Surface Engineering for Corrosion and Wear Resistance Application
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Lecture -09
Wear Part – I

Hello. So, in this talk I will discuss about the Wear and also, the way it can be prevented by different Surface Engineering techniques in details. So, this will be covered in two different talks and it may be continuous, it may be fragmented as well.

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So, if you just quickly go through the wear it is basically the surface dependent failure of the component. And you can define it in this fashion, like it is the progressive loss of materials from the surface due to relative motion between the surface and a contacting substance and substances.

So, the difference between them wear failure and also the failure due to compressive and tensile loading is that, whenever you talk about wear the compressive load comes into picture. And if you talk about the difference between the failure other mode of failure, by compressive loading and that of wear these are as follows in wear.

There is always a relative motion between the two surfaces, but in compressive other mode of compressive failure like compressive failure, the both the components are static in nature. And as a result of which you find that when the component fails by compressive loading this failure occurs very quickly, but in wear failure occurs at a much slower fashion it is progressive in nature and it is very much controllable.

So, if you talk about the different factors, which are responsible for wear, we wear properties of the material, it is mainly hardness to some extent toughness of the material and coefficient of friction as well. So, if you talk about coefficient of friction, then again the surface energy comes into picture.

So, coefficient of friction is very important and whenever you talk about any wear phenomena the it comes into picture, especially when the wear is adhesive in nature and if you see coefficient of friction this is nothing but defined as the resistance against movement of the body. It is very much dependent on the weighting surface and also the media.

Now, if you quickly go to the coefficient of friction, so there are several laws of friction, which is the basics of the basics which end it can be derived from which are taught in the plus two level. So, which is nothing, but as follows, the static friction is always may be greater than that of dynamic friction.

Friction is independent of the sliding velocity, friction force is proportional to the applied load and it is independent of the contact area. So, friction is very much dependent on the combinations of the materials and obviously, it depends on the to some extent applied load. Because, but coefficient is not dependent on the load, because it is a ratio between the applied load and that of friction force friction force and applied load.

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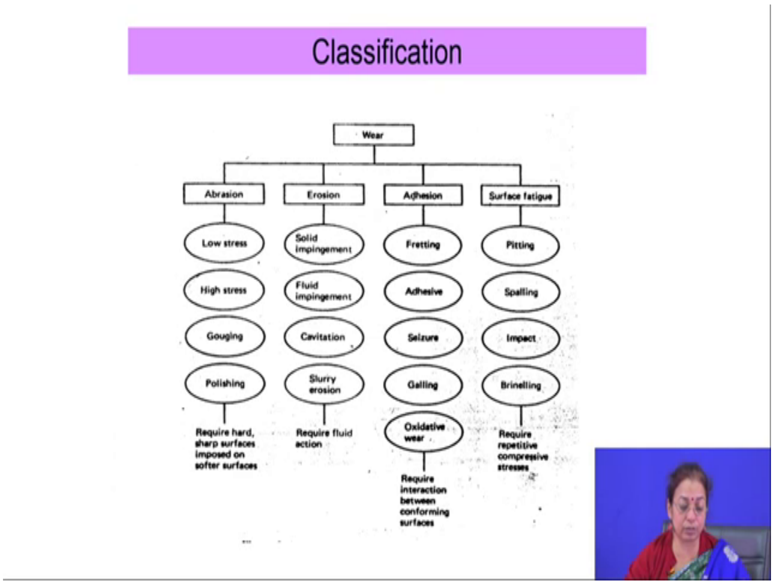

Now, wear it is a very interesting phenomena and it is very much in a word you can say that wear is progressive in nature, for the wear to occur there has to be relative motion to between two surfaces and wear is actually measured in terms of the loss of materials. So, usually most of the wear there is loss of materials from the surface except a few.

But you will find that, there are different ways by which wear occur depending on the; depending on the kind of wetting surface the component is facing. And also the hardness differences between the surfaces the environment which the component is facing.

So, it is a kind of relative property of the materials. So, if you say that wear is the wear resistance of the material is quite good or quite bad or does not have any or you cannot define that wear property by a single value; as in case of tensile strength or may be yield strength.

So, its very much a relative property it depends on the environment, it depends on the applied load, it depends on the sliding velocity so many factors come into picture and finally, it also depends on the material to material combinations which combinations material of materials you are using.

So, wear mode in summary can be divided into four different categories; one is abrasive wear, adhesive wear, erosive wear and that of surface fatigue, these are four different categories or modes by which wear proceeds. So, each category is having its own characteristics and several subcategories are also there under each category.

So, unless and until you know the way wear has proceeded it is very difficult to take the precautionary measure, in order to prevent the wear phenomena because your ultimate objective is to have the material with improved wear resistance or minimum wear in service. So, that the component the serviceability increases to a large extend.

Now, if you talk about the in general 4 modes of wear, 4 basic modes of wear they are abrasive wear as I mentioned. So, which is nothing, but which is because of the between the two wetting surfaces having large difference in the hardness then this kind of wear usually occurs. So, when a very hard surface actually moves over the softer surface, the kind of wear the kind of failure or material loss that occurs is called abrasive wear.

Then naturally in summary you can say that abrasive wear requires hard or soft surfaces to get imposed on the softer surfaces. So, there has to be large difference in hardness. If you talk about adhesive wear; adhesive wear usually initiates by the typical adhesive mechanism. So, it requires interaction between the conforming surfaces.

So, when there is metal to metal combinations you will find that adhesive wear it is very high as compared to that of metal to ceramic combinations or metal to non metal to that polymer combinations. So, this is because of the adhesion forces acting between the two surfaces. And surface energy plays a very important role as I have mentioned you. Lower is the surface energy differences higher will be the degree of adhesion.

So, third mode of wear is basically the environment, so when wear the as I mentioned you for wear, it is the primary requirement is that there has to be the load applied load usually it is compressive in nature there has to be relative motion between the two surfaces and has to be mechanical interaction. So, when the mechanical interaction occurs between the solid as well as liquid and gaseous species you call it as erosion.

In case of abrasive adhesive or surface fatigue the two surfaces are solid in nature the surface of your interest and wetting surfaces they are solid. On the other hand when wetting surface is liquid or gaseous species you call it as erosion. So, erosion basically requires fluid action or gaseous velocity action, actually gas velocity action.

So, there is usually mechanical interaction between, flowing fluid or flowing gaseous species and, then you call the term use the term erosion. And surface fatigue it requires the fluctuating stress instead of static compressive stress. Further where to occur that compressive stress is very important or compressive load is very important or applied load is very important when the applied load is fluctuating in nature then phenomena is like fatigue phenomena.

So, where it actually increases to a large extent and then you call it as surface fatigue. It is called surface fatigue, because it is basically wear phenomena which is again aggravated by the fatigue phenomena from the surface. These are the four different important categories of the basic categories of wear.

Now if you quickly go to the sub categories again, there are several subcategories under each category. Like under abrasion there is low stress abrasion, high stress abrasion, gouging wear, polishing wear. Under erosion there is solid impingement, fluid impingement, cavitation wear, slurry erosion. In case of cavitation erosion and slurry erosion you always call the term erosion.

In case of a adhesive wear, there is fretting wear, adhesive wear; there is a seizuring, galling and oxidative wear. And in case of surface fatigue, there is pitting wear, spalling wear, impact wear and brinelling wear.

Now, if you quickly go through all subcategories of wear you will find that, there are several characteristics that there are completely different characteristics. And from the characteristics you can distinguish between each wear with others. And the reasons or the genesis behind each category of wear is different from others.

The reason behind low stress, abrasion will be different from that of high stress abrasion, the reason behind solid impingement is different from that of fluid impingement, but main basic reasons may be the same. For example, if you talk about low stress abrasion, high stress abrasion, gouging wear and then polishing wear the one single point which is common for all the cases is that there is hardness difference between the meeting surface and that of your substrate.

So, this hardness difference is responsible for the wear to occur. And the typical mechanism of wearing is because of the abrasive action. If you see the adhesion wear, different kinds of adhesion wear again one common point is that initiation is basically because of the adhesive interaction between the two surfaces.

Now the after the initiation how the wear proceeds, depending on that different categories are defined, they should talk about erosion for wear then the single point which is common for all the erosive wear is that there is a fluid or gaseous species which is operating in the environment. If you talk about surface fatigue, the single point which is common for all the wear is that, the surface is the component is subjected to or system is subjected to repetitive loading instead of static compressive loading.

And another important features about these all things which I need to mention is that, apart from the characteristics you will find that in 75 percent of the cases, where proceeds by the loss of material. So, when there is wear phenomena, usually there is loss of material from the surface, it is progressive in nature. So, it is not really very fast as is very fatigued or as is compressive failure of the component, but it is progressive in nature.

Another special feature is that in most of the wear there is loss of material except a few like in case of brinelling galling, these two types of wear seizuring, these three types of wear there is minimum loss of material, but there is the reshaping of the component.

So, you can also redefine the wear in terms of the following sentence like progressive loss of material or shape of the component because of its interaction with the mechanical interaction with the environment when there is a relative motion between the two surfaces.

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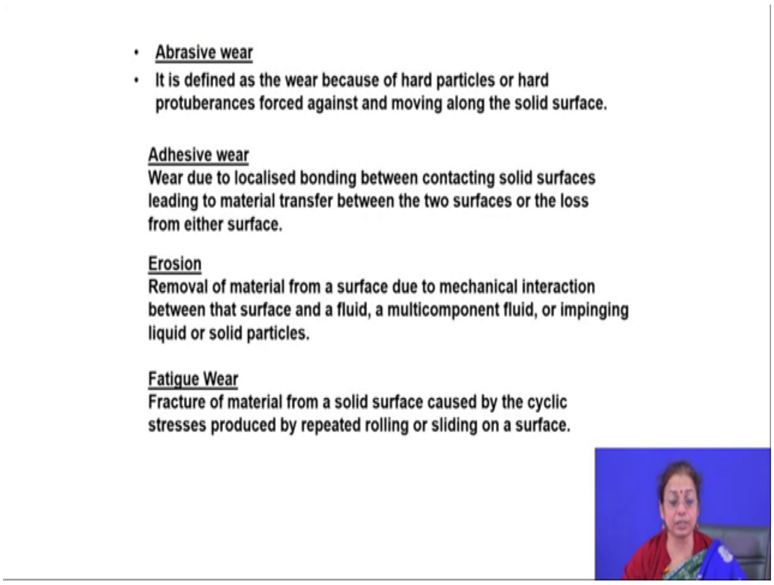

Now, quickly I will go through each mode of wear as well as sub modes, in these particular talks. Now if you talk about the abrasive wear, which is defined as the wear because of the hard particles or hard protuberance forced against and moving along the solid surface. So, one when hard surface moves over the softer surface you call it as abrasive wear.

Adhesive wear is the aware due to localized bonding between the contacting solid surfaces, leading to material transfer between the two surfaces or the loss from the other side. Erosive wear is the removal of the material from the surface due to mechanical interaction between the surface and the fluid and the multi component fluid or impinging liquid or solid particles. And fatigue wear is the fracture of materials from the solid surface, caused by the cyclic stresses produced by repeated loading or sliding on the surface.

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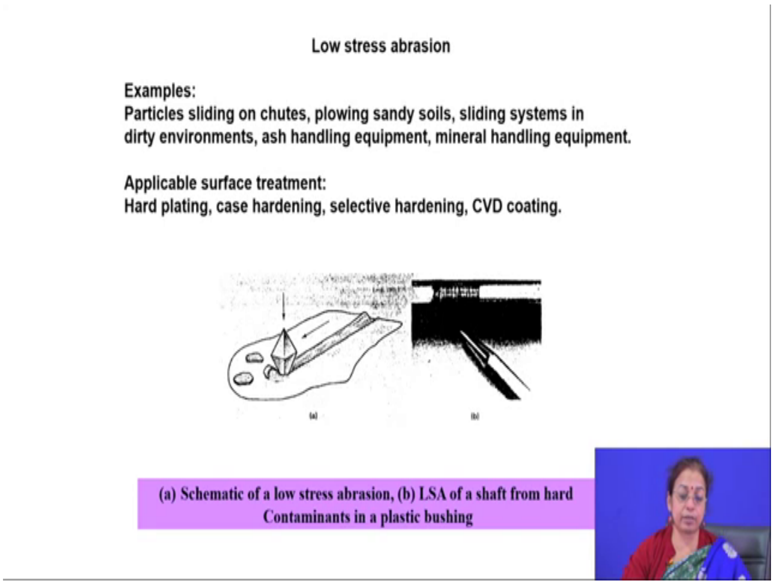

Now, coming to the different subcategories we will try to discuss about different sub mode by which the wear proceeds, because as I mentioned you even though there are main four different modes by which wear proceeds, but you cannot really characterize them by a single categories for a single characteristics.

Like for example, if you say characteristics of abrasive wear they may be there may be several characteristics of abrasive wear and one type of wear different from that of other. So, depending on the characteristics; characteristics is dependent on the situation environment so many factors. And depending on the characteristics you will find that the mode will also change.

So, depending on the mode there are different names of wear are they are do exist and you have to basically distinguish between each modes by observing the characteristics. And usually characteristics of the wear is observed or you can conclude on the characteristics of the wear by micro structural observation at different scale.

You can go for scanning electron microscopic observation, for knowing the features of the wear, where you get different features because after the wear you are interested to see the characteristics of the wear, you have to go for direct observation of the surface. And that is very much important and as a result of which except scanning electron microscopy no other micro structural observations give you observe give you the informations about the surface features.

So, it is very important that you see the surface and then get to know about the characteristics of the wear after each wear. So, as I mentioned you the different subcategories. So, if you quickly go to one by one like abrasive wear, ebrasive abrasive wear maybe subcategories into 4 types; one is low stress abrasion, high stress abrasive wear, gouging wear and then another kind of where is polishing wear, these are the 4 different subcategories of the wear under a basic category.

So, one by one we will try to discuss these wear phenomena. So, if you quickly go to the low stress abrasive phenomena it as the name implies it is low stress process. So, when the now how do you define the low stress and high stress process and the distinguishing or maybe the distinction between low stress and high stress or threshold stress beyond which you call it as high stress is nothing, but the yield strength of the component when the component starts deforming.

So, when the stress level is below the yield strength of the component it is low stress abrasion. So, again you can understand that this is very much dependent of the dependent on the material which you are dealing with. So, if it is copper its low stress value threshold stress value will be different from that of steel in magnesium it will be different from that of copper. So, it is very much dependent on the material of your choice.

So, when the low stress or may be stress at a or maybe compressive stress lower than that of the yield strength of the material is applied on the surface usually, the surface and applied over the surface and there is a relative motion between the two surfaces the kind of wear that precedes is called low stress abrasive.

And in low stress abrasion then if you are interested to know the mechanism by which the failure occurs if it is lower than that of yield strength of the material naturally how could the wear occur there is no chance of deformation there is no chance of fracture. So, how the wear occurs wear really occurs by the mechanism of the abrasive flowing action. So, there is cutting mechanism which basically plays important role to cause the wear. So, the typical examples are particles sliding on chutes, plowing sandy soils, sliding system in dirty environment, ash handling equipment and mineral handling equipment.

So, in all cases you see that stress is quite low, but very hard surfaces moving over the soft surfaces this is the low stress abrasion phenomena. So, if you talk about the minimization of low stress abrasion. So, this is low stress abrasion though it is low stress abrasion naturally, you can say that if you compare the kinetics of the low stress abrasion with that of high stress abrasion.

Naturally, wear rate will be much lower, but still it can be a dangerous form of wear because, after the wear is over we will see that the surface basically there is loss of material from the surface; even though it is a slower process. It will take less time to cause the overall degradation overall failure of the component, but there is failure in a progressing fashion and you will also lose the structure to a large extent.

So, you have to think of the preventive measure or you have to think of the way by which you can minimize this kind of wear. So, what is the thumb rule? You basically apply a thin coating which is hard enough to reduce the abrasive wear phenomena. So, go you can go for hard plating, you can go for case hardening, you can go for selective hardening, CVD coating, these are all coating techniques you can apply to have a kind of thin hard layer on the surface.

And when there is a very thin hard layer on the surface naturally, even though there is a hardness differences between the surface there is no wear from the surface. So, if you quickly go through the as I mentioned you earlier the each and every soft categories is having its own distinguishing characteristic features.

So, if you just quickly go through the characteristics features of low stress abrasion this is nothing, but very thin fine scratch formation on the surface. So, scratches will be there on the surface and only scratches will be there. So, from the scratch mark you can say that the wear has occurred, because of the slow stress abrasion there will not be very kind of visible deformation on the surface because you are applying very low load.

So, there is no chance of deformation, but hardness difference is playing very important role. So, you will get lot of scratches on the surface. So, this is schematic of low stress abrasion. So, this is I mean the side view of the that schematic view of the shaft from, hard contaminants in a plastic varnishing.

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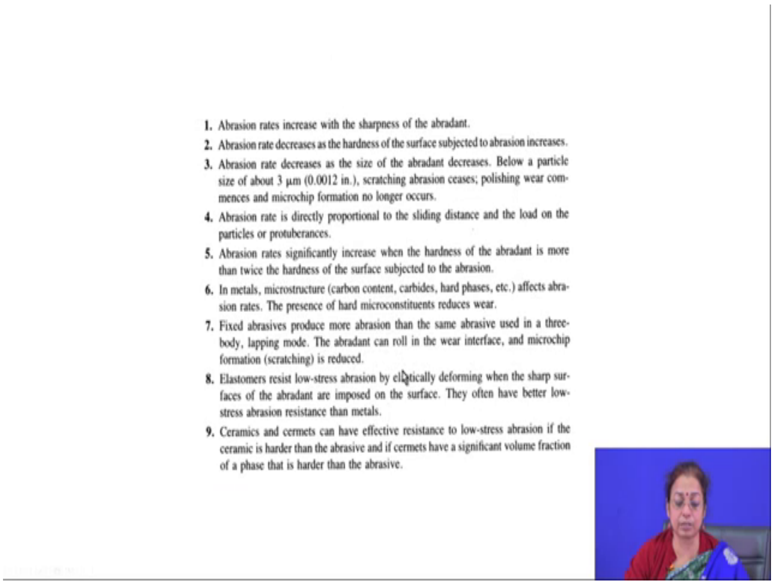

So, this is very interesting thing, now if you quickly go to the abrasive wear. Abrasive wear characteristics or the wave by which you can control the kinetics of the abrasive wear, these are as follows that is abrasion rate increases with the softness of the abradant.

As you go on increasing the surface naturally, abrasion rate increases because this is cutting phenomena, this is basically its low stress abrasion low stress abrasion this is the cutting which is the main mechanism of the loss of material. So, as you go on decreasing the softness of the abradant, you will reduce the abrasion rate, it decreases as a hardness of the surface subjected to abrasion increases naturally as your material hardness increases it will be decreasing.

So, basically if you are as you mentioned that, if you apply very thin hard layer on the surface you can increase the you can decrease the wear rate to a large exchange. Particularly when you shows stress abrasion, but what is the limit of that? If you go on increasing hardness naturally hardness difference will be reduced, but if it exceeds the hardness of your wetting surface then there will be failure of the wetting surface in the same fashion. So, what is the limit? Limit is that 1 to 1.5 times the hardness of the wetting surface should be the hardness of the base metal.

Then abrasion rate decreases as a size of the abradant decreases, below a particle size of about 3 micron scratching abrasions ceases, polishing wear commences naturally micro chip formation will be there. It is directly proportional to the sliding distance and the load of the particle if you go on decreasing the load, naturally rate of the wear decreases.

And its slightly increases when the hardness of the abradant is more than twice the hardness of the surface subjected to the abrasion. In metals micro structures play very important role in determining the abrasion rate, the presence of hard micro constituents it basically reduces wear. That fixed abrasive produces more abrasion than same abrasive used in three body lapping mode.

So, basically if there is loose particles naturally, you will find that they it will be lower than that of hard particle, when it is hard in nature and it is fixed in nature. Elastomers resist low stress abrasion by elastically deforming when the soft surfaces of the abradant are imposed on the surface. They often have better low stress abrasion and abrasion resistance and ceramics and carbons can have higher resistance to low stress abrasion because they are naturally harder.

So, low stress abrasion the basic characteristics features is that, there is very fine scratches on the surface and you can reduce or minimize the kinetics of the low stress abrasion by typical hard ceramic layer coating on the surface.

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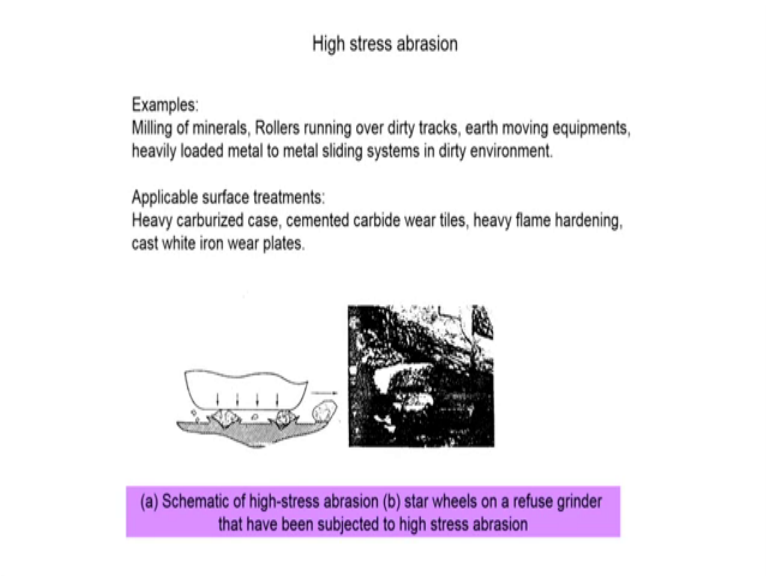

(a) Schematic of high-stress abrasion (b) star wheels on a refuse grinder that have been subjected to high stress abrasion

Now, next kind of abrasive wear is the high stress abrasion. So, as I mentioned you the difference between low stress and high stress abrasion is that, in low stress abrasion the stress level is below that of yield strength. And in high stress abrasion the stress level is higher than that of the yield strength of the component.

So, when the stress level is higher than yield strength of the component what happens naturally, there is another phenomena which plays important role that is deformation of the surface. So, deformation plays a very important role. So, apart from cutting there is also deformation. So, cutting action depends on not only the hardness differences, but it also depends on the softness of the wetting surface softer the wetting surface naturally more will be the scratching action.

But if it is usually if the stress is very high naturally there will be deformation as well there will be micro deformation, subsurface crack formation and the failure of the component because of the wear. So, in high stress abrasion the basic phenomena is that there is deformation apart from scratching or cutting phenomena there is also micro deformation subsurface crack formation and failure of the component. So, this is about the high stress abrasion.

So, high stress abrasion usually occurs in milling of minerals, rolling running over the dirty tracks, earth moving equipment heavily loaded metal to metal sliding systems in dirty environment. So, here you find that in all cases the hardness difference is there in addition to hardness difference the stress is of very high magnitude. So, when stress is very high magnitude there is local ease localized deformation subsurface crack initiation and then you will find that failure of the component.

So, by that process you will find that if you see that characteristics features of the high stress abrasion you find that, there are scratch marks and also there are naturally lot of groups formation on the surface. These groups give you information about the micro deformation and subsequent failure phenomena.

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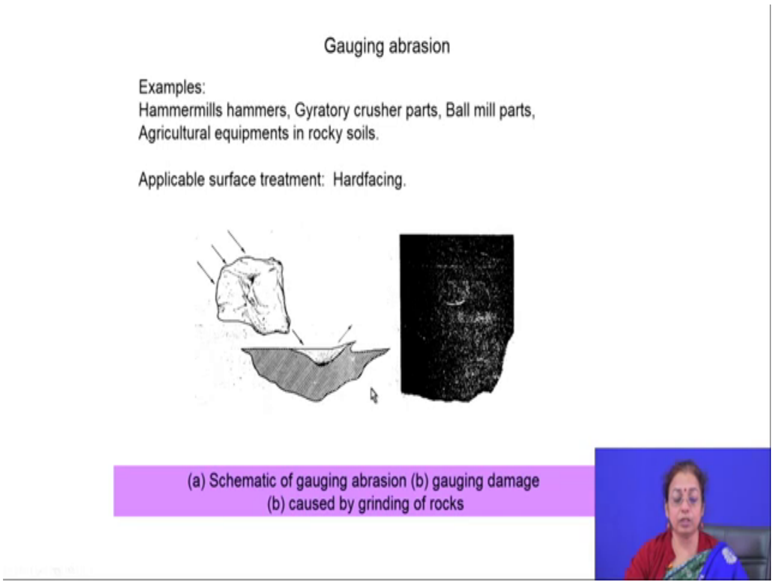

Now, if you quickly go through the another type of abrasive wear that is gauging abrasion wear, here actually this phenomena is a little different you call it as gauging abrasion, when the component is subjected to very heavy load for a very short period of time, that is when the component is subjected to impact loading then you call it as gauging abrasion.

So, in gauging abrasion for example, in case of gyratory crusher, hammermilles hammers, ball mill parts, agricultural equipments in rocky soils. The heavy particle or very heavy component come in contact heavy components come in contact with another surface with the very heavy striking load for a very short period of time.

So, they are again the same phenomena is responsible, there is deformation of the material from the surface subsurface cracking subsurface can be crack initiation and failure of the component. If you see the surface after the gauging abrasion wear, you find that there is lot of deformation zone, highly deformed zone along with that there is a very small scratches on the surface, in addition to that there is also lot of group formation on the surface. So, you can get rid of this kind of wear by typical hard facing operation.

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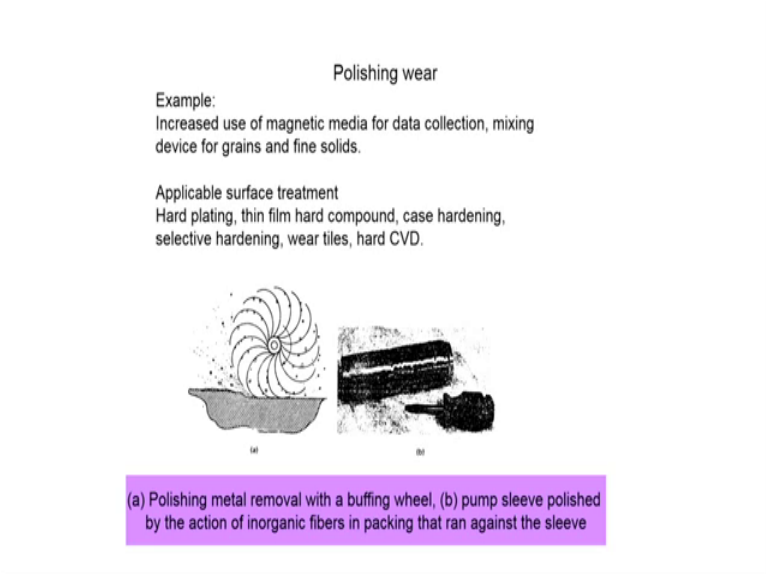

(a) Polishing metal removal with a buffing wheel, (b) pump sleeve polished by the action of inorganic fibers in packing that ran against the sleeve

Then finally, polishing wear is again another kind of wear, which is under abrasive category, but it is called polishing wear because the surface looks like polishing. So, polished surface, this is very very much insidious kind of wear because after this wear even though you have not noticed that wear has occurred, there is loss of material from the surface. So, this is the main reason behind this kind of wear is the hardness difference and also softness of the wetting component is very low. So, when the roughness and softness of the meeting surface is quite low then the way the material removal occurred you call it as polishing wear.

So, increased use of magnetic media for data source a data collection, mixing device for grains and the fine solids in those cases those particular component if you see the surface, after prolonged duration of operation you will find that, very fine scratch marks are there, but surface looks very much bright its appearance increases.

So, this is typical example this has occurred because of the polishing wears. So, typical surface treatment which you can apply for improving the fatigue, polishing wear is that hard plating, thin film hard compound, case hardening, selective hardening, wear tiles and hard CVD. So, these are typical surface treatment techniques applied. So, if you are interested to get rid of polishing wear you have to harden the surface carefully.

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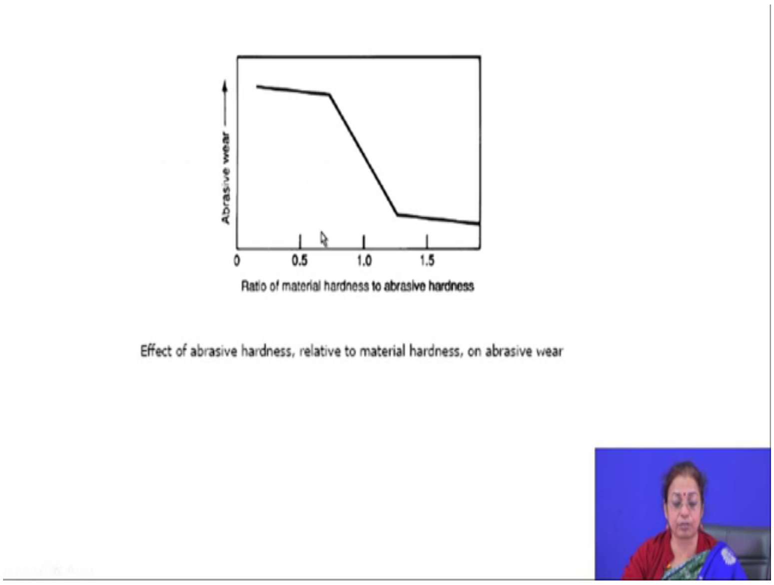

Now, as I mentioned you that, abrasive wear almost all kind of abrasive wear can be prevented if you increase the hardness of the surface. So, up to what extent you should improve the surface? So, improve the hardness of the surface usually, it is observed that when the component surface hardness is 1 to 1.5 times of that of hardness of the base metal of the wetting surface, then only you can you get best result.

Otherwise you will find that if the hardness difference is low large naturally the wear occurs in the other body mating surface. So, when you increase the hardness of the component to reduce the abrasive wear you have to reduce the hardness to a value of 1 to 1.25 of that of the wetting surface. So, that you minimize the we added to a large extent and there is no wear of the mating surface by that process.

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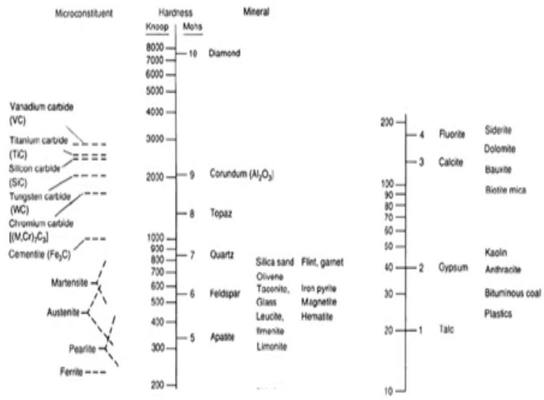

Hardness of some minerals and alloy microconstituents

So, if you talk about the hardness enhancement, there are different types of components available or compounds available materials are available for hardness enhancement, you can directly form those materials on the surface by different treatment as well as you can go on having physical or chemical vapor deposition process for development of the different layer on the surface. So, if you know your purpose and if you know the component which should be applied for which application, then you can easily choose different technique and by that process you can improve their property to a large extent.

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So, in the next talk we will discuss about the abrasive mode of wear and erosive mode of wear these other modes of wear in detail.