Technology of Surface Coating
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Lecture 36
Assessment of Friction and Wear of Coating

Assessment of Friction and Wear of Surface Coating now let us see what is the Significance of Low Friction and High Wear Resistance for a Mechanically Functional Coating and this is going to be a requirement for a mechanically functional coating in that there will be a sliding between two parts, and these are known as Tribo Pair so it is in fact the tribology of this coating and by that we simply understand that it is actually the friction where and lubrication aspect of this coating.

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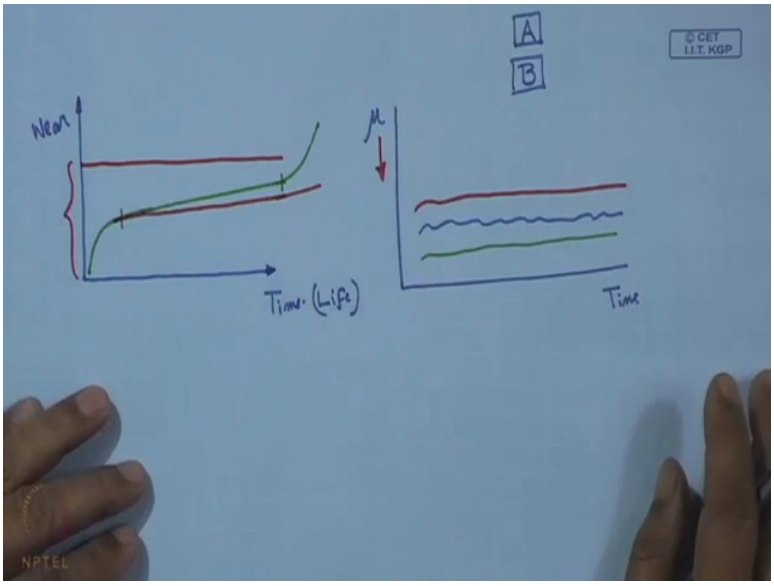

Now one thing we understand that this functional requirement of any mechanical components, so we now consider a mechanically functional component and there for any mechanically functional component we can draw such graph and on the X axis that is the time scale or what we can call life of that part, service life, and on this, that is actually the wear of the part. Now mechanically functional means we can put this in this category, all the mechanical components subjected to this kind of friction and wear it can start from conventional slide guide, it can be screw nut, it can

be (())(02:24) even it can be any cutting tool or a forming tool where continuously this tool is subjected to high load, high speed and even temperature.

So these are the environment under which one mechanical component has to work and in that case this Wear and Time so that graph that means the progress of Wear with time that limits the life of a component and it is obvious that for reliability of service we have to limit somewhere the wear, say this is the limit and that is the magnitude and how quickly this part or the component reach that limit or how long it is for this part to reach that particular limit.

So it can be even it can reach very quickly or it can take a long time and there we find immediately the surface property of that part which is in continuously rubbing action, say a bush and the general of that particular shaft which are also in continuous sliding rotation say screw and nut, now in this case Wear means wear on the screw or wear on the nut. Now, when it is the bush, bearing and the general that is the portion of the shaft which is inside that bush and which is rotating if there is wear and if it exceeds certain limit and that limit is set by the operational requirement and that is actually specified by the designer of that component considering the safe operation of those part.

And here this limit is the given on Wear and at the same time what is also important to understand that this is friction or say co efficient of friction and this is also time. So when we have two elements of a pair say A is in contact with B that means this is one component of the tribopair and that is in B, so A and B it may be screw nut, it can be (())(05:29), it can be two gears, it can be surface of the cutting tool and the chip. So always there is A and B in continuous contact and because of that which is very important to hold the geometry of the important component and at the same time it is also necessary to reduce the co efficient of friction to its possible lowest value.

It is obvious that when they are rotating that frictional force and as a consequence of that power loss due to friction that is of immediate attention to one application engineer so from metal selection point of view it is obvious, the choice will be obvious to have the surface of A and surface of B they are designed and formulated in such a manner that the friction value becomes very low, so here also we have scope of all sort of research development that means between A

and B what will be the co-efficient of friction and it can go like this or it can be above this value or it can be low and it may even change with time.

If we have some surface modification on A or on B to have the desired effect on this value of mu which should be brought down at any cost and also Wear Rate has to be brought down and this is the limit and this limit can go up or go down depending upon the stringent requirement or where we can be little bit liberal to set the value of Wear whatever may be the case, here also we can see a graph for any mechanical component it follows like this and then it goes like this so this is more or less the presentation of a Wear graph that means at the very beginning it starts with a high rate and then the rate slows down and this portion which is more or less straight and that is actually mechanical wear zone. This is initial breaking zone and here Wear takes place, Wear occurs at a very fast rate.

Now, the thing is that when it is the question of friction and Wear off surface coating, one has to look for a particular coating on a surface say the component A and B maybe on the component A we have to have proper surface modification either in the form of coating or just by changing the physics I mean the basic features of the surface of that particular component so that the part A with coating with B in contact then the curve can also take a different shape and our objective will be always to flatten this or to reduce this initial rate, that means the rate of increase will be as low as possible.

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Now here, what we find few of those parameters which can affect this thing and this can be summarized or highlighted here that means these are the factors which in general affect Friction and Wear. If we consider only the mechanical characteristics it is going to be hardness and modulus of elasticity and also fracture toughness. Now when it is the body to bodies in contact it is also absorption of that surface it is a tendency to absorb, get absorbed and it can be a physical phenomena or a chemical phenomena and that may greatly affect this particular Friction and Wear.

Now chemical reactivity, adhesion to that particular surface and having a chemical reaction making a bond formation and that will resist or restrict the movement and at the same time because of this reaction, a part of the material can be removed because it will lose the basic property of that component which is submitted to this high speed high load rubbing associated with maybe high temperature then maybe an environment where this Wear is also augmented so this particular environment can also favor rapid Wear. So these are the thing one should look at and here the chemical reactivity is one of the particular issue.

Now comes surface roughness and apparent area of contact from our common understanding we feel we can feel the surface is smooth or rough and without looking into the chemical aspect or metallurgical aspect that means metallurgical affinity or chemical affinity, even we get a feeling that rough surface means it is going to give higher value of friction force resistance to motion and as a result as a consequence there will be higher magnitude of Wear or the growth of Wear may take place at a higher rate.

So the surface roughness definitely it is a geometrical characteristics of that particular surface and along with surface roughness rough of the surface per unit area of contact and true area of contact so these are the thing coming in picture will definitely those are the thing one has to consider and then comes Load, these are the external input that means the normal load under which these two parts are working then comes the sliding speed then temperature and environment.

Environment means it is a humid atmosphere or dry atmosphere, if it is a oxygen rich atmosphere or it is under normal vacuum or if it is under ultra high vacuum. So taking those factors which are highlighted here definitely one has to find out what is going to be the friction

and the wear finally which determines here this wear and friction and finally they are going to decide what will be the service life and the level of performance and whether that particular A and B it is a good matching tribopair which favors proper functioning of the mechanical component or they are not at all matching pair and they should not be screened as one of the tribo pair, favorable tribo pair.

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Now various tribo pair we can look in actually when we talk about this friction and wear off coating it is in fact, it is actually the whole idea here this is a one step in the process of characterization. Now in the characterization we have seen how this hardness value may affect the quality of coating whether it can be selected or it is not a coating for functional use similarly this is also this step this is also going to be one of the screening step and a ranking step.

So what we can do at best that in this tribological test involving this two component which are having some modification of the surface with a coating or without a coating so they have to be tested and this test is some sort of a simulation test and that we shall discuss in the following section but let us look into various tribo pair which we can see in commonly what we can identify and see in practice.

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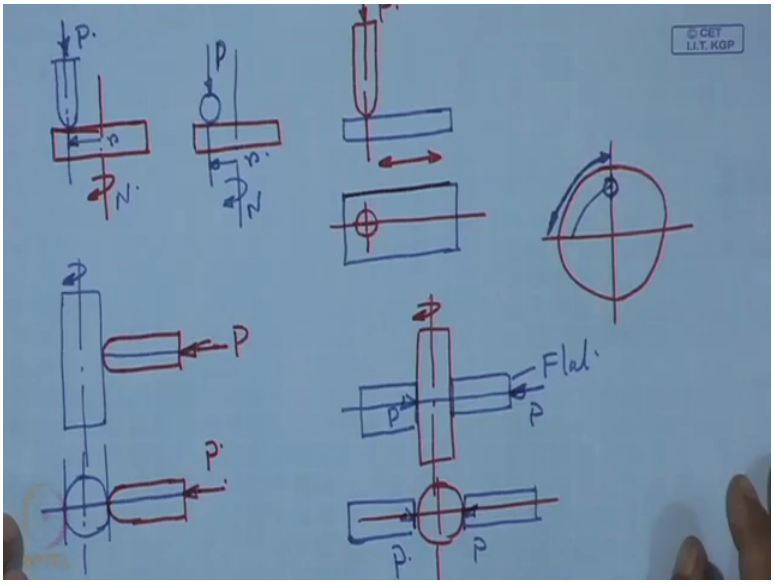

One is simple Pin on disc that means this is a disc. This is a disc and which has one axis of rotation and then on that we can put either a pin or a ball and of course there are all peripheral arrangement so that they are properly fixed in fixture and its serves like a apparatus, so this a pin and this pin is loaded with a force P and this an RPM N and this is the contact I mean this is the radius where this pin is in contact and instead of that pin we can also have one ball, so this is going to be a ball which also have to have a ball holder and the principle of operation would be same.

So this is RPM, so there will be a load and this is the radius so this is called either pin on disc or ball on disc. So whole idea here that this disc which will be which will be coated. so on this coating this ball will be held or the pin will be held against with a force and then they will be allowed to rotate and in this case we expect this wear resistance or weakness in wear resistance whether they can give a good value of friction or a very high value of friction so all those preliminary information can be can be generated and this will be a very important test in screening that is the preliminary screening of those tribo pair. That means whether they can be used in actual machine building as component for reliable service and performance of the machine.

Now pin on flat, what is exactly mean by this pin on flat this is going to be actually a table like look like and here what we have on this it can be a pin so here what we see this is actually flat,

this is going to be the top view and then we have the pin here. So this is actually reciprocating, here it is unidirectional rotation and here this pin is stationary with a force P in contact with this table and that is a reciprocatory motion and here also this pin or the ball those are stationary and this disc is rotating.

We can also have similar thing with the disc, so this will be something like, here we can show it from the top view, so this is the disc, and here we can position the either the ball or the pin and then it instead of a continuous rotation it will have a oscillatory motion say through quarter of a turn so this will be an oscillatory motion it will reciprocate and as a result of that this will move forward and in the reverse direction and there we can expect this sliding mark so this another example of oscillatory sliding using one disc.

Then pin on cylinder, now pin on cylinder means this is going to be a cylinder and this is the axis of the cylinder which is rotating against this we can have one pin and which will be in contact, so this is one way and here we have the front view, so this is going to be the pin that is in contact, so this is example of pin on cylinder that means the pin held against cylinder and that is stationary and loaded with force P.

Now flat on cylinder, now this is something like this here we have a cylinder, so this is rotating and from two sides we can hold two flat plate from two sides and if we see the front view it looks like, so this is going to be the orientation, so this is actually flat on cylinder so these are the flat and loaded with force P from both ends, so this is also another tribo pair.

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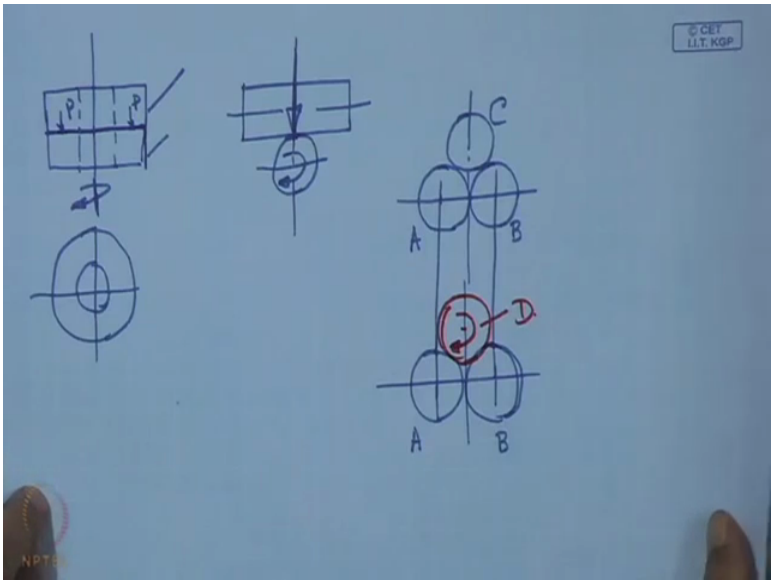

Now comes a thrust washer, so in thrust washer what is done one washer will be held stationary so this is one washer with this center line and this will be held against this one which is rotating. So there will be a thrust force so the top one will be held against a force against this one so there will be the contact force and the bottom one that will be rotating, so this is also another tribopair, this is stationary and this is rotating but both are just like washer. So this is actually thrust washer.

Cross cylinder, cross cylinder they can also form one tribopair in that so this is one cylinder at the top and at the bottom this is another cylinder so they are at right angel. So this is stationary, the top one is stationary so here we have the load and this bottom one that is actually rotating. So this is also another tribopair so this is a cross cylinder so that we can see. This is also used for assessment of friction co-efficient or the friction force and that of the Wear.

Now Four Ball Tester, Four Ball means actually if we see the top view then we have three balls here this is the top view and then we have the third one it is something like this so that is the top view and all are resting on a horizontal plane and if we now consider the front view so considering the front view what we going to get here.

So this is going to be this cylinder so that means this is A, this is B and that is C. So this is A and that is B and C is behind A and B and here what we have to do we have to bring the cylinder D so that means this is going to be a cylinder here and this is going to be a cylinder like this and

this will be actually a cylinder which will keep on rotating and the force will be supplied from this side, so this is also one tribopair where this top one D that is actually rotating it is a having a sliding spin and this is supported by A, B and C. So this way also four ball constitutes one tribo system where also one can assess the friction, force and also the wear in the tribo system.

So these are the various tribos pairs which can be used actually this is going to be a simulation test simulating the actual situation for, actual situation which is prevailing in the actual engineering system and just for selection of the material for making those components of the actual system we have to have to carry out a simulation tribological test, it is for ranking or screening the particular tribopair and this is here what we are considering the material aspect whether materially material wise whether that selection is compatible and selection is justified and we have a proper selection.

So it is Simulation Test for Friction and Wear. Now one thing we have to definitely here careful that this simulation test means as close as possible to the actual system and actual condition otherwise this will lose its purpose and relevance that means where it is the force, the velocity, sliding velocity in and also the environment and also low temperature or high temperature tribology that has to be also taken into consideration the coating whether it is going to be used at high temperature or room temperature or a moderate temperature whether this coating is going to be used in severe humid environment or it is going to be in the dry environment whether it is going to be in high vacuum, so all these should be arranged and all this condition should be maintained to make this test meaningful and the results useful.

Tribometer, now this is actually the machine where all the apparatus where we can carry out the tribological test. Now tribological test now this is done this can be carried out in a pin on disk, we call it pin on disk machine or ball on disk machine, this is a common thing in all sort of tribological assessment of coating or any component which are under sliding or rolling contact and this is actually the tribometer.

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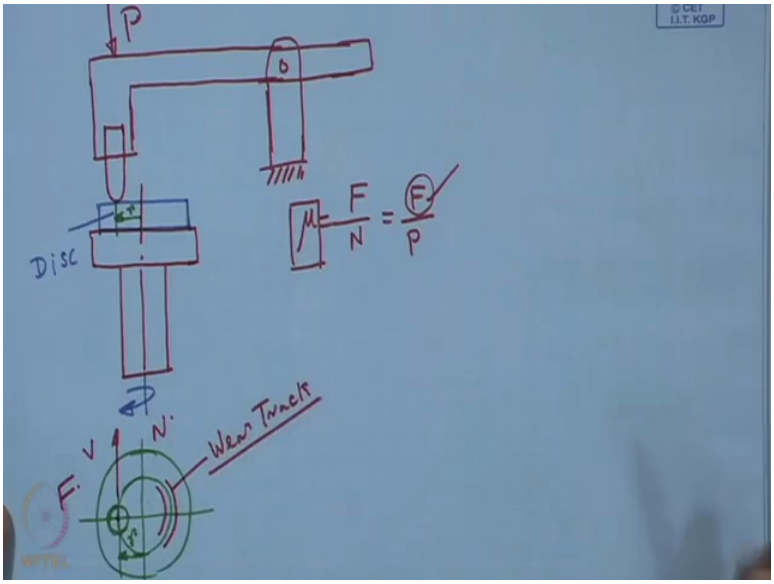

Now basically in tribometer what we have, we have a table and this table is a rotating table so on this rotating table with proper fixturing we have to have the holding of the substrate so this is the substrate and here we can put this substrate and all these are standardized considering this international understanding that all this test should be conducted under a well set well specified condition so that this results can be compared, results can be analyzed and from there we can find out the meaningful results, meaningful observation which can be useful for further use of this results in actual application.

So this is going to be the specimen and this is the disc and this is at a rotating table, now on that table what we are going to have here we can have a pin or a ball so let us consider this to be the pin and this pin will be actually held inside a pin holder and this is actually one arm, this arm is pivoted at this point and here what we apply that is the load in most cases a load means this is actually a dead load is applied it can be say for example it can be as low as 1 newton or millinewton it can be as high as few tens of newton it depends upon how we are going to simulate the situation following the actual system or actual conditions.

So this selection of the load and selection of this RPM and then what we find here clearly that this is going to be the radius that means the radius, sliding radius. So here what we find if we consider the top view, so we can find say this is the location of the pin, so pin is in contact at this radius and this is the radius R, so depending upon the radius RPM can be changed and here this

load is fixed for a particular assessment and what we have here actually this is the normal load and for this, this is going to be the circle which will be followed by this point which is submitted to sliding.

So this is the circle which will be followed by this point of contact between the pin and the disc and ultimately a wear track will generate on the surface. So first we can see a line appears and then this line will increase its width about its mean position that means this is going to be wider with passage of time and this is, this we call the wear track, wear track on the disc, wear track. So this wear track will be continuous ring like thing and this we can, one can recognize on the top view and what is important to know in the direction at this point this is the sliding velocity and this is also the direction of friction force which we can show by this symbol F.

So if this friction force has to be continuously monitored, this friction force, so this friction force has to be continuously monitored and then F by N, F by N that is going to be the co-efficient of friction or say in this case this is F by P, P is actually the normal load so this is actually co-efficient of friction, since P is constant all through so co-efficient of friction that will be a true reflection of the friction force or friction force is reflected by this co-efficient of friction.

So here two thing we can look at, that this force has to be continuously monitored and on this arm, this arm it is almost like a elastic member, that means it subject itself to some kind of very precise close I mean restricted deformation and in that case what we have, we have a strain gauge type sensor that is a transducer it can be LVDT type Linearly Variable Differential Transformer or Piezoelectric type.

Your sensor or transducer that can measure this friction force with high possible precision to have capturing the data which will be very useful for analyzing the whole performance of the coating so this is actually the strain gauge, piezoelectric type or LVDT that will be put here and in this direction as the force is acting that will be recorded in this direction, in the direction of the velocity and that is exactly the job of this tribometer, continuously monitoring and recording the force of friction.

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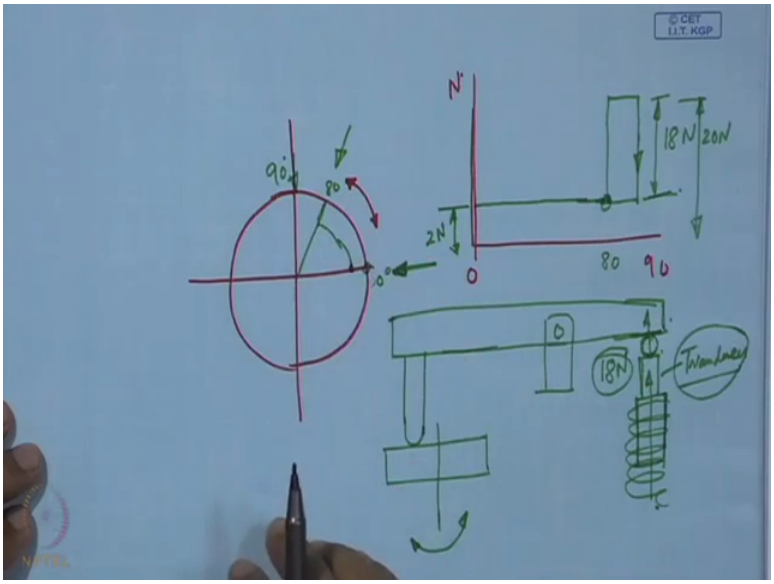

Now this is a Rotating Specimen we can have a rotating specimen continuously rotating or we can have reciprocating specimen. Now, as we have already mentioned if we consider just one disc, this is a disc so either it can rotate continuously or it can reciprocate, similarly what happens, we can have a load which is constant or which is variable this is particularly important, this variable load that is also to simulate one real life situation that means this tribometer that is to be one versatile machine, versatile device to simulate most of the situation as they do exist in in practical life and it is where we try to simulate this situation.

That means in reciprocation say for example the reciprocation is from 0 to 90 degree say this is the start from where it reciprocates and it goes to 90 degree and then coming back to its original position and here we have the load, normal load. Now what we can put, normal load say for example like 2 newton, so 2 newton from the where the very beginning, from the start so as it starts reciprocating we have a 2 newton load.

However when it makes about 80 degrees, it is 0, it is 80 and 90 degree, one quarter of a turn and then moving back , now when it comes to 80 degree say for here this is 80 degree, the load should increase immediately so that has to be arranged in the tribometer to simulate a very special situation as demanded and in that case what we can see that in this tribometer, this is the pin and then we have this arm, horizontal arm, this is the pivotal point and that is the extension of the arm and here say we have the disc which is actually oscillating.

So this is actually a oscillating over say 90 degree as we have shown here so here what happens, here we have a point support with a ball and just below that we have one electro-magnetic device and which will be energized in this direction this electro-magnetic device and which will force this transducer to apply extra 18 newton, so this 18 newton comes from this side it is an additional load and this load is applied when this rotation, when this oscillation is just upto 80 degree, that means when this rotation has taken place through 80 degree immediately there is an activation.

That means there are all what we call this capture switches are there, so one switch is here and this is another one so at the moment when it comes to 80 degree immediately this is activated and the load is applied and this is actually 18 newton, so total load applied between 80 to 90 that becomes actually 20 newton. So this is continuously this way it is working and after moving to 90 degree that means this limit again it is brought back to 2 newton that means this load is 18 newton that is withdrawn.

So this 18 newton that is set by the transducer and for that what we have here one electro-magnetic coil and that current has to be set in such a manner that this transducer only exert 18 newton and that will be recorded here and accordingly the current setting has to be done here so that 18 newton is displayed in the display unit and which is the force exerted by this piezoelectric transducer. So this is also another very special application and this is also to simulate a situation where in actual condition load is actually, it is a reciprocating device where at the end of the reciprocation, almost at the end of the reciprocation, the load which is applied against the disc that keeps on changing and that is increased to a higher value.

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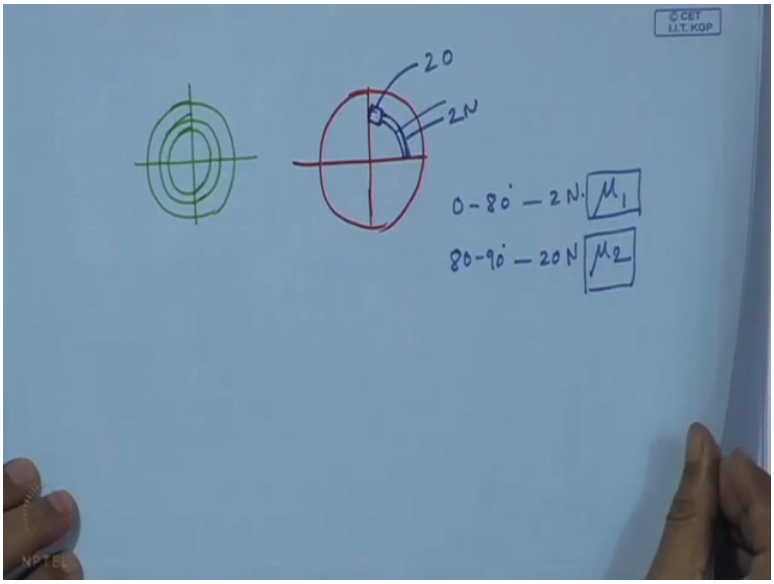

Now here what we can see that in normal case we expect a wear track of uniform width. However when it is this type of system is special tribometer, this is for a conventional tribometer and which is has a unidirectional movement but when it is this reciprocatory tribometer with alternate sliding in this case we do have the disc but here reciprocation is restricted only to 90 degree and what would be interesting upto 80 degree we have a wear track of this width because the load is now 2 newton and then from 80 to 90 within this 10 degree because now the load is 20 newton the shape of this wear track that will be little bit enlarge.

So we expect this enlargement of this wear track over this and that will be recorded and also the friction, co-efficient of friction that should be also measured from for 2 newton that means for 0 to 80 degree it is for 2 newton normal force and we have a friction value mu 1 and from 80 to 90 degrees, this is going to be 20 newton and for that we have a friction co-efficient that is mu 2 and the instrument should have proper electronics hardware to capture those signals one is corresponding to 2 newton normal load and in the last phase it is going to be friction co-efficient which is corresponding to 20 newton. So we understand this constant load, variable load, alternate sliding and unidirectional sliding.

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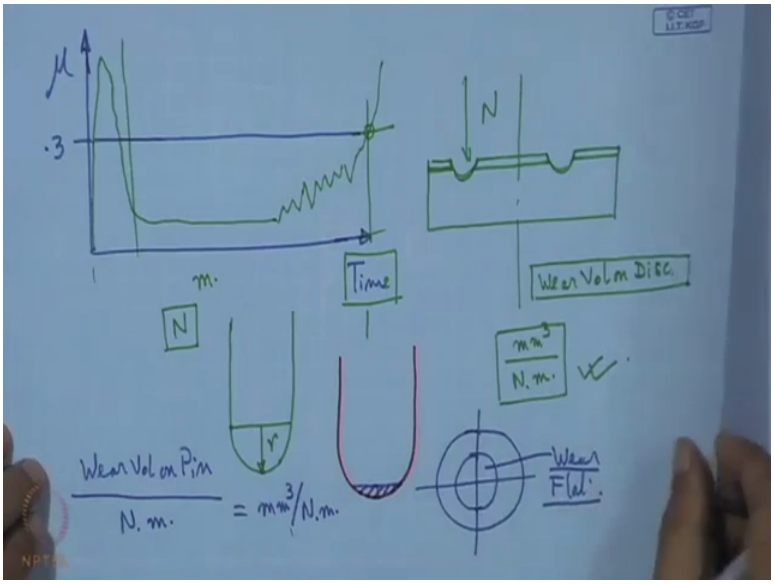

Evaluation of Performance of the Coating, now this evaluation of performance of the coating, here actually what we see that it is actually the co-efficient of friction and on this side we have the time and it is a standard practice to put 0.3 as the life of coating. That means when this coating friction co-efficient exceeds 0.3 then we can say the life is totally exhausted that means for a matching tribopair one has to keep the friction value well below 0.3 and a good tribological coating can give a value much below 0.1 and that is the performance level of a tribological coating.

So here we can see that from the initial stage it may so happen that this friction value goes up as it starts with this normal loading it can go up and then it can fall and it can go like this and finally depending upon how this coating survives and how does it last there can be some partial fracture of the coating and that will be recorded like this and then it goes like, it goes up and this means that the coating is removed.

So what we actually meant to say here that this monitoring the value of friction with time that gives a clear indication about the performance of the coating as reproduced or as pictured by this tribometer and at the very beginning this coating shows a very high value and this may be a phase what we normally call running in period. So the geometry of the pin and that of the coating on the disc, they adjust itself and once that is stabilized it come to a very good value.

Now this to get a very good value obviously at the very beginning what we have said that roughness of the substrate surface that its high point sub surface as far it is, apart from the chemical inertness or very low chemisorption those conditions are there hardness of the substrate that should be also properly monitored and that should be also properly taken care of and then only a tribological coating at the top of that it can work. But this map clearly shows how good or how poor the coating is and how long it can survive.

So looking at this graph one has to find out different graph for the same coating it can be a PVD physically vapored deposited or CVD coating, it can be galvanic root, it is a particular material and also the structure of the coating as it develops because of the synthesis process whether it is in the fine atomic scale or it is grain coarsening, all this methods will come in picture apart from the basic roughness of the coating. So this is one thing one has to look in, in this total map friction versus time.

Now measurement of Wear and Wear co-efficient, now this wear co-efficient actually as we see the wear track and if you see the cross-sectional view what you can find that this is going to be the cross-sectional view of the coating if it is the frontal cross-sectional view, in that case this is actually the coating and what is the volume that is removed from this wear track and this volume can be calculated that means wear volume on disc, this is one wear volume on disc.

So this is one of the thing one can measure and then what we have to also look in that means the normal load that is the normal load which we express as in and also the distance travel, this we can express as time but this can be also expressed as say for example by so many meters so this is the distance travel by this spin so this is also one way, so now it is newton meter, so newton meter so wear volume that is in millimeter cube divided by newton meter and this newton meter, newton means the normal load here and how much distance it has travelled so that we know as the wear co-efficient for the disc.

Similarly for the pin, it can be pin or the ball, so this is the original shape of the pin it has certain radius but because of the wear we can have. So this is the pin, now because of the wear this area may be removed, it has disappeared so on the pin what we get it is something like this it is an wear flat area, so this is actually the area that is called Wear Flat. So this wear flat, so from this

width of this wear flat diameter and this depth that is also calculated, this volume can be also determined.

So the wear volume on pin divided by this newton meter that means this normal load travelled a distance of so many meters, so wear volume that also is given by millimeter cube per newton meter of this distance travelled and the normal load, so from this we can have fair assessment of the wear performance or wear resistivity, wear resistance and also at the same time this friction so this is one of the thing one has to look in.

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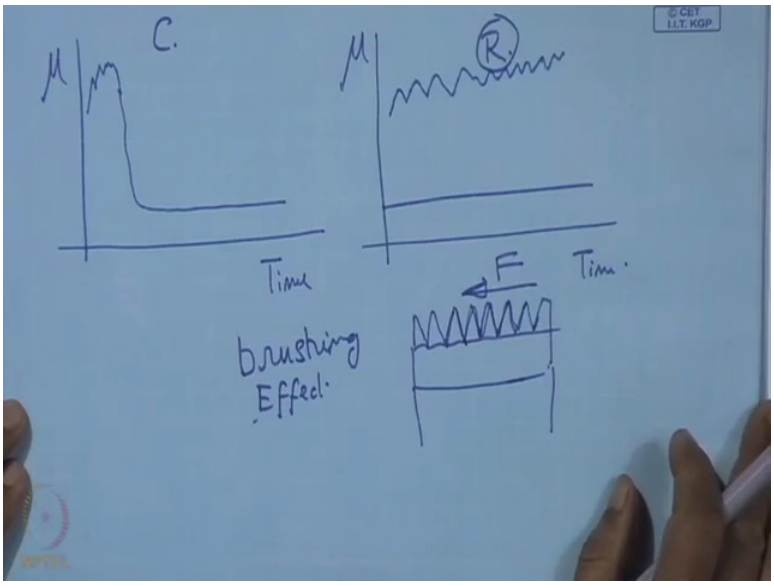

Now comes, if it is a reciprocating sliding in that case what happens we can illustrate quickly this to with time, and this is continuous sliding and that is reciprocating sliding, a rough coating there is a fair chance that initially it may be rough and it can come down because of this running in period and smoothness. So it is moving in the same direction and we have a smoothening effect, but when it is a reciprocating coating there is the chance there is a risk that it can go like this and it will not come to a very, assume a very low value.

So chances are remote, the reason is as follows, if it is a reciprocating coating in that case the rough surface on the coating which is on the substrate, so there is the sliding force which is force of friction and it is actually changing its direction so this columns which are tin like column they are subjected to this alternating change reversal of the force and this is exactly called brushing effect and because of this brushing effect there is every risk that this coating architecture this

coating which is build up here that can be torn here and ultimately that whole coating will be removed and force will be quite high.

So when it is a otherwise rough coating which is produced by any vapor deposition process it is important to smoothen it or to polish little bit and then only to put in alternating sliding but when it is unidirectional sliding in that case after a initial rise it can come to a very low value of friction because of this running in and smoothening of this coating.

So this way we can look into this various aspect of tribometry that means the measurement, the science and engineering of measuring the co-efficient of friction then the resistance to wear of the coating and for a particular coating, the behavior it can vary depending upon the structure of the coating, crystallographic orientation of the coating and sometimes the coating is also sensitive to humidity.

A particular coating which runs and works excellent, its remarkable performance is well noted under high vacuum that shows a very poor performance when it is just a humid atmosphere similarly, a coating which cannot work under a light load work pretty well under a heavy load. Similarly, a coating which cannot work at a low spin can work at a high spin, but in some cases we do also need coating which can work under heavy load and low spin because in those cases there is chances of stick slip and jerking motion and which is not very stable and that will create problem for micro movement of any mechanical device so as a result of that what we find the problem in those mechanical system.

So naturally in those issues we can determine or we can rank the coating according to the requirement and this requirement may be high speed (())(57:07) it can be low speed high load, it can be high temperature, it can be high vacuum or it can be oxygen atmosphere or it can be even humid atmosphere. So with all this aspects taken into consideration this measurement of the co efficient of friction and the wear on the coating.

These are definitely a guideline for ranking and screening the coating so that finally those materials can be properly chosen and selected and one of the best tribopair can be engaged in building the actual mechanical system and mechanical device.

So with that we can make a summary of this discussion that pin on disc or ball on disc machine known as tribometer is commonly used to assess tribological performance of a coating. The test conducted in tribometer is a simulation of the actual situation and an effective simulation requires acceptable similarity between actual system and the test specimen and condition. The test can be effectively used for ranking coating materials for functioning at different condition of load, speed, temperature and environment.