Video Course on Tribology

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Lecture No. # 16

Solid &Semi Solid Lubricants

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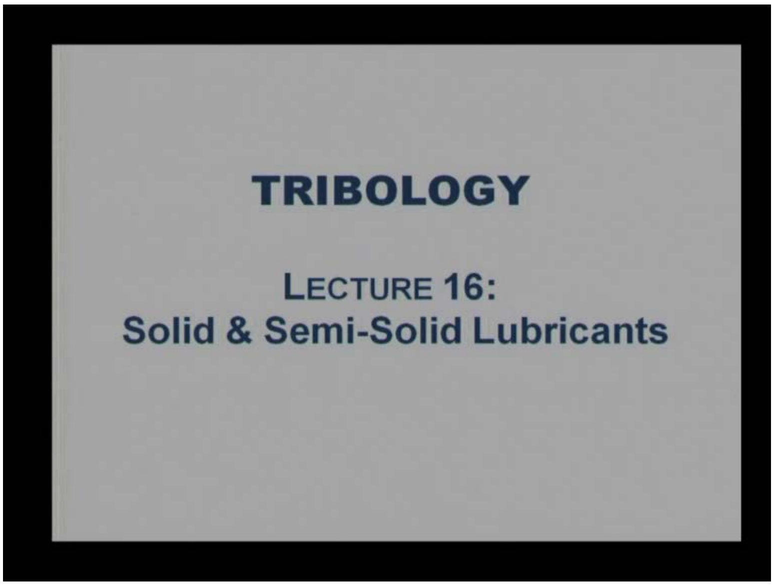

Welcome to sixteenth lecture of video course on Tribology. Today's topic is solid and semi solid lubricant. Solid lubricants were discussed in previous lecture mainly on polymer based solid lubricants. Today, we will be continuing with the solid lubricant as well as we will cover semi solid lubricants.

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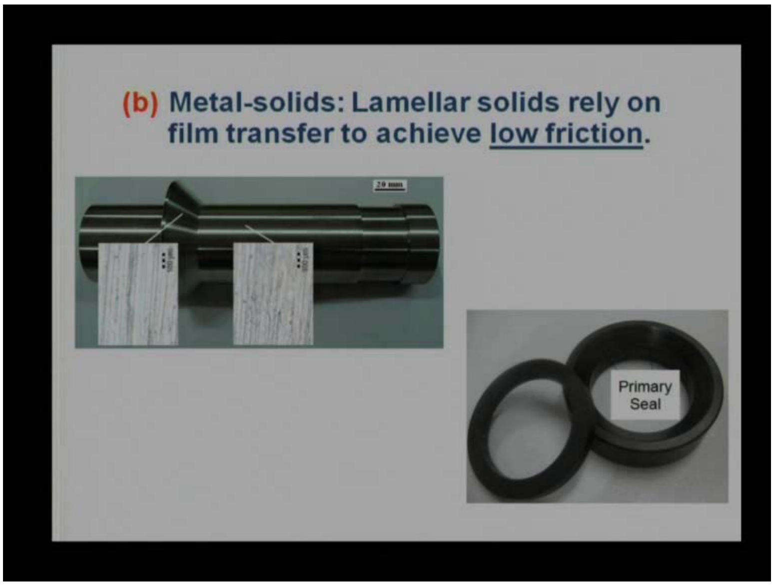

Second category in solid lubricant is metal solids as it was discussed, described in a previous lecture that we are emphasizing the word solid because the metal can be used as a liquid lubricant also at high temperature but, we are not mentioning about those in solid lubricant. We say that metal solids basic phenomena, basic mechanism behind solid lubricant particularly metal low lighted is a transfer layer solid lubricant deposit a transfer layer on the metals which are going to interact and that as that transfer layer is a lubricant layer. Just for example, we have here the two figures, two photographs. This is a stainless steel shaft. Finally, finished and having very low surface roughness a component which comes in interaction is this carbon graphite seal. As I mentioned in previous lecture, we can use solid lubricant as a bulk metal or bulk material or we can use as a final 115 to 20 micron thick coating. Here in this case, we are using a solid lubricant as a bulk material when this carbon graphite seal comes in a contact with the stainless steel and operating condition. It transfers layer something like this. You can see the black marks on the stainless steel shaft.

These black marks have come from the carbon graphite and the layer has been transferred the stainless steel. Till this layer is transferred coefficient of friction will be high after transferring this layer coefficient of friction reduces something like a initially coefficient of friction may be .4. But, after getting transferred, coefficient of friction reduces as 0.2 0.151 0.5. So, this is what we can say the lamellar solid these metal are generally transferred. So, that is why the layer by layer can be removed from the material and once they get transferred on the surface, metal surface or the component surface which are interacting then they remain there at that inter phase for some time.

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Before they dislodge or removed from the surface. So, we say that these lamellar solids rely on a film transfer to achieve the low coefficient of friction. One of the common example is a molybdenum disulphide, well known solid lubricant, well known lamellar solid. We say that in this material has a layered structure and that layered structure it can be described based on a molecular structure you can see there are sulphur molecules, they are molybdenum disulphide or molybdenum sulfide molybdenum molecules and this sulphur molecules. So, more strength between the sulphur molybdenum and sulphur is high while there is a layer structure. After this layer there's another layer and these layers are connective with the sulphur molecules only or bond between sulphur molecules. That strength of that bond sulphur to sulphur is relatively weaker compared to molybdenum sulphur bond.

And their strength or shear strength will be weaker in tangential direction because of that so they can sustain compressor load. But, shear strength is very low so they can be removed layer by layer from the bulk material. So, I say that molybdenum disulphide has strength; it can sustain even 700 mega Pascal compressive strength. If it is able to sustain up to 700 mega Pascal compressive stress then, is as good as a steel but, tangential strength is very low and as far they can be use as a solid lubricants because of the low tangential strength.

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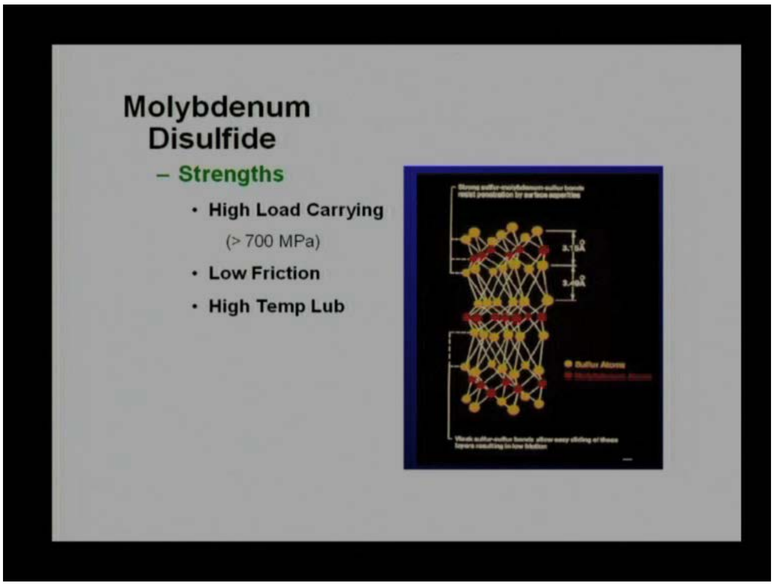

They can be used as a low coefficient low friction of components. One good point is that they can sustain very high temperature. This is the major reason why an arrow space related products molybdenum disulphide uses a lubricant. We have very high temperature. The stability or whatever the components meet at a high temperature they act as a lubricant also.

So, it is not only the molybdenum disulphide acts if it is the molybdenum molybdic oxide. That will also act as a solid lubricant. There are some weaknesses of a molybdenum disulphide solid lubricant. You say that oxidation rate increases in presence of oxygen. This oxidation happens a 350 degree centigrade and in presence of only air, no other oxygen available other than in air. This oxidation happens a 450 degree centigrade. That is why one average we say the rapid oxidation happens over a 400 degree centigrade but, there’s a contradictory point. What we say that strength is high temperature lubrication and here we are mentioning that 400 degree centigrade will oxidize. It is a contradiction generally whenever there is oxidation temperature we try to use lubricant below that all lower than that.

But, here even after getting oxidize it makes a Molybdic oxide which acts as a solid lubricant. That is why even after oxidation this molybdenum disulphide can be used as a lubricant. That is why you say that it is high lubricant high temperature lubricant and the temperature even up to 1000 degree centigrade is not big problem for the molybdenum disulphide. Wherever there is a problem with moisture, if environment has a lot of moisture then, molybdenum disulphide will not act very strongly or get attached to the surface very strongly. In that situation we will get dislodge or removed from the surface and that is a problem for molybdenum disulphide. Access to humidity we cannot use a molybdenum disulphide as a lubricant.

And as a previously I mentioned that almost of the solid lubricant they work with a transfer layer most stable from thickness for the molybdenum disulphide is a 15 microns. If we deposit a thickness more than 15 micron than may be in the few cycles of few 100 cycles that layer will thin down to 15 micron. You may there is know there is no point to deposit very thick layer or molybdenum disulphide does not really work much. However the thickness is a lesser then 15 micron; naturally the components are while operating life will be slightly lesser than what we get with the 15 micron coating. Couple of more solid lubricant, you say the carbon can act as a solid lubricant. It has a very high temperature, good properties of the high temperature and that is why they act as the good lubricant particularly the high sliding speed. Here temperature stability is even up to 500 to 600 degree centigrade. However, because of the lack of ductility generally they are not very much recommended but, fine rather (( )) form of the carbon is a graphite which shows a lamellar structure then lamellar structure can be utilized as the solid lubricants. That is why we can say graphite acts.

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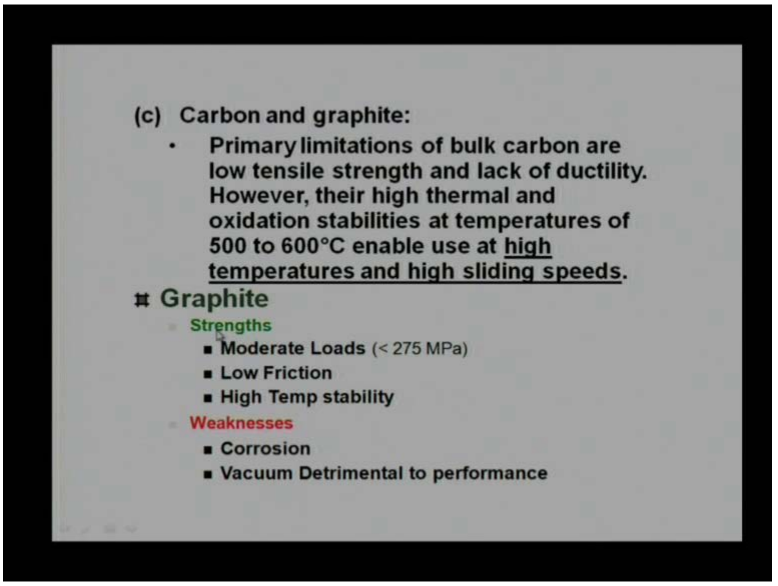

As the solid lubricant it has certain strengths certain weaknesses. So, strength is is not it cannot sustain as high load as molybdenum disulphide but, it can sustain modern load the load generally or if we express it in terms of in terms of stress; it can sustain its raise up to 275 75 mega Pascal. It shows the low co efficient of friction and also has a high temperature stability. You say many time temperature stability it can go up to 2000 degree centigrade. They do not disintegrate, they do not change a material properties up to 2000.

But there's oxidation or there's a lack of the moisture then properties will deteriorate major strength of the graphite is a moisture in presence of moisture they walk very good lubricant. They act as very good lubricant but, if there is no moisture available then there will problem coefficient friction will increase may be say 3 times to 4 times. Another problem with graphite is that they act as corrosion agent. That means this is not this kind of a solid lubricant is not good for every solid material. Take an a typical example of carbon for use a carbon with graphite or graphite solid lubricant with a copper copper will get corrosion because of a nature of graphite. Another thing is that in in a presence of vacuum they start out gassing they start vaporizing and then that is a detrimental to the solid lubricant. So, whenever there's a vacuum problem we know very well polymers cannot be used, graphite cannot be used we need to use molybdenum disulphide. That is what most of the aerospace application molybdenum disulphide is used as solid lubricant.

This is how the typical microstructure shown of the copper of the graphite says that if they are in perfect structure they can sustain load but, if the load is increased beyond their capacity as mentioned in a previous slide 275 mega Pascal stress; then they get distorted they get damaged. So, the beauty of the lamellar structure is removed in a situation. It will not longer the lamellar structure. It will be distorted structure that means as far load is very high coefficient friction will increase drastically because of the distortion of their structure. This diagram shows a bond length you say that between layer to layer is a 3.35 Angstrom which is higher compared to within layer that which is around 1.42 Angstrom. The longer the bond length regain act as a layer structure and one layer can slide on other layer.

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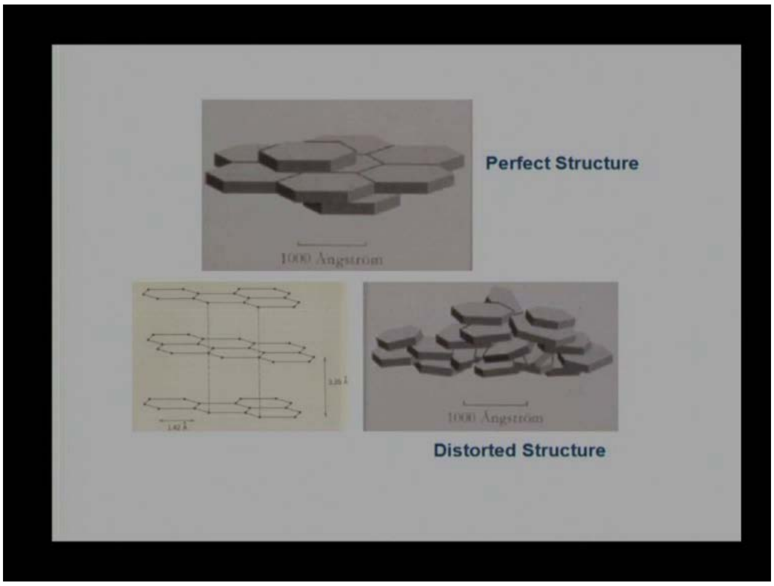

We did a good number of maximum and so on a carbon graphite material and figure out carbon graphite really requires moisture to act as good lubricant but, how much moisture? So, what we did we used one rotary joint filled with a water. So, this is a rotary joint I am showing here. It has a seals; this is a primary seal, this is a secondary seal. Both are carbon graphite seals and this material is a stainless steel you are using the stainless steel. So, that water is not going to corrode this surface stainless steel is a resistance against the corrosion or against rust and there is a spring action. Spring is shown with this structure. This whole, this this o shaped figures then when you fill it with complete water and try to find out the coefficient friction between the stainless steel and carbon graphite. It reaches even the 0.4 0.5 but, we reduce this and just allow some moisture to be made.

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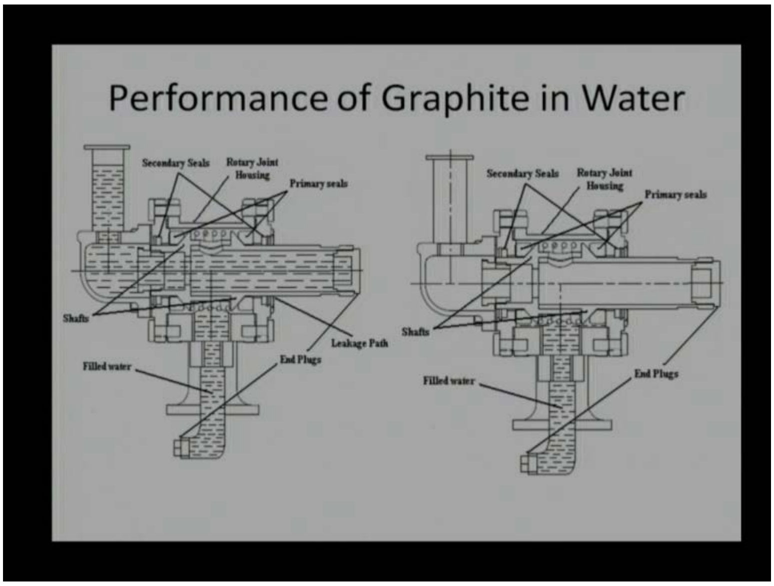

Water you can see here water level is almost negligible. Only a small tip of a stainless steel is dipped in water. What will happen in this situation? Level or availability of moisture between the inter phase carbon graphite and stainless interface is reasonably low and you find the coefficient friction is very low. In this case is equivalent 0.15. We do not use the moisture at all and in a when this this structure or this unit at 100 degree centigrade, if an high coefficient frictional must .25.

So, moisture is necessary for carbon graphite but, too much moisture is more problematic. At the very high level of moisture they get more and more wear rate because layer formation or transfer of the layer on the stainless steel is very high and thicker the layer, better will be the structure. It will get damage immediately will get in wear debris immediately. So, first is that rate of the transformation is high and that the the deformation or dislodging of that transfer layer is high. Because of that there is a high wear rate as well as coefficient of friction is also reasonably high in this situation overall. So, I can say that maximum wear occurs under complete water environment where water environment too much water is present. That means we should not use too much water and minimum wear occurs minimum wear occurs under the vapor lubrication. When they are just sufficient moisture available which makes vapor water vapor and then they act as a gases lubricant.

So, let us situation with carbon graphite. Now, if you try to summarize a carbon graphite or graphite structure what we say? They have a high thermal thermal stability we know up to 2000 degree centigrade but, they are is a limitation first thing is the moisture will not remain there, water vapor will not remain there. At high temperature and because of the coefficient friction will increase wear rate will increase. Because of that so there's a practical difficult, a practical limitation on carbon graphite. There is another good point is that a this low coefficient friction basically depends on a moisture and some experiments done in the lab indicates that and when there was analysis of a component failed during the world war 2; it was a indicated they are clearly as a high altitude.

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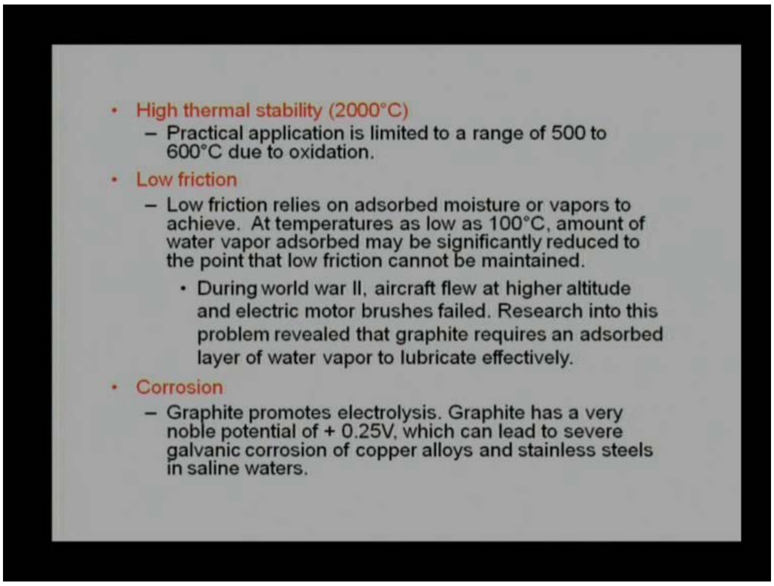

Generally, electric motor brushes carbon graphite is used to make ah electric brushes they failed and after doing a research during analysis it was figured out that absorbed layer or water wear water vapor which was suppose to lubricate effectively what is lost from the surface as well that they was a high coefficient friction and high wear rate during world war 2 in equipments which was used. As I mentioned, it corrode the surface has it has a potential of a plus 0.25 volts. Whenever compo materials have this kind of potential they will corrode the few material surfaces and that is why I say that it will cause a galvanic corrosion of copper alloy and to some extent stainless steel.

But in presence of say salt which is available or some sort of acid environment; last solid the lubricant what we are discussing in present lecture is a based on ceramics. So, the ceramic materials good point of the ceramic material is they have a less chemical reactivity and they have high temperature stability. So, that is why the this kind of lubricant can be utilized for the high temperature applications but, they have a brittle structure. That is why we say that the coating thickness should not be more than 0.5 mm. More than this thickness then there will be a fragmentation, fracture of that layer because of the brittle structure and we should not use that.

Now, to deposit this kind of a coating we have special techniques available fast and cheapest technique is the plasma strength, detonation gun is another one and finally, is a electrolytic deposition. It is more like a dipping coating. Coating is deposit by dipping that substance making the electrode connections while coming to the detonation gun we use high velocity to impact kinetic energy to the surface and gives some sort of penetration or diffusion mechanism. So, that coating remains in contact with the material which require coating. Plasma spring is generally high temperature coating. It is easier one to deposit the high temperature and then cure. It may be at the here here environment curing or good regulated temperature environment. Only problem with a plasma spring is a dimensionality there's a possibility adhesion in dimension.

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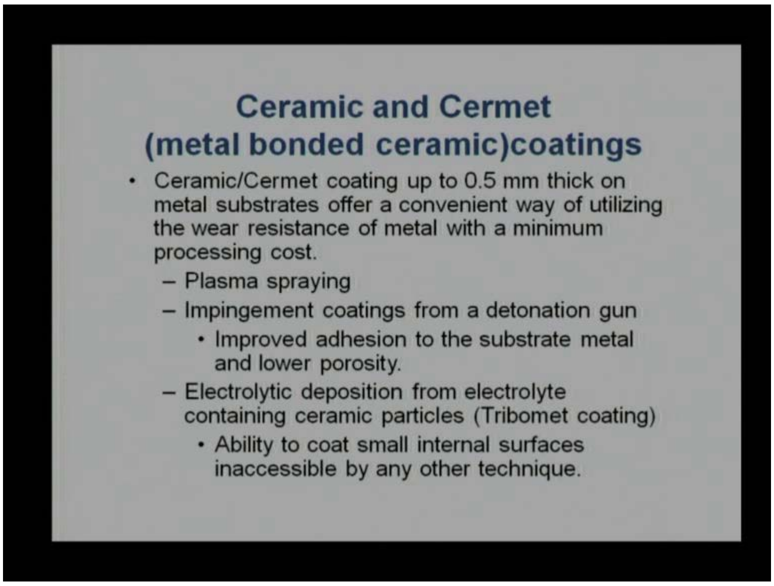

So, we need to after doing this kind of coating. We need to do a super finishing operation on this components and these coatings are now well known for us as a wear resistance compared to the friction reduction compared to the lubrication reduction in friction occurs because of the low chemical reactivity or low adhesion. But, aggression will be there as they have a very high hardness. That is why they are known as a wear resistance coating compared to friction reduction coatings. Now, we will start with the semi solid lubricant and a typical example is a grease number of are materials or which act as a semi solid on the gels. They can be uses a lubricant but, grease is a more popular. It has a wide application compared to any other semi solids. So, that is why we are discussing about greases.

Now, in grease if you see the structure; it looks like a jungle. You have seen this structure. I can assume there are number of ah wooden pieces, these are the actually fibers. They make structures such a manner liquid cannot escape easily. So, this structure need to be filled with a lubricants. That is why I say that it has it consists of the base one as well as additives and thickness and this is what we are showing here they are the thickness. These thickness make structure in such a manner that liquid cannot easily escape from the, that integrator part or may be can assume that it acts as a sponge and this sponge has a capabilities to retain the lubricant within it. It can be in layman language it is is like this sponge.

And these thickness fibers are roughly 50 5 to 20 percent. Oil which is basically used to lubricate surface contains from 75 to 95 percent. In addition we may require additives to reduce oxidation at high temperature, to sustain extreme pressure, high load if there is a water environment to avoid corrosion of the components or may be some water repellant. So, these can be acted as a act as additives. Coming to the base oil which is a main constituent; so the base oil can be mineral oil can be synthetic oil. More popularly in this is the synthetic oils are used because of they we can design these oils and with proper properties. Coming to the mineral oils sometime we say the low viscosity oil or high viscosity oils. In stocking the low viscosity, generally they use for the low temperature because with increase in a temperature, we know the viscosity will decrease. That is why the high temperature we use in fact high viscosity oils because at the temperature increases they will turn out to be low viscosity oil. At the high temperature but, when we measure the viscosity and we code the viscosity generally 40 degree centigrade and classification basically is of 140 degree centigrade, 40 degree centigrade low viscosity has a low overall volume uses a 30 to 50 centistokes.

Coming to high viscosity even to the high viscosity may be say 200 centistokes by 1 it is raises to the 100 degree 1150degree centigrade with the temperature the this kind of oils should be utilized. The viscosity will turn out to again the low viscosity so effectively we what we are talking about the high viscosity oil at the low temperature. But, they will turn out to be low viscosity at the high temperature and this kind of viscosity low viscosity oil can be utilized for the low load and high speed application. Particularly high speed application is emphasizes over here. Because the high speed application there will be more and more shearing. If there is a more shearing more friction more friction means heat generation will be more, temperature will be high and again the viscosity will turn out to be low if we use a very high viscosity. So, they will not be much effect of using high viscosity acts as a losing adhesion.

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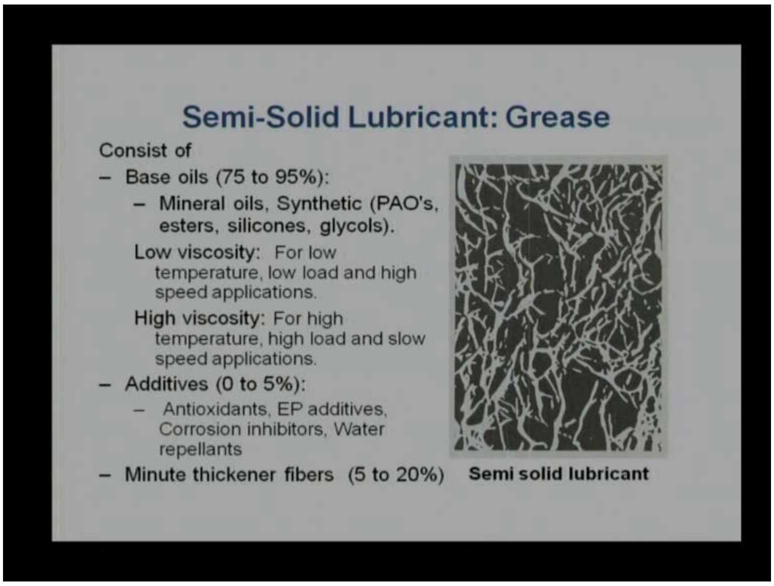

Well coming to the high viscosity when application I mentioned of the high temperature another application is high load. If the load is very high and we do not want the oil to be squeezed out from a inter phase then we should use high viscosity oil and high load with a low speed operation. It should not be the high load and the high speed operation then we, you need to use a good lubricant. Ordinary mineral oil or ordinary high viscous mineral are cannot be used for this kind of applications and I mention a last is ah thickness which act as a fiber on other the make a structure they are main component and that is why I say when grease life is over grease need to be discarded. Reason is oil is getting separated from a thickness or what we say grease is bleeding or grease bleeded that is why we need to replace this grease with the new grease.

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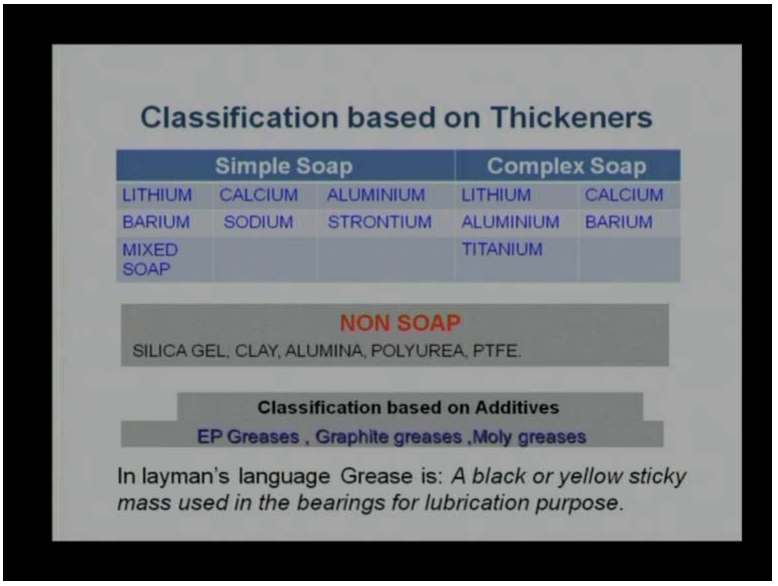

Which is a new and oil is retained within fibers. Coming to the thickness we say thickness can be defined in number of categories we would we call as a soap based thickness. The process in the thickness are made to convert in grease or to find the grease they are generally simple soap base, complex soap base and their other kind of a non soap base also where the clay is used to make grease however the soap based greases are more popular or most commonly used unless we require the high temperature application or see that the load applications. Again a simple soap we use only one acid with the metals while in complex soap we use two acids. When there is two acids, there will be hybrid a structure wherever there is hybrid a structure it is more possibility to sustain high temperature. That is why the complex series is can be used for the high temperature applications or simple soaps can be used relatively low temperature applications. One of the most commonly used simple soap grease is a calcium based soap grease which is most commonly used and many times call all purposes grease is because it has a temperature sustainability up to 65 degree centigrade and a operating temperature is not going beyond 65 degree centigrade calcium grease will work very nicely generally used for the low speed applications ever a lithium grease is not gaining a more popularity because of the structure because of its high temperature stability even in a lithium can be used as a complex series.

So, lithium grease is a most known more popular from temperature stability point of view or operating temperature point of view. As I mentioned there are non sub grease is also they are basically clay based and they are mixed also with the solid lubricant and see here the p t f e is grease is can p t f e reacts as a solid lubricant in that there are some synthetic greases or poly urea ceramic paste alumina silica gel there are time sometime we call classified grease is based on their additives. We govern one of the popular name is a merely greases is of based on molybdenum disulphide grease, graphite greases. The solid lubricant is used to reduce a coefficient friction to transfer layer and basically a grease is used as a carrier media in that as well as sealing medium.

E p e p greases with the e p additives are mixed with grease and what we say that in the layman's language grease is a more like a black or yellow sticky mass. when It have always has a some sort of a fatty acids which is stick to the surface is a sticky mass most commonly used for the bearings talk about any rolling element bearing by and large grease are used as a factor lubricant. That is why say that in layman language we can say there's some thick mass used for the lubricating the bearings.

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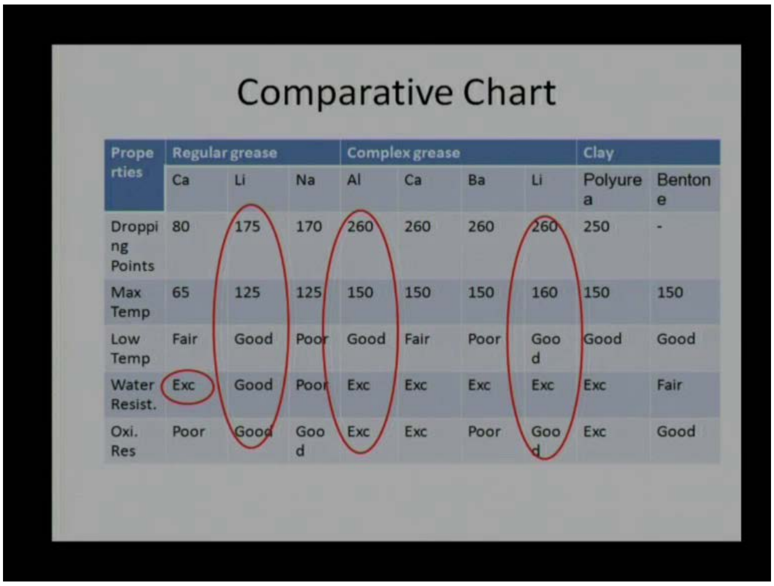

Properties	Regular grease			Complex grease				Clay	
	Ca	Li	Na	Al	Ca	Ba	Li	Polyurea	Bentone
Dropping Points	80	175	170	260	260	260	260	250	-
Max Temp	65	125	125	150	150	150	160	150	150
Low Temp	Fair	Good	Poor	Good	Fair	Poor	Good	Good	Good
Water Resist.	Exc	Good	Poor	Exc	Exc	Exc	Exc	Exc	Fair
Oxi. Res	Poor	Good	Good	Exc	Exc	Poor	Good	Exc	Good

Now, this slide shows a comparative chart so that we have clear idea which grease should be selected. I am just giving this example because we made a 1 a test setup for 1 textile machine and we were supposed to operate the bearings at a 2500 degree centigrade. Assembly was made and before supplying that assembling at a setup to us vendors started working, wanted to check with the motor which was used is sufficient to supply a power and not. That is why we use calcium based grease of course, without knowing that that is calcium base grease you use a ordinary grease which are available in market and use that grease. And surprisingly within a few minutes whole grease turned out to be black powder and whole assembly was stopped. Motor was not able to supply the power. That is why he (( )) he called me and he says that so what should I do? I did this and before supplying to you have I checked in my we simply say we just change ah bearing because once grease filled in a bearing we need to replace a bearing replace bearing and use a lithium base grease which was supplied to him and interestingly that said after that never failed. It worked very well. It is just a high temperature which makes a calcium grease as ineffective grease and lithium which can sustain a high temperature can be used as a good grease for that the application. So, this chart show the comparisons. We say the dropping points first the dropping points is a maximum temperature at which grease can be utilized. After there a bleeding will be very high almost all complete oil will be removed from the surface or within structure of grease. So, when we use calcium but, no way we should use more than 80 degree centigrade. However we call as a maximum operating temperature keeping a factor of sustain to a we should not utilize more than 65 degree centigrade at all while lithium based grease can be used for the 125 degree centigrade there’s a use different of 60 degree centigrade’s. Generally operating temperature is the 40 degree centigrade when you operate it friction will be there, heat generation will be there.

And that is causing increase in the temperature of 55 to 60 degree centigrade temperature can be assumed for a high high speed applications. Now, there’s another kind of the sodium base grease which has as operating temperature 125 degree centigrade but, which the problem is that it cannot be use for the low temperature applications. tThey start freezing and another thing is that they do not they they are very reactive with the water environment. They should not be use with water environment. They make it start making components and they will turn out to be in a fact to solid ineffective greases, ineffective semi solid lubricants. When coming to the complex greases where the two acids are used, we can see that improvements significant improvement. Calcium base grease there is a calcium base here it was only 80 degree centigrade.

When we use with a alter two acids then it can sustain maximum temperature or you say that the bleeding starts 200 and 60 degree centigrade. Of course, maximum operating temperature is still restricted 150 degree centigrade. Still that that is temperature is far above than a 65 degree centigrade temperature. Even lithium base grease is also 125. So what we can say the complex grease is it is made it gives maximum advantages, the calcium base greases. It does not give that much advantage to the lithium base grease. You can see that lithium base grease that the complex structure has a 2 acids or which requires a more manufacturing steps is a 160 degree centigrade while here it is 125 degree centigrade. So, improvement in this operating temperature is not very very high. And of course, with all other parameters they are working fine and they show the good resistance, good performance.

Coming to the clay based say the (( )) based, we can see that it is a all as good as a complex greases more or less complex greases have 260 degree centigrade as a dropping point. Well polyure has 215 and operating temperatures are also more or less same we say 150 150 150 160 150. So by and large we can say that maximum temperature, operating temperature for the grease is 150 degree centigrade. You should not use more than that. Whenever the temperature more than 150 degree centigrade, we should switchover to some lubricating oil which have a heat carrying capacity or heat dissipation is a much faster compared to greases. And another important thing is that, if whenever we choose first if there is water environment and temperature is a 50 to 60 degree centigrade which it choose a calcium because this is a economic, is a least costly or is not as expensive other the greases. And we have a doubt about the operating temperature, we are not sure then which we choose a lithium base grease because, the lithium base grease is a costlier but, it gives a good performance from every angle which in temperature, low temperature, water resistance, oxidation resistance, in that way. When coming to the complex greases we can find out the all good performance from aluminum based greases or lithium based greases. But, lithium complex will be costlier compared with simple lithium greases. So, unless it is (( )) require we should not use. This is from this slide. It shows what is the importance of mineral oils or silicon oils or synthetic oils. What we talked to a previous slide about the thickness using different thickness or the performance will change.

But when we talk about the thickness and like the thickeners particularly the lithium base, or aluminum based or polyurea based we need to think about what should be the carrier fluid or what will be the waste fluid which is used with grease. Here the, if I am assuming that we are choosing a lithium base grease for our applications from the three categories; there is a mineral oil, there is a Easters and silicon's. Silicon is one of the costlier. That is why we say that overall lithium base grease based on the silicon oil will be costly. Coming to the mineral oil; mineral oil is cheaper than the synthetic oils then the cost will be medium of course, we talking a medium because we are comparing with calcium that is is calcium has a lowest cost. Now, what we get from this and we do good processing then temperature can be increased and this case we are talking about the lithium with plus mineral oil plus some additive package including the heat resistant package; you find that maximum temperature it can sustain up to 150 degree centigrade which was with a previous slide we talk about the complex lithium base grease. However the minimum temperature you can see that it is cannot be operate the lesser than minus 40 degree centigrade. We want a better performance, the low temperature we can switch over to the different lubricating oil different base oil what we are doing here mineral oil is been replaced with the esters. And that the operating temperature, low operating temperature is minus 75 degree centigrade. So, almost 35 degree centigrade differences coming just by changing the lubricating oil. However, the cost is increasing and it is getting penalty at the high temperature.

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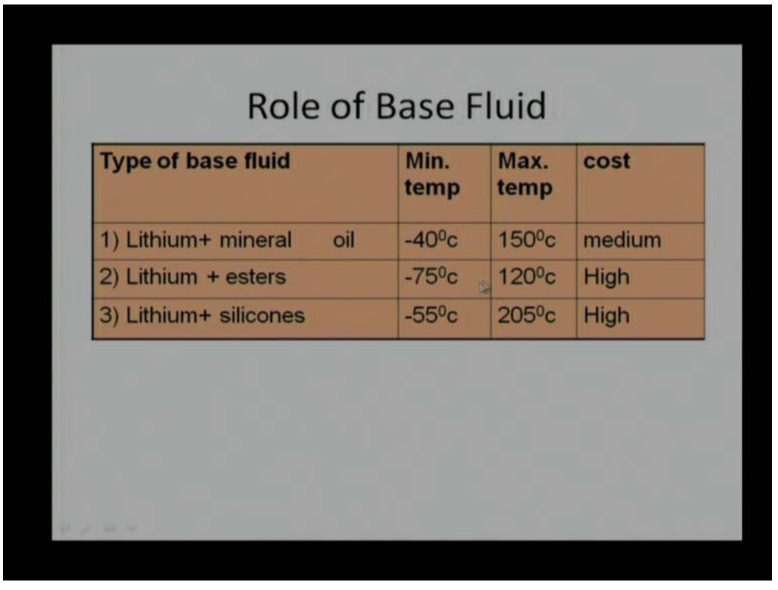

Type of base fluid	Min. temp	Max. temp	cost
1) Lithium+ mineral oil	-40^{0}c	150^{0}c	medium
2) Lithium + esters	-75^{0}c	120^{0}c	High
3) Lithium+ silicones	-55^{0}c	205^{0}c	High

Well we want the overall very good performance, low temperature good performance, if the high temperature good performance then we should choose lithium base grease based on or with the silicon oil which is also popular grease but, a high cost grease.

Now, this slide shows a some advantages of the grease compared to a solid lubricants as well as liquid lubricants. Compared to solid lubricant we say that one of the major advantage is a it remains in a contact with a surface that can be replaced easily and the liquid lubricant we require frequent supply of the lubricant. That is why we say that is a less frequent application is needed when they are comparing with a liquid lubricant. Comparing with a liquid lubricant we say that it is it is it is come it seals effectively that means from a environment contamination will not come easily and it will not be requiring very tight seal, an ordinary seal you will can be utilize effectively with greases. Good point about these greases is that as they are not able to, they are not allowing the contaminants to come into contact with the metal surface. They can be water resistance also and the important thing is that even the worn out parts can be used effectively with the greases. It reduces the vibration, it reduce a impact loading, it can sustain the shock loading.

So what we say that it gives a maximum comfort. That is why the most of the rolling element bearings even they develop a small pits or the initial surface initially. They can be used effectively with greases that will give the good results this is catch shows, I am just assuming there is a one, initially the solid surface and when solid surface develop pits may be did the effect loading then if the pits naturally that they will be a vibration. If any rolling element passes on the surface it will come with a some sort of contact and non contact, contact and non contact and the stiffness will be very high low when the metal to metal contact is there they will be high stiffness. And there is no metal to metal contact stiffness will come down. So, there’s a continuous variation stiffness that will induce vibration phenomena. And if we are using the greases what will happen in this situation? Grease will fill these pits. When the pits are filled then vibration level will be reduced. They will act as a damper. They will act as a reduction in noise agents. They will reduce a noise in overall.

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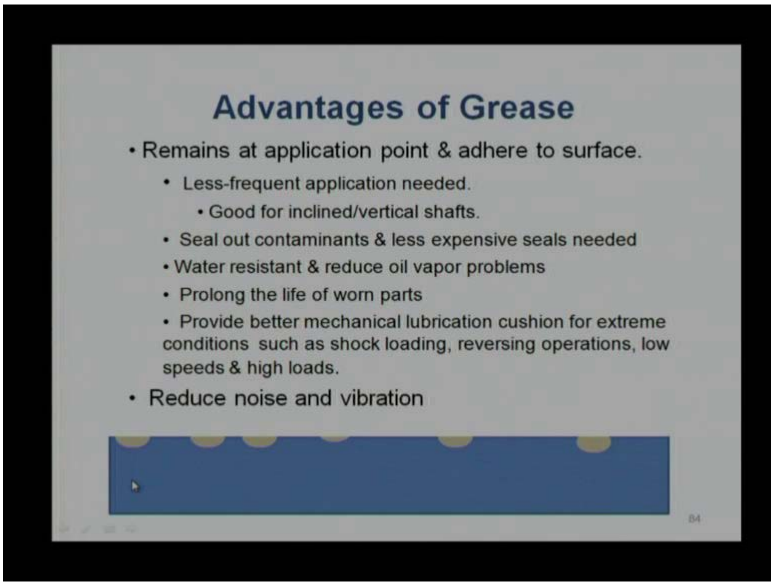

So grease is effective to reduce a noise, to reduce a vibration, to reduce the impact loading on the surface. They have capabilities to absorb the adhesion by just by deflecting from the surface and the gaining machine.

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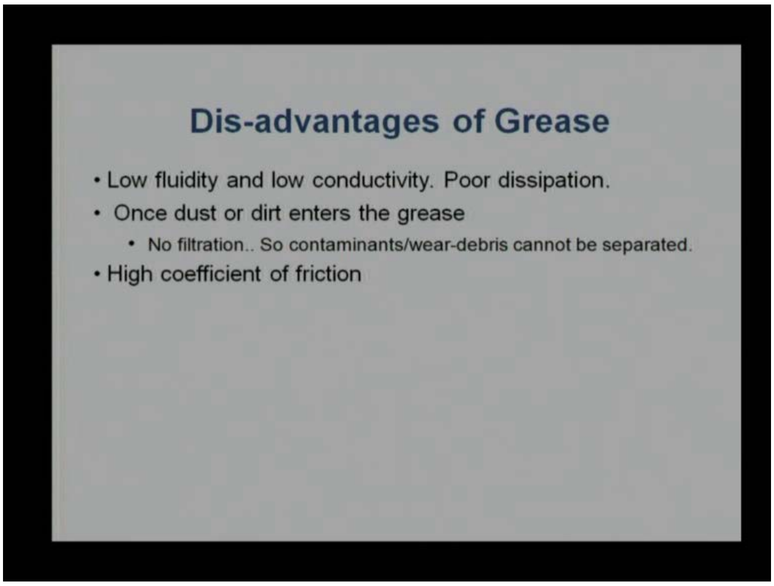

There are number of disadvantages of the greases. What we say that has a low fluidity. So, heat dissipation is a problem because they have a low connectivity also. We mention about the advantages that it grease retains a or avoids a particles to come into contact or avoids contamination to come in a contact with the solid surface. It prevents, prevents a contamination to come into a contact but, problem is a once a contamination is start coming one way another they reach to the surface; then grease will try to retain those contamination with the surface. That means it has a advantages. it that They are able to avoid, prevent the contaminant to come into contact but, once they come in a contact there is there no problem. We need to replace the grease. There is no other way. We cannot do any filtration on that kind of grease.

So it has advantage as well as disadvantage. Then only show high coefficient friction compared with liquid lubricant but, low coefficient of friction compared to solid lubricants. Now, as I mentioned to show the high coefficient of friction but, few experiment indicate, not necessary high coefficient friction is done or is achieved by the using a grease as a lubricant.

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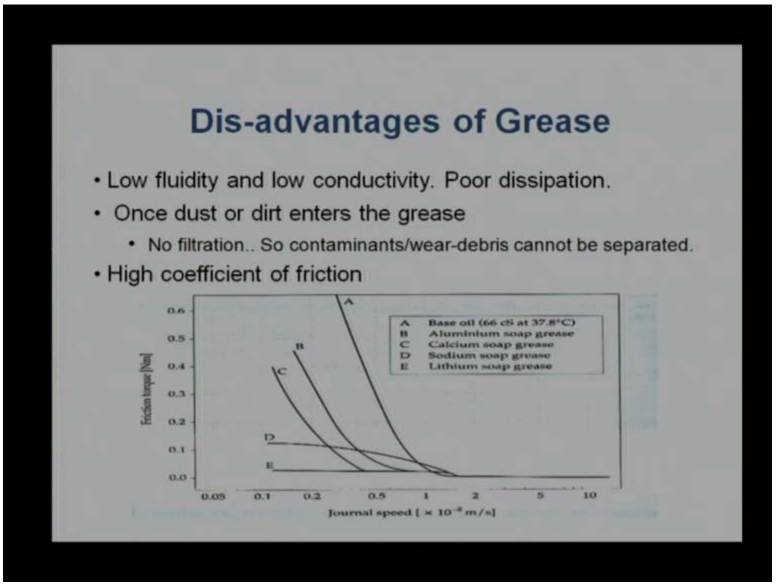

We can many time mentioned that they show low coefficient of friction typically the operating speed is low. This so this chart indicates the friction talk generally related coefficient of friction and this axis shows a speed or sliding speed in meters per second. You can say that each are which is used you are using on a liquid lubricant. It showing very high friction because there is no hydro dynamic action and when the applied load is high; the this lubricant is simply squeezing out without effectively reducing the coefficient of friction. Now, if we increase a grease, so b is a aluminum base, c calcium base so m base and then finally, comes a lithium base there is an change in increase.

They see a different behavior the load carrying capacities are different and that also indicates the lithium base grease is showing very high load carrying capabilities as well as a more or less same constant friction force. When I compare e verses a; we can say e is showing much lesser coefficient friction compared to a. A is a liquid lubricant. So, stating this one, is the high coefficient of friction from the grease may not be 100 percent correct.

It is for the high speed application. For low speed application, this sentence is not correct a low speed application and a high load we can see that lithium base grease can show better performance compared to liquid lubricants. We have some methods to characterize or characterize grease. Well we call as a cone base method you can see this cone over here and this black surface or the grease surface. We point for the surface or this con point comes in a contact with the these surface and allow 5, we allow 5 seconds is a free fall of this cone. Of course, the guided one free fall of free fall particularly in vertical direction of this cone. Within a 5 seconds whatever the depth of the cone is achieved with the grease; that informs us what is with the grease is a consistent or not or how much plastic deformation can this grease can sustain. That is why that they are different numbers given to that and of course, this grading is done by NLGI. What we call is the one of the American institute and national lubrications grease grease institute National lubrication lubricating grease institute; that is why the NLGI word is used. We characterize grease with NLGI grades.

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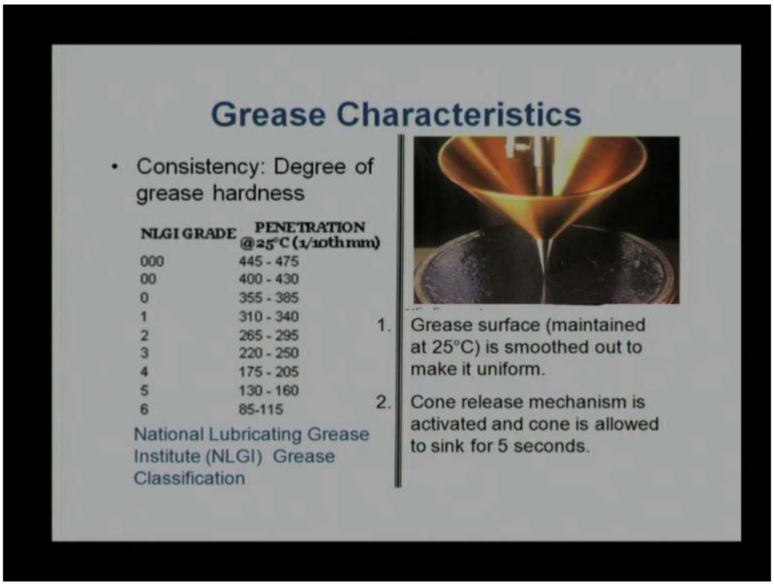

So, the triple 0 they act like a like a lubricant and what grade of this penetration or this kind of experiment is done? Either 25 degree centigrade and this number signifies as a 1 10th of mm. Within 5 seconds, if you your are using this grease within 5 second this will cone will penetrate up to 44.5 mm, maximum is 47.5 mm. The cone will fall within increase up to this level.

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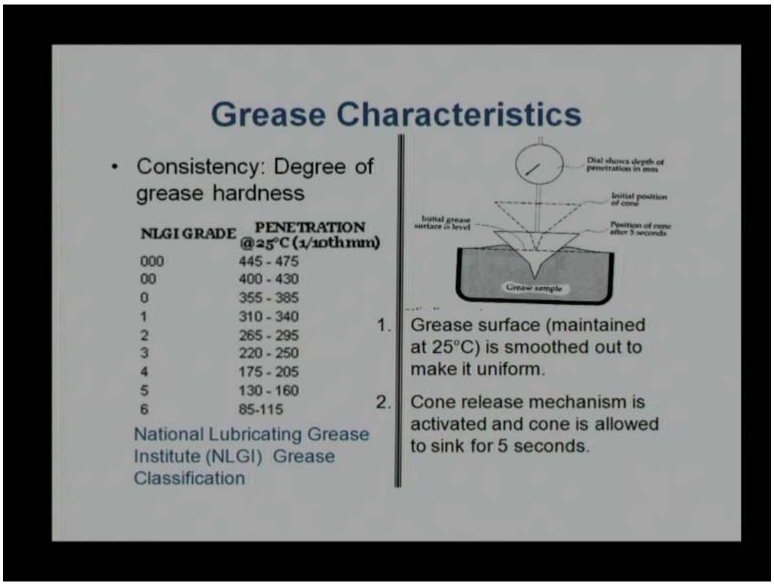

Now, this is catch is clearly indicating how do we measure it. There is a dial gate, this is initial position of the cone and we are allowing for the 5 seconds to fall in grease. And of course, you can able to see the grease is displaced from this place to this place. That is why we have able to get this kind of shape. As the depth of penetration reduces, we call consistency of the grease is increasing. As we say NLGI 6, grade grease is solid grease. (( )) NLGI triple 0 grade grease is a liquid grease. A flow ability of NLGI 000 grease will be very high compare to NLGI 6 grease. By a large we use a second or third NLGI greases for the rolling element bearings are common applications. To model this kind of grease we use some sort of fluid law may be Newtonian law, may be shear thinning law, shear thickening law or binding law but, we know very well the grease act as a pseudo plastic. They show the shear thinning behavior but, they also show some resistance in the initiating or in other words we say that grease gives a some resistances initially does not move. Shear rate will not be develop at all. That means initially shear stress will be there and after that it will can show some sort of deterrent fluid are some non internal fluid or shear thinning behavior that we can use, we can add this tau 0 in this component. That is why we say that for grease we can find out tau I, interface shear strength as a tau p. This initial shear stress required to flow the lubricant, flow the grease. This is the viscosity over here and this is a velocity radiant, it is another constant which is that an, is lesser than 1 is a shear thinning and is greater than 1 is a shear thickening. And what you say that increase there will be a tau p value, there will be eta b value, there will be hang value.

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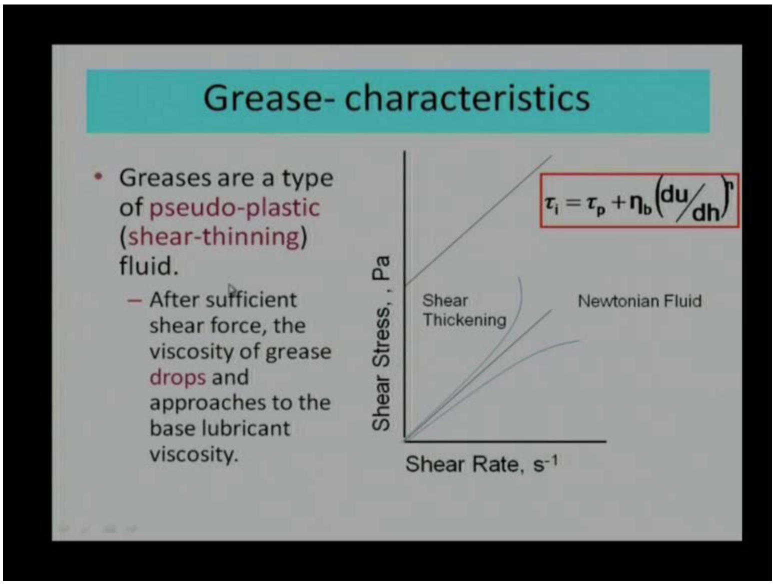

So, there will be three constants; we need to find out to characterize a grease. Effectively we need to find out three parameter; tau p and v and n that is why say that initially to define a tau v we required some initially shear force. So, viscosity of grease drops and approaches to the flow ability of liquid. To the more emphasizes on grease character grease characterization; I can take a same example which we took an previous lecture when we define the viscosity there is always an moving surface stationary surface and grease also show similar kind of layer structure, can be removed layer by layer. Now, to find out initially tau 0 because we mentioned about relation tau p. To find out the initially tau p we need to experiment this in a Rheometer. We will, what is a rheometer will describe later but, in a rheometer at 3 rpm, we operate that rheometer at the 3 rpm the distance as a size of a rotor.

And whatever the resistance come, whatever the yield stress comes; that will turn out the tau p. To find out the two remaining constant; eta b and we can operate 300 r p m or 600 r p m or 1 reading a 300 r p m or other the reading as a 600 r p m and find about the resistance, what is the shear, what is the yield stress. Once we know the yield stress; other two other readings and we can substitute tau p which we determine at the 3 rpm and velocity gradient and obtain this as based on that we can find out what will be eta b and what will be the n. So, over all these can be characterize by operating grease in rheometer at 3 rpm and 300 rpm 600 rpm or option is of thus we can operate both the 2 we can take 2 different readings.

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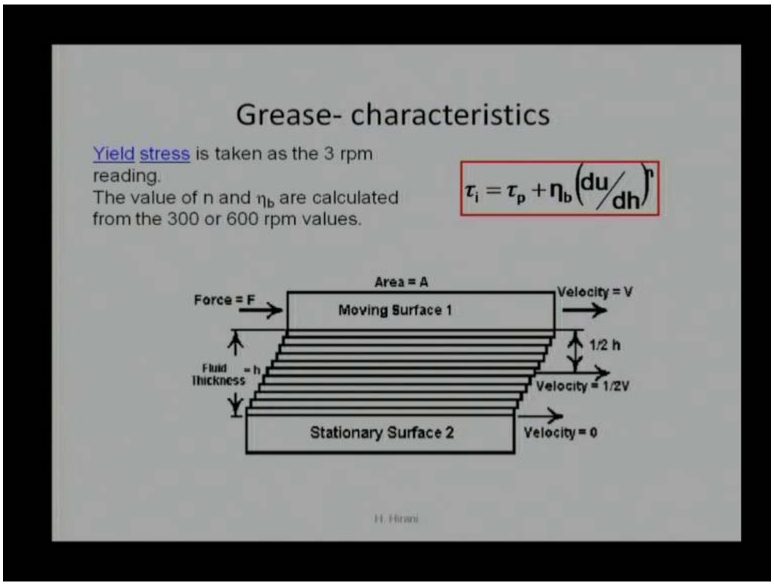

So, the 300 rpm and if some change comes; we can take two separate readings; 300 rpm as well as 600 rpm. I believe that operating 3 rpm there is a tau p, operating at 300 rpm may give 1 constant and operating a 600 rpm may give another constant. So, we require 3 conditions. Now, as I mentioned the, this is can be classified based on, also on additives which we mix in grease. And one of the common additives, the extreme pressure additive. The similar kind of additives are so are use in a liquid lubricant and we discuss with a liquid lubricant additives when this kind of topic will be same and thus why I am describing only in one topic there is a extreme pressure attitudes for the grease there remain same for the liquid also. You can say how they act. They are basically boundary agents, they chemically act with the surface.

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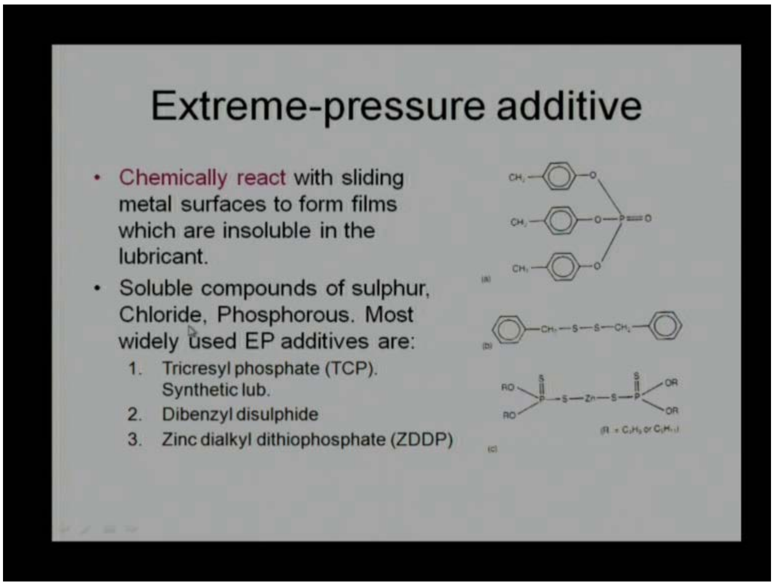

They corrode the surface, make a very thin layer on the surface. That corrosion is done purposively. That is why we scale we call that as a sacrificial layer. The sacrificial layer is made immediately and to avoid future corrosion or feature deterioration of the surface. They act as a wear resistance layer. That is why I say that chemically it a this kind of attitude they chemically react with the sliding metal surface to form films which are insoluble. Mind it these additives are soluble in lubricant but, they male coating on the metal surface which is insoluble. That is a very good action of the extreme pressure additives. That is why I say these additives are soluble. They are soluble compound of the sulphur chloride or as chlorine on phosphorus.

And the most commonly use additives may based on the metal and chlorine phosphorus and a sulphur are t c p and di benzyl di sulphide and this is most commonly use an engine oil what we call is z d d p. So, when there is a phosphate it has a zinc also. Zinc is one of the very good anti wear additive the metal. And the chemical structure also shown over here they have a bond over here which can act with the surface and make a complete these additives attached to the surface also. But, there will be with chemical action there will not be only physical action. Bond additives generally use a polar and to get attracted to the surface and make a bond while in this case they make they have a bonds which play with metal surface and then this bond makes chemical or react with the chemically with a metal surface. There are some friction modifiers which are used with a grease and we are mentioning again a this topic in greases reason being they are same lubricants or the same lubricant addictive which will be discussed again in, should be discuss again a liquid lubricant. But, I want to just restrict only on in one of this topic either grease on liquid.

So I am just using the two addictives in a grease and one, few more in a liquid lubricant. Now, when we use a friction modifier; we say that they increase of film thickness or the increase film strength to avoid the surface to surface contact. Major purpose of using this kind of modifier is to increase a firm strength. So that film or that coating is able to sustain more load and possibly then they should provide some cushioning. A fact also, that the two surface is remaining without much contact. Now, by a large friction modifier we know that they are used as boundary additives.

They are solid lubricants. You see that these all are solid lubricants; molly grease based on the molybdenum disulphide, tough and grease based on p t f e graphite grease and again solid grease. So, these are used with this kind of greases and one of the experimental leading which we have is based there is indicate what is effectiveness of grease when we mix with graphite. So, when the graphite is not mixed at all; the well load limit is 160 kilogram and various scars, which we we done we do an experiments. With experiments on this graphite this kind of viscosity that is the 0.6 mm m is 1. When percentage of the grease carbon graphite is increasing we are able to see that it reaches to one mature stage, 225 kilograms which is a significantly higher compared to 160 and scar is also coming down.

So this is a beauty of graphite. With this trying I am to close this lecture. We will continue on the lubricant in next lecture. Thank you. Thanks for your attention.