Video Course on Tribology

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Lecture No. # 16

Solid &Semi Solid Lubricants

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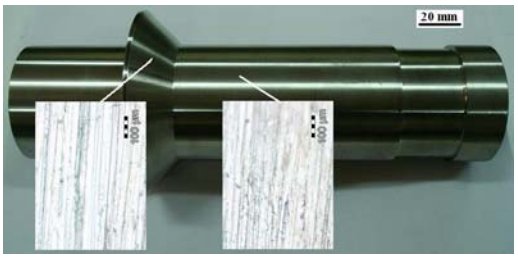
TRIBOLOGY

LECTURE 16:
Solid & Semi-Solid Lubricants

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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(b) Metal-solids: Lamellar solids rely on film transfer to achieve low friction.



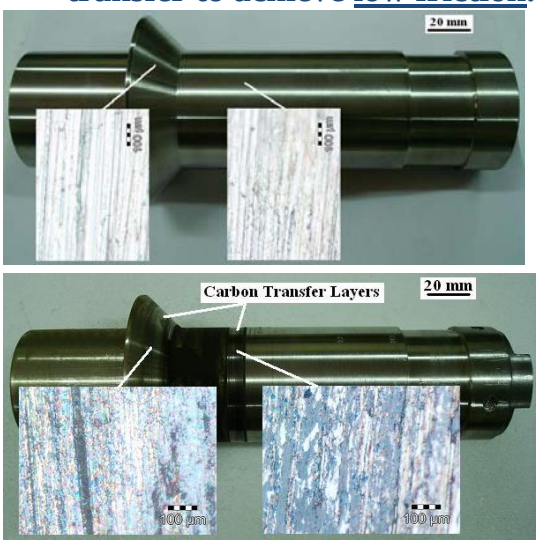


Second category in solid lubricant is metal solids as it was discussed, described in a previous lecture that we are emphasizing the word solid because the metal can be used as a liquid lubricant also at high temperature but, we are not mentioning about those in solid lubricant. We say that metal solids 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 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 to 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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(c) Metal-solids: Lamellar solids rely on film transfer to achieve low friction.





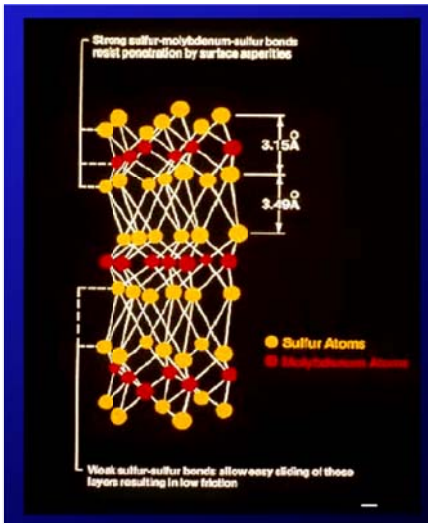
Before they dislodge or removed from the surface. So, we say that these lamellar solids rely on a film transfer to achieve the low coefficient of friction. One of the common examples is a molybdenum disulphide, well known solid lubricant, well known lamellar solid. We say that in this material has a 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 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 as they can be used as a solid lubricants because of the low tangential strength.

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Molybdenum Disulfide

- **Strengths**
  - **High Load Carrying**
    (> 700 MPa)
  - **Low Friction**
  - **High Temp Lub**
- **Weaknesses**
  - **Rapid Oxidation in Air over 400°C (!!!)**
  - **Moisture Detrimental to performance**
  - **Film thickness ~ 15 μm**



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.

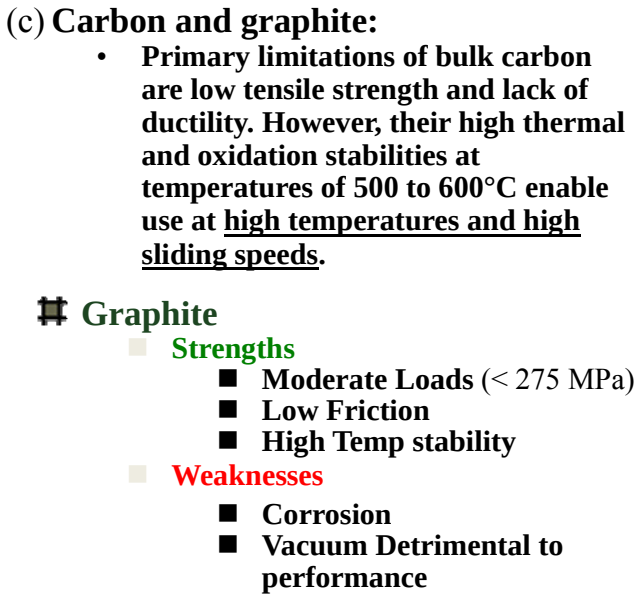
So, it is not only the molybdenum disulphide acts if it is the molybdenum molybdic oxide. That will also act as a solid lubricant. There are some weaknesses of a molybdenum disulphide solid lubricant. You say that oxidation rate increases in presence of oxygen. This oxidation happens a 350 degree centigrade and in presence of only air, no other oxygen available other than in air. This oxidation happens a 450 degree centigrade. That is why on 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 oxidized 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 I previously mentioned that almost all the solid lubricant 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 then may be in the few cycles of few 100 cycles that layer will thin down to 15 micron. You may know there is no point to deposit very thick layer or molybdenum disulphide does not really work much. However the thickness is lesser then 15 microns; 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, in form of the carbon as graphite which shows a lamellar structure then lamellar structure can be utilized as the solid lubricants. That is why we can say graphite acts as the solid lubricant it has certain strengths certain weaknesses. So, strength 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

stress; it can sustain its raise up to 275 75 mega Pascal. It shows the low co efficient of friction and also has high temperature stability. You say many times temperature stability it can go up to 2000 degree centigrade. They do not disintegrate, they do not change a material properties up to 2000.

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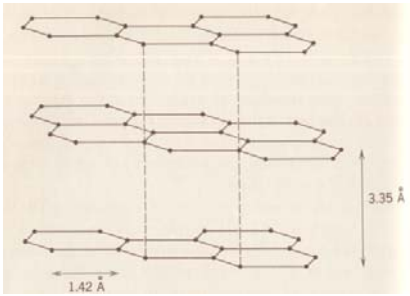


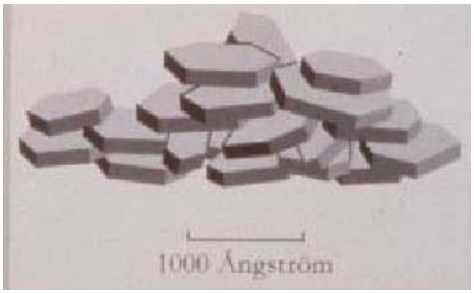
But there's oxidation or there's a lack of the moisture then properties will deteriorate major strength of the graphite is a moisture. In presence of moisture they work very good lubricant. They act as very good lubricant but, if there is no moisture available then there will be problem. Coefficient 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 a typical example of carbon for use a carbon with graphite or graphite solid lubricant with a copper will get corrosion because of the nature of graphite. Another thing is that 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 no longer the lamellar structure. It will be distorted structure that means as for 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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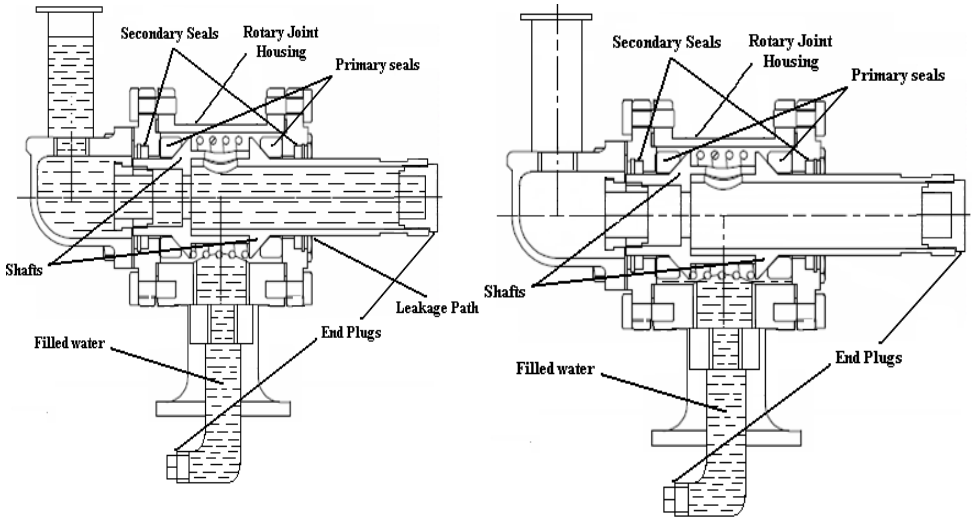




We did a good number of maximum of and so on a carbon graphite material and figured out carbon graphite really requires moisture to act as good lubricant but, how much moisture? So, what we did we used one rotary joint filled with water. So, this is a rotary joint I am showing here. It has a seals; this 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 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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Performance of Graphite in Water



NOTE: Maximum seal wear occurs under complete water environment, and minimum wear occurs under vapor lubrication.

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 when this structure or this unit at 100 degree centigrade, a high coefficient friction must be .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 damaged immediately; will get in wear debris immediately. So, first is that rate of the transformation is high and that 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 under the vapor lubrication. When they are just sufficient moisture available which makes water vapor and then they act as a gaseous lubricant.

So, let us see the situation with carbon graphite. Now, if you try to summarize a carbon graphite or graphite structure what we say? They have a high thermal stability we know up to 2000 degree centigrade but, they 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 there's a practical difficulty, a practical limitation on carbon graphite. There is another good point is that this low coefficient of friction basically depends on 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 indicated they are clearly at a high altitude.

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- High thermal stability (2000°C)
  - Practical application is limited to a range of 500 to 600°C due to oxidation.
- Low friction
  - Low friction relies on adsorbed moisture or vapors to achieve. At temperatures as low as 100°C, amount of water vapor adsorbed may be significantly reduced to the point that low friction cannot be maintained.
    - During world war II, aircraft flew at higher altitude and electric motor brushes failed. Research into this problem revealed that graphite requires an adsorbed layer of water vapor to lubricate effectively.
- Corrosion
  - Graphite promotes electrolysis. Graphite has a very noble potential of + 0.25V, which can lead to severe galvanic corrosion of copper alloys and stainless steels in saline waters.

Generally, in electric motor brushes, carbon graphite is used to make electric brushes. They failed and after doing a research during analysis it was figured out that absorbed layer of water vapor which was supposed to lubricate effectively, what is lost from the surface as well that there was a high coefficient friction and high wear rate during world war 2, in equipment's which was used. As I mentioned, it corrode the surface. 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 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 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. 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 materials 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 environment curing or good regulated temperature environment. Only problem with a plasma spring is a dimensionality there's a possibility of adhesion in dimension.

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Ceramic and Cermet (metal bonded ceramic) coatings

- Ceramic/Cermet coating up to 0.5 mm thick on metal substrates offer a convenient way of utilizing the wear resistance of metal with a minimum processing cost.
  - Plasma spraying
  - Impingement coatings from a detonation gun
    - Improved adhesion to the substrate metal and lower porosity.
  - Electrolytic deposition from electrolyte containing ceramic particles (Tribomet coating)
    - Ability to coat small internal surfaces inaccessible by any other technique.

So, we need to do 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 semisolid lubricants and a typical example is grease. A number of materials act as a semi solid or the gels. They can be used as lubricant but, grease is 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 wooden pieces, these are actually fibers. They make structures such a manner liquid cannot escape easily. So, this structure needs to be filled with lubricants. That is why I say that 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 thicknesses make structure in such a manner that liquid cannot easily escape from this. That integrator part or may be can assume that it acts as a sponge and this sponge has capabilities to retain the lubricant within it. It can be in layman language it 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 repellent. So, these can 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 the synthetic oils are used because 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 in high temperature we use in fact high viscosity oils. Because as 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. This kind of oils should be utilized. The viscosity will turn out to be again the low viscosity so effectively 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 emphasized 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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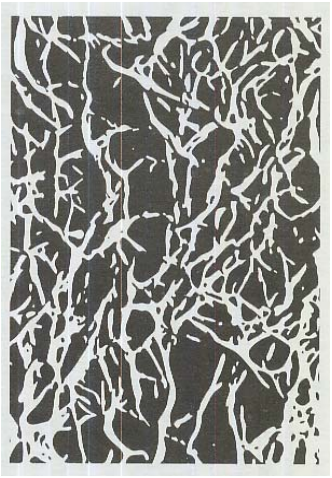
Semi-Solid Lubricant: Grease

Consist of

- Base oils (75 to 95%):
  - Mineral oils, Synthetic (PAO's, esters, silicones, glycols).

  Low viscosity: For low temperature, low load and high speed applications.

  High viscosity: For high temperature, high load and slow speed applications.
- Additives (0 to 5%):
  - Antioxidants, EP additives, Corrosion inhibitors, Water repellants
- Minute thickener fibers (5 to 20%

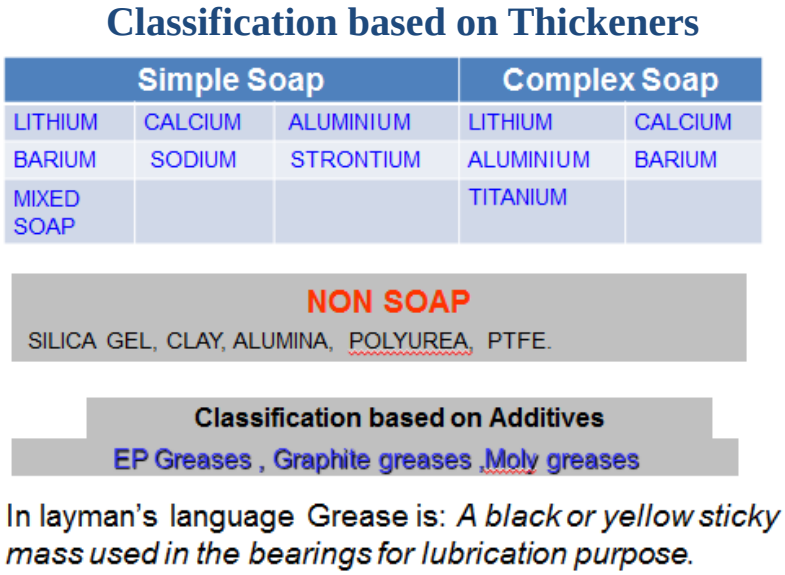


Semi solid lubricant

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, need to use a good lubricant. Ordinary mineral oil or ordinary high viscous mineral cannot be used for this kind of applications and I mention a last is thickness which acts as a fiber on other to 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 bleeder that is why we need to replace this grease with the new grease.

and oil is retained within fibers. Coming to the thickness we say thickness, can be defined in number of categories. We would call it as soap based thickener. 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 structure wherever there is hybrid structure there is more possibility to sustain high temperature. That is why the complex series 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 called all as purpose grease because it has a temperature sustainability up to 65 degree centigrade and operating temperature is not going beyond 65 degree centigrade. Calcium grease will work very nicely generally used for the low speed applications. Even lithium grease is not gaining more popularity because of the structure, because of its high temperature stability, even a lithium can be used as a complex series.

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So, lithium grease is mostly known, more popular from temperature stability point of view or operating temperature point of view. As I mentioned there are non-soap grease is also they are basically clay based and they are mixed also with the solid lubricant and see here the

PTFE is grease can PTFE reacts as a solid lubricant in that there are some synthetic greases or poly urea ceramic paste, alumina silica gel there are sometime we call classified grease is based on their additives. We govern one of the popular name is merely greases, 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.

EP greases with the EP additives are mixed with grease and what we say that in the layman's language grease is more like a black or yellow sticky mass. It always has some sort of fatty acids which sticks 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 lubricant. That is why say that in layman language there's some thick mass used for lubricating the bearings.

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Comparative Chart

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 test setup for one textile machine and we were supposed to operate the bearings at 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 or 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 called me and he said 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 bearing because once grease filled in a bearing we need to replace a 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 calcium grease as ineffective grease and lithium which can sustain a high temperature can be used as good grease for that application. So, this chart shows the comparisons. We say the dropping points first. The dropping point is the maximum temperature at which grease can be utilized. After there bleeding will be very high almost complete oil will be removed from the surface or within structure of grease. So, when we use calcium but, no way should we use more than 80 degree centigrade. However we call as a maximum operating temperature keeping a factor to sustain. 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 huge different of 60 degree centigradce'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 speed applications. Now, there's another kind of sodium base grease which has as operating temperature 125 degree centigrade but, the problem is that it cannot be used for the low temperature applications. They start freezing and another thing is that they are very reactive within 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 significant improvement. Calcium base grease was only 80 degree centigrade.

When we use with different 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 to 150 degree centigrade. Still that temperature is far above than 65 degree centigrade temperature. Even lithium base grease is also 125. So what we say the complex grease gives maximum advantages, the calcium base greases, does not give that much advantage to the lithium base grease. You can see that lithium base grease that the complex structure has 2 acids or which requires more manufacturing steps is 160 degree centigrade while here it is 125 degree centigrade. So, improvement in this operating temperature is not 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 polyuria based, we can see that it is all as good as 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 is more than 150 degree centigrade, we should switchover to some lubricating oil which has a heat carrying capacity or heat dissipation is much faster compared to grease. And another important thing is that, whenever we choose first, if there is water environment and temperature is a 50 to 60 degree centigrade, choose calcium because this is economic, is least costly or is not as expensive as other 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 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 aluminium based greases or lithium based greases. But, lithium complex will be costlier compared with simple lithium greases. So, unless it is essentially required we should not use. This is from this slide. It shows the importance of mineral oils or silicon oils or synthetic oils. What we talked in 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 aluminium based or polyuria 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, if I am assuming that we are choosing 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 are talking a medium because we are comparing with calcium that is the 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 talked about the complex lithium base grease. However the minimum temperature you can see that it is cannot be operated 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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Role of Base Fluid

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 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 it remains in 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 comes to seals effectively that means from an environment, contamination will not come easily and it will not be requiring very tight seal, an ordinary seal 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 reduces impact loading, it can sustain the shock loading.

So what we say that it gives a maximum comfort. That is why 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. Catch shows, I am just assuming

there is one, initially the solid surface and when solid surface develop pits may be the effect of loading then if the pits naturally that they will be a vibration. If any rolling element passes on the surface it will come with some sort of contact and non-contact. Under non-contact the stiffness will be very 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 noise in overall.

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Advantages of Grease

- Remains at application point & adhere to surface.
  - Less-frequent application needed.
    - Good for inclined/vertical shafts.
  - Seal out contaminants & less expensive seals needed
  - Water resistant & reduce oil vapor problems
  - Prolong the life of worn parts
  - Provide better mechanical lubrication cushion for extreme conditions such as shock loading, reversing operations, low speeds & high loads.
- Reduce noise and vibration



So grease is effective to reduce 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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Dis-advantages of Grease

- Low fluidity and low conductivity. Poor dissipation.
- Once dust or dirt enters the grease
  - No filtration. So contaminants/wear-debris cannot be separated.
- High coefficient of friction

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 grease retains or avoids particles to come into contact or avoids contamination to come in contact with the solid surface. It prevents a contamination to come into contact but, problem is once a contamination starts coming one way another they reach to the surface; then grease will try to retain those contamination with the surface. That means it has advantages. They are able to avoid, prevent the contaminant to come into contact but, once they come in a contact there is 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 advantages as well as disadvantages. 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 experiments indicate, not necessary high coefficient friction is done or is achieved by using grease as a lubricant.

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Dis-advantages of Grease

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- Once dust or dirt enters the grease
  - No filtration. So contaminants/wear-debris cannot be separated.
- High coefficient of friction



We have many times 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 using on a liquid lubricant. It showing very high friction because there is

no hydro dynamic action and when the applied load is high; this lubricant is simply squeezing out without effectively reducing the coefficient of friction. Now, if we increase grease, so b is aluminium base, c calcium base so m base and then finally, comes a lithium base there is a 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 to the surface or this cone point comes in contact with the these surface and allow 5 seconds is a free fall of this cone. Of course, the guided one free falls 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, National lubrications grease institute that is why the NLGI word is used. We characterize grease with NLGI grades.

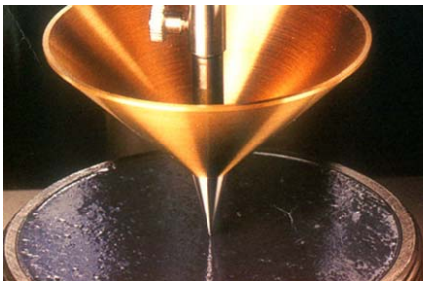
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Grease Characteristics

- Consistency: Degree of grease hardness

NLGI GRADE	PENETRATION @25°C (1/10th mm)
000	445 - 475
00	400 - 430
0	355 - 385
1	310 - 340
2	265 - 295
3	220 - 250
4	175 - 205
5	130 - 160
6	85-115

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1. Grease surface (maintained at 25°C) is smoothed out to make it uniform.
2. Cone release mechanism is activated and cone is allowed to sink for 5 seconds.

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

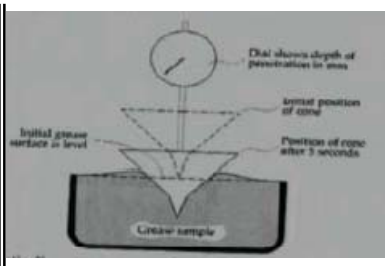
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Grease Characteristics

- Consistency: Degree of grease hardness

NLGI GRADE	PENETRATION @25°C (1/10th mm)
000	445 - 475
00	400 - 430
0	355 - 385
1	310 - 340
2	265 - 295
3	220 - 250
4	175 - 205
5	130 - 160
6	85-115

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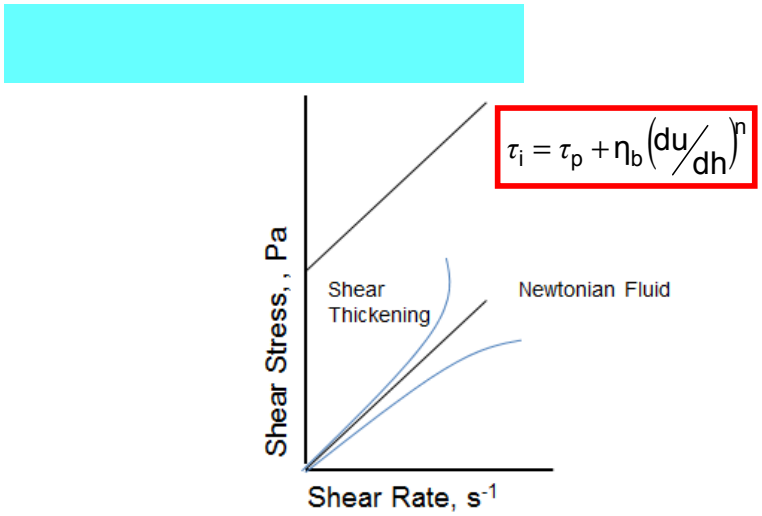
1 Grease surface (maintained at 25°C) is smoothed out to make it uniform.

2 Cone release mechanism is activated and cone is allowed to sink for 5 seconds.

Now, this catch is clearly indicating how to measure it. There is a dial gate, this is initial position of the cone and we are allowing for the 5 seconds falling in grease. And of course, you are able to see the grease is displaced from this place to this place. That is why we are 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 compared to NLGI 6 grease. By and large we use 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 developed 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; τ_p and v and n that is why say that initially to define a τ_v we required some initially shear force. So, viscosity of grease drops and approaches to the flow ability of liquid. To emphasize more on grease characterization; I can take the same example which we took in previous lecture when we defined 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 initial τ_0, use relation of τ_p. To find out the initial τ_p we need to experiment in a Rheometer. We will, what is a rheometer will be described 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 τ_p. To find out the two remaining constant; η_b and we can operate 300 rpm or 600 rpm or 1 reading a 300 rpm or other the reading as a 600 rpm 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 τ_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 η_b and what will be the n. So, over all these can be

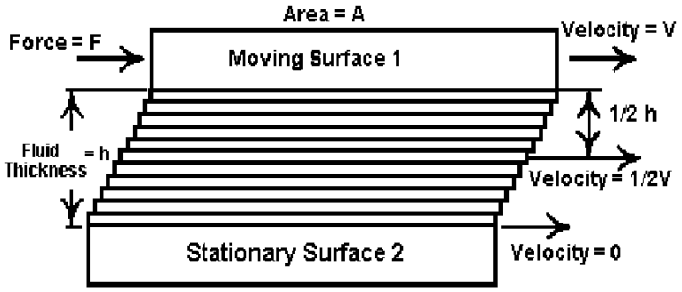
characterizes by operating grease in rheometer at 3 rpm and 300 rpm 600 rpm. Thus we can operate both the 2 times we can take 2 different readings.

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Yield stress is taken as the 3 rpm reading.
The value of n and η_b are calculated from the 300 or 600 rpm values.

$$\tau_i = \tau_p + \eta_b \left(du/dh\right)^n$$

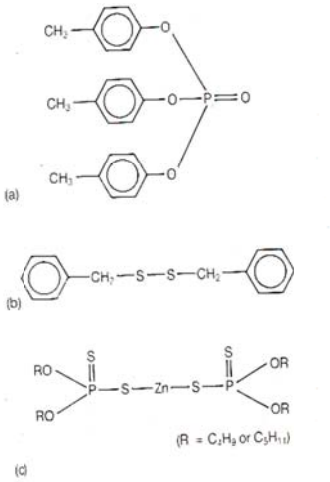


So, the 300 rpm and if some change comes; we can take two separate readings; 300 rpm as well as 600 rpm. I believe that operating 3 rpm there is a tau p, operating at 300 rpm may give one constant and operating a 600 rpm may give another constant. So, we require 3 conditions. Now, as I mentioned, this can also be classified based on additives, which we mix in grease. And one of the common additives is the extreme pressure additive. The similar kind of additives are used 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 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 act chemically with the surface.

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Extreme-pressure additive

- Chemically react with sliding metal surfaces to form films which are insoluble in the lubricant.
- Soluble compounds of sulphur, Chloride, Phosphorous. Most widely used EP additives are:
- Tricresyl phosphate (TCP). Synthetic lub.
- Dibenzyl disulphide
- Zinc dialkyl dithiophosphate (ZDDP)



They corrode the surface; make a very thin layer on the surface. That corrosion is done purposely. That is why we scale we call that as a sacrificial layer. The sacrificial layer is made immediately to avoid future corrosion or future deterioration of the surface. They act as a wear resistance layer. That is why I say that chemically 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 make 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 used additives may be based on the metal and chlorine phosphorus and a sulphur are TCP and di benzyl di sulphide and this is most commonly use an engine oil what we call is ZDDP. So, when there is a phosphate it has 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 complete 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 bonds which play with metal surface and then this bond makes chemical or react chemically with a metal surface. There are some friction modifiers which are used with grease and we are mentioning again this topic in greases reason being they are same lubricants or the same lubricant addictive which will be discussed again in, a liquid lubricant. But, I want to just restrict only on one of this topic either grease on liquid.

So I am just using the two addictive's 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 is based on the molybdenum disulphide, tough and grease based on PTFE graphite grease and again solid grease. So, these are used with this kind of greases and one of the experimental readings,

which we have, is based. This is indicates effectiveness of grease when we mix with graphite. So, when the graphite is not mixed at all; load limit is 160 kilogram and a various scars occur after performing 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 the beauty of graphite. With this toying I am to close this lecture. We will continue on the lubricant in next lecture. Thank you.