Tribology

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Module No. # 03

Lecture No. # 06

Wear

Welcome to 6 th lecture of video course and Tribology, topic of today's lecture is wear, so w e a r. It is not clothing, it is a mechanism with which material deteriorates and loses its performance. In my view, wear is more important compared to friction and a common definition of lubrication, which is generally given a number of books is that lubrication is provided to reduce friction. I believe that there should be change to the lubrication is provided to reduce a wear, because the (()) on a wear is much more dominant compared to the friction.

A general comparison, I can say that co-efficient of friction from 1.00 can be reduced to 0.05 by a better design. This factor makes 20 times difference. If I verify do a good design, wear can be reduced by 100000 times that is more dominating factor. I can choose a very good material pair, or material pair with a solvent lubricant in this, that case wear will reduce significantly in 10 is to 5 times, which is very significant.

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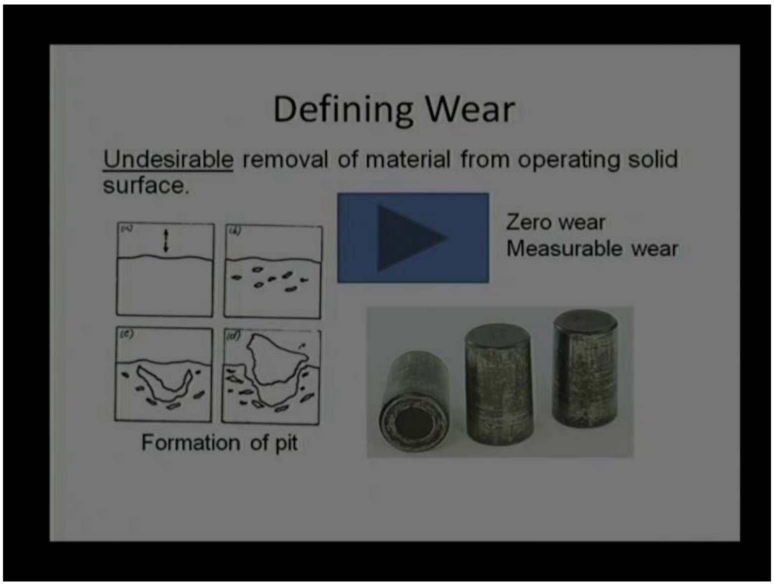

So, to understand all this must start with a lecture wear and a definition, so that undesirable removal of material from operating solid surface. The word wear is defined as undesirable removal of material from operating solid. I use a word undesirable, keeping in a mind that, there are two definitions; one is known as a zero wear, other one is measurable wear. Zero wear means, there is a wear, but that is not going to cause as much. In fact, it may increase the performance it is for betterment, so that is not undesirable; however, miserable wear where the undesirable wear occurs or undesirable removal of material occurs, just you highlight that.

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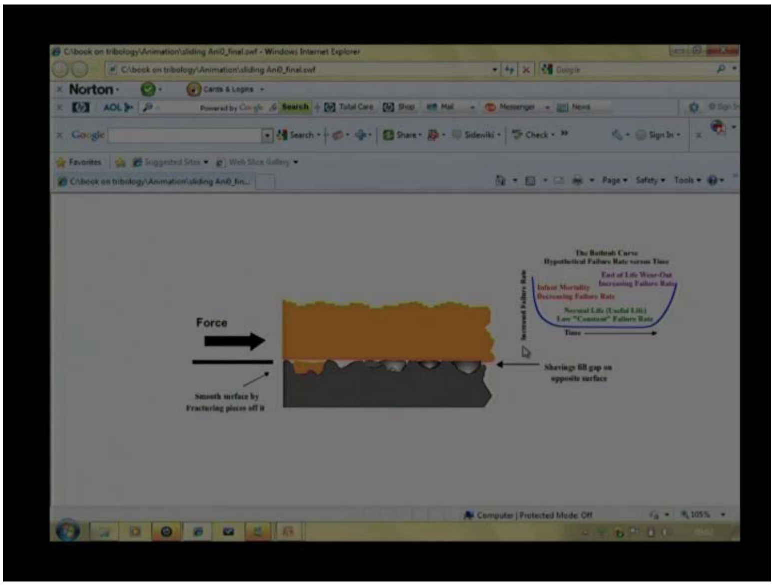

Let us see one small animation, let us see this, there is a two, there are two material pair orange and black. Orange is moving against the black, force is applied to push the black, but after some trails, there is some asperity detachment from material 1, as well as some asperity detachment from material 2, this is zero wear.

Here the detachment of asperities are smoothing the surfaces, and filling the gaps or valleys, bringing overall roughness to negligible level, that is why we, when we refer this bath cub curve we say, there is a possibility of very high initial wear rate. It slowly comes down, reaches to the steady state condition and after certain duration, it increases reason that, this is an infant mortality, that means, in the childhood material has bound to wear out more. Then, it will reach to normal life, where it has to show its own function, when that function life is over, then wear rate will increase, this is an off component life.

So, we are more worried about this, and part to estimate what will be the life of component, and we are more worried about this study part, which is going to tell when component or is going to about to fail and what will the maximum life which we can achieve from this. And this is a hypothetical condition, not necessary every curve, every wear curve will be like that, there is a possibility of continuous increase in a wear rate, it will never be in steady state condition, there is a possibility, that is why we need to understand wear mechanism properly.

As I mentioned earlier, that this is a zero wear which is not is not going to matter much to us, component is improving performance that will be always advisable, that will be always targeted. However, there is another kind of wear which is a miserable wear. In this, there are four figures shown, a, b, c, d and what we are trying to show, a formation of pit which generally occurs if there is a low a there is a cyclic loading and this cyclic loading is shown with the this two arrows. That means, there will be a mean value, there will be a higher value than that and a lower value than that.

So, when the component or when a surface is subjected to this kind of cyclic loading, there is a possibility of formation of cracks within the surface. If there are too many cracks, they will agglomerate, they will make a one big crack and may be after certain duration, certain life cycles, this whole attachment will get detached. And this is what we known as a fracture mechanics, component is getting or component is losing some material, a pit is formed on a surface and that is why is name is given as the formation of pit. This is undesirable, if there are more and more number of pits, we know very well there will be some noise generation, there is a discontinuity in motion and quite possible rolling motion is getting in a sliding motion also, there is some sort of increase in a friction. We should avoid as far as possible, this kind of failure and that is target to study the, that is the main purpose to do the study on the wear and wear mechanisms.

Let us see, this roller surfaces, these are roller surfaces, we are able to find or some scratches, some deformation of surface or we can say it is losing it is losing some dimension, some tolerances quite possible in this square may be 20 to 50 micron and 20 to 15 micron change in a dimension of (()) means a lot, it is going to change a performance from one domain to another domain or we can say from full film lubrication to the mixed lubrication, to the boundary lubrication is the huge variation of coefficient friction occurs.

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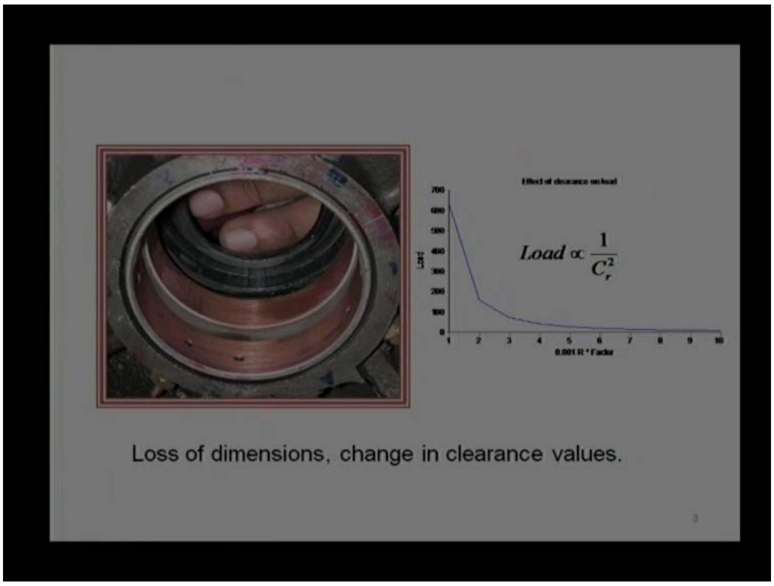

Just to elaborate that, we will take another example, which we have shown also in the first lecture, this is a sliding bearing this is what we say Crain Sharp hearing it has a middle Groof or supply for oil. But we are able to see the scratches on the surface, this is scratches may be 20 to 30 micron deeper, may occur may be because of some particle or hard particles and particles or some oxide, which form in engine, those particles will remove this surface, make some group or may be display material, so the roughness increases and that change in dimension is going to change the clearance, what we say the general bearing generally have clearance of 0.1 percent of its radius or is radial clearance is 0.001 into radius, that is a very very low.

For 20 M M radius of the sharp, we are keeping 20 micron clearance and we are keeping 20 micron clearance and this kind of wear occurs, this is going to increase a wear by, increase increase the clearance by 40 40, additional 20 percent; that means, 40 micron clearance, a performance will be very very back.

Just to elaborate that, we can refer to this curve we can say that, when the clearance is equal to 0.001 are than load caring capacity some are 625 Newton. As the clearance is increasing two times, then wear load caring capacity is coming down to the 115 Newton. So, from 625 Newton to 150 Newton that is a six substantial change in load carrying capacity, the compound it is bound to fail in that case, was working in hydrodynamic domain and suddenly started working in a boundary lubrication domain, as a huge variation in friction and performance will deteriorate, support will decrease and it may cause whole failure or failure of whole system.

So, we need to understand that we need to avoid this kind of failure that is why I have written here that is the loss of dimension that changes the clearance value. And if` this kind of loss of dimension happen, if there is an interference fed between the shaft and sleeve on top of that, which many times we use in bearing, in a rays is mounted, if the push fed on a shaft and if this kind of a wear occurs, a loss of dimension occurs, what will happen the inner rays will try to run with the clearance fed which is going to fail the bearing completely, then that should be avoided.

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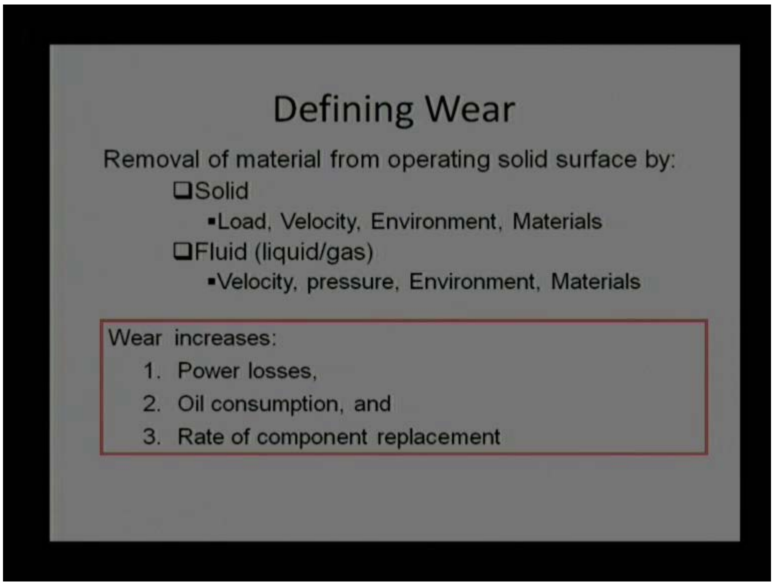

So, let us come back to the wear definition. Once if you know importance of the wear topic, we will come to the again why why the wear occurs, it is the removal of material from operating solid surface occurs by solids or by fluids. So, both the both the motions, both the kind of wears are possible, is a solid may cause the solid wear, or fluid may cause fluid wear. When there is a wear by solid surface, then dependent parameter or, of a parameter which are going to affect the performance will be load, velocity, environment and materials. If there is a good hardness of material, or good compactness of material and wear will be lesser; if environment is a friendly, wear will be lesser, larger velocity (()) large will cause more wear except the hydrodynamic domain.

And high load may, will cause high wear, except the few cases where a low load may cause some vibration and larger load will avoid that vibration. When we treat wear by a fluid topic, we say that it depends on the relative velocity and depends on the applied pressure or induced pressure; here we do not use the word load. It is more pressure, because we know there will be uniform distribution; while in case of the load, there is a more concentrated load also. So, that is why we use the word here, the pressure that depends on the pressure. Of course, the remaining two parameter will be the same environment and material, a material is a can sustain or can absorb the wear energy then it will sustain its life, it will be longer life.

Many times we say the harder material is preferred, but it is not always the case; harder material may have a lower toughness, lower energy absorption and many times it will fail much earlier stage compared to the softer material which are, which need to be studied properly, when we should choose a softer material, when we should choose harder material, what is the reason behind that, will be studying in this topic.

Now, this block says wear increases, but before that, we can I can add this wear is never a cut of strophic failure. We will never get immediate failure due to wear, immediate failure will be because of some other reason wear is a gradual, it is more like our life, we gradually decay in our performance from 25 years to 50 years to 75 years and that is the wear, our bone joints are getting borne out. So, we will not able to run that much fast, we will not be able to do that much physical work, same thing happens to the all machines.

So, value it is a gradual, it does not happen immediately, if an if it is happening immediately, that will be there will be some other cause of failure, it will not be just failure or in other word, wear may initiate other cause for a spontaneous failure. But wear itself will not be allowed or will not be able to cause immediate failure of the component, but it causes some other problems, say wear increases the power losses, the friction losses will increase this there is a wear of the surface, and here I am talking about the miserable wear, I am not talking about the zero wear, I were not talking about the initial wear, where the asperities are getting damaged or deformed or wear displays for the betterment. If that kind of wear occurs, that is good for us, or good for our machine.

Second, is a oil consumption, if there is a wear is more than oil, consumption will increase. There is the possibility of leakage, access will leakage from the interphone and that will start consuming more and more lubricant or we need to supply more and more lubricant. And finally, we say that if there is a more wear, there is naturally possibility of replacementing or replacing that component with a new, a newer component. So, in short wear does not cause this spontaneous failure, but surely it is going to cost, power is going to cost, oil is going to cost to replacement.

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So, indirectly it is costing us, if we are able to avoid it, there will be economic benefit to us and we won those economics benefits. When I talk about the wear mechanism, it is difficult to talk about the wear mechanisms, there are too many wear mechanisms available, and we will have given theories theories and theories on wear mechanism. As far as my knowledge is concerned, there are more than 35 mechanisms. When we start, there will be we can say there is a abrasive wear, there is a adhesive wear, and there is a cavitations wear, there is a corrosion wear, erosive wear, fatigue wear, and fretting wear, the each topic can be further sub divided in number of categories.

Let us say abrasive wear we are talking about the polishing, polishing is a good phenomenon to give final finish to surface, but many times it is not advisable to us. Scouring, the scratching, grinding, gouging, they are all subdivisions of abrasive wear. Coming to adhesive wear itself, the magnitude is changing where does the low magnitude addition, medium level addition, high level addition, where there is a cold or there is a hot, a number of divisions are there, basically basic mechanism will be same, but magnitude will change, that is why the relations will change, dependence on the different parameters will change. When we talk about the cavitations, basically we are talking about the solid verses liquid, it is something like a some bubbles are getting burst and because of that burst, bursting of the bubble, there will be access of pressure which would be directly imaging high liquid with the high velocity in the surface and that will cause some failure and that will be known as a cavitations failure.

Similarly, there is a corrosion wear, there is a combination, corrosion happens because of the chemical action, it increases the porosity of the surface and if there is a mechanical action on that, naturally there will be easy wear out of that surface, lose particles how or we say that porous layer will be easily removed by mechanical action. So, there is a combination, chemical and mechanical and by enlarge we say them, wear is a mechanical. So, that is why I have written here, it is having chemical nature; that means, initiation happen because of the chemical action and finally, resell or removal of material happens because of the mechanical action.

There is a another kind of wear which is we know the erosive wear, it happens again because of the liquid or the high velocity liquid or high velocity particles also. Particles, they are generally more common to cause erosive wear, may be typical example is fly ash; if it is a high velocity fly ash, images directly on surfaces, it will causes access of wear. Another wear is fatigue wear, and one category of the fatigue wear itself is the delamination, it can be a surface wear or it can be a sub surface wear. So, we there is a there is a division possibility or we can classify accordingly and there will be a different theories to treat these topic.

And finally, is a fretting wear, I take a very good example, I say that do nothing no no movement between two surfaces, but a still there is a possibility of wear. If you get a chance to open any nut and bolt connection any time, open it and you will find some sort of black powder or red color powder comes out of those nut and bolt connection. I am talking about the ferrous materials. if the nut and bolt connection are made of the ferrous material, whenever you open you will find some particles, some black powder, some red color powder comes out of that and that is a fretting wear.

We are talking about a micro motions, micro motions which are induced with vibration, even though there is no relative velocity, but there is a micro motion, there is a micro slip phenomenon happening, it will again and again nock the surface and will cause some failure, some removal of material and even the particles which are getting removed from the surface, those will increase this kind of wear.

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So, we usually generally we avoid it if we understand all this mechanisms. I have given a one of the example of aggressive wear, what we are calling a polishing wear, I took this example because most of the time we say that polishing is favorable phenomenon, it should be done and if it is done, what are the problems? We can see the first figure in this case is the liner figure, it is a engine liner where polishing happened. If this kind of the polishing happens, what will will be the result if the surface is texture to retain the lubricant, the texture will be removed and if that texture is getting removed, we are losing a performance.

If I say some sort of diamond shape given to the liner to retain the lubricant to keep those diamond shape as a storage for a storage purpose and if those diamond shapes are getting polished, naturally that performance will come down whatever we optimize the surface to retain the lubricant properly, those will be removed some other performance will come, because the polishing is going to generate some other surface, some other group parameters which may not be optimized or optimal parameters naturally because of that some problem will come.

I can take a very good example about the carbon graphite and a stainless steel, we are able to see these black marks on a stainless steel surface, these surface, these mark have come directly from carbon powder and here it has done intentionally, what we are saying that let carbon graphite transfer its layer on the stainless steel, because adhesion between the stainless steel and carbon graphite is higher compared to cohesion between graphite and graphite.

So, a weak interface will be made between graphite and graphite surface, but good adhesion will be made between the carbon graphite and stainless steel. Once this is the thing layer is getting deposited, carbon graphite layer is getting deposited on the stainless steel surface, and we are going to reduce coefficient of friction and subsequent pair. In another word, initially there will be high wear, because of the transformation earlier from carbon graphite to a stainless steel and subsequent to that, wear rate will come down, friction will be reduced.

It all may be coefficient of friction initially around 0.3, 0.4 and subsequent to transfer of this layer, coefficient of friction may reduced to the 0.2, so almost 50 percent benefit is on that and we decide now. If somebody by mistake thinks, oh this surface is getting dirty; oh some black marks are there. I want to polish at every new operation and get good performance, then he is mistaken, this layer have been deposited intentionally, it has the basic physics behind that, and somebody without understanding it tries to remove, now this is dirty surface, it should be clean before assembling, then he will cause unnecessary failure of the component, unnecessary wear of surface and higher power loss.

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So, that is the polishing wear right, a wear wear itself is a complete subject and we require a maybe say 40 to 45 lecture itself on the wear, we do not have that much time. So, that we will do, we will try to cover this wear in four lectures and basically, we will cover a abrasive wear, adhesive wear, corrosive wear, erosive wear fatigue and fretting wear, this important topic will be covered, remaining topic which can be derived from this basic mechanism remain same, like a number of subdivision under a abrasive wear can be treated in similar manne, only the coefficients will vary, parameters will vary to some extent.

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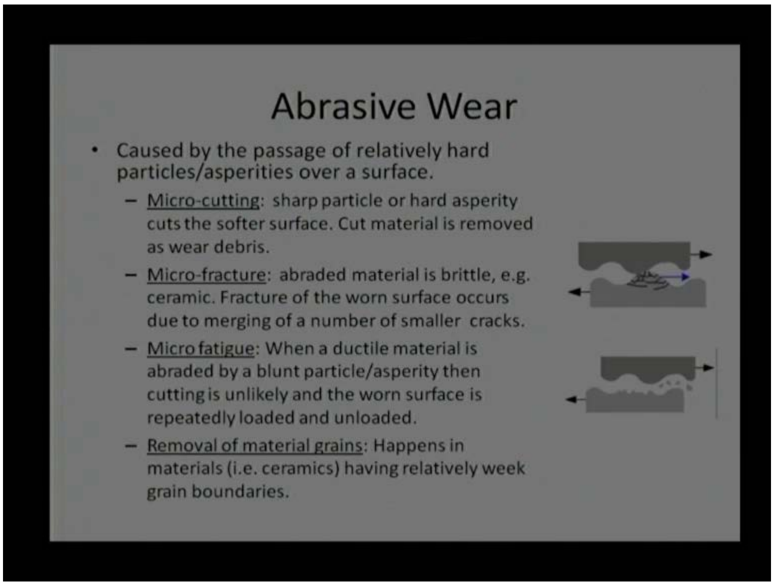

Now, if we come to the abrasive wear, we say we have basically four mechanism which will give physics of abrasive wear and depends with the material is ductile or brittle, mechanism will change. Let us take an example of micro cutting, we are talking here the sharp particle have asperities; if there are no sharp particles, it will shift to the micro fatigue. So, if the more sharpness, it will cause micro cutting; if the laser sharpness is more roundness, then it will cause micro fatigue; if the material is brittle, it will call micro fracture or directly removal of the grains.

So, depends on the weather material is ductile or brittle, physics will slightly change, relation will slightly change, and whenever the particles or materials is getting removed from the surface, we will call this as a wear debris if the material is getting displaced may be initially due to fatigue or some sort of proving a fact, we will not be able to gain or wear debris. It will be just a resurfacing of the surface, rate of debris is a lose particle and those lose particle may further increase or decrease wear rate, depends on the operating parameters.

Now, this is a typical example for micro fatigue, we say that two surfaces are moving relatively may be top surface can move right hand side, lower surface can move left hand side. That means, there is a relative velocity in a situation may be anything, absolute motion of top surface has a relative moving to a right side, and bottom surface is a stationary, still there is a relative motion or top surface is stationary, bottom surface is moving against the top surface, then again there is a relative motion.

What will happen because of relative motion and asperities of the blood, they are not very sharp, they are not conical, maybe can say that these asperities are spherical in nature. So, it is going to cause again and again stress of the surface, stress is induced and it turn out to be cyclic loading of the asperities, again and again load, again unload, again load and unload, that will cause some threat of crack formation in the asperity itself, or may be the beneath the asperities.

So, after certain duration, certain cycles, this will get fracture and due to fracture, they will be new surface generation which may be smoother or worse than earlier surface, depend on the rate of the loading which we are applying. If the rate of loading is very very high, there are more chances that this surface will make a big pit in a surfaces itself which should be avoided, this is what we say the micro fatigue generally caused by a spherical cavities, micro cutting is caused by a conical cavities, and there will always be a mixture of these two.

Similarly, macro fracture, it is cause a cause, it generally occurred in a ceramic material more brittle materials where particle cohesion is not much higher and there are made up with a some sort of cohesion, which may not be having very high value. And some time when they are weak, having a weak grain boundaries and they are not treated properly, and ceramics materials will deteriorate using due to the wear phenomenon that the whole gain will come out or get separated from the parent surface.

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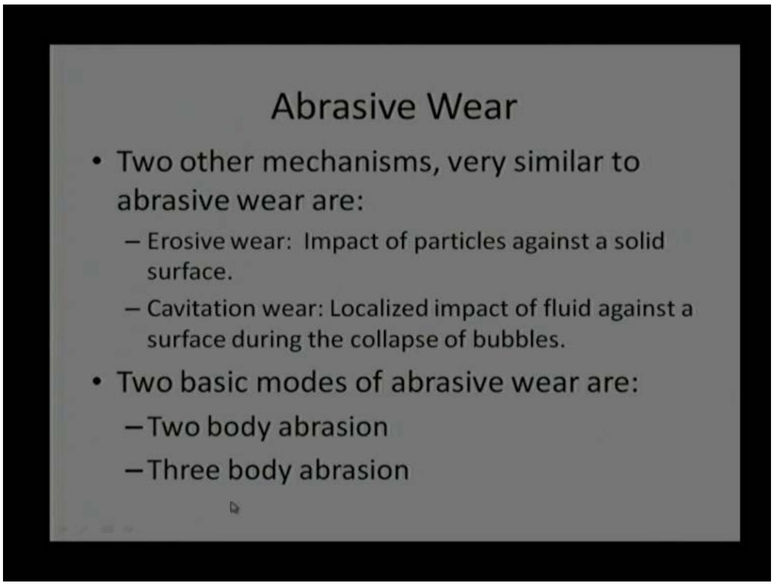

This abrasive wear is having a very common mechanism with erosive wear and cavitation wear; only the difference is that, in abrasive wear we are talking about the two solids or we are talking about the particle, not with the impression not with the impact, but sliding, sliding comes on in motion. So, the wear, abrasive wear is generally solid verses solid, but particles are not coming with the high velocity; while in erosive wear, we are talking about the particles which are come attacking the surface with a relatively high velocity.

When we talk about the cavitation, we are talking about the liquid which is making bubbles or bubbles are induced, because of one process or one way or another way and they are getting burst; releasing the high pressure unto to that pressure, surface is getting damaged. Now, further we will come to the wear, we say that basic modes of the wear abrasive wear can be further classified based on whether their asperity verses asperity or particle verses asperities. If asperity verses asperity interaction occurs, we call as a two body abrasion where a particle verses asperity interaction happens, we call a third body or a three body operation assuming particle lose particle as a third body.

We have already have a two surfaces soft surface and harder surface and there will be some particle in between. Naturally, a question arise, is a two body operation bad or three body operation is bad, which should be preferred? Experiments show that two body abrasion is causing slightly higher wear rate compared to three body abrasion, and a slightly may be again a subject to, many times we have observed that three body abrasion cause only 10 percent damage compared to two body abrasion.

So, number of parameters is going to affect particle shape, particle size or everything will matter when we talk about the abrasive wear by three body abrasion, the phenomenon or mechanism.

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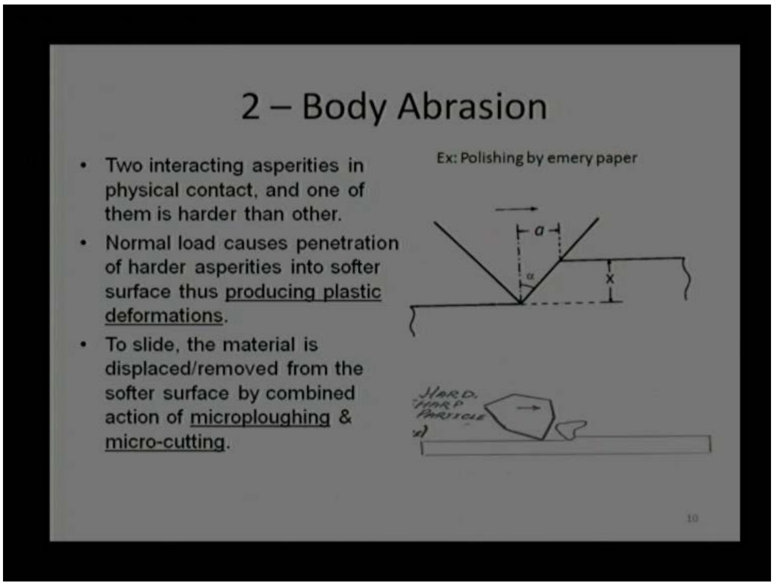

Let us start with 2 body abrasion, we will try to develop some quantified quantification of the relation and how this wear can be reduced, once we have modeled mathematical model, we can play with parameters. So, what is written here, the example is given as a polishing by emery paper, you must have seen in number of manufacturing operations where the final finish is given by polishing paper, or we call it emery paper which has a grid which has abrasive particles and they are manufacturing the surface are giving final finish to that, but that is a desirable, here we are talking about is a undesirable which should be avoided.

So, we in this case, we can take conical asperity, we are the half cone angle is alpha, and when the due to depth, the depth is occurring at the radius a; is a conical line. So, wherever the interaction happens, there will be a circular cross section and circular cross section will be having some radius. So, I am, we are talking about that radius as a and this will occur whenever we load harder component against the softer component, under load, this asperities will penetrate softer material to balance the load to bring in come equilibrium and we, if we provide a sliding to the surface, then there is a possibility of dragging this asperity against the soft material, the two options, material gives this path or soft material gives a path to the harder asperity, displays the material to the other side, a possibility is the completely remove that material from that surface. If harder asperity is coming, material is simply getting detached from the surface.

Both the possibility are possible, both the possibility are there, some time we get more plowing effects, some time we get more cutting effect, but there will be a balance of these two. And sometimes, there will be only elastic deformation; there will not be any plastic deformation, if the applied load is much lower. In that case, we are not going to lose anything, it is only deformation of the material and elastic limit and regaining that shape.

However, to develop the relation we are assuming whatever the material is getting transferred or whenever there is a sliding of the harder asperities against the softer material, we are assuming that whole material is getting detached, cut from the parent or soft material, that will give you, gave us a very high value of wear, then in we can introduce some co efficient, some probability, the probability may be 10 is to minus 3, 10 is to minus 4, 10 is to minus 5, that can be determined by experimental lessons, because we cannot really get this overall good results. If they are too many asperities, all asperities have a different heights, different radius different shapes.

So, we assume, let us take a one asperity and assume the same shape of all the asperities, causing similar phenomena, and there is equal distribution of load, all asperities are sustaining same load which is totally hypothetical, not very close to its realistic value, But we than in that case, we need to bring a good statistically model which will be slightly complicated, will not be able to judge. So, that is why what we do, we take a simple example, develop the equation, find out some unknown parameter, do experiments and figure out what is that parameter, that parameter may be a constant or non dimensional that shows some probability of the success. If the probability is very high, wear rate will be very high, because we are talking a extreme case; if probability is lower, then wear rate will be lower.

Just to understand that, we will come back to the slide, we say that normal load causes penetration which is been explained and it is causing a plastic deformation, in actual there will be elastic deformation also. We are assuming 100 percent plastic deformation and there will be micro cutting and micro plowing, but we are assuming all micro cutting, detachment of surface that asperity or that material completely from the surface.

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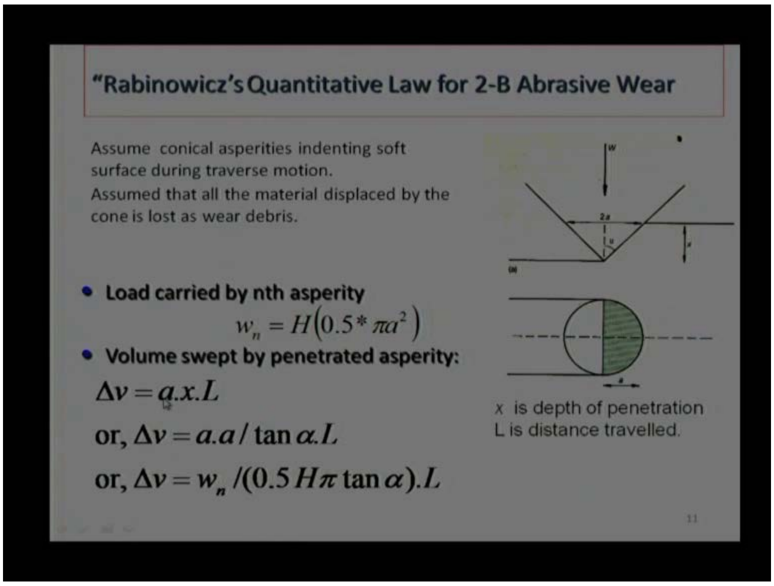

And in this case, where we assume the radius is a; that means, diameter will be 2 a as this is a conical shape, area here is a pi a square, but I will take half of that and multiply with hardness. Because our assumption is the plastic deformation, material is undergoing plastic deformation, and easiest way for that is you multiply with the hardness; if it undergoing elastic limit, then I will be multiplying it with yield strength or proportional limit.

So, we say the one asperities, one asperity, harder asperity when penetrate into the softer surface, softer material contact radius or the surface will be a, and it will be circular cross section. So, pi a square is area and point it is touching is a pointed. So, there will be a area will be 0, average area will turn out to be 50 percent of pi a square. We are multiplying with the hardness to find out load sustained by one asperity and we need to find out the volume, because we are talking about the we are talking about the wear rate or we want to find out how much wear will occur on that surface.

So, in that case, we need to find out what is the swept volume, how much volume has been displaced, that can be figured out that from the radius, distance which is travelled and depth of the penetration. So, depth of penetration is x, radius of the cone is a, and radius of a cone at the contact surface is a, and total distance is travelled by this asperity is l. We can express the depth of the penetration in terms of cone angle, that will turn out to be a by 10 alpha, here alpha is half cone angle.

Rearrange this equation by substituting w n instead of a square, what we get is w n asperity load on one asperity or load sustained by one asperity 0.5, the 50 percent hardness pi 10 alpha into distance travelled by this asperity, like in two integration if there is continuous phenomena, but asperities are generally just discontinuous. So, we assume some asperities, may be number n, we do not know whether n is a 1000, 10000, 100, it can be anything.

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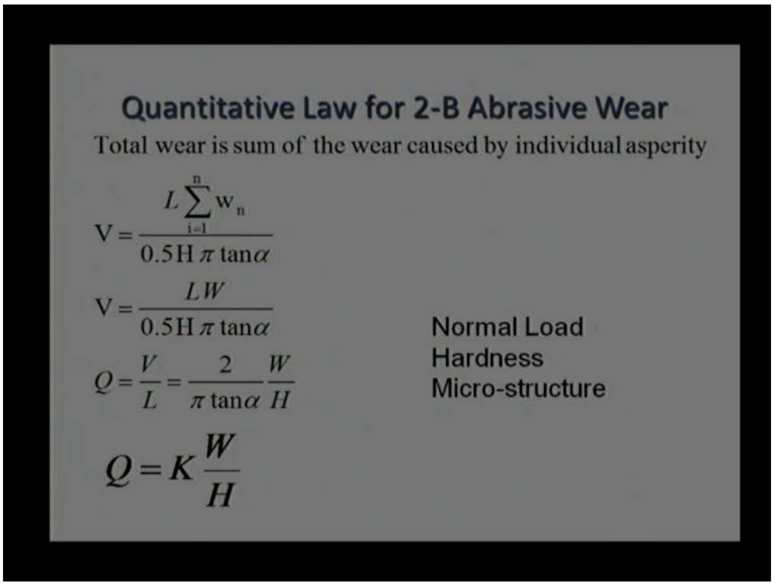

What we need to do is summation, asperities 1 to and n, load can be different in every case. So, summation will turn out to be over a load, over all normal load which is applied, distance can be easily calculated, it can be easily measured and 10 alpha we do not know, that is a statistical parameter.

First few asperities will be 1, may be 10 degree may be few asperities it will be 80 degree, few asperities it will be 50 degree. So, still we are assuming there is and statistical parameter, we are not taking any decision. However, the hardness of the surface is measurable, so L is measurable, H is measurable, W is measurable, all which is applied, we arrange this equation something like that L, W and H. And if you are trying to find out volume per unit length, that will be V by L assuming that is equal to Q, expression done turn out to be 2 by pi 10 alpha W by H, this is measurable, this is measurable and this is a we do not know, we have taken some approximation. I can treat this as a one constant, and I can figure out when I can do the number of experiments on that, what will be the value of this constant.

So, we say Q is equal is to K a constant need to be determined by doing number of experiments W applied load and hardness of the surface. So, we need to find out this K, it generally depends number of parameters and when largely depends on a chemical nature of the material and environment. If we change environment value of K will change, if you change the material value of K will change. Other than this, there is a affecting parameters W which is proportional and may increase the load, Q will increase; increase the hardness, Q will decrease, but is not always a case. In case of the ceramic material, we need to find out whether the material has that much energy, absorption capabilities. If the energy absorption capabilities are is not there, even increasing hardness is not going to help us, because wear phenomena will change, it will cause some more fraction of the surface compared to abrasion.

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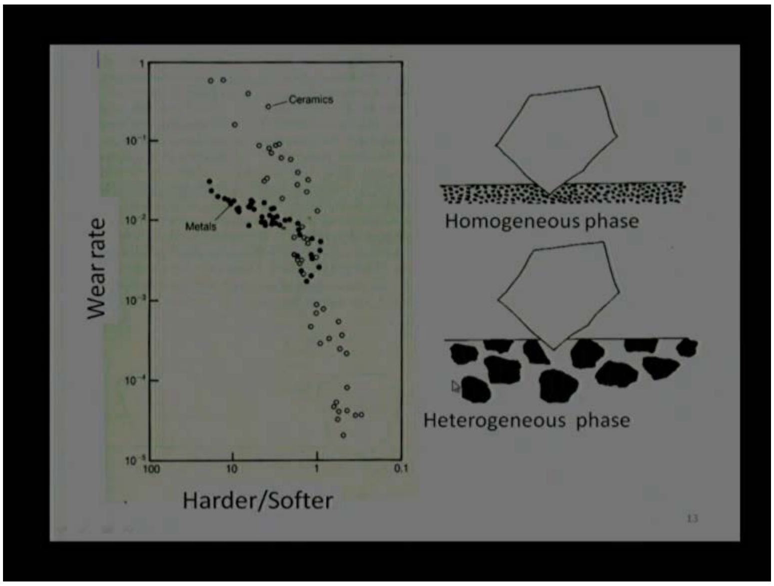

We have couple of curves, sub experimental results, this shows the dependence of hardness, but this slides shows that it is a, it is not only the hardness, it is the ratio of hardness which is important. What is the hardness ratio of harder to softer surface? If hardness is very very high, let us take a 10, hardness of hard surface verses or compared to the softer surface is very high, then wear rate will be very high. However, the surface this hardness is equal to 1, there still there will be wear rate. It is nothing like I keep 60 H R C hardness of one surface and 60 H R C of hardness of other surface and I try to slide one surface over a other surface, there will not be wear, surely there will be wear, even though there is equal hardness, there will be some wear asperities. However, asperities can be treated as a cantilever and the height is different, if the height is too high, it will act as a very very week aluminum surface, it will simply rupture from the surface.

So, even though for the equal hardness there will be wear rate and that is indicated here, even the wear rate is this ratio is equal to 1, is still there is a hardness, there is a there is a hardness something. Now, if this hardness ratio decrease; that means, wear wear rate will come down, but of the other surface it will not be for the one surface. There is another possibility of material combination, we say that whether material is homogeneous or heterogeneous. If the material is homogeneous, wear rate will be lower, there is a more closeness of the particles and displacing those particles will be slighting difficult, there will be more resistance on that. But if material is heterogeneous, then it can absorb more energy, but it will cause more wear rate, may plugged out easily, it can be simply, it can be removed easily. So, depends on the homogeneity or heterogeneity of the material, behavior or wear behavior will be different, that was the two body abrasion.

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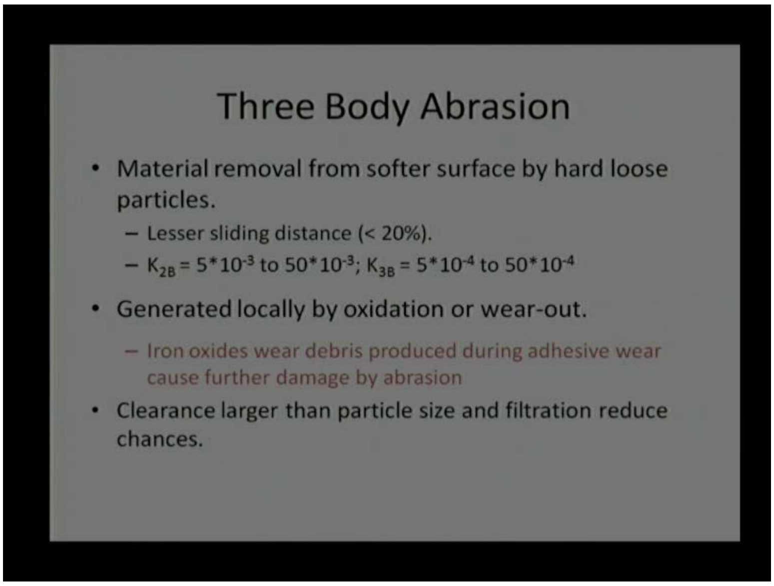

Now, we can think of the three body abrasion also. As I mentioned earlier, initially that two body abrasion is more harmful compared to three body abrasion and this slide is giving reason for that. We say then particle is detached from the surface, it does not have any rigidity, if you allow movement of the particle, there is a possibility sliding as well as rolling. And rolling, because of it has a lesser coefficient of friction, rolling will be more dominant, for the same force, rolling will be more dominant compared to sliding if the shape is proper. Of course, if the shape is very irregular and one dimensional shape, then sliding will be more.

But if the particle has a more like a spherical shape, you push it; there will be more and more rolling. So, what we can say for loose particle, even though the hardness is very high, for loose particle, there will be over all lesser sliding distance, because there is a more rolling distance. And if that is a case, wear rate will be reduced, it will be much lesser, most of the energy is been absorbed in the rolling action, that is why if I if I compare constant K, if the two body abrasion and three body abrasion are maybe say comparison between three body and two body, what we are gaining, this is wear rate maybe say is non dimensional number, wear rate maybe say 5 into 10 raised to minus 3.

This is just an assumption, I am not talking that wear rate will be like this always, depends on the material combination, but if the wear rate is something like at 5 into 10 raised to minus 3 for one Tribosphere. If I come to the three body abrasion, it will be reduced by 10 times, it will be 5 into 10 raised to minus 4, and again there is an approximation, an absolute value not 100 percent. But chances are there, wear rate will be decreased significantly, maybe say 1 or magnitude, reason being particles are rolling more, causing lesser damaged to the surface. But again that depends, rolling ratio will depend on the shape of the particle; if the particle is spherical, is having irregular shape, or more like a diamond shape which will cause more and more scratching or lesser scratching.

Depends on the shape of the particle, we can find out that wear rate is much lower or higher side, this particle or third body generally occurs, because of oxidation and it detachment of oxide oxide layer from the surface or some other wear phenomenon, may be because of the adhesion, junction formation occurs and that there is a that fragment of the surface, or removal of the adhesive pair, adhesive junction that may be generated as a wear debris, that will cause abrasion, always the adhesion is leading to the abrasion, three body abrasion.

Interesting thing is that, if we know clearance between surfaces, there is a larger than particle size, then this third body abrasion will not cause much damage. In other word, we know the particle size which is getting generated between the two pair, two surfaces, in between a one pair, then we should keep clearance in a such a manner particles which is coming or which is interposed between the two surfaces is not going to cause much failure.

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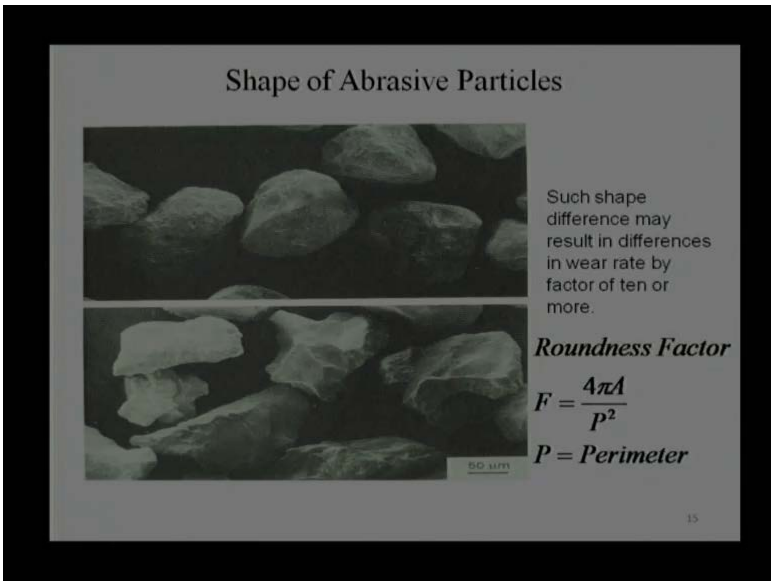

To find what is the fact is (()) is finding the roundness factor, roundness factor F is generally given as a ratio of 4 pi into area, area of cross sectional area of the body divided by perimeter square.

If I think about this spherical shape, the cross sectional is a pi r square, r is the radius. So, this will turn out to be 4 pi is pi r, 4 pi square r s square and we know the perimeter of the circle is 2 pi r, so its square will be 4 pi r square. So, over all roundness factor will turn out to be one; in other word, if the round parameter is equal to (()), that will cause a lesser or is a least wear, three body abrasion compared to irregular surface and that is the reason, many times we use particles for the lubrication and particle shape is kept as a spherical shape, which is not going to cause any failure, which is not going to cause abrasion of the surface, that will be always advisable, choose particle shape in such a manner which causes lesser abrasion, if we are using particles as material to lubricate the surface.

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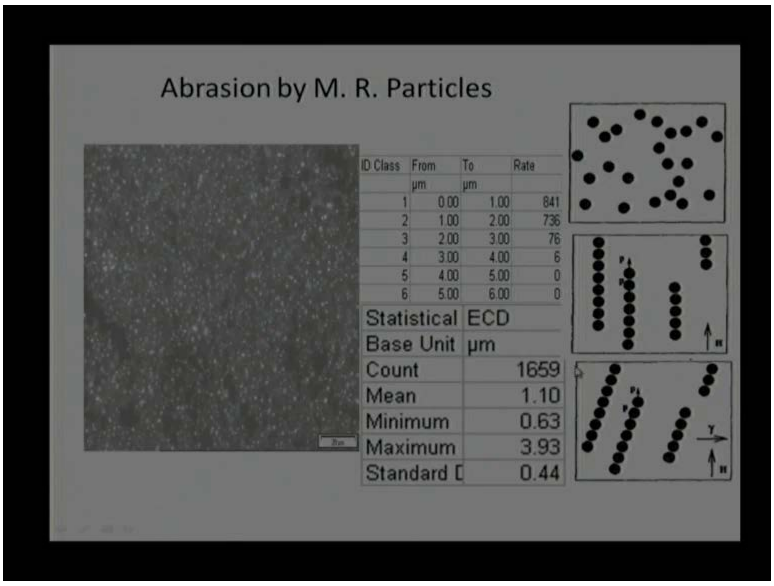

I can take very simple example to demonstrate practical particle size, but we say that M R fluid magneto rheological fluid where the particles are used or iron particles are used. may be having good hardness, generally we try keep this particle as the sphere. Just to give more information of M R fluid or magneto rheological fluid, we can assume there is a one cell filled with the liquid and these are the some solid particles in that and this liquid works with the magnetic field. That means, if I apply a magnetic field, this field is shown in by H in direction, if we apply this magnetic field, this iron particle will chain up, again this is the ideal one not necessary particles will always chain up, they can make clusters, they can make a 3 4 rows 3 4 columns, not equal in size is something like a particle may come attached to this point, get attached to this point and next particle will get attached to this point.

However, between two columns there will be repulsion, so they will get separated, but filling of this gap is possible, that means not necessary it will always be the chain, there is a possibility of the cluster formation which we have observed in number of times in a lab, it is cluster formation compared to chain formation, and this cluster formation increases the strength of M R fluid which gets solidified. However, if now if I apply a tangential motion, if we apply some shear rate, there is a possibility of bending of this particle chain, (()) but this is as a velocity is applied, this particle should abrupt the contacting surface.

If we do not keep the spherical shape, the particle do not have a spherical shape, then there is a possibility of scratching of confiding surfaces where the M R fluid is confined, those surface will get damaged, because iron is relatively harder material and if we are trying to keep seal, use seal or rubber seals to stop leakage of these M R fluids, relative velocity will try to damage that rubber, rubber is very very soft. So, we are keeping soft material, but against this iron particle, but we are keeping spherical shape, we are trying to keep think about or maybe say 90 to 95 percent energy is used for the rolling purpose, it is not utilized to abrupt the surface. So, if we are able to keep that, we can make very good mechanism or is the liquid or small liquid which shows the good results.

I have one slide or images which say that 20 micron is its size, this size and these are number of particles in an M R suspension. We know very well at this particle are much smaller, more than a 20 micron, and if we see the particle distribution, what we get, it is a 0 to 1 micron, around 841 micron particles in that; in one patch, 1 to 2 micron around 736, 2 to 3 micron is 76, and hence 3 to 4 is only 6 particles, beyond this size there is no particle.

If I take a mean value, we say that mean value turn out to be 1.10 micron, minimum and maximum is 3.93, there is some sort of deviation of particles. So, here we are keeping two things, one is a spherical particle and as well as particle size smaller, lesser the particle size lesser will be the abrasion; as the clearance is more, particle size is lesser, then it will simply roll you to not get abstracted anywhere and abrasion will be low.

However, if particle size is increased, and the clearance is placed between which rate the particle has to move is reduced, think over clearance is only the 20 micron and I am getting the particle size of 25 micron, naturally it will not be able to roll easily. It will try to damage the surface, either increases the clearance or removes its asperities one way or another way or corners or remove is edges and make shape in such a manner which can easily pass from 20 micron gap.

So, there is a possibility of these two, and we can reduce abrasion by choosing proper size of the particle, choosing the shape or making the shape of particle, In many times if we are not able to complete round shape, particle turn out to be round, will increase the roundness factor during the wear process itself, sharp edges will be terminated or will be smoothen or rounded, it will give a good result.

So, with this I am trying to close the lecturer on abrasion wear. Next lecture will be more emphasis given on adhesive wear, which is very important. We know that adhesive wear is not as harmful as abrasion wear, and most of the components are failing because of abrasion, but adhesive wear can give or we can leak to the abrasion wear, it can give some particles or generate debri which causes the failure due to the abrasion. So, they are dependent on each other, thank you for your attention.