Surface Engineering for Corrosion and Wear Resistance Application

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Lecture – 11
Wear Part – III

Hello now coming to the IIIrd Part of Wear where we will discuss about the fatigue wear surface fatigue wear.

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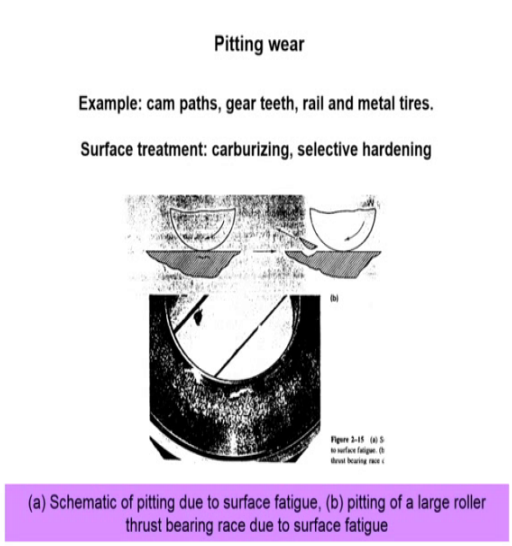

(a) Schematic of pitting due to surface fatigue, (b) pitting of a large roller thrust bearing race due to surface fatigue

So, if we just quickly remember that under surface fatigue category there are 4 sub categories of wear. So, basic difference between surface fatigue wear and other kind of wear is that in surface fatigue the load is actually captivating in nature instead of static compressive for other case of wear.

So, in this particular case we observe usually 4 different types of wear or wear proceeds in 4 different modes; one is pitting wears, spalling wear, impact wear and brinelling. So, now, coming to the first type of wear that is pitting wear so, basic features or may be common features common feature of all types of wear is that, there in all cases the load is actually fluctuating in nature and as a result of which the pitting is the main mechanism for initiation of the damage during wear.

So, in case of pitting wear the name is after the look of the surface after the wear has occurred. So, after pitting wear you the surface looks like small small pitted they pitted surface pitted zone. So, if you see the pitted wear surface you will find small small pits on the surface and the pits are pit area as well as pit depth depends on the kind of applied load as well as the meeting surface.

And in this particular case again you will find that the typical load is fluctuating in nature and examples of the pitted pitting wear, is cam paths, gear path, rail and metal tires. If you see the cases you will find that in all cases the component is subjected to heavy load which is compressive and 0 compressive and 0 in nature that is fluctuating in nature and there is also sliding phenomena. So, sliding velocity is there or sliding movement is there in addition to that there is that compressive 0 kind of loading.

So, in this case what happens is that because of compressive wear 0 loading there is sub surface crack initiation at the point of discontinuity. So, if the component is coated surface then at that point of interference there is pit initiation or crack initiation. If it is a component of composite in nature, then you will find that at the interference between the second phase and matrix there is crack initiation and as soon as the crack initiates it propagates at a much faster rate and causing the chip formation and then materials get removed.

So, after the end of the wear you find lot of pits on the surface the typical surface treatments are carburizing, selective hardening. So, in this case if you are interested to combine the pitting wear or any kind of pitting wear you have to be careful about toughness as well in addition to hardness. So, carburizing operation then typical hardening and then you have to go for tempering operation selective hardening you have to go for and then you have to if necessary you have to go for the tempering operation.

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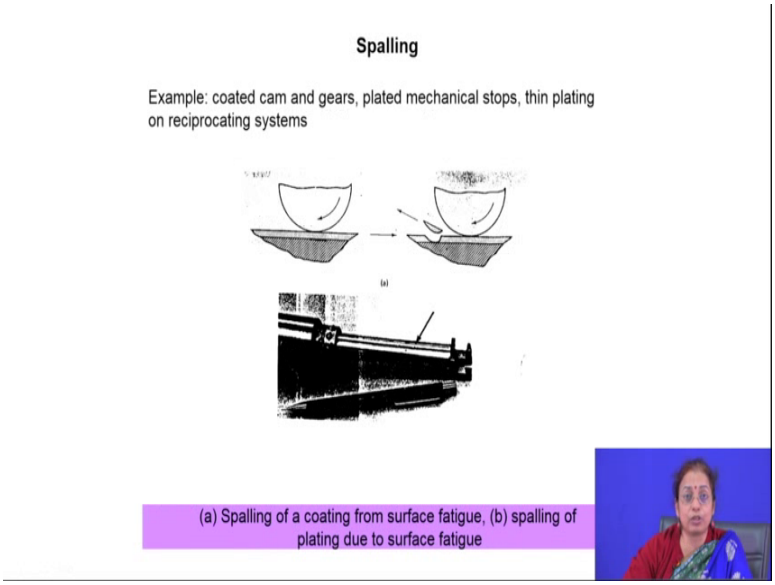

So, these are the treatment you have to follow in order to improve the service life of the component under the action of pitting wear. Spalling wear is a kind of wear where is where there is collision continues collision of the material from the surface. This is the typical kind of wear which is observed on the coated system having very week interface.

The examples include electroless plating, electroplating CVD physical vapor deposition Chemical Vapor Deposition in those all coated component it subjected to fatigue loading or compressive and 0 wear loading during wear you will find that the problem starts or crack initiation occurs at the interference between the coating and that of substrate and then subsequently there is failure of the material by sub surface crack formation and crack propagation process.

So, spalling wear is quit dangerous form of wear. So, where there is possibility of spallation or spalling wear then you have to avoid the coated surface or use the surface or use the surface treated component where the interface is very much strong and adherent. So, typical examples are like coated cam and gears plated mechanical stops thin plating on reciprocating system there basically you find this kind of wear.

So, if you are interested to get rid of this kind of wear you have to think of applying a coating which is or applying hard face clear which is hard as well as tough in nature and better avoid the coated component in those cases.

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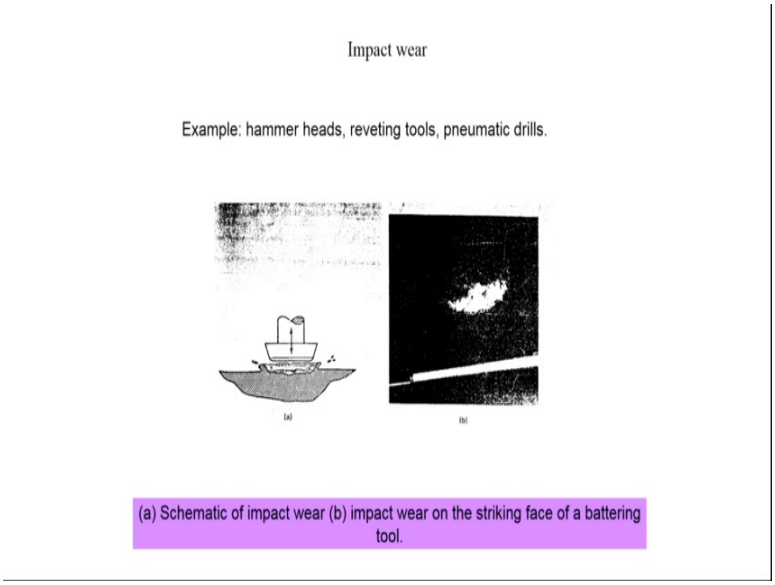

Third type of wear is impact wear again here impact flooding heavy load is applied on the surface for a very short duration and then again if load is released. So, they are the kind of wear you see is called impact wear. So, this is again pitting wear or fluctuating loading, but loading unloading time is very less actually very low.

So, loaded for a very short of time and then very short duration and then unload it load for a very short duration and unload it. So, when the component is subjected to heavy loading and unloading for a very short duration they are the kind of wear you for you see is called impact wear. Typical examples include hammer heads reveting tools pneumatic drills. So, which is subjected to heavy loading for a very short period of time and then immediately after that you unload it.

So, very high compressive loading and unloading this is responsible for these kind of wear. So, if you see their surface you will find that there is deformation on the surface, then there is sub surface failure and then removal of the material in chunk. So, usually if you see the surface you will find very big holes on the surface in a present in a discontinuous fashion.

So, if you are interested to get rid off or minimize or take precautionary measure to minimize this kind of wear you have to look for the hard facing operation and hard facing different iron cobalt or nickel base super alloys or hard faced alloys are available.

So, you apply typical weld overlaying technique in order to develop the hard face clear on the surface and that layer will help the component to avoid that impact wear.

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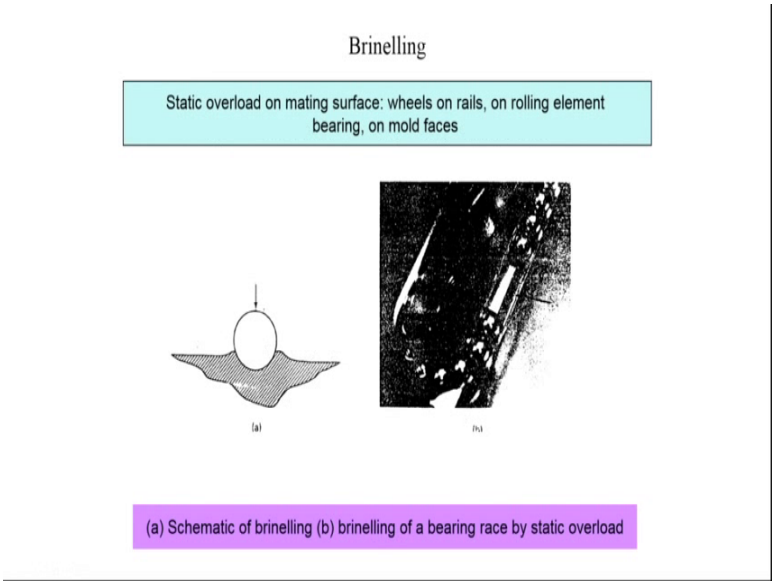

And finally, brinelling is a kind of phenomena which again is a wear, but in brinelling there is no loss of material, but de shaping of the component. So, brinelling is a kind of phenomena which again occurs on the wheels on rails rolling elements bearings on mold faces where the there is static overloading of the component or may be when you keep the car in the haling environment were hailstorms are they are.

So, they are basically small small stones they basically get indented on the surface of the car body. So, after the indentation is over you get indented mark on the surface though there is no material loss, but basically there is shape de shaping of the component or de shaping of the body.

So, that is of no use naturally you have to repair it, again this is the loss of the component. So, if you are interested to get rid of brinelling then again you have to avoid the typical impact phenomena or otherwise you have to apply very thin elastomers on the surface which will actually which is a shock absorber and subsequently reduce the probability of the brinelling brinelling wear in actual service.

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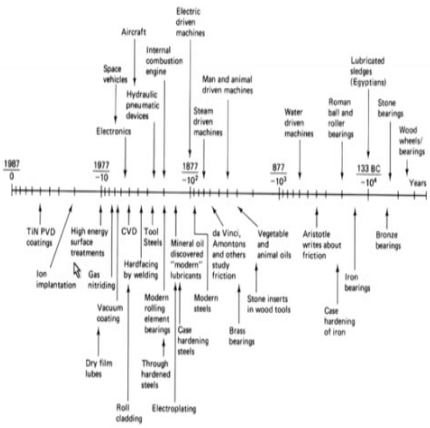

Chronology of tribosystems and techniques to deal with wear (after Dowson).

Now, in summary we can say that we discussed about different types of wear and particularly adhesive wear, abrasive wear then erosive wear as well as surface fatigue. So, in all kinds of wear the different though they are of different modes, but one special feature which is common for all kinds of wear is that if you increase the hardness naturally you can reduce the probability of wear.

So, this is the first thumb rule. So, if you can increase the surface hardness by some extent, you can certainly reduce the probability of wear. Second important thumb rule is that if you can reduce the coefficient of friction you can definitely reduce the wear phenomena or probability of wear. Third thermal is that, if you just reduce the hardness differences naturally that the other way that it increasing the hardness of your component or reduce the hardness differences then naturally you can reduce the probability of this type of wear.

And finally, you can also reduce the probability of this particular wear by typical application of lubricants when it is specially the adhesive wear driven mechanism.

So, these are the different ways by which you can compare the probability of different types of wear and this is the slide which shows you the information about application of different surface treatment techniques seems the last decades and also. Since last several years which are applied on the component in order to reduce the probability of the wear in service.

For example, in the bronzes there will be they are used to be bronze bearings, then iron bearings, then case earning of iron is old process for improving the hardness and reducing the wear rate of the ball and roller bearing process in 133 BC.

Again if you see the wear driven machine there they people applied different types of wires in order to reduce the coefficient of friction in man and animal driven machine. Then is steam driven machine they applied different types of the different modern steel they applied instead of typical iron or if that iron was replaced by different modern steel which was having higher wear resistance property.

In addition to that the lubricant application is very much was quite common since over long first decades and years and finally, the steel was tool steels was invented and when tool steel was invented it was having very high hardness. So, hydraulic and pneumatic devices internal combustion engines they were actually replaced or they were developed by manufactured by tool steel.

And hardfacing and weld overlaying were another of very important technique who is started operating since 18 19 1900 77 or so. Even 1900 since 1900 this started applying CVD and also hardfacing weld overlaying roll cladding roll cladding. So, these are very old technique, but still came long after the actual application of the lubricants.

Then vacuum coating technique came into feature in 1977 and after the invention of laser and electron beam people started applying the laser cladding, laser surface treatment process and then ion implantation PVD coated substrates. So, right now if you just see the scenario people do apply weld overlaying people do apply nitriding, carburizing process different laser or electronic beam or plasma base process as well as physical vapor deposition and chemical vapor deposition technique in order to improve the hardness of the surface and as a result of which they is the just get improve performance of the component.

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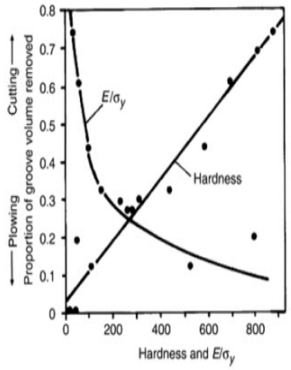

Fig. 10 Influence of hardness and E/σ_y on dominant wear mechanism. Source: Ref 5

Now, if you quickly go through the rule of hardness on the wear you will find that as you go on increasing the hardness naturally you will find that this is the case for abrasion and abrasive wear as well as illusive wear. If you just go on increasing the hardness naturally you will find that after a certain hardness value cutting mechanism play important role.

And on the other hand the elastic modulus also plays very important role the, of elastic modulus and difficult surface energy which we saw earlier that it plays important role in determining the coefficient of friction.

So, as you go on deducing the E by that surface energy value then you will find that coefficient of friction also deduces and as a result of which you will find that then wear volume also increases. So, basically if we just quickly summarize you will find that the material parameters which play important role in determining the wear behavior of the component their hardness, their Young's modulus, their surface energy, their toughness. So, these all parameters play important role in determining the wear behavior of the material.

So, whenever you design any component or improved wear resistance you have to think of the kind of wear that is operating and also think of the materials parameters which you are based on with your designing the component.

Now if you quickly go through the different wear parameters as I mentioned you wear parameters and also material parameters wear parameters means the different types of wear which are operating and the characteristics of the different kinds of wear. You can easily understand the characteristics of different kind of wear when you discussed about different modes of wear.

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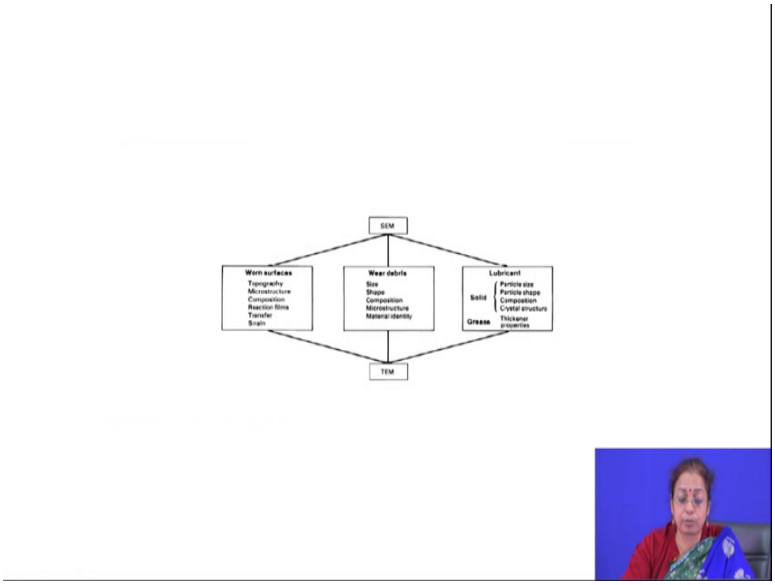

So, for example, if you talk about characteristics of no stress abrasion that there the surface looks like find scratching full of find scratches. When you talk about high stress abrasion on the surface there is formation of deep scratches as well as the holes on the surface, when you talk about typical polishing wear then surface looks like polished in nature.

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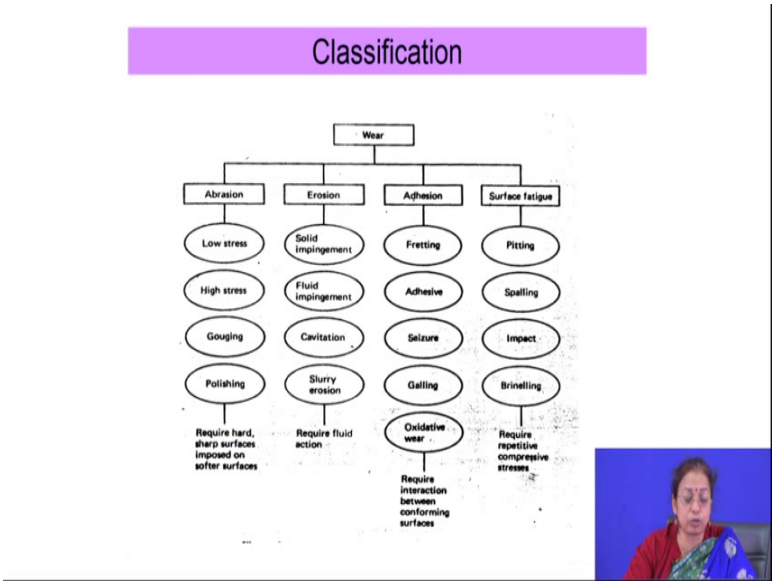

When you talk about gouging wear again on the surface there are presence of big holes on the surfaces along with that there are also scratch marks. So, these features are very important to be noted down otherwise it would be very difficult for you to recommend typical surface treatment technique which you are applying for combating that kind of wear.

Similarly, if you talk about characteristic features of the erosion in solid impingement there are very fine pit formation. Fluid impingement there are always a impingement marks as well as pits are there. Cavitation erosion there are formation of big cavities on the surface in slurry erosion again there are formation of large numbers of pits on the surface having discontinue having typical directionalities.

If you talk about adhesive wear in forfeiting wear you will find that on the surface there is small small pit formation as well as fold formation. Simple adhesive wear you will find there is always a point of the adhesive joint formation which are present and the.

So, pits are there in a discontinues pits fashion. In seizuring there is actually joint formation between the two surfaces in galling wear there is again the flue of the surface is observed the material is material flow. And as a result of we say de shaping of the component and in oxidative wear there are presence of oxides on the surface which if you are interested to know you can to go for typical X ray diffraction analysis to know the kind of oxide that is forming and how it is present on the surface.

Similarly, in surface fatigue also pitting phenomena pitting wear can be concluded on by observation of the surface you will find small small pits are there. Spalling wear you will find spallation of the coating on the surface, in impact wear you will get impact mark on the surface and in brinelling there is dent formation.

So, these are typical characteristics of different kinds of wear and one important thing that is that you should know is that depending on the characteristics you have to know which kind of precautions you should take or which kind of surface treatment techniques you should apply in order to get rid of different types of wear.

Now, if you quickly go through the ways by which you can measure the kinetics and mechanism of wear it is very important. Whenever you see the failure of the any component you have to first of all from the investigation on the failed surface you get to know about the kind of failure that is predominating in that particular component for a given application. But on the other hand it is important that you should also known the way by which you can measure the kinetics of that particular failure as well as know the mechanism of that failure.

So, if you quickly go through the kinetics of the wear measurement there are different ways by which kinetics of the wear may be measured. So, like pin on disc wear testing machine ball on disc wear testing machine different machine different wear testing units are available where the component is used as a pin somewhere, the component sometimes is used as disc as well and there is a relative motion between the two surfaces you can just have the stimulated condition where applying lubricants by increasing the temperature by applying the different different different liquids in between.

So, that the component the environment is little bit simulation simulative environment as that of is used in actual condition and then you have a relative movements between the two surfaces. So, the movement may be the sliding, it may be reciprocating movement, it may be fatigue movement these all movements you can always control externally with the help of the software and where have you can vary the load, you can vary the time.

So, what you do is that you try to find out the total amount or material loss or you measure the masters of the material as a function of time, as a function of the sliding velocity, as a function of applied load, as a function of temperature, as a function of the

media concentration or media composition. So, these all things you measure and then finally, find out the specific wear rate or normal wear rate as a function of time.

So, this for example, in case of abrasive wear you have you do not give any kind of lubricant you just have the abrasive meeting surface and your surface is there is that component surface. You have the relative movement between the two surfaces, if it is adhesive wear then your another meeting surface must be of similar composition based on the actually were based on the actual service condition of the component.

So, that adhesive joint formation is promoted, in case of surface fatigue you can have fluctuating motion instead of static motion static compressive loading of the surface in case of pitting wear you can always induce pitting motion between the two surfaces with the help of the oscillation.

So, like that you can simulate the condition. So, that different modes of wear as I had discussed they are actually their condition is fulfilled and at the end of the wear test if it is erosion testing then in that case your media is not solid and that kind of testing which you apply is a little different there. Basically you have the media which is made of which is full of liquid or foreign particles solid particles disperse in the liquid.

And then you have the movement of your component directive movement of the component which is done by either by moving the liquid or may be by movement of your component and then at regular interval of time you measure the loss of mass because of the wear.

Usually, we will find that in all kind of wear abrasive adhesive and surface fatigue these all kind of wear; wear rate is proportional to that of the hardness of the surface like higher the hardness of the surface lower will be the wear rate wear rate will be proportional to the applied load inversely proportional to the hardness of the surface wear rate will be proportional to wear will be the proportional to applied load and wear will also be proportional to the sliding distance.

So, there is typical Archard equation which actually gives you information about the kinetics of wear or rate of wear which actually which is nothing, but it is proportional to applied load, proportional to that sliding distance and inversely proportional to that of

hardness. And there is a proportionality constant which is actually called k and coefficient incase of adhesive wear it is completely coefficient of friction.

But in case of other mode of wear along with coefficient of friction there are also several rather factors which come into picture, but it is a constant value for the specific materials combination thin if specific environment.

So, by this particular ways you can measure the kinetics of the wear and if you are interested to know the mechanism of wear then you have to go for typical micro structure observation of the field surface after wear. So, usually what you do is that you take the fail surface, you do scanning electron micro structure observation after proper without proper cleaning because if you clean then you will lose own debri.

So, without cleaning you will see it under microscope you see what are there on the surface and if it is naturally high vacuum scanning electronic microscopy you have to clean the surface you cannot take the component along with the own debri. But if it is low vacuum scanning electro microscopy you can always see it with the debri. So, if it is high vacuum system then you have to collect the debri.

So, you can analyze it separately, you can collect the debri as well as surface then you can go for X ray diffraction analysis to know what are the phases that are present in the debri as well as what are the faces that are present on the surface. And you can also do micro hardness measurement on the surface to see whether there is any change in hardness. But typically if you do scan electronic microscopic observation and X ray diffraction technique you get the idea about the mode by which the wear proceeded in your case.

So, scan electron microscopic observation is very important it gives 75 percent of the information and X ray diffraction technique gives you information about the composition change on the surface. For example, after were usually there should not be any change in composition.

But if it is adhesive wear there may be some compound formation at the interface between the adhesive joints because of change in temperature because of the vicious combination. For example, you go on having the movement of copper on aluminum

surface. So, in that case copper and aluminum there if you. So, go through the face diagram you will find that a lot of aluminite formation at the in the phase diagram.

So, if you if there is adhesive joint formation if temperature is very high over there you will find that there is aluminate formation at the interface. And that aluminum aluminate will naturally would not be there as aluminite and then adhesive joint because in that case mode of wear will be seizuring kind of things neither in copper aluminum combination there is a seizuring phenomena. But if that aluminate forms then naturally during wear the aluminum will get detached from the aluminum surface because aluminum is having lower hardness.

So, as it detaches as it is detached from the aluminum surface it gets accumulated at the interface between copper and aluminum. So, when it gets when it gets accumulated at the interface between copper and aluminum naturally it would aggravate the wear further because, after that if you see the wear mechanism, it would no more be the typical adhesive wear it would be abrasive wear because, the aluminates are harder than both copper and aluminum. So, when they are present as hard particles at the interface they will cause the wear of both copper and aluminum. So, this is very interesting phenomena.

So, whenever you talk about adhesive wear you find that initial mechanism of wear or initiation of the wear it is because of adhesive joint formation, but propagation occurs because of 3 body 3 body wear actually. So, these 3 body wear can be abrasive wear can be adhesive wear can be anything, for example, if at the interface there would be copper formation then naturally the 3 body because of 3 body wear the wear rate would be reduced to a little extent because the presence of copper would act as the lubricant.

So, after the three body wear you will find that there will be loss of contact between the two surfaces. So, as a result of which it helps in reducing the wear kinetics. So, the three particles which are forming at the interface is very important and which gives you information about the mechanism of wear. So, as a result of which it is very important that after the wear is over you basically collect the own particles and then do exotic analysis to know the kind of particles that has found and to also infer informations on the mechanism of wear.

So, this is what is shown here for example, what you do for the mechanism of wear you have to analyze the own surfaces you have to see do see the do the own debri analysis

properly and you have to also see the or analyze the duplications lubricants which was added if at all during the service. And finally, you can go for also transmission electron microscopic observation, if you are very much sure about any layer formation on the surface.

So, these in a joint way gives you or combineling combinedly these all investigation give you information about the mechanism of wear and when you know about the kinetics and mechanism of wear it is very easy for you to judge the to accesses the reliability of the component in actual service as well as to take precaution. So, that the failure does not occurred because of the wear.

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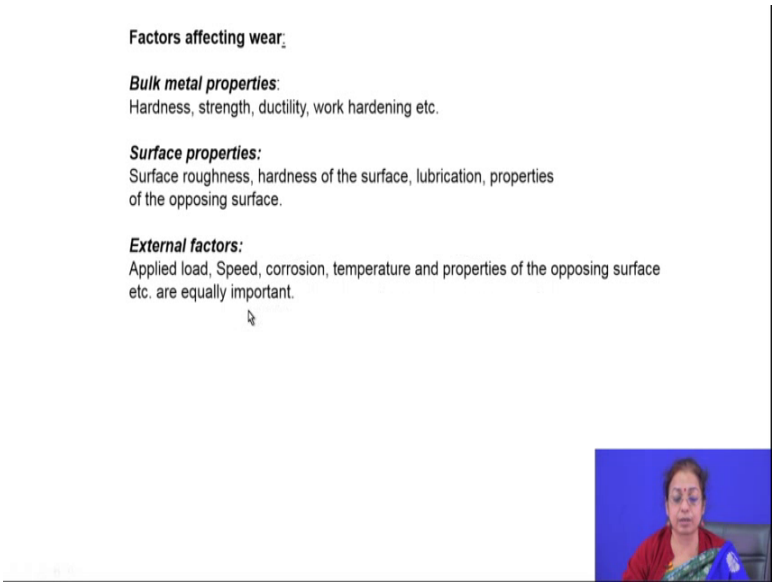

So, in this talk we discussed about different types of wear and then we discussed about the parameters which influence the wear the external factors which influence the wear kinetics. The way you can measure the wear kinetics and also mechanism and how to improve the or minimize the wear rate of the material or component in service.

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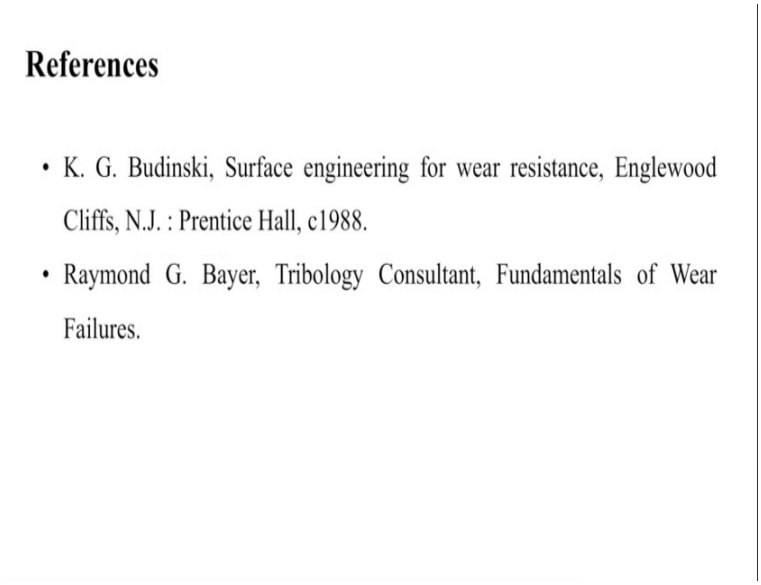

Thank you very much.