tensile stresses which are in later direction.

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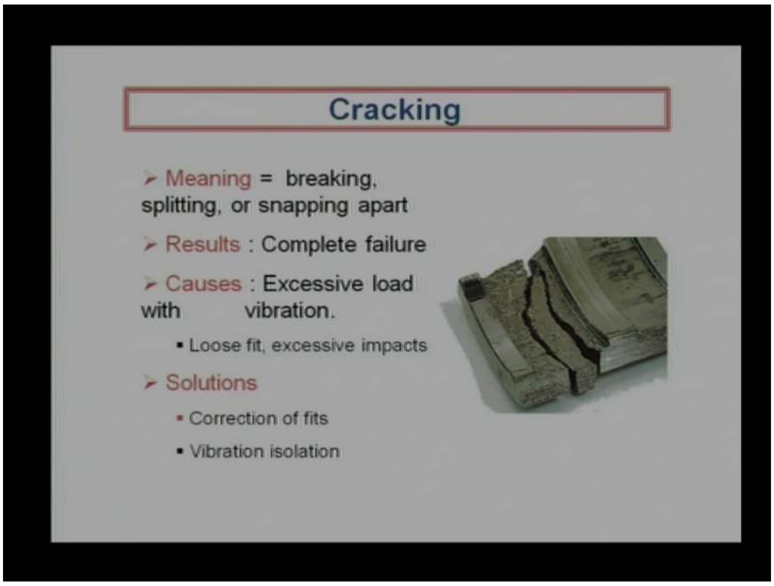

So, end of the fatigue comes with the cracking, many times we have we apply very, very, very high load on the surface not intentionally but because of the some main function; some sort of over load or some sort of misalignment or some problem in assembling the components, than what in that case happens very high load will generate a crack through and through from top to the bottom surface.

And this known as an extreme case of the failure that may happen as a spontaneous also within few 100 cycles. we talk when way whenever we talk with fatigue, we talk about large number of cycles but this may happen even 100 hours and not 100 hours we say when 100 cycles. So, what we say that the cracking is ultimate failure may be intensive also. It is it is going to spilt the component, when component is a plate nature it will not have any function or functionality will be 0.

It is a complete failure, it cannot sustain it will not we do not have any time left for its operation. majorly happen with excess load but here in addition to excess a load the vibration is also there. The vibration of the reversal load is there or some sort of impacting is there, than this kind of failure will occur. When, we are talking about the vibration we are talking along with loss fit. if there is a form fit vibration will not affect there is a but there is loss fit vibration is going to affect the results is going to impact again and again the way we understood the erosion, where individual particles where there but the whole bulk material metal will impact with much larger velocity much larger impact energy.

We can solve this kind of problem by providing suitable fits choosing proper fits so that wear is getting a solution from the fits from the system design. similarly, we can think about vibration as solution again .We are saying that wear of fair phenomena the cracking is getting solution from some other strings is not tries in material is not choice of lubrication but it is complete system design if I want to remove this kind of problem I have need to think from other the angle. we have one case study on a cracking related to the roller bearing which will discussing in a next Lecture. Let's discuss about the final wear mechanism for this course.

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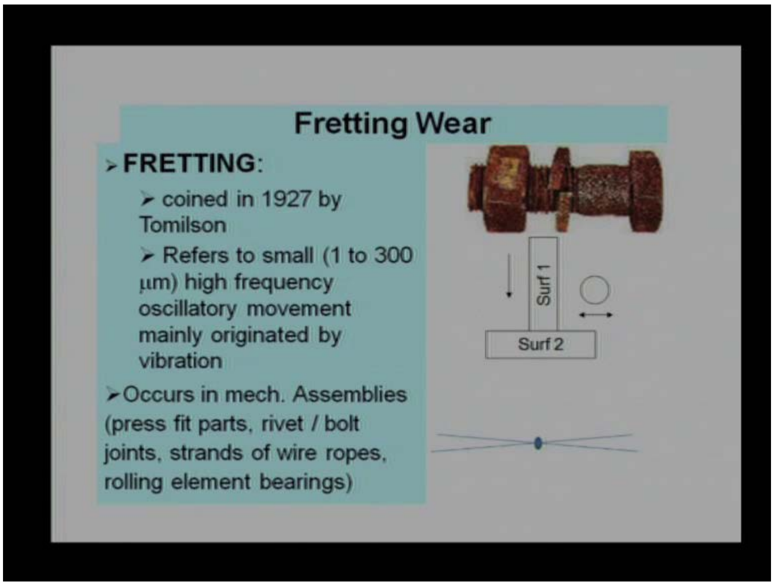

As, I mention initially; there are more than 34, 35 wear mechanism. We cannot cover all the wear mechanism because this course is a not exclusively for the wear we have selected 6 wear mechanism and in that 6 less of the 6 wear mechanism. Fatigue wear is a last mechanism.

It was coined; this term was coined in Tomilson. Tomilson is a famous guy, who has given the molecular theory of friction. It should share that there is a molecular attraction between surfaces and he purposes some sort of empirical relation to find out what will be the coefficient of friction and it could show that softer material will have more problem related to molecular fraction. When we talking about fatigue we are talking about, very low magnitude vibration, low magnitude and high frequency vibration energy is coming but at a low magnitude or low amplitude were proper word we can that the low amplitude. Amplitude is in terms of 1 to 3 hundred micron, it will not be detected easily. Some machine is running and will not be able to see the vibration as such but 1 to 3 hundred micro vibrations between two components happening and that is calling in the fatigue wear. This is the high frequency; low amplitude so over all energy comes in higher side. Addition to that is the oscillatory motion are some we are saying this kind of mechanism this kind of failure generally occurs in assemblies number of possibilities it can be press fit; it can be coping; it can be riveted joint; it can be bolted joint where there is a possibility a micro slip.

So, we have studied about the friction mechanism, static and kinetic coefficient of friction. We know very well when we are applying reinforce there will be some asperities irregular surfaces and one surface as to claim on other surface quite possible we apply. Some force low magnitude surface will move and the micro and nano scale and come back that will not be easily diagnostics from the outside but it is happening and that is, that micro motion; that low aptitude motion is causing the fatigue wear. Now this is the one of the common example of course, what I show, I shown a sample is more like rested assembly but we are not talking about the failure because the corrosion we are talking about the failure about because of the fatigue.

If you open this nut from the bolt, will find some sort of powder that will not be corrosive powder but that will be a particles coming from iron or related to that. Of course, corrosion is increasing the wear rate but it is not initiating. Initiation happens because of the fretting and after that there is more and more surface areas are reliable some chemical activity of this particle is higher side. That is causing failure. Just to demonstrate same thing what we have saying there are let us take one surface and other surface they have a contact they have contact under the load, that means contact is under the stress. In addition they as getting some sort of oscillatory motion; some sort of predict motion which as continues and we talking about this motion of the in terms of the micro, which will not be detectible. That is going to be cause a problem.

In other word, I can think about engine mechanism. you can say there is plank and there is inch, this engine not going to will be a stationary is a point which is plane point, plane line which is a in related to the inch will remain stationary but this line will move up and down continuously. It will be vibrating so what will happen this is a there is a relative motion; it will impact upper surface; it will impact at the lower surface and that impact is going to generate our micro in scale particles continuously impacting micro and nano scale particle will be removed from the surface and as a particle removed increases, this oscillation also will increase with the material is not there to restrain this plank amplitude, than amplitude will continuously increase.

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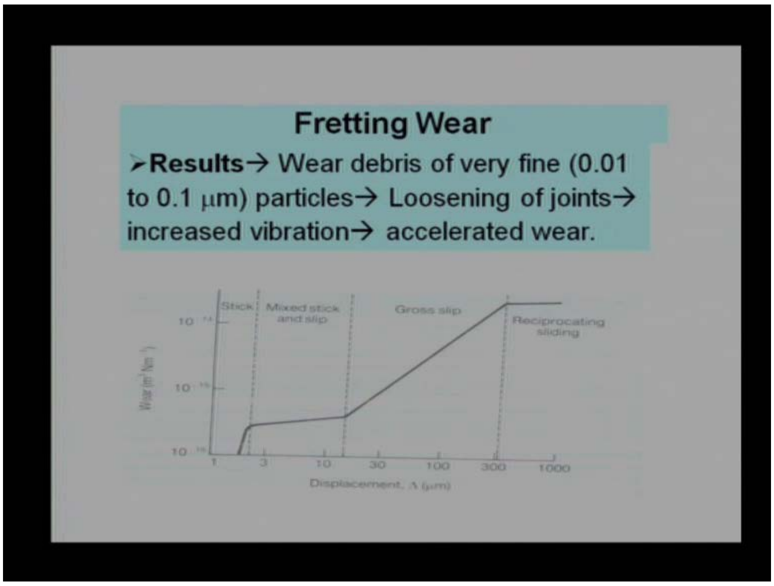

So from micro slip to slip and the gross slip phenomena will happen like that and is why we are saying that fretting happen something like that. Initially there is stiff phenomena we are pushing, it to certain value and reliving. If the load is we are not bring intentionally but load is coming from outside of from other factors that will cause some slip micro slip. Initially the slip is a low magnitude slowly material as getting removed from the surface the slip will turn out to be gross slip and then that gross slip is harmful it is something like that we brought a new component new assemble even never used it was lying in a on the table or this is a some assembly, which was vibrating with very small magnitude, that magnitude vibration created a problem and whole system collapsed. Because of the fretting corrosion of fretting wear, this is what which mention in many times nut and bolt connection kept as it is when you open it after that, it will not be able try to reason being that most of the powder from the nut and a bolt will be removed.

Thread profile will get damaged and you again retry in the nut bolt connection, it will not be because there will be loss connection or thread otherwise. We need to recondition those threads if you want to reuse the some way. So this is what I mention about it introduces micro slip to the gross slip and that cause failure.

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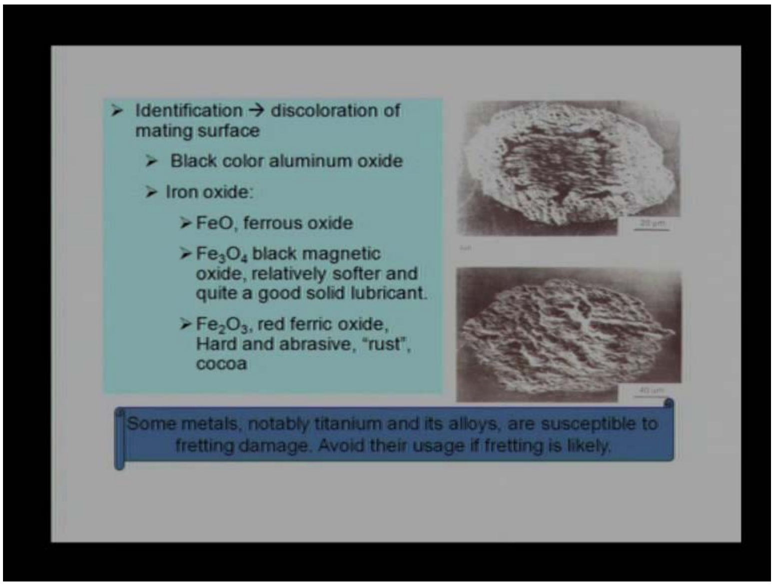

These are the couple of pictures from outside surface it look very nice, very shining and no problem as such. When you open it and look at them, micro scale this is the 20 micro in scale thing can see the pit. Pit is generated outer surface is not damage much of course, you are showing an irregular surface but pit is generated at the at the center of this. Where outer surface remain without much motion but at the center most of the material is been removed and it depend on the material, they have different color a something like a if I am using aluminum material I will find some sort of black color aluminum oxide mounting when I open assembling the failure will be there. Similarly, when we are talking about the iron material, is iron material than it can be either iron oxide or ferrous oxide or can be the black powder which we generally observe that is iron oxide again and here there are red ferric oxide which may can see up we have get in some less.

So, either black color aluminum or black color iron oxide is one option and red color which is most frequently we get because of the rusting nature and is slide difference within rust and corrosion. We use word corrosive wear initially but here the word is coming with rust is only the small change. We say that corroding media if it is in water then it is a rust if corroding media is something else than it is corrosion. So ,with the wide water is acting as corrosive media then whatever the phenomena happen that is are rusting how wise it is a corrosion.

And if we understand the kind of fretting corrosion, fretting wear. In this case, I am using word again and again fretting corrosion, because fretting is starting point and when it generate number of particle and if there is air available or medium is available in a manner all those particle will get oxidized. when they get oxidized, the hardness also increase and that is why they increase the wear rate so many times we use the word fretting wear and many times we use word fatigue corrosion because static is fatigue mechanism leading to the corrosion and overall increase in a wear rate the mechanical action continuously. so fatigue come corrosion and mechanical action is at fatigue corrosion wear.

Now, we say that if we know the material table we know which material are susceptible towards the fatigue phenomena than we should never use those material if we know the vibration phenomena is going to happen there like titanium. Titanium very well the very costly material, if it is not use properly it will cause failure. You must heard about this fatigue failure of the bone joints. we know, there is a bone cement which will be rustic in the motion of implant but if there is a some micro crack in that there is a motion that will give you almost some micro stabilizing in the gross slip, that will cause damage of the impact so that is also related to the fatigue wear which can be studied in detail if you go and micro scale, nano scale on that.

Now this is the last slide on the fretting wear, we can continue wear topic in our next lecture. I will prefer to use a word wear analysis where we try to analysis the wear mechanism. Now, we have a studied various mechanisms but when we see the failure in totality without any one wear mechanism is going to be pointed out or you will give the results or combination of the wear mechanism are going to give these results. so that kind of wear analysis important, whether we should choose material or we change the material or we should provide a lubricant or we change the system design; how to deal with the problem that will come in a wear analysis. That is the we are going to discuss on the next lecture; thanks. Thanks for your attention, well we will discuss on wear analysis next lecture, thank you.