Video Course on Tribology

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Lecture No. # 01

Introduction

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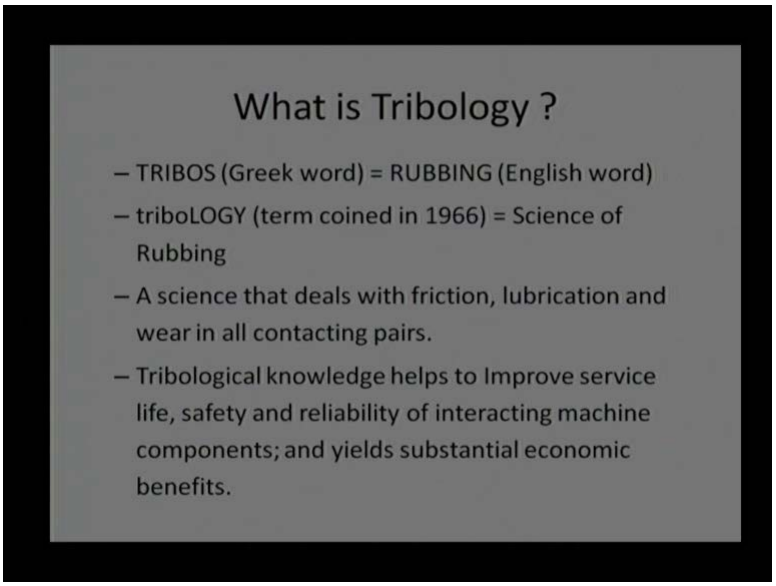

Welcome to course on Tribology. This is the first lecture, introduction to Tribology. First question comes in mind to what is the meaning of Tribology. Is it related to travels? Is related to anyway some village related thing? In real fact it is not. It is been derived or this word has been drive from Greek word TRIBOS meaning of TRIBOS is rubbing. So, you can say the Tribology is science of rubbing. This is one of the easiest meaning or easiest definition of Tribology. However, slightly difficult definition is that Tribology is science that deals with friction lubrication and wear of all contacting surfaces.

Here, meaning of the contacting surface is that two surfaces which are an intimate contact and subjected to load have some relative speed. So, contacting pairs having relative speed subjected to load comes under the tribological field. We need to understand that subject or thus contact here using tribological knowledge. As I mentioned, this is slightly difficult definition reason behind is that friction itself is a

statistical parameter. It can never get constant value of friction even though if you repeat experiment again and again will never get constant value. You can get some mean value and some misunderstand variation.

And ratio of mean to extended deviation will always vary depending on whether is the direct contact, mix lubrication or full film lubrication. Better the lubrication mean to standard deviation value will increase. Another point is that we where kind of mechanism we have too many mechanism may be more than thirty two mechanisms. So, understanding all those mechanisms is slightly difficult. That is why we say that this is slightly difficult definition and lubrication science itself is a complete subject and we need to much friction, wear and lubrication in one subject that is why its slightly difficult definition. However, if we understand friction, wear and lubrication gets some knowledge and apply those knowledge to the real machine components.

It will lead to improve service life, improve shift softy of the components, increase the reliability of the system. So, if you are able to achieve all this naturally they will be drastic substantial economic benefits.

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So, you can say this tribology is most important for all machine elements. We need to understand this machine elements science related to friction, wear and lubrication of these mechanical elements. To get a better feeling let us start with few examples.

First example which I am showing in this is carbon graphite seal. This carbon graphite seal is made from powder by competing and centering that powder and when it comes into contact with is stainless steel shaft or some other material; there is the possibility of intimate contact, relatives large sliding and applied load. So, it makes a tribo pair. You can see there is some mark some destruction on the surface. It appears some material is removed from this surface and transfer to some other material this is known as adhesive wear occurs because of tribological phenomena, but, it can be delete it can be restarted it can be reduced, by proper knowledge of the tribology.

If you can reduced that; this kind of surface irregular surface can be reduced. That will reduced smooth or roughness increase smoothness and if there is smooth the surface more and more contact then there is a possibility of lesser stress. It as a lesser stress serviceability will service life of the component will increase. Another view, if I make extra smooth its absolute nanoscale smooth surface that will also cause some problem. So, we can say there is always a trade off between roughness and smoothness and understanding that understanding that trade off we require good tribological knowledge. So, we require this course.

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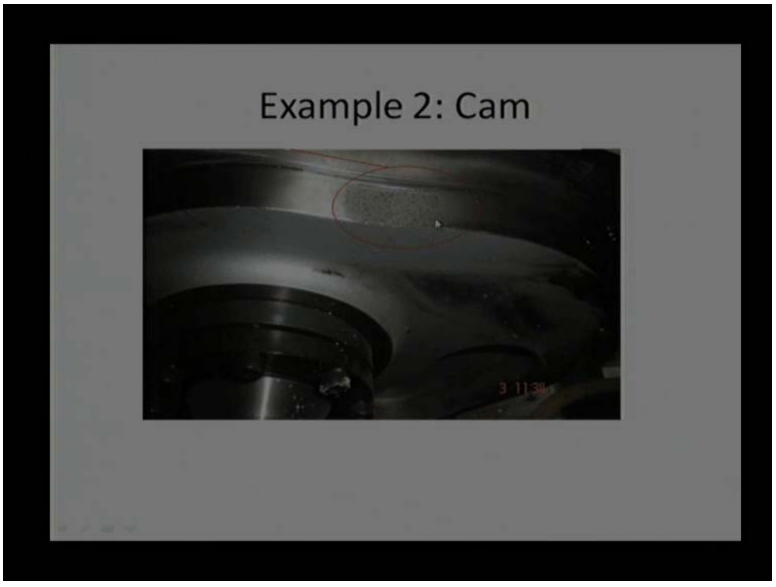

This is what I have shown earlier there is adhesive wear. We call as adhesive wear because occurs because some intimate contact between new surfaces and then removed from one surface to other surface or transfer from one surface to other surface. Let us

take another example. There is cam, you know cam is used to impact rotary motion and cam follower appear can be used to change rotary motion to the sliding our (( )) motion when cam failure occurs or occurred in one tooth paste company, one tooth paste factory where this kind of the pitting failure occur this pits was generated because of the fatigue wear.

You know very well if we drive car on irregular surface there will be lot of noise, vibration that will cause fatigue. Same thing happen in this case. Due to irregular surface or we say that number of pits noise generation increased. That caused machine failure. That can be avoided if you have proper knowledge related to tribology and this can be named as this figure or can be named as pitting wear of cam surface.

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Let us take another example related to journal bearings. We know journal bearings are used to support radial load. Generally they have infinite life if they are properly designed.

I have shown the two figures left hand side figure is bearing of an Ice engine or it call as a crane shaft bearing. You can see the number of crashes on this bearings surface or we know in term this as abrasive wear. Well, right hand side this an another aluminum bearing is also an general bearing, you can see there is a more amount of the wear. What we call as rubbing wear where the sharp touches to the bearing surface and runs along with that. Try to scratch the surface with more contact. You can say this kind of wear

occurs when there is a heavy load on a bearing or relative speed is low. Sliding a speed is lesser than desirable.

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This kind of failures can be avoided by enhancing the relative speed, reducing load or flittering the lubricant, but, we require proper knowledge to target those ends, to that we will that is why we required tribology course. Let us taken another example of magnetic bearing you see magnetic bearings are known for non-contact levitation, zero wear. We did this experiment in our lab assuming that common in magnetic bearing under reputation levitate shaft without any contact, but, it did not happen shaft was tilted its shown, started is loading on the bearing surface and due to that edge loading you can see there is a enormous wear. It is not only levitation frame, but, even it cause a much more as compare to and ordinary nonmagnetic bearing.

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So, we required good knowledge, good tribological knowledge to design this kind of components. We can name this figures as wears scar due to edge loading as I mentioned shaft tilted is shown under operating conditions and cost edge load. We did not impose any side load in edge load in that. It happens is. So, unnecessarily operating conditions. Let us take another example this multi row roller bearing is four row roller bearing and I am showing only the figure of outer ring wear cracking happen under savior operating conditions you can see there are deep cracks through and through cracks.

Now, these cracks happen if we do not mount bearing properly. So, these bearings fail because of improper mounting. That can be avoided if we grow through tribology course understand physics of tribo-pairs and we can really avoid the failure of this big roller bearing which cost huge amount. It is not only initial cost, but, spot edge of cool rolling milk cost much more production loss.

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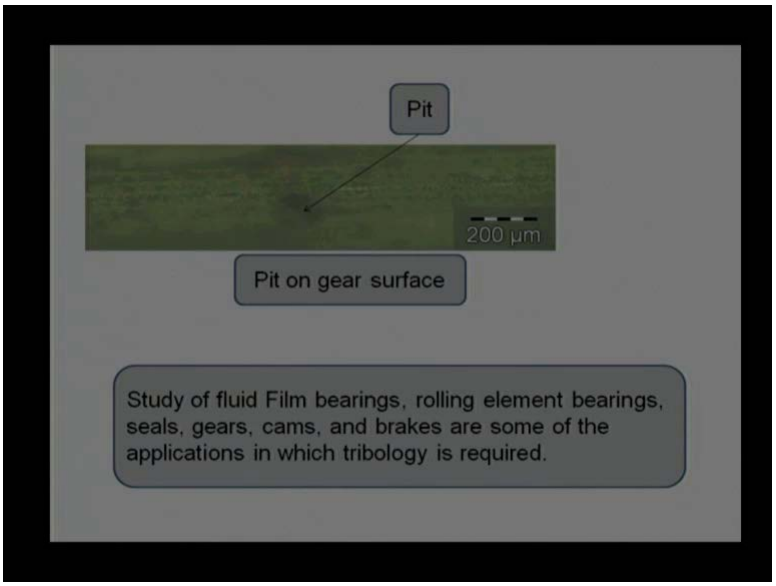

So, here over all much higher lost compare to bearing costs of this. This is another figure you have we are showing the gear failure this is assume picture of gear tooth. You can see there are one pit second pit third pit. So, this happens near the pit circle damager, just below the pit circle damager. Due to this kind of picture ration get operation gen is lot of noise and which is generally not acceptable by customers. So, we need to open assembly gear box and replace this gear. That means, this pit is causing production in service life of gears. That can be avoided by proper lubrication if you understand lubrication properly we can avoid this kind of failure or we can reduce this kind of failure or we can say enhance life of the components.

So, this is shown a pit and we can label this figure as pitting failure of gear surface. Apart from this examples there are number of other examples, number of other kind of fluid film bearings. There are more than 20,000 rolling element bearings. Number of seals elastomeric polymer, ceramic scenes, cams various kind of cams in the break materials, every of this component involve some tribology and we need to understand tribology to do a better design of this machine elements.

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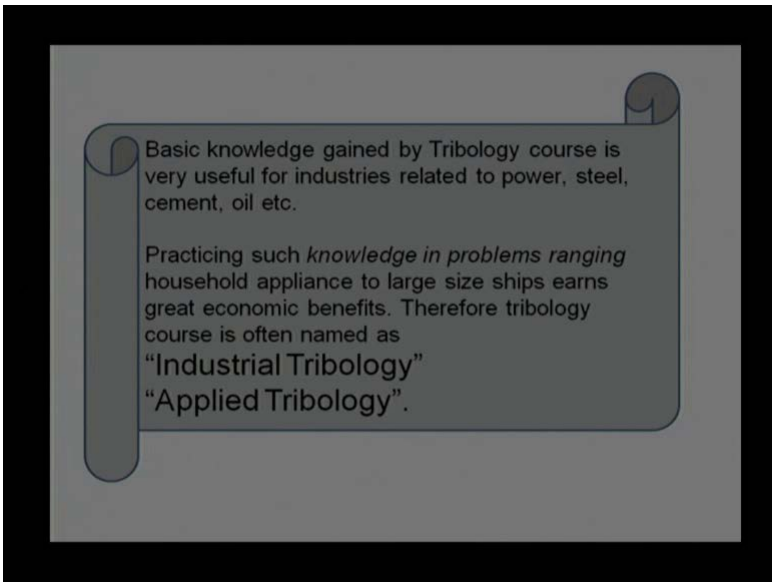

So, we can say if we understand the basic knowledge; we gain basic knowledge of tribology that will be helpful in a industries like power generation industry, steel, cement, oil industries.

Apart from these major industries even we can use the tribological knowledge in household appliance as well as very big machine component or big machine assemblies like ships, aircrafts. As this course is highly related to the practice industry; that is why many time this course is known as industrial tribology, applied tribology.

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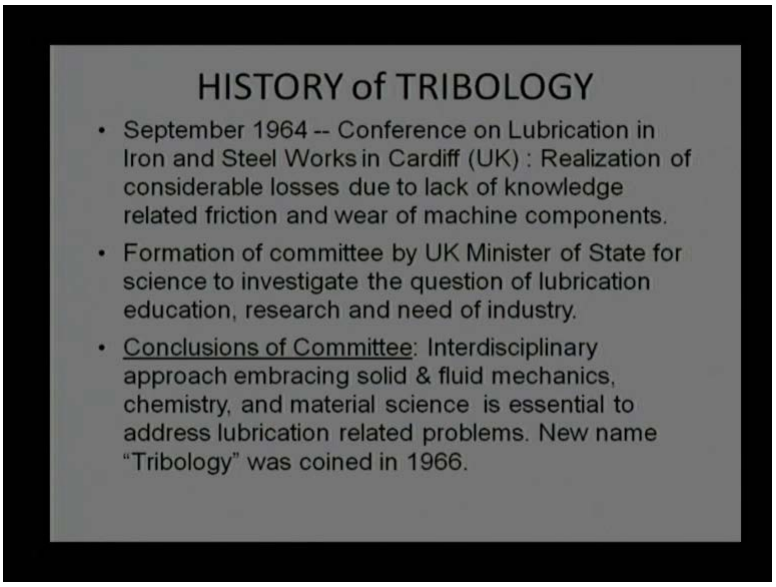

So, once again welcome to this course. I believe I have conveyed the meaning of this course importance of this course. Let us just go back how this course is started. How this topic was coined. In somewhere in 1964, there was one conference in UK Cardiff; where most of the engineer service engineers from an iron and steel industry participated, they issued, they expressed failures which happened in there industry and to surprise this kind of failure happened because a lack of knowledge related to the lubrication, related to the friction and wear. These points word convey to UK minister of the science and he wanted to reduce this kind of losses. He formed a committee to look at look into those matters related to friction and wear of those industries.

This committee took almost two years and gave final conclusion that reduction and friction and wear of iron and steel industry machine components is not an easy task. It requires inter disciplinary approach. It requires knowledge related to solid and fluid mechanics, chemistry of lubricant, material science of surfaces, bulk material also. So, that inter disciplinary approach was essential to address problem raised in conference 1964. And there was no common word available the committee chairman Peter Josh contacted oxford in dictionary people and then came up with a word tribology. As I earlier mentioned the tribology is derived from the word tribos which mean rubbing.

So, thus easiest definition science related to rubbing is tribology. But, difficult definition is difficult definition is this course, this topic is related to friction and wear of contacting surfaces which involve number of difficult topics.

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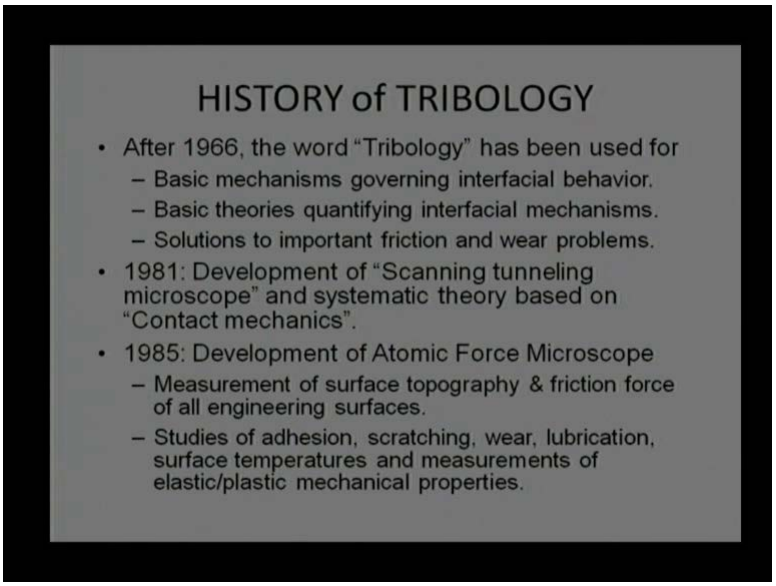

To continue this course after 1966 when that term was coined; wherever people have given mechanisms governing interfacial behavior that mechanism must turn be termed as tribological mechanism.

Wherever the theories were used to quantify interfacial mechanism; theories where related to tribology. Wherever solution where impact were given to reduced friction and wear problem; solution will termed as tribological solutions. Major development happen in somewhere in 1980's due to development of scanning tunneling microscope that provides good surface reference profile in non-contact surface profile without damaging to the surface.

However, one major drawback of this esteem was conductivity it require material to be conductive. So, it could not be enhanced, it could not be use for almost every material. However, that was satisfied in 1985 where the development of AFM. We have we known as atomic force microscope was developed. Major purpose major aim of a f m is to measure surface the typography and some addition it can use can be use for the friction force measurement requiring number of tools. This kind of instrument can be used to study adhesion which causes of adhesive wear, adhesive friction, scratching. It causes abrasive wear, some other wear mechanism like fatigue wear, corrosive wear, lubrication thin or thick lubrication. It can be used for finding elastic and plastic mechanical properties of the surfaces.

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So, after 1985 we can say that big who came in tribological field were this components where used extensively to study almost all tribe-pairs to understand this tribo-pairs enhance sufficiency of move machine elements and get overall economic benefits. Interesting! This course has been taught in number of engineering colleges and science colleges at the alimentary level. Only problem is that this course as been thought at very basic level. The meaning of the basic level is that most of the, these laws which are given or written in books of base on experimental results.

It is something like friction force is proportional to normal load. In other words if friction force is constant normal load is constant, coefficient of friction will remain constant irrespective of temperature condition, irrespective of lubrication conditions which is absolutely wrong. This kind of sentences or these kinds of laws are applicable in very narrow domain. Let us taken an example we say static coefficient of friction is always greater than kinetic coefficient of friction right. It is only used for the metals. The most of the polymers static coefficient of friction is lesser than kinetic coefficient of friction. And have velocity higher coefficient of friction occurs.

So, this loss which we studied in earlier classes we are restricted to very narrow domain. It cannot be applied in general. We require a course with wear where we can understand this loss and we can utilize for almost all machine components. Another problem is that why we this course has not been taught in earlier engineering colleges and science

colleges. The reason I can say is that this course is a slightly complicated and it interconnects a number of subjects, getting mastery in number of subjects and teaching that course is slightly difficult. That is why it has been always avoided. But, we require two integrate knowledge come from solid mechanics, fluid mechanics, chemistry, material science etc etc. in one course and that is why we are purposing this course.

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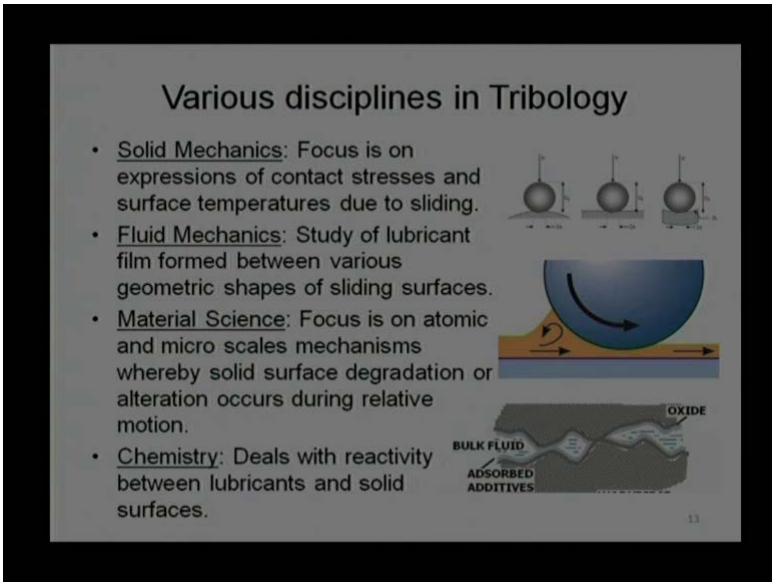

So, that overall economic benefit can be achieved is through learn and then apply on machine element components. As I mentioned that we want to integrate number of subjects in one subject. Naturally, we need to think what are those subjects? I can broadly see there are four subjects which we need to be integrated into one subject; one is the solid mechanics, course fluid mechanics, material science and chemistry.

Solid mechanics is generally related to the forces, stresses strings will be interested to find out what are the contact stresses as a function of surface temperature during sliding. Now, this can be contact, can be between two convex surfaces, convex science, flat surface convex and concave surface. Interesting thing about this subject is that what we generally treat it as point contact or line contact. It never happens. It is always the surface area contact which need to be examined properly to get overall good results. When you think about the fluid mechanics they are more interested to find out will there will be any fluid film between contacting pair? If there is a fluid film we now contacting surface can be avoided or contributing two surfaces can be avoided.

That will help minimizing wear, reducing the friction and bringing more and more stability in friction experiments. In another words if the surface is lubricated; friction behavior will remain by and large and the same level slide extended deviation. But, if the surfaces are under dry contact then, there is more chance of friction, variation or extended deviation. The values of friction will be higher. Similarly, material science it deals with atomic and micro scaling, micro scale mechanisms. We understand how surface is degraded. If we understand the surface degradation degradation then we can modify our fluid mechanic and solid mechanics Related theories and get better and better results. Final subject which we are planning to integrate is chemistry. We know the lubricants have some chemical form. You want to know whether those chemicals will spread uniformly on the surface, will attach two surfaces strongly. If it is possible then, requirement of the lubrication or wheel lubrication will reduce. That will help us in reducing overall cost required for lubrication of wheel, lubrication of the surfaces.

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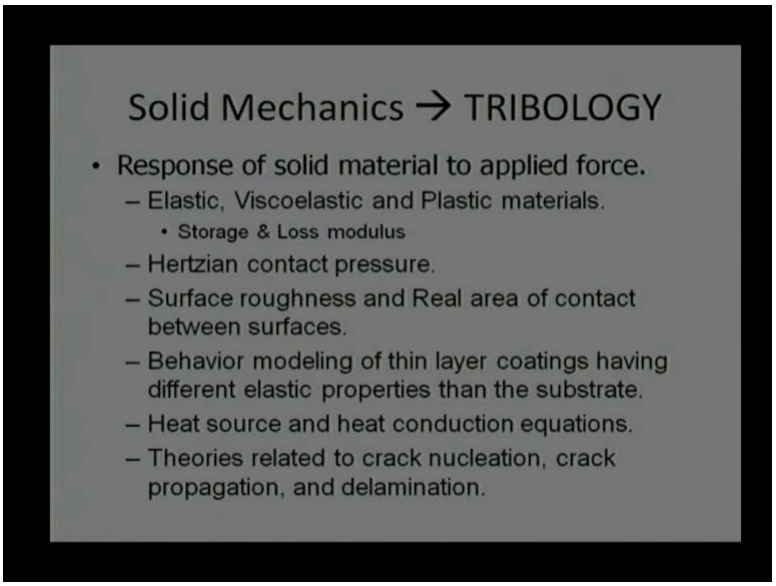

So, we are planning to integrate these courses in one course name as Tribology. Some more detail about the subjects, the solid mechanics you say that solid mechanics is related to the applied force. Under application of force; material may behave as elastic material, may behave as visco elastic material or may behave as plastic material. Generally we distinguish between this material based on storage and loss modules. If very high storage modules we can say the material is elastic, very high loss modules we can say material is visco elastic or viscose nature. What are the important topic in this

subject is something like a word hertz a contact we need to find out what is the hertz an contact pressure.

What kind of stress it will develop? But, this is also related to the surface softness by changing the surface roughness as in contact facial can be changed as we know changing surface roughness will change real area of contact. So, that will change contact pressure. Sometime we required thin layer modeling of the solid surface if the top layer is behaving different manner compared to the bulk material. Solid mechanics to some extent will be related to the heat source because of the heat generation due to friction and heat getting conducting away from the surfaces. So, we are involving heat equation to get overall good results. In addition to that, we will be using some sort of friction mechanics where we need to understand how crack is nucleated. And the loading condition how that crack propagates and finally, delaminated from the surface. So, you relate friction mechanics with solid mechanics. So, that we can utilize this subject for Tribology courses.

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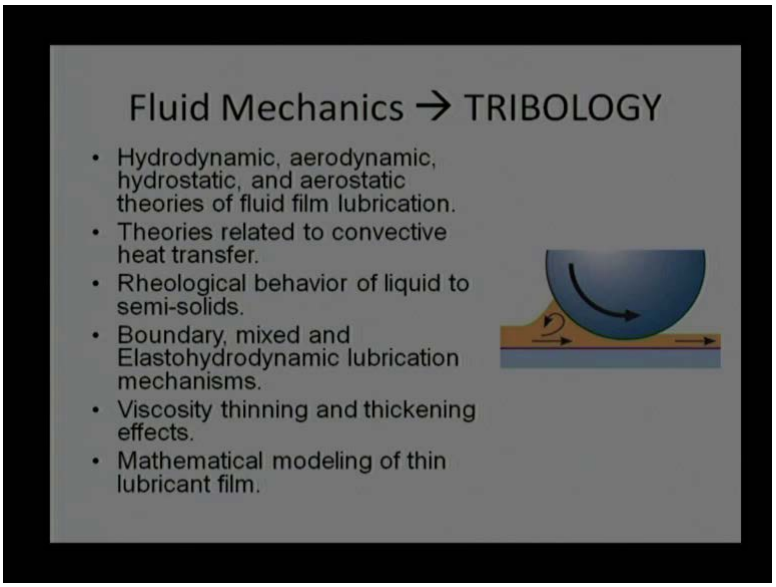

Coming to the fluid mechanics there are two major type of the fluid mechanics; topics in this one is that pressurized, one self pressurization or external pressurization. This kind of fluid which we are using, we can name this topic as hydrodynamic aerodynamic hydrostatic and aerostatic van large hydrodynamic and aerodynamic mechanisms will remain same only fluid and fluid property will change.

In aerodynamic, we need to account compressibility of the air. So, governing equation will involve density term. Well, in hydrodynamic case, density term can avoided because under pressure liquid is generally non-compressible and that will simplify to some extent. Solution, in other word aerodynamic solutions will be slightly difficult compared to hydrodynamic solutions. Similar case is with hydrostatic and aerostatic aerostatic means we are using some compressible gas hydrostatic we are using liquid, but, under external pressure.

We are pressurizing from outside as well in case of hydrodynamic aerodynamic pressure is generated because of the related velocity is self pumping action. Apart from these theories will be trying to related relate the convective heat transfer, coefficient in solid mechanics is generally connection is treated well in fluid mechanics. Connection heat transfer can be treated properly will be studying some rheological behavior of liquid. We know viscosity will vary under temperature under velocity of sliding conditions.

We will be studying the liquids along with semi-liquid. It is taken extreme a typically example of the grease. Grease is a semi solid substance. If you want lubricate bearings with grease; we need to have rheological model and two use that rheological model we need to understand fluid mechanics. We will be studying something like boundary lubrication, mix lubrication and elasto hydrodynamic lubrication. Typical example given for the elasto hydro lubrication is rolling element bearings, gears and easiest way to study the elasto hydrodynamic lubrication is that this the roller of slander sliding against surface. It may be convex surface, concave surface of flat phase that for mathematical treatment we can always make up here with one convex surface and another flat surface.

Same theory can be utilized irrespective of whether flat surface, convex surface or concave surface by changing the factor reduce and is we if we understand a factor reduce model we can utilize or we can analyze all kind of machine elements under elasto hydrodynamic lubrication. As I earlier mentioned; viscosity is function of temperature. Increase in a temperature, viscosity will decrease, but, it is only for the liquids it is not for the gases. In gases under high temperature condition more and more molecular activity will occur. That will create more and more disturbance in fluid parts. That will enhance viscosity.

So, there is a basic difference within viscosity of gases and viscosity of liquids. When we pressurize lubricant oil it gets treated there is possibility of viscosity increase under pressure and we need to do a mathematical modeling of this viscosity behavior. Apart from that will doing some mathematical modeling related to thin film lubrication, may involve liquid, may involve gas, may involve solids, but, if you want quantification we need to mathematical modeling.

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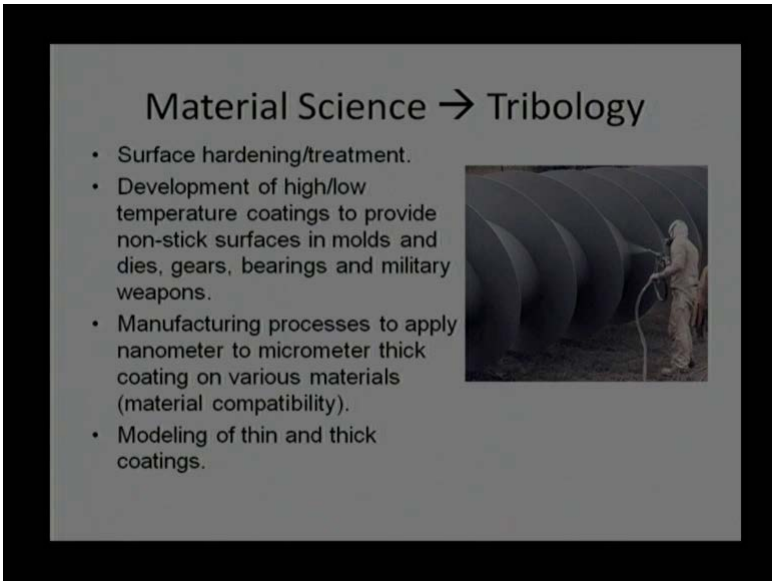

Coming to the material science; I can see material science as changed tribology significantly. matching the surface properties we can change wear behavior many times, by just coating few micro level coating on the surface surface life can be changed can be enhanced significantly. Take an example of simple needle which is used to a stitch the clothes. If I do not quote with common steel it may get corroded, it may get blunt, it will not be useful. But, just lengthen coating on that needle enhanced is the life may be say ten years twenty years under coating thickness will not be more than ten microns. By changing the material of the surface, you just change material properties of the surface.

We can increase the service life significantly. Similarly, we have seen cars all cars are quoted may be the toughen coating that will provide better look, better appearance of that car. So, its coating changes drastically service life of the component. Coating can be thin coating or thick coating or it can be just a surface treatment, surface hardening like sharp paining. Short paining increase the hardness of surface, causes the lesser processing

deformation under subsequent loads. So, that enhances its properties to sustain wear or to torrid wear, it may substance or component much more wear resistant.

We can go ahead with a number of high temperature coatings also. Some time we can use simple solid materials or say solid lubricant and we can rub on the surface get overall good results. Take an example of cam surface if we rub cam surface with molybdenum disulfide powder; it will show much lower friction for at least couple of hours before that layers is deeliminated. To form a attach it either we can use the carrier flout along with molybdenum disulfide or we can use some manufacturing process to invite that practical on the surface.

So, that it can be easily removed from the surface. So, it is important for us to understand what are the manufacturing processes behind these coating technologies or what are the different coating technologies. And again if you want to quantify the tribological behavior of coating then we need to model thin and thick coatings mathematic treatment is essential for that. Coming the chemistry that plays a major role and in fact, many chemistry background people are good tribologists. Taken an example of anti wear additives developed by (( )), take an example of surface tense developed by the cams.

Example of extreme pressure additives developed by the cams, but, we can utilize this additives to enhance service life, to increase load carrying capacity of machine components. However, we need to understand what is the compatibility of these lubricants with process fluids. If we understand chemistry of process fluids we can be utilizing this processes fluid as lubricant itself of by using adding some additives in those processes fluids we can avoid extra lubrication requirement.

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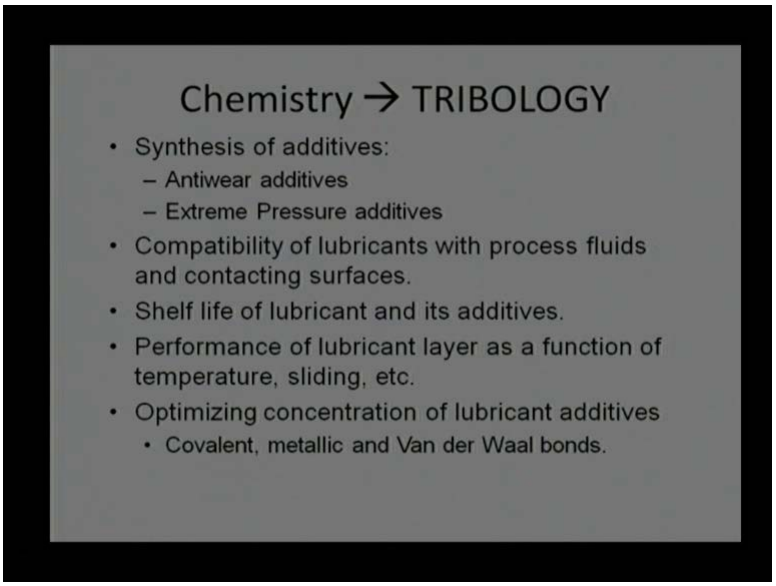

So, we need to understand the chemistry of lubricant to do that. Understanding chemistry of the lubricant will give some knowledge related to shelf life of lubricants and its additives we know very well all additives have some shelf life.

If oil is kept it will get oxidized if is not try treated properly and performance of lubricant is generally function of temperature, sliding speeds if there is a two very high relatives noise sliding speed; naturally there will be possibility of sharing of additives which are mixed with lubricant. So, you know if you are going for very high relative velocity application will be requiring quite different additives compare to additives require for the low speed operations. Further understanding chemistry will help what kind of percentage or what percentage will suit overall requirement of lubricants.

Many times we use just few percent of additives in lubricant which may not be right. Sometime .1 percent, .2 percent because many times additives they conflict each other taken example of detergent. It will try to remove the surface, layer from surface while extreme pressure additives they get on the surface. If I mix these two without proper understanding one shelf one additives will remove the surface and other additives will get attached with surface and overall result will turn out to be 0, no use. We have we need to have proper understanding between these two kind of additives. Once we have proper understanding that will help us. Sometime understanding of this additives requires

whether and this is are getting attach to the surface due to covalent bonds, metallic bond or weld bond pounds.

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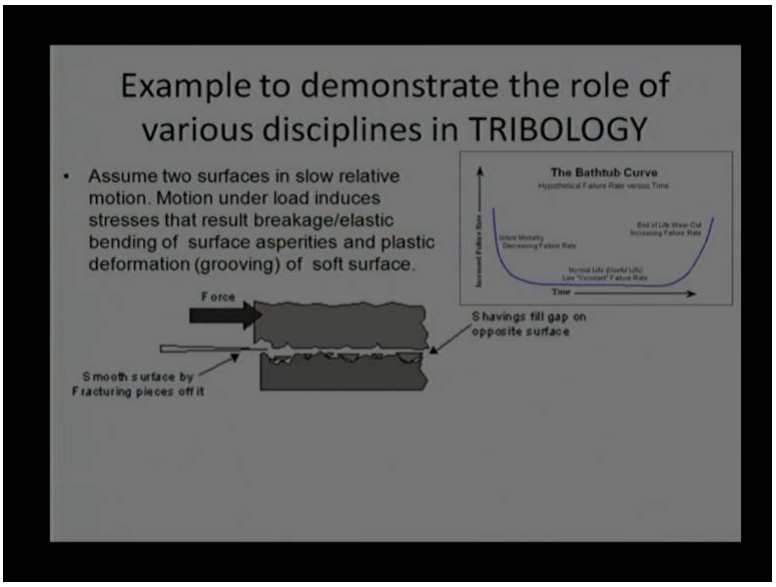

So, modeling of these bonds, modeling of this force is is important for us. Let us take one of the very simple example and try to relate these subjects. I am just showing in this figure component one component two. Now we try to push component with some tangential force. What will happen? Due to irregular surfaces in contact there will be number of barriers. Either this barriers need to be elastically deformed or ruptured. Then only this top component can move related this component or else it will not build to more. If it ruptured and there is a possibility of further generation of irregular surface and if this happens continuously machine component will loose is thickness in no time.

However, we if we use this properly then there is a possibility that there is a low contact and lubricant layer is playing intermediate role or lubricants they are getting load. They are supporting load from component one and transferring to other one. So, there are using as a cushion between two surfaces or they are able to express stresses more uniformly. A more area comes into picture comparative low or lesser area due to irregular surface and if I try to project this on one curve, I say that in trying to relate wear rate with a time sliding time what we get?

Initially there is a irregular surface. It will wear out it will give more and more derby, but, due to lack of further asperities and possibility that no uneven surface is generated or

other surface; there is a possibility of lesser wear and reaching to one steady state after sometime. While we that is why we call this time 0 to this time as a bedding time. It may take few hours, it may take more number of hours or may cause catastrophic failure depending how we are treating these two surfaces, how are we designing this two surfaces. You know very well after long time again surface will wear out.

If wear is consistent; that may wear occur due to increase in clearance between two surfaces, lesser thickness remain after sometime or may be some other reason. So, generally this part of curve is plotted or used to find out what will be overall overall life of the component. We need to do detailed understanding about these two components how they will come in a contact, whether they are making any adhesive bond or not. If there is a adhesive bond between component one and component two then there will be excessive wear. Even if the one surface is very hard compare to other surface what will happen in that case? Hardest surface will scratch rough soft a surface. However, with hardness of the two components is same.

And they have some sort of toughness and ductility then this surface will, asperities will simply tear away without generating additional surface problem on this other component and this behavior will occur. But, we if we are we using the some ceramic components and there is a possibility of fracture of the asperities; very high rough surface will be generated after tearing those asperities. Then there is a possibility that these two curves match this line and this line much removing this intermediate path. So, there is a possibility of failure in this. We will continue with this topic in our next lecture. Thank you for your attention.