Video Course on Tribology
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Lecture No. # 15
Lubrication Classification

TRIBOLOGY

LECTURE 15:
Lubricant Classification

Welcome to fifteenth Lecture of video course on tribology. Topic of today's lecture is lubricant classification. In our previous lecture we studied hydrodynamic lubrication and figured out that viscosity is one of the important parameter for lubrication but, it is not necessary for all kind of lubricants. Viscosity is very important for liquid lubricants their other kind of lubricants which we are going to exploit today that is what the name of the topic is lubricant classification. Very common sense says that lubricant can be classified based on their molecules, structure strength between molecule attractions or we say the overall attraction forced between the molecules.

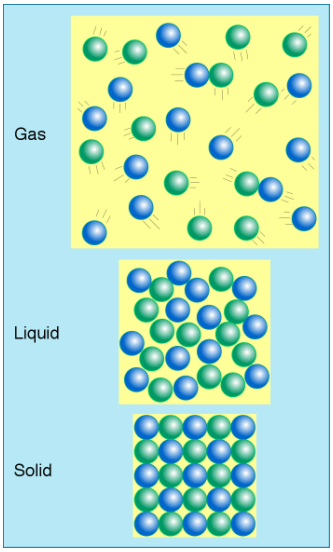
We know very well in gaseous state, molecules are distant or not attached to each other. However in the case of liquid force of, attraction is more they come closer or we say the particle density is more. In case of the solid, particle density is maximum compare to liquid and compare to the gasses. So, based on this molecular structure we can divide lubricant as gas lubricant, liquid lubricant and solid lubricant. In addition to that, we have one more classification what we call as semi lubricant or semi solid lubricants if they have state in between

liquid and solid, they have probability but, they show initially some resistance. That is why; we say lubricant can be classified as a gaseous lubricant; as a liquid lubricants; semi solid lubricants and solid lubricants.

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Classification

- Gaseous lubricants
- Liquid lubricants
- Semi-solid lubricants
- Solid lubricants



Every lubricant has its own characteristics, they prefer in different situations may be gaseous lubricant which has a very low viscosity, lot of gap between the molecules. That will give very, very low resistance against the flow in that case coefficient of friction will be very low but, because of the molecular structure they are not able to sustain much low that means they can be used only for this kind of lubricant for very, very low load applications. A solid lubricant can sustain very huge amount of the load; they will not be getting quizzed out. So, they have more applications when the load is very high. In the extreme cases of the load and extreme cases of the speed, they need to choose proper lubricant. Before that, let us see what is the importance of the lubrication? It has been realized one way or other lubricants are the important. We have one table, it says that it has been picked up from the wear control hand book reference is been defined or given on this table. It says that comparison between hydrodynamic lubrication and squeezed lubrication will be explored in our next

module: Elastohydrodynamic lubrication, boundary lubrication, solid lubricant and unlubricated.

Unlubricated does not mean that, is not lubricated there is a possibility of a natural oxides on the surface but, we emphasizing that we are not doing anything intentionally, no lubricant intentionally has been supplied or applied on interface.

So, when we compare wear rate between the unlubricated case and solid lubricated. What we get almost difference of one hundred, if I say wear rate is 100 units for unlubricated case. We may reduce this lubricated wear with solid lubricant to the 1 percent of that the huge difference. We say that component life can be increased by 100 times by properly choosing solid lubricant does not mean that all solid lubricant will be very good with every interface, there is a need of comparability between the solid lubricant and metal on which, we have applied or polymers or ceramics on at which interface they have been applied. Similarly, when we compare boundary lubrication and Elastohydrodynamic lubrication; what we find, there is huge difference boundary lubrication, if I assume the 100 x or 100 units we are going to get a much lesser wear rate may be say 0.1 x or 0.1 percent of the boundary lubricant.

What is huge difference here on some what we are talking about the boundary lubricant we are talking the solid lubricant; they both have same almost same film thickness at the interface. Solid lubricants are strictly attached to the surface; boundary lubricants require carrier fluid to flow. But detachment and attachment will be continuous process, well in case of solid lubricant many times if once it is detached from the surface it will be difficult to again attach that. That is why; wear rate may be initially moderate or low if solid lubricant is removed from the surface, wear rate will be increase and one average wear rate with solid lubricant will be higher compare to the boundary lubricant of course,

which we have learned by the physics of this mechanisms so we can use solid lubricant as a boundary lubricant we can use carrier fluid with solid lubricant.

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Importance of Lubrication

Table 7.2 Typical values of wear coefficient K for lubricated sliding wear (from Peterson M B, in Peterson M B and Winer W O (Eds.), *Wear Control Handbook*, ASME, 1980, pp. 413-473).

Type of lubrication	K
Hydrodynamic and squeeze film	$<10^{-13}$
Elastohydrodynamic	10^{-13}–10^{-9}
Boundary	10^{-10}–10^{-6}
Solid lubricants	$\sim 10^{-6}$
Unlubricated (severe wear)	10^{-4}–10^{-2}

And that is one of the most commonly used one of the solid lubricant as a molybdenum disulfide has been mixed with lubricant; it has been mixed with greases so that grease and on the liquid lubricant they act as a carrier fluid and wherever it is required solid lubricant or lubricant film is required, solid lubricant or molybdenum disulfide is occupied or occupied that space. Now, before starting, the coulomb lubricant classification is important to understand, how to define liquid lubricant or solid lubricant or any kind of lubricant. The question comes, how to define lubricant many times when we drive a car on the semi road you find car is sleeping coefficient of friction is very low. So, that should be advantage to us, I can say the sign is acting as a lubricant. Sometime maybe when the surface is uneven, we get most low because of that less range of contact, lesser friction. We can say that in this case gravels are also acting as a lubricant but, that is not case when we talk about the tribology when we understand the physics and understand the science of lubrication. You say, lubricant can be differing defined based on the properties. You say that lubricant needs to provide low but constant and controllable friction. If sometime the lubricant is providing coefficient of friction equal to 0.1 and sometime 0.5-0.6; then it is uncontrollable coefficient of friction. It should not happen and most commonly happen with the sand or gravels they do not have any control coefficient of friction. Coefficient of friction continuously changes it is lower than solid role but, uncontrolled we do not have much control on that coefficient of friction. We say that, from that angle gravel assigned cannot be called as lubricant in addition to that we have requirement it should not attack the tribo surface attack in the sense majorly maybe with

nominal or very low level is fine but, it majorly which is visible that should not happen or substance which is going to attack the surface severally or which can be easily quantified.

Then in that case that will not be acting as a lubricant so first thing is that you should provide controllable coefficient of friction second thing is that you should not damage the surface and finally, it should not be again and again provided. There is a possibility of some lack of the lubricant, any moment, temporally, so, we require stickiness to the surface. Instead of happening at the movement where we are unable to supply lubricant; and then system lubricant should be having some adhesiveness with the surface.

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How To define Lubricant?

- Often Dust, Sand or Gravel on surface of Road reduce friction.. Does it mean those substances are lubricants ??
- To be on conservative side, we need lubricant to:
  - ✓ Provide low but constant & controlled friction.
  - ✓ No attack or damage to tribo-surfaces.
  - ✓ Preferably adhere strongly on one surface.

So, lubricant can be defined based on this it should provide low coefficient of friction and controllable coefficient of friction; second it should not damage the surface and; third preferably it should attach the surface or attach to the surface. Now, we classify the solid lubricant as a solid lubricant, semi solid lubricant, liquid lubricant and gasses lubricant all this are the very big groups we will not be covering everything in detail but, to some extent will learn the classification. So, remaining of this lecture will be understanding classification of the solid lubricants. See, solid lubricant they are basically materials which are having solid state and they show low coefficient of friction or low shear strength.

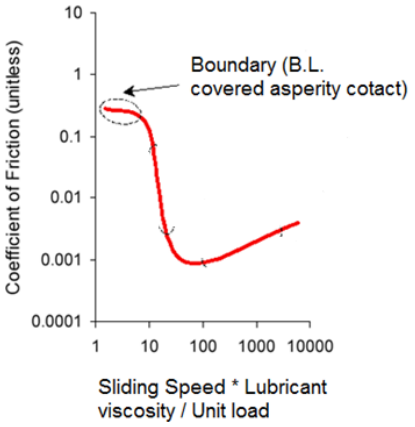
So, we can say the solid lubricant any solid material which can be placed between tribo-pair surfaces and can shear more easily. Under a given load condition, then tribo material then served that means; third substance in use between the two materials or tribo-pair and it should be easily sheared. Now, if I go back to our original Steinbeck curve we defined there boundary lubrication is it interesting to note that solid lubrication also can be defined the similar state. It follows more or less dry lubrication loss only there is a magnitude is

decreased. You say that, coefficient of friction in solid lubricant can be related to shear force and applied load. The coulomb law can be used for this kind of lubricants because they are dry, they are not liquefied they do not have flow possibilities to major extent and that is why; we can define using coulomb's law or based on even Arc hard equation we can define a wear rate.

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Solid Lubricants

- Any solid material, which can be placed between tribo-pair surfaces and can be sheared more easily under a given load than the tribo-materials themselves.
  - Coefficient of friction in dry lubrication is related to the shearing force and the applied load.
- Boundary films are formed by interaction of the tribo-surfaces with the solid lubricants.



Now, we say that boundary films have formed by interactional tribo surface with a solid lubricant. In the presence of the solid lubricant and they will be some mechanical rubbing because of the tribology is defined based on mechanical rubbing. There is a possibility of a film of solid lubricant getting transferred to the materials in contact. And large that is a mechanism, where it works before starting solid lubricant we want to explore what are the advantages and disadvantages and when we should recommend solid lubricants.

First point comes it is more effective than fluid lubricant, fluid may be liquid lubricant, gasses lubricants and grease also has probability, so I can define the grease also the fluid so all three, gaseous liquid and solid so liquid gasses and semi solid. Solid lubricants are better and are more effective than those lubricants particularly in the high load conditions. Whenever, the load is very high lubricant will try to get quizzed out from the interface and if there is a solid lubricant which has more bounding strength with a surface will remain in contact. They will be more effective compare to liquid lubricant, compare to gaseous lubricant, compared to semi solid lubricant.

Second point, second advantage is mentioned over here is a high resistant to deteriorate. They do not get deteriorate; they do not get easily oxide in a storage or common space. They have relatively high temperature stability. Unless vacuum is been created where that they degassed they will try to vaporize. In addition to that, there is a third advantage is been mentioned that it is highly stable or the solid lubricants are highly stable even though at high temperature condition because they have high molecular attraction. Their structure is more stable; they can sustain more temperature; come back to liquid lubricant compared to gaseous lubricant. I can say the gaseous lubricant because gaseous lubricants have a much better properties at the high temperature.

They have a more molecular randomness and then they try to give more viscosity so the high temperature case gaseous lubricants are preferable. But solid lubricants are stable. They do not change their molecules structure very easily at a moderate temperature. They are stable against radiation. They have lesser chemical activities, that is why they can be used in reactive environments. We talk about the nuclear cases, solid lubricant as preferable.

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Advantages & Disadvantages of Solid Lubricants

Advantages	*Disadvantages*
More effective than fluid lubricants at high loads (high pressure). High resistance to deterioration in storage. Highly stable in extreme temperature, radiation, and reactive environments. Permit equipment to be lighter and simpler. *Superior cleanliness*	Poor self-healing properties. A broken solid film tends to shorten the useful life of the lubricant. Poor heat dissipation. This condition is especially true with polymers due to their low thermal conductivities. Higher coefficient of friction and wear than liquid lubricated bearings.

This fourth advantage is really very, very big advantage as a main motive to promote solid lubricants. You say solid lubricant permit equipment to be lighter and simpler. Let’s take an example of liquid lubricant. Liquid lubricant need to be pumped, see they require pump; they require pipe lines; they require sealing’s; they require some brigs to tie, overall system will turn out to be complex. A number of components are going to be involved and there is a possibility of the leakage also. That is why the last advantage is been mentioned they have

cleanliness. Solid lubricant can maintain the cleanliness. There will not be leakage as of the liquid lubricant. So they are better than liquid lubricant from that angle even better than semi solid lubricant like greases. They do not require many equipments. Once they have been coated on the surface for certain duration. Of course, their life is not infinity they get coated on the surface for some stability time. One may say anything like that once you coat the solid lubricant, apply a solid lubricant block it will lost for the forever.

Have a finite life however in liquid lubricant we can say liquid lubricant without any additives. Additive which is not going to get depleted they can show infinite life which is also very hypothetical case. They have longer life than solid lubricant but, not infinite life. Now, coming to the disadvantages when we should not recommend solid lubricant that is one of the important things is that they do not have self healing properties. Any lubricant, which does not have self healing properties when has been distorted from the surface detach from the surface solid lubricant cannot go back and heal that defect. So wear rate will change. There will be transition that is why; we say that in those situations wherever the more precision is required with more reliability is required either we should use a solid lubricant with carrier fluids or some mechanism should be there. The self healing devise is been utilized with solid lubricant. This says that, a broken solid lubricant shorten the useful life of lubricant if are designed solid lubricant for the 1000 hours and quite possibly it shows only 10 hours, 12hours, 15 hours. Another disadvantage about solid lubricant is their thermal conductivity and heat dissipation capabilities. They work only with a conduction there is no convection. Radiation is highly coming to the picture and for conduction we do not have any carrier fluid; we do not have any cooling agent and nearby or passing through and then divides, then heat dissipation will be difficult.

Whatever heat generated will be accumulated at the surface and inversely increase the temperature but, if there is a cooling device available, cooling fluids are available which can cool surface, then this kind of a solid lubricant can be recommended. But, if there is no availability of cooling agent or cooling devices then, we should not recommend reason being that solid lubricant already show high coefficient of friction compared to liquid lubricant coefficient of friction so heat generation will be more at the solid lubricant interface compared to liquid interface and in that case if in addition to that there is no provision to carry away the heat and applied load is very high relatively speed is very high then we should not recommend a solid lubricant.

Last disadvantage is been mentioned over here is at high coefficient of friction and high wear rate. Now, wear rate is one of the subjects to think. In this case we say the wear rate of the solid lubricant itself can be counted at the wear rate. Sometime people say that wear rate of the material which come in interface, here the coating as been applied or solid lubricant is being applied, if it wears out then it is going to give condition as unlubricated condition. Wear rate will increase so first wear rate of the solid lubricant and subsequent wear rate of the metal which are at interface or it will be high and of course, a coefficient of friction will be high because they have high bounding strength with interface and they do not show or do not give very low coefficient of friction, low shear strength because of the solid structure or a solid state, they will have a higher shear strength compared to the liquid interface or liquid state.

Then starting a solid lubricant, now we say that one way to applied a solid lubricant or pass a solid lubricant or supply solid lubricant and interface is simply rushing component with solid lubricant or rubbing component with solid inter solid lubricant. Just to elaborate, what I am trying to convey I am showing two diagrams or two photographs. Both the photographs are the same eccentric cam and this eccentric cam has been coated been rubbed with molybdenum disulfide powder. Molybdenum disulfide powder, somewhere is lesser than 1 micron size when we rubbed it we have found really a good semi surface of the cam. When we operate this came at the may be say 60 rpm and where lab experiments after 3 hours operation we find molybdenum disulfide has been removed from the surface. We can see the worn out the surface over here this worn out surface clearly shows that there is no molybdenum disulfide, it the molybdenum disulfide has been removed from the surface.

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Solid Lubricants

- Powder (5 nm to 5 microns) or thin film
  - **Self-healing**: Use of carrier fluid





So, that is a major disadvantage we have to apply molybdenum disulfide that has been removed. So, easiest way is that use some sort of carrier fluid with molybdenum disulfide. Carrier fluid will be a continuous media to supply a molybdenum disulfide at the interface. They will keep depositing this kind of the coating on surface. May be say that coating when we applied and then removed, applied and then removed, it will slightly be like boundary lubricants. Overall wear rate will be lower, that is why we say the molybdenum disulfide can be mixed with liquid lubricant, can be mixed with greases, they show up better performance. However the problem comes to the filtration. If filter is a very low rating or we say that beta rating is very low in that case, and molybdenum disulfide also will get filter that means in that case we need to choose a proper filter. Now, there are two important requirements which need to be wearing there from a solid lubricant. We say that it should be able to support the applied load. It should not tear away. It should not happen that the structure of solid lubricant to get started. Many times when we did number of experiment; we found graphite happens to be getting distorted in the structure. Sometime it is effective, sometime it is not effective under high load condition they should not be any significant distortion. That is why it is mentioned over here deformation or loss in its strength, they should not have creep behavior.

Most of the polymers have the creep behavior, if you applied stress may be say 20 or a 25 mega Pascal they will show a good performance. Initially, with the time the performance will deteriorate, because of the creep behaviour, they start flowing, they will show the different properties. So, as for as possible they should not lose the strength. If solid lubricants are losing strength then we should not use those lubricants for that kind of loads. We should use those lubricants at slightly lower load or load which can show without creep behavior and; second thing is that we need to choose coefficient of solid lubricant as per the desirable

coefficient of friction. Few solid lubricants, shows the coefficients of friction 0.0 5; few solid lubricant show the coefficient of friction 0.1; since solid lubricant 0.2; few solid lubricant 0.3.

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Solid Lubricants

- Powder (5 nm to 5 microns) or thin film
  - **Self-healing**: Use of carrier fluid





  - Two primary property requirements.
  - Material must be able to support applied load without significant distortion, deformation or loss in strength.
  - Coefficient of friction and the rate of wear must be acceptably low.

So, depends on the condition what kind of coefficient of friction is decided. We should use coefficient of friction and similarly, we should use rate of wear which is acceptably low. It should not happen that we are designing component for the very high line and we are choosing solid lubricant, possibility of wear and that will reduce wear that will increase clearness. That may reduce overall service life or operating life of the component. Now, I mentioned one way to give or apply a solid lubricant on material which is coming in contact like cam.

But this is another way we use solid lubricant as a bounded coating that means they have some sort of binding agents with those binding agent, we try to apply a solid lubricant. There are number of binding agents which we can classify according to their structure. We say the organic binders and inorganic binders. Organic bind are generally have temperature limit, they are particular resins and which are having sticky behavior, they lose their behavior at the temperature more than 300 degrees centigrade. That is why; this kind of coating or this kind of solid lubricant coating should be used when the operating temperature or we say the maximum temperature is lesser than 300 degree centigrade. At the high temperature, they will start liquefying, will start flowing and the solid lubricant will not be adhere, that will not be remaining effective.

But with the operating temperature is lesser than 300 centigrade then we can use resins based binders and we can apply strict solid lubricant to the component with their desire. Similarly, we have inorganic binders. Here the metal component metal composition comes into picture some time use ceramics also. We use mixture of all that remain stable at the high temperature. The temperature can be even reach up to 650 degree centigrade. This is quite huge and most of the tribo interfaces are effective. This kind of binders is effective to the 650 degree centigrade. Of course, the research keeps always on and many people make resin binders which are can be operated 350 degree centigrade, 400 degree centigrade but, still that is from research point of view not from the commercial point of view. What is mentioned here is more common which is available in market.

Now, when we have this kind of binders mix pigments or what we say that solid lubricant as a pigment and that the binding agent. So, that can be applied or on the surface by spraying some velocity. You impinged at the some velocity which will make undeleted surface and again deposit the solid lubricant on the surface. See, another word is that if they have chemical potential and in that case the dipping will also help however there is also possibility that we can brush it mechanically during solid lubricant, mix with component is run and mechanical condition brushing condition from the couple of hours may be 3 hours 5 hours and all components will get coated. This molybdenum disulfide will also deposit on interface by using this kind of coating, this kind of metals. You say that spraying, is one of the common technique it can be thermal spray or it can be used as the velocity Gun spray is very commonly used technique while dipping is less expensive when we do not have extensive number of component, so you are trying to use initially to more experiments they can use a dipping.

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Solid lubricants as Bonded Coating

- Made up of a combination of binders & lubricating pigments.
    - Organic binders: resins. Stability < 300°C.
    - Inorganic binders such as metal salts or ceramics. Temperature stable (permit bonded films to be used in temperatures above 650°C).
- Application by spraying, dipping, or brushing.
    - Spraying: Commonly used.
    - Dipping: Less expensive
- Note:
    - Surface preparation is very important to remove contaminants and to provide good surface topography for lubricant adhesion.
    - Air-cured coatings are temperature sensitive.
    - Heat-cured coatings can tolerate higher temperature .

Only thing is that solid lubricant need to be mixed properly with fluid. Now, few notes of few conclusions based on what we have mentioned in this can be said that to apply solid lubricant as a coating form, we require good surface preparation. Some irregularity on the surface will help us to easy deposing, a depositing the solid lubricant on the surface so that is why; most often we use a emery paper to rub the surface make slightly irregular surface and then apply solid lubricant on the surface. Surface preparation is important.

Now utility of the emery paper rubbing can be serial number wise one is giving slightly rough surface another thing is that is removing the contaminations from surface. We know if there is a contamination on the surface then adhesiveness between the solid lubricant and parallel material will not be that much, because the contaminations generally have a low shear strength and then adhesive that bounding will be reduced. It will remove, if you rub with emery paper is going to remove the contamination to some extent and of course, if we keep again after rubbing a number of hours, again oxide layer will be formed, will not be effective, that means rubbing, as well as immediately after that deposition of the solid lubricant, will help.

Sometimes, we use temperature coating like we are talking about the resins based or we are talking about the binders to be mixed with pigment. Naturally, cooling or particularly curing

is important in the acid, those situation it can be air-cured that allow temperature to fall as for the environment or other one is a control film as when we call heat-cured

coating heat-cured coatings means we control to regulate may be say 500 degree centigrade. For some temperature or 5 for some hours then 300 for some hours, so that it gives very stable coating on the surface but. We can say the heat-curing coating can be last long compared to the air-cured coating and of course, they air-cured coating will be better than no curing surface if we apply coating on the surface and immediately use, it will not be that much stable but, if it is cure properly then it will be having more and more stability. Now, we can classify solid lubricants based on their molecular structure. You say that easiest one is polymer we have lesser chemical reactivity but, they have low melting temperature, than we have some metals in solid form. We using the word solid metal, solid because, we know very well the metal also can be used a as a liquid lubricant. When melting with operating temperature is very high and then metal really flows so we do not want to mix this together. We say in this case we are particularly using metal in solid form .Finally, come to the cermets. Cermets are generally mixture of ceramics and metals. Metals are used at the binders for ceramic material and we know that ceramic material have very high temperature, high melting temperature and this kind of composition can be used for the high temperature applications.

We have found number of applications or I think we have seen number of application of the solid lubricant. It may be number of bushes, you see the washing machine, you see any juicer mixture we find this kind of bushings, polymer bushings they act as solid lubricant indium. We do that duel purposes they support the rotating shaft and they support, they also use as a lubricant there, both the sources together. We assume also as separated in the rolling element bearings. Rolling element bearings we have inner ring and outer ring and then they separate along with rolling elements. If we do not separate all the rolling element will club together at one place and then will show high load carrying capacity the 180 degree and remaining 18 degree it will not show any load carrying capacity. So, we required proper control load carrying capacity and control friction that is why; we use cages or separate term that is why we are writing here that it can be used or this kind of solid lubricant can be used with cages. It can be polymer base complete one or it can be some sort of a brass mage but, with solid lubricant applied, a solid lubricant coating applied on electrical brushes generally they are carbon based or graphite based or carbon graphite mixture.

They use others one block lubricant I am just showing one example, which we have done in our laboratory is a carbon is graphite seal rate.

Now, what is the disadvantage of this kind of rings? The number of advantage are huge in number. This seal is used to stop the steam leakages. Steam itself is a high temperature fluid or we are talking of about the rotated stream is 120 degree, 130 degree, 150 degree centigrade. So, we required seal which also get self lubricated. When we talk about the self lubricated, naturally the question comes whether they have solid lubricant along with other composition. May be in this case, it is mixed with the antimony carbon graphite renews as a solid lubricant, where the antimony has been used as to increase the connectivity to increase impact résistance. But problem with this kind of seal rings or this kind of block solid lubricant is that if there is a wear we can see wear marks on that. If there is a wear then the intent function will not be fulfilled. Then they start losing the intent function and that will turn out to be a failure.

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Classification of Solid Lubricants

- Polymers
- Metal-solid
- Cermets.

- Applications
  - Cylindrical bushes (Plain bearings)
  - Separator (Cage of rolling bearing)
  - Electrical brushes (Additive to carbon-graphite)



So, we need to use some other mechanism so, there is a self healing property comes in this kind of block lubricant. Also this is not coated a complete one block and one way is that you push with its springs so wherever there is a wear and getting pushed with helical spring again regain its position. Even though wear out thickness is decreasing but, is coming back to the

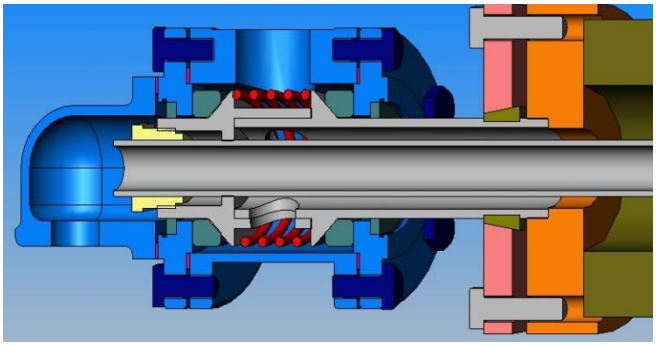
same position. This is what one diagram shows. The seal ring is what we call as a rotary joint completely on it you can see the steam goes in and try to push this kind of stainless steel shafts. There is one stationary joint and other rotating joint and these are the seal rings. This is a radial kind of seal ring and this is another seal ring which I showed in a previous slide. This is sealing which we are talking about the wear out occurs. And if there is a leakage of the steam then there is a loss of the required fluid that we required to stop it. Now, if there is a seal ring getting wear worn out or there is a wear on the seal ring there is a spring over here which pushes the shaft against that, if the thickness of the seal ring is reduced because we are already use pre comprise test spray, it will adjust position of the seal ring.

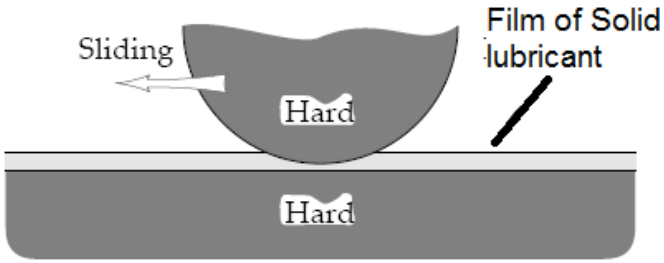
So, that means if we are using a solid lubricant as one block they should be some arrangement which gives a self healing property to the solid lubricant. How it will be failure, how if we do not use this kind of the spring and use a seal ring may be say after couple of hours. Seal ring will wear out and then intent function will not be fulfilled and leakage will start. So, within couple of hours we need to remove the seal ring and we need to replace it with new seal, which will be very tedious opening and closing this kind of assemble itself take a number of hours.

So, if operating life of the seal ring is only few hours ,then we should not be utilizing this kind of seal ring that is why we use this kind of adjustment device which gives overall favorable research to us. Another mechanism is that use of a solid lubricant as a thin film coating on the surface. Now, when we say thin film coating it as an advantages, first thing is that it will not wear out very easily. it has been observed with decrease in a thickness, bonding strength increases significantly. It will not be sheared out very easily; can sustain much higher load. It can sustain high fatigue load also with a thin film.

So, depends on our applications we can use this kind of coating but, only problem even in this is that, if there is a wear out then intent function will be lost and will be we need to be very accurate or we need to be able to estimate properly. When the wear will occur and before that we should be ready to replace this kind of a component. So, there is mechanism to use this kind of coating of course.

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We can use carrier fluid when we are relying on this kind of coating, can use carrier fluid on that along with the solid lubricant. Now, one of the major groups of the solid lubricant is a polymer. We say that the polymers are suitable to bear the light loads if you applied a load with high magnitude load, then they have a coefficient of friction.

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Polymer: Suitable to bear light loads

- **PTFE** - Very light load applications. Poor adhesion of PTFE to other materials is responsible for very low μ (<0.1). Specific wear rate 10^{-4} mm^3/min.
- **Nylon** - similar to PTFE but slightly harder (Specific wear rate 10^{-6} - 10^{-5} mm^3/min). μ ~0.25. Light load applications.
- Synthetic polymers: Polymers filled with glass, carbon, bronze, lead. Specific wear rate of PTFE & Nylon ~ 10^{-7}
- Thin layer of polymers material bonded onto a metal backing.

But, we know the coefficient of friction into normal load will give the friction and that is the friction force very high rate of heat generation. And they have poor dissipation. Heat dissipation and thermal connectivity is very low then, they will not be able to dissipate the heat. Then heat accumulation which will increase the temperature of this components and if

the temperature increases then there is a possibility of plastic flow of this kind of polymers which will lose intent function or it will cause loss of intent function. That is why; we say polymer should be used for the light load applications only but, sometime we use polymers as a binding agent fine.

PTFE is one of the well known concept is being utilized in number of distensile cells by due-com or say du point company which is new well known company for the PTFE du point which gives the name as a Teflon for PTFE. They do not use the word PTFE, they use Teflon coating and I remember we do Teflon coating on the car also, gives a nice appearance. We know that the extra environment will not impose much load on the surface and that it is a shinny surface, glossy surface so that kind of coatings are all we required.

But, major thing is they have poor adhesion to the metals that is why they cannot be easier you need to rub at hard or apply more mechanical force to transfer polymers or PTFE from the block to the surface where we want to coat. They show generally low coefficient of friction that is because of the they have a spherical molecules and this spherical molecular structure is very advantages because they have easy gliding on the surface. As for they have low shear interface a shear strength or they make interface with low shear strength however they have high wear rate they specific wear rate is 10 is to minus 4 and units are also mentioned earlier is a mm cube permanent. When we want to reduce wear rate often we choose nylon. Nylon is one of the most commonly used component, most of the times where nylon bush are used or wherever a slightly high hardness is required, higher life compare to this kind of wear rate. We say the lesser wear rate is required. Then we can use nylon also easily available in an open market. However, the only disadvantage of nylon in place of the PTFE is high coefficient of friction.

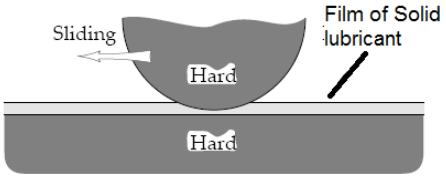
The coefficient of friction is 0.25 that means we lose almost 2.5 times energy compare to that again. We are using the word they need to be utilized only for a suitable for the light load applications. The specific wear rate is lower by 10 to 100 times compared to PTFE. However, PTFE has major advantage of the coefficient of friction and we do not want to lose it that is why many times we use synthetic polymers, PTFE is mixed with some other polymers to heated. The low coefficient of friction and high life of low wear rate so both low wear rate and low coefficient of friction by synthesizing by hybridizing with other polymers or other components that is why we are saying that polymers if it is mixed or PTFE is mixed with glass carbon or glass fibers they increase the strength. When they increase a strength, wear

rate goes down and it has been observed the wear rate turn to be only 10 is to minus 7 of course, specially wear rate is to 10 is to minus 7 compare to 10 is to minus 4 almost 1000 times increase in life when we are using a synthetic polymers. This is mentioned over here if we do not want to go ahead with low strength of the polymers we should use some sort of metal base. When polymers are with a PTFE or Teflon they are applied on a thin layer on the metal surface. This strength goes phenomenally high the strength is almost equal to the metals. If they are very thin they applied the thin coating the few micron coating on the surface they show very low coefficient of friction, they show very high strength, we get win-win situation and this has been already shown in a previous line. This figure if we apply to polymers, if I assume this is the metal and this is the polymer they give very high one because their strength is increased, they can sustain more load whatever load is applied they will deform to some extent and deformation possibilities are lesser because this is not complete bulk polymers.

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Polymer: Suitable to bear light loads

- **PTFE -** Very light load applications. Poor adhesion of PTFE to other materials is responsible for very low μ (<0.1). Specific wear rate 10^{-4} mm^3 /min.
- **Nylon** - similar to PTFE but slightly harder (Specific wear rate 10^{-6} - 10^{-5} mm^3 /min). μ ~0.25. Light load applications.
- Synthetic polymers: Polymers filled with glass, carbon, bronze, lead. Specific wear rate of PTFE & Nylon ~ 10^{-7}
- Thin layer of polymers material bonded onto a metal backing.
- Low thermal conductivity of polymers inhibits heat dissipation. Premature melting failure.



In the bulk polymer, then deformation will be numerous but, is a thin coating at the polymers and the back with a support. The support provides, reduces the deflection and then this kind of coating can survive. However, there still is a problem even though the strength is

increasing but, thermal connectivity is not increasing that is why if we use a metal which as a very high thermal connectivity. In that situation, will get win-win situation or we will get both favorable cases high thermal connectivity overall of this cam made structure high strength and low friction that is a win-win situation.

Now see the structures of PTFE which are called as ploy tetra fluoro ethylene you can see they are all balls. We know the ball will roll easily and that is why they show very low interface strength. If the free surface as this kind of structure and they under compression deform that is why if the coefficient of friction will increase with increase in a load. When they do not follow coulomb's law completely but, to a light load application yes they follow. As, this slide clearly indicates that this name was given by du point that the Teflon they do not use word PTFE they use Teflon that is the name given as the trade name by this company. However in this slide, also we are trying to show what the strength of PTFE is and what are the weaknesses of the PTFE? Say PTFE does not react easily with number of substances so they have more chemical stability, they remain in same position, same structure for longer time without reacting, without changing their structure, they change the structure under the load condition under the high temperature but, not in chemical environment.

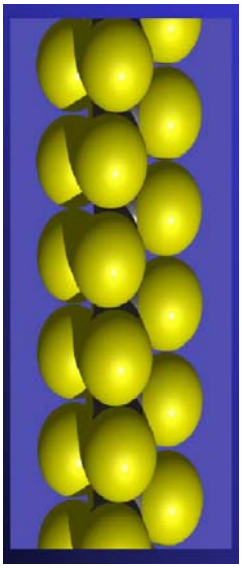
And it has been mentioned that, they have more in attendances this is basically the athletic and all hydrogen bonds were replaced by the flouring. So, that gives very high chemical appear chemical stability to the component they have low surface energy that is why they show low coefficient of friction, they have low shear the strength of the interface. And of course, there is low velocity is permitted low wear rate is also there. One of the interesting, major advantage of a Teflon or PTFE is a nontoxic behavior can be mixed with fluid and it will not harm to the body. That is the reason why the most of the utensils are coated with Teflon they do not spoil the food. They show the low coefficient of friction so we can cook food with much lesser oil compare to what oil is required without Teflon coating. And they can use in number of pharmaceutical applications. This is major advantage of the PTFE. However they are some weaknesses say it is soft so wear rate will be high. To reduce the wear rate,

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Poly Tetra Fluoro Ethylene (PTFE)

(Teflon– Trade name by Du Pont)

- Strengths
  - High chemical stability. Great chemical inertness, because of carbon fluorine bonds
  - Very low surface energy. Low Friction (0.1). High P, Low V
  - Nontoxic- useful in pharmaceutical and food industries.
- Weaknesses
  - Too soft, High wear rate
  - Poor creep resistance, Low load capacity
  - Poor thermal conductivity. High thermal expansion. Temp limit (250°C)
  - Vacuum Detrimental to performance.



We need to do something with PTFE. They have poor creep resistance. That is another reason why we use PTFE with metal base or we use with some support they are poor. They have poor creep resistance if they are used in a bulk but, few molecular thick layer are been 0.5 mm thick layer will not show that bad creep resistance, creep behavior. Thermal conductivity is a low that is why again we required hybridization with polymers, other fibers or metals which will increase a thermal conductivity. Now, this is a final bad thing about PTFE. We say the vacuum is detrimental they start vaporizing, they start degassing the component that is why they are not effective at particularly when they are used in vacuum situation that is why; we cannot use this kind of solid lubricant in extreme gasses.

Now, as I mentioned in previous slide most of the disadvantage of PTFE. See advantages are very favorable but, there are disadvantages and we need to do something after learning word PTFE can do. Most of the disadvantages of PTFE can be overcome by using fillers to increase the strength by impregnating it with metals to increase thermal conductivity and we can since say that by synthesizing this polymers and it has been also mentioned over here that with suitable rigid backing PTFE can withstand or reduce the wear rate. It can withstand high temperature load or high load that is stress level can be even a 100 mega Pascal. But maintaining a still low coefficient of friction when coefficient of friction is consistent but we

are talking about static coefficient of friction and kinetic coefficient of friction. They are almost same when we are using PTFE that is major advantage of PTFE.

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- Most of disadvantages of PTFE can be overcome by using fillers (glass, carbon) & impregnating it with metal (bronze, lead) structures… SYNTHETIC POLYMERS.
- With a suitable rigid (metal) backing PTFE can withstand wear under extremely high loads (100 MPa) or more, with a friction coefficient of 0.1 or less and virtual freedom from stick-slip sliding.
- NOTE: Two polymers in sliding contact will normally operate at significantly reduced speeds than a polymer against a metal surface.

So, if I talk about the liquid lubricants without sliding, without relative velocity coefficient of friction will be high. That means static coefficient of friction maybe as high as 0.25 and dynamic condition when the sliding is started and hydrodynamic film is completely made. Coefficient of friction reduces to 0.001, huge difference between 0.25 and .0 0 1 that I am sure is going to give stick way phenomena, unless we support hydrodynamic action with some other action. In the case of PTFE they show the same static coefficient of friction almost a same kinetic coefficient of friction, there is no variation that is why we say that it is almost free jump from stick phenomena. That is why PTFE can be utilized because as I say PTFE alone cannot be utilized we need to mix with some fillers need some support.

So, that thermal connectivity is increased and sustainability to resist the compressive force increases. Now the finally, it is coming as when two polymers in sliding contact should not be utilized if I am using one polymer I should use other metal reason being when we are using polymers with interface at the metal or in ceramic polymer will get dispositive at the surface itself will make thin layer, so if I use two bulk polymers, do not have much use I use one metal and one bulk polymer then it will have better results. That is why this note comes. Two polymers in sliding contact when

normally operate at significantly lesser speed, then a polymer against metal surface one is metal as a high thermal conductivity and high sliding is speed means high friction heat; high heat means required high dissipation which in case of metal has but, otherwise it will happen. So, we say that kind of polymers will be recommended then we have low speed condition that is sliding is speed is very low then we can use two polymers may they turn out to be cheaper they may be nontoxic and can be utilized easily but, sliding speed is higher than we required by polymers may be say the few meter per second. In that case is a one polymer should be utilized with other metal surface but, sliding speed is almost negligible than we can utilize with two polymers together. Will be continue with classification of solid lubricant in our next lecture thanks for your attention thank you.