Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations
Prof. Dr. D. K. Dwivedi
Department for Mechanical and Industrial Engineering
Indian Institute of Technology-Roorkee

Lecture-19
Surface Damage: Melting Wear and Corrosive Wear

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and you know that we are talking about the various types of the wear mechanisms and under this heading we have talked about the adhesive wear, abrasive wear and erosive wear now we will see some today in this presentation will see some other forms of the wears such as melting wear, corrosive wear and diffusive wear.

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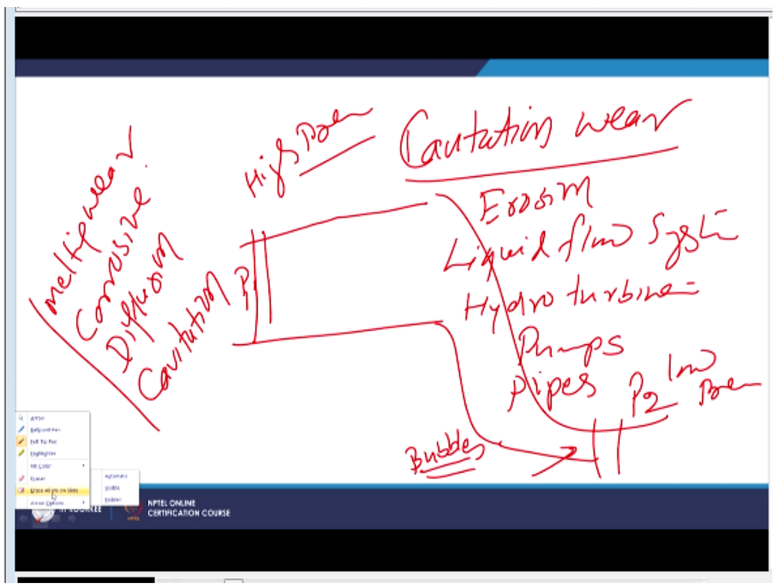

Apart from that there is one more type of the erosive wear which is called cavitation. So we will start this presentation in fact from the cavitation itself this type of the wear which is cavitation wear is a form of erosion which takes place in case of the liquid flow systems where are liquid flow systems like hydro turbines, pumps which are used to handle and transport various types of the liquids and pipes wherever the flow of the liquid is taking place.

So in these systems like say there is always variation in pressure from 1 point to another say this is point 1 or section 1 where pressure is p1. And this is another section where pressure is p2 so, when the fluid flows from the high pressure zone to the low pressure zone. Under those conditions liquid tend to form the bubbles due to the evaporation.

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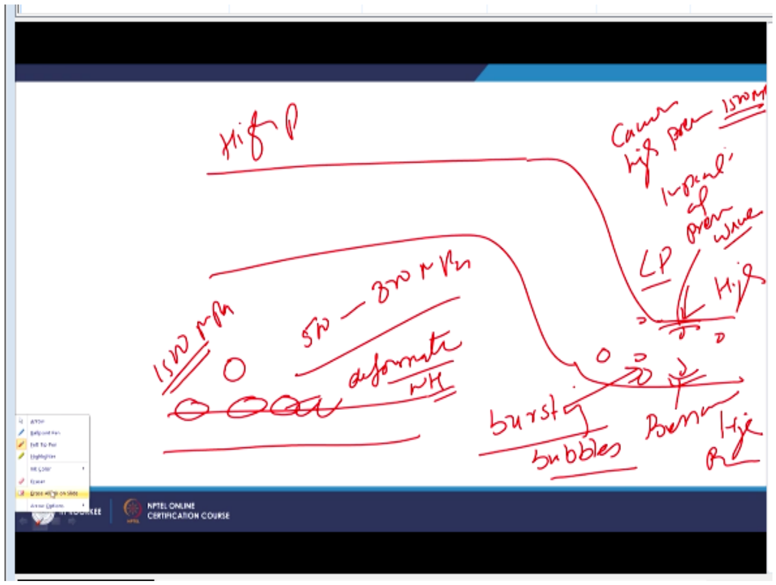

So, these bubbles these formation of these bubbles in the liquid flow systems like say these bubbles have been formed in this location. And again when these will be passing through the region of the high pressure zone. So, this is low pressure zone, high pressure zone. And again say it goes in some high pressure zone then once these bubbles have been formed.

They have been formed they are bursting of the bubbles results in the development of the movement of pressure ways or shock ways. So, pressure ways on bursting of the bubbles move and as soon as this pressure waves hit the metallic surfaces. So the impact of these pressure waves with the metallic surfaces like inner wall of the pipes or impeller in palms or turbine bleeds in hydraulic turbines.

So, these impact of the pressure waves causes development of the very high pressure at the location where in the vicinity of the region bursting of such kind of the bubbles take place. So, this pressure may be as high as 1500 mpa since most of the metals which are used for such kind of the applications they will be having this strength of around say 500 to like say 800mpa.

And development of the high pressure waves and impact of high pressure pulses which are created due to the bursting of the bubbles leads to the surface layer deformations, say this is the location where such kind of the pressure is being created. So near surface layers which are being subjected to high pressure of the order of say 1500mpa. So, near surface layers are subjected to the surface layer deformation.

So, like say 1 bubble had busted it adds created as this kind of pressure so, little bit deformation near the surface layer will take place. But the continued bursting of the bubbles over a particular region and then continued surface layer deformation will be leading to the continuous work hardening of the material.

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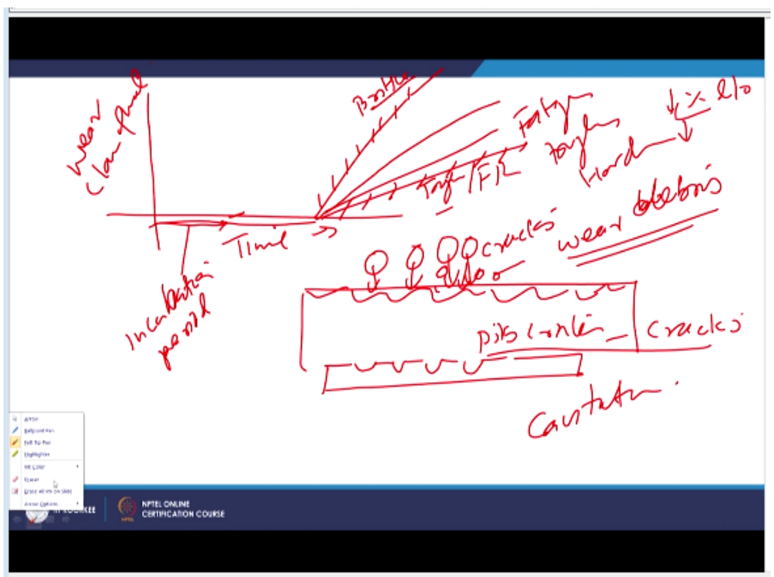

So, the location where such kind of the hardening is taking place say this is the surface which is being continuously subjected to the above bursting of the bubbles and the pressure waves are being generated. And causing the near surface layer deformation. So after some time material is work hardened to such an extent due to the continuous deformation that material looses it is ability to get further deform.

It is work hardened to such an extent that it is stats showing cracks at the surface. So, development nucleation of the cracks and their growth eventually when the collations of such kind of the cracks take place. The material is removed in form of the small pieces which will be coming out in form of the wear debris. So, wear debris is basically generated at the end of the collations of such kind of the cracks which are being formed.

And these cracks are being formed due to the continuous bursting of the bubbles which is creating high pressure near the surfaces causing the deformation. And deformation is causing the work hardening once the material is looses it is ability to get further deform it is starts developing cracks. And when the collations of such kind of cracks near the surface takes place material is removed in form of a small pieces.

And so wear debris is generated mostly you will see the surface if such kind of surface is observed at the surface you will see that there are lot of the pits and cracks, craters are present on the surface like this. So, the pits, craters and cracks are the typical features of the surface is which are subjected to the cavitation. So, if we try to see the loss of material as a function of time under the cavitation condition.

Then initially it takes some time to deform the surface layer to such an extent that crack development takes place. And thereafter the collations of the cracks leads to the removal of the material in form of a small pieces. So, initially there is no removal of the material. So, this time material is subjected to the like pressure waves due to the bursting of the bubbles under the cavitation conditions.

But the immediately there is no removal of the material there is no material loss of material in the beginning. So, this time period is called incubation period, this is the period where near surface layer deformation will be taking place material will be work hardening. Thereafter crack nucleation will start and there collations will be causing the material loss.

So depending upon the ability of the material to get deform this time may be less or more if the material can be deformed to larger extent prior to the nucleation and growth of cracks and so, in that case the it will this incubation period will be longer and thereafter it will start getting means material loss will start increasing as a function of times with it will be by enlarge linear relationship. However depending upon the kind of material it is a like fatigue resistance, toughness and hardness.

This slope may be low or high if material is higher resistance higher work hardening capacity and higher toughness. Then it will offer the lower wear rate as a function of time if the material is having less ductility less percentage elongation lower work hardening capacity higher hardness in then in that case material will tend to behave like brittle materials and the wear rate will be high.

So, the material those which are hard and brittle materials they will show higher wear rate as compared to the tough and the fatigue resistance material under the cavitation conditions. So, we can say the tough and fatigue resistance material will b showing the lower wear rate as a function of time due to the cavitation as compared to the hard brittle materials however it has also been observed.

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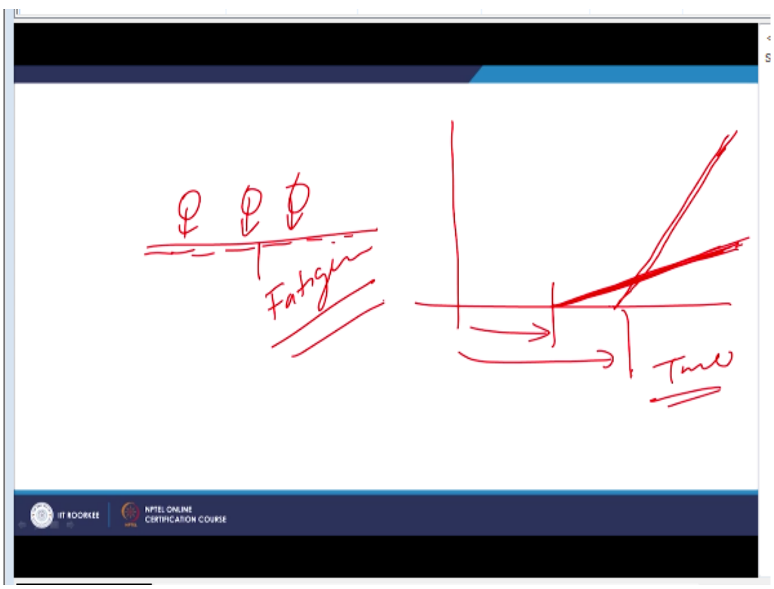

If we directly compare the materials which are very hard they will delay the crack nucleation in the beginning but because it takes some time for surface to reach to such an extent once the crack nucleation in hardening brittle material is starts. The wear rate takes place at higher rate on the other hand surface is will be deformed very easily if they are of lower strength, lower yield strength.

Then in that case surface may experience the lower nucleation period but they which will they will also be showing the lower wear it has a function of time. So, incubation period and the wear rate as a function of time these are the 2 different things it maybe low or it may be long. Thereafter once the incubation is over thereafter the rate at which material loss as a function of time which will be taking place that will again depend upon the material characteristics.

Those materials were cracking nucleation it is growth is easier they will be experiencing higher cavitation wear erosion rate as compared to the cavitation erosion as compared to the materials which are tough and fatigue resistant. Because under the cavitation conditions there is continuous bursting of the bubbles and so there is a repeated, there is a continuous loading of the different magnitudes on to the materials.

So, material which is experiencing the cavitation conditions by enlarge will be experiencing the fatigue loading. So, the fatigue behavior of the material it is work hardening capability and the ability to resist the crack nucleation and growth. These are the 3, 4 important factors which determine the cavitation, erosion, resistance. Now going back to our this melting wear.

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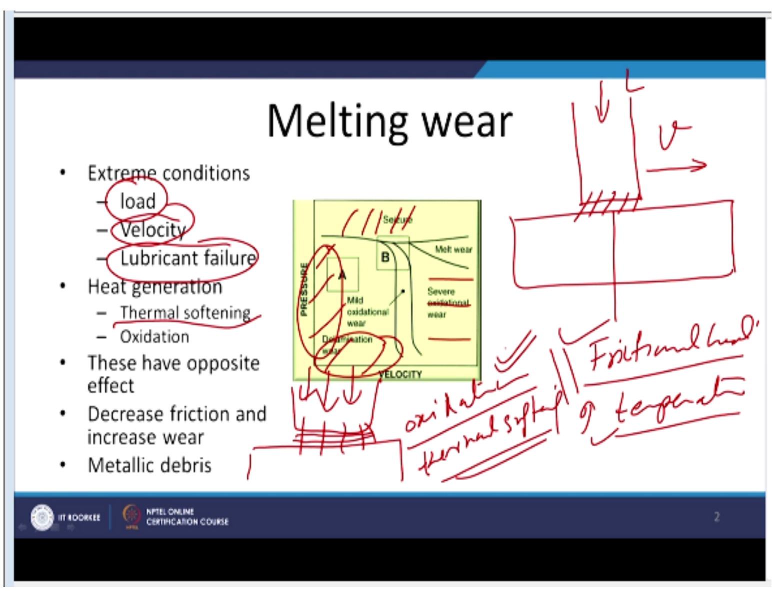

In case of the melting wear now we know that whenever the metal to metal like say under adhesive wear conditions when the load value is too high. And the sliding speed is also high under those conditions lot of frictional heat will be generated at the interface. And when the frictional heat is too high then it will be causing the significant rise in temperature of both interacting surfaces.

So, rise in temperature actually works in 2 ways 1 is it will be causing the oxidation of the interacting surfaces. And another thing which will be the experienced by the material is the thermal softening**.** So, these are the 2 opposite kind of things like say this is the interacting surface if it is getting softened. So, the peaks and value will be collapsed easily and under the given load conditions the metallic intimacy will be increasing.

On the other hand oxidation will be leading to the formation of oxide layer at the interacting surfaces. And such kind of oxides will be reducing the direct metal to metal contact tendency. So, it will be resisting the wear and friction, so depending upon the extent of heat generation rise in temperature. The two factors will be playing opposite roles like oxidation will be reducing friction and wear.

On the other hand thermal softening will be increasing the friction and the wear behavior. So, these are the 3 conditions which can lead to the excessive heat generation like load, velocity and the lubrication conditions. When the lubricant failure takes place then also heat generation excessive frictional heat generation leads to significant rise in temperature. So, the limited heat generation limited rise in temperature will be reducing the wear due to the oxidation.

While significant rise in temperature will be leading to the excessive thermal softening and which in turn may in lead to the increase in the friction and the wear rate. So, this is what we can see from this diagram when the load and the velocity is limited it lead it has materials most of the time experience is the mild oxidative wear. And when the load and the velocity are on the higher side it experiences the severe oxidative wear.

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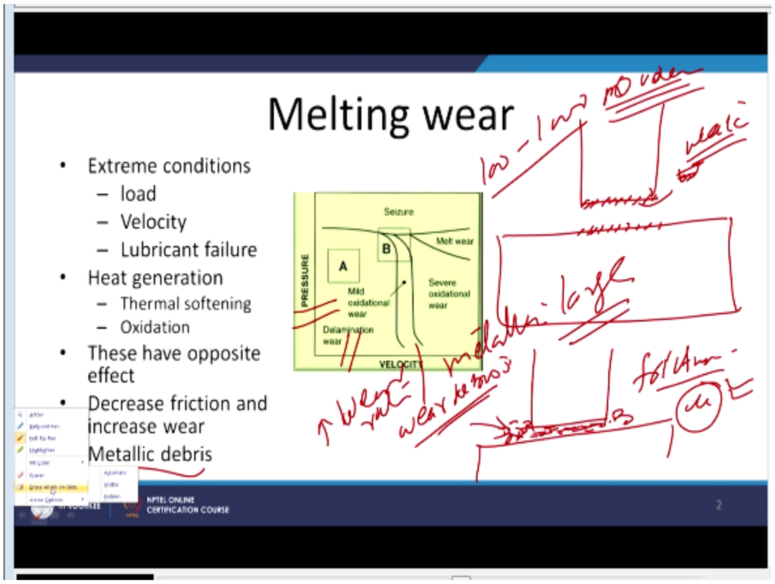

When the velocity is high and pressure is also high it leads to the scissor wear and when the higher pressure and further higher velocity leads to the melting wear. So, the melting wear is a typical situation where at the interface heat generated or the rise in temperature is such high that little bit thin layer of metal is Melton either one or both the sides depending upon the interacting melting point of the interacting material.

And this thin layer of the material which is actually thin layer of the material which has melted this is very weak. So, presence of thin layer of liquid metal which has melted will be actually reducing the friction force. Because it will not resist the movement in any way. So, as soon as the melting wear starts the friction is reduced. But since this molten metal under the pressure it will be squeezed out from the interacting surfaces.

And so it will present outside the zone where interaction is taking place under the pressure. So, if they squeezed out molten metal will again be solid defying and be removed in form of the wear debris. So, such kind of the wear debris will be developing at very high rate and therefore it will be causing the higher wear rate of the material. And most of the time this debris is metallic in nature the particles are large in size.

So, in generally if we see immediate formation of the molten metal leads to the reduction in the friction. But a significant increase in the wear rate takes place and this may be 100 to 1000 times of the normal oxidative mild oxidative wear which is observed. So the melting wear rate is 1000 to 100 to 1000 times greater than the mild oxidative wear which will be observed under the lower pressure and lower velocity conditions. And these are the conditions under which the metallic debris will be generated which is much larger in size.

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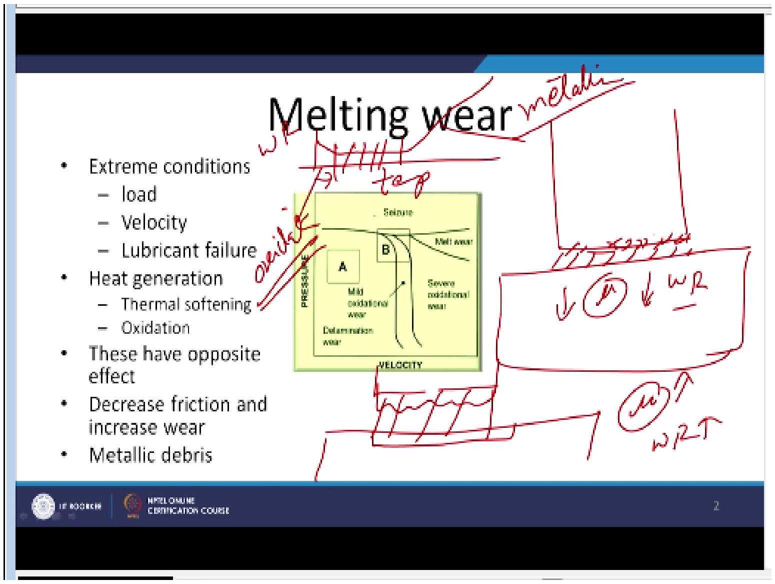

So, if we see another aspect if the rise in temperature is not that much in that case excessive heat generation will be leading to the rise in temperature of the both surfaces. And in case of the significant rise in temperature where all the thermal softening is not much then excessive formation of the oxide layers both the sides preventing the direct metal to metal contact which will be reducing the friction as well as it will be reducing the wear rate.

But another situation where the pressure is high and softening has a started so, in case of the increased softening due to the higher frictional heat and higher temperature will be leading to the collapse of near surface regularities which in turn leading to the increased metallic intimacy will be increasing the friction as well as this will also be increasing the wear rate of the material.

So, this is the difference where initial rise in temperature is good so, if we just try to see the temperature of the interface verses wear regulation ship initially there may be marginal drop in the wear rate as a function of temperature. But thereafter it is start increasing rapidly. This initial drop in wear rate as a function of the rise in temperature is activated to the increasing oxidation tendency at the interface which is reducing the direct metal to metal contact well further increase in temperature leads to the intermediate situation where it strikes a balance between oxidative and the severe wear.

And further increase means significant increase in temperature leads to the severe metallic wear conditions where the wear rate will be high or even the melting wear can be observed at the interface.

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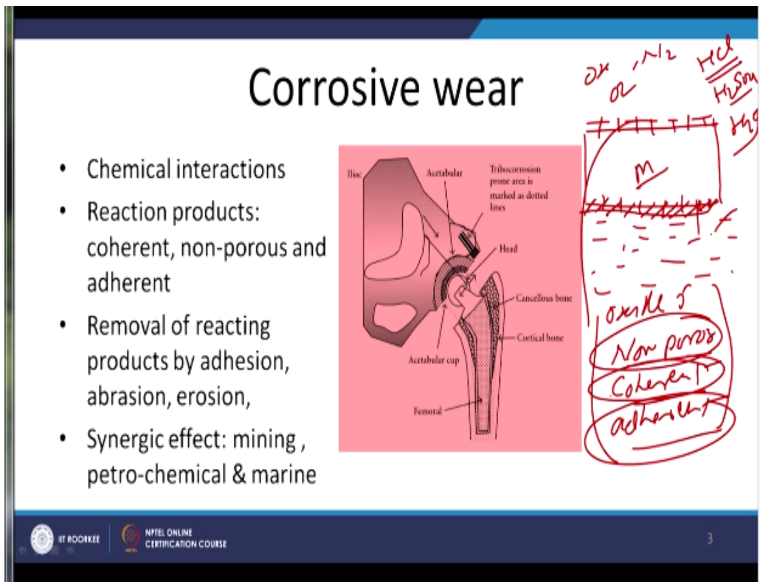

Now corrosive wear is the another type of the wear where like we know that most of the metals interact with their surroundings in presence of gases like oxygen, nitrogen and the environmental conditions like chlorides or sulphates or simple H2O in moisten in environment. So, what happens that metals interact with the gases like oxygen and form there oxides these oxides can be of the two types.

One when oxide is non-porous, non-porous means porosity is absent it is oxide is non porous, it is coherent means it does not break easily and it is adherent means it remains attach to the surface. So, if the oxide of such kind is formed due to the interaction with the environmental gases and the metal which is being considered. Then such kind of formation of such kind of compounds at the surface which are non porous, coherent and adherent these oxides will isolate the metal from the surrounding metal.

So, access of the surrounding gases to the metal will be stopped and if it is stopped then further oxidation or further formation of the reaction compounds will be stopped. And this will lead to the means stopping or a prevention of the corrosion. So, this kind of the oxide formation or reaction product formation is favorable from the corrosion point of view especially when the reaction products are non porous, coherent and adherent.

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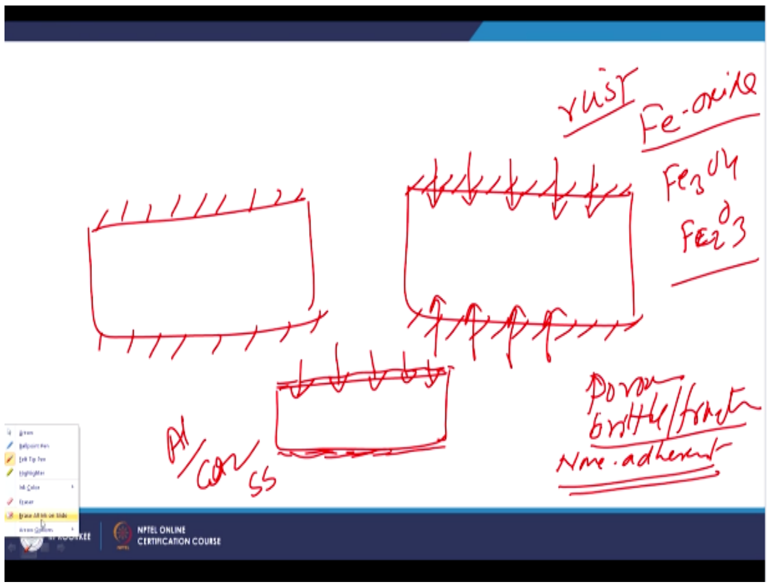

But there can be another situation where we have the reaction products are such that oxides or the reaction products being formed at the surface or porous. They are porous and they are like say the brittle not coherent. And they fracture easily and they are non adherent type, so they have tendency to get peel off or get removed from the surfaces. So, if it is porous then they will allow access of the environmental gases to react with the metal continuously.

So, corrosion will continue if and this kind of the situation is further facilitated if the oxides are brittle and they fail or fracture easily under the whenever they interact with the surrounding and they are adherent means they get removed easily. So, if the reaction products are being formed at the surface and they are getting removed, so removal will be leading to the exposure of the fresh metal again to interact with the environmental gases.

And this will promote the continuous corrosion of the metal, so formation of the rust is an example where different types of the iron oxide like Fe_3O_4 or Fe_2O_3 is formed. So, such kind of the oxides are non porous brittle and they are non adherent they get removed easily from the surface especially when the component is interacting with the other components, so these will allow the corrosion to continue.

On the other hand other metals like aluminum, chromium and stainless steel where the chromium is present in large quantity. So such kind of the oxides means aluminum oxide layer when it is formed it is non porous, it is coherent it is adherent. Similarly the chromium oxide layer which is formed is also of this kind where it is non porous, non coherent, non porous and it is coherent and adherent.

So, it prevents the further oxidation of the underlying metal and that is why what will see that whenever the stainless steel components are left under the mean condition we see that they remain unaffected by the environment and that is why they are called stainless. On the other hand normal carbon steel or alloy steel they sometimes tend to get rusted, so they lose their color, shiningness and even the loss of the material takes place.

So, that happens primarily due to the formation of the reaction products onto the surface is of such kind where continuous reaction products and corrosion of the material takes place and which in turn leads to the loss of the material.

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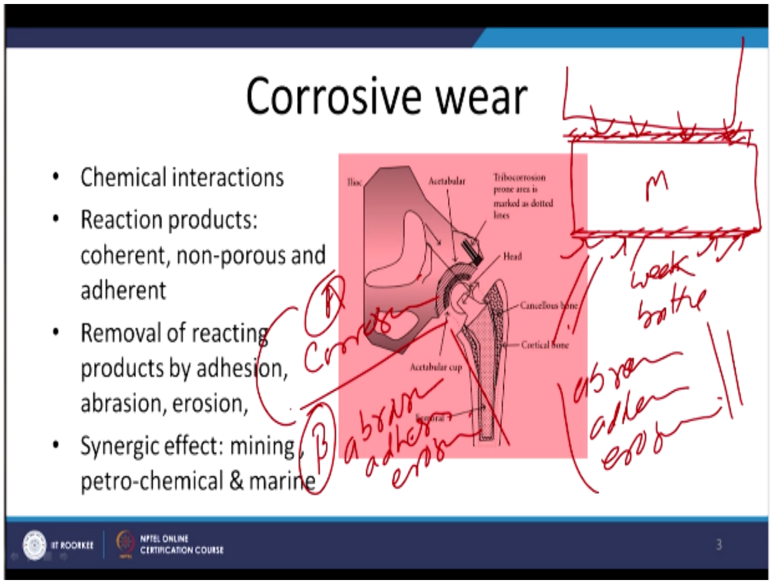

Now so another aspect related with the corrosion is that not just the formation of such kind of the reaction compound is important. But sometimes we see that it corrosion products are getting damaged very badly whenever component is interacting with the other mating components or other mediums during these service. For example if this metal is interacting with the surrounding and forming certain kind of the reaction products at the surface.

And if these reaction products are weak, they are brittle and they are non adherent kind then during the interaction with the other materials like during the adhesive wear, during the abrasive wear, during the abrasion, during the adhesion or erosion. So, interaction of such kind of surfaces where such kind of reaction products being formed during to the corrosion and interaction of the such kind of the surface is where these contradiction products are being formed.

Then due to the abrasion, adhesion and erosion these reaction products will be removed easily and will be exposing the fresh metal surface for further corrosion. So, under this condition the 2 things will be happening 1 is the corrosion of the metal surface at the same time removal of such kind of corrosion products by the abrasion, adhesion, erosion etc., as per the kind of the service conditions which are being experienced by the component.

So, here basically the 2 material removal mechanisms are working 1 is corrosion and another can be like abrasion, erosion, adhesion or it can be anything else. So, here both combined effect of both A and B category of the mechanisms of material loss will be acting.

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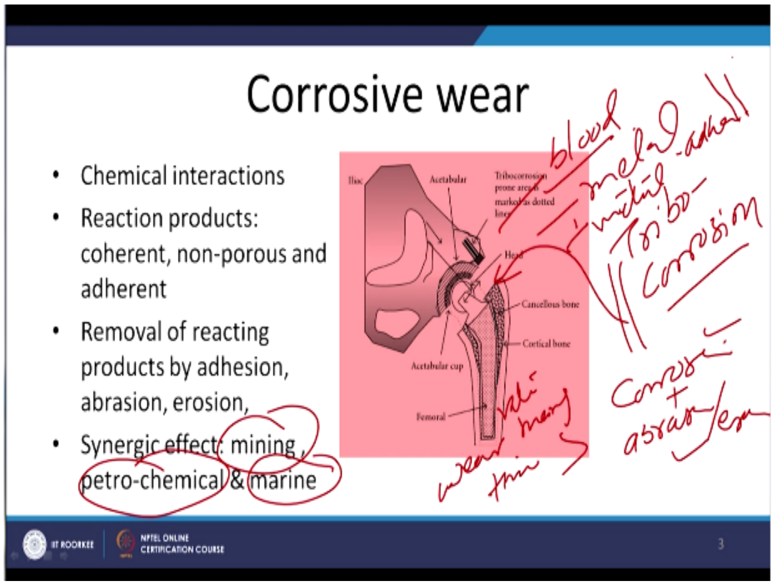

So, this kind of the corrosion is called tribo-corrosion where 1 tribological mechanism is already operational. At the same time corrosion is also combined with this situation, so all the components which are used in mining, in petro chemical industry as well as in marine under these 3 sectors will see that most of the components will be experiencing both combination of the adhesive, abrasive and erosive wear.

As well as the corrosion and the kind of and when both these factors combined together like corrosion+abrasion or erosion. Then what we observe that wear rate is many times greater than the combined wear which can take place just due to the corrosion or due to the abrasion. So, this is called synergic effect of the corrosion as well as the another tribological mechanism which is operational.

So, whenever there is a synergic effect we find that wear rate is taking place at a much higher rate and this kind of the wear is also observed means tribo-corrosion conditions are also observed with the human body parts when the implants are made means certain body parts are replaced using the metallic parts. So, they are the blood reacts with the metal components at the same time the direct rubbing of the metallic pieces during the operation like the different types of the joints which are replaced in the body.

If with the metallic components, so the metal to metal interactions in that case will be causing the adhesion. At the same time the reaction of the metal with the blood will be causing the corrosion.

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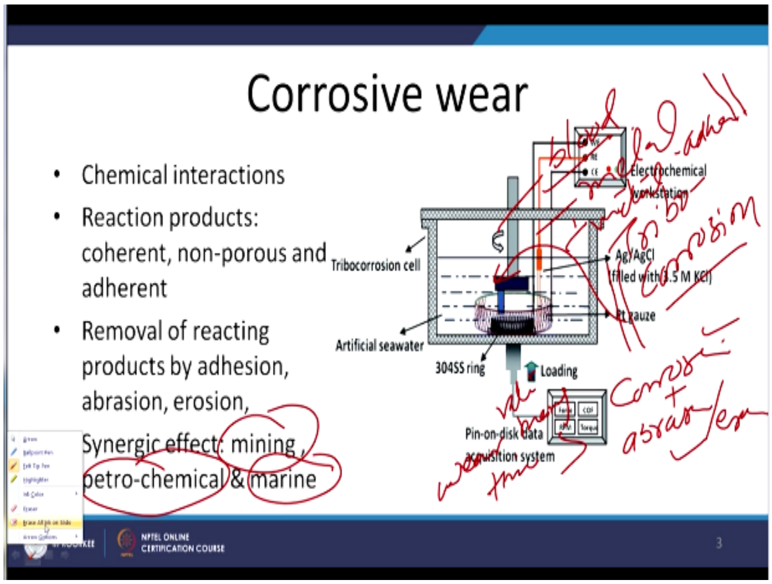

So, combined action of both these will be leading to the tribo-corrosion conditions.

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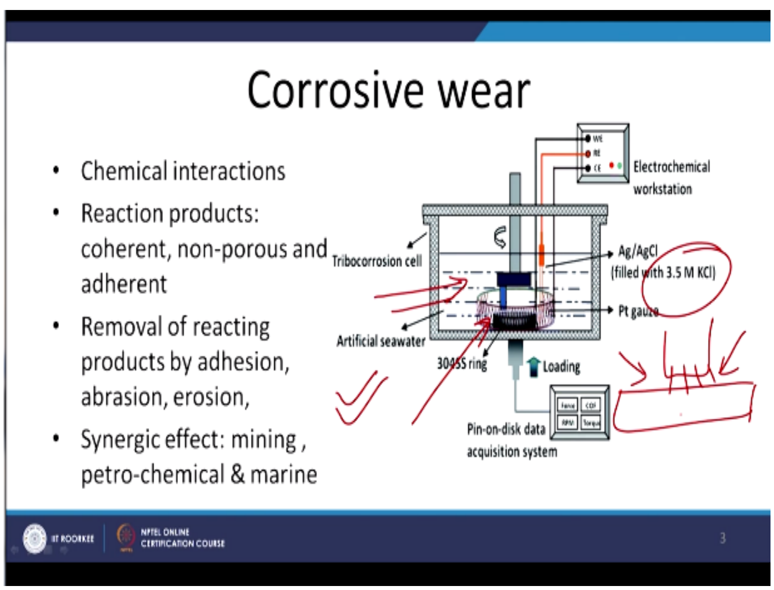

So, to test the behavior of the material under such conditions means the typical kind of the setups have been used for investigation behavior of the material under the different conditions like the corrosive media is placed and then the component being tested is rubbed against the another counter surface to see how does it behave under the different kind of the environments.

Like here in this case maybe 3.5 Mole KCl environment which is being used to have the artificial sea water conditions. So, whenever a component interacting with the another component and in the corrosive environment then behavior of the material with regard to the wear resistance is investigated to see really what kind of the tribo-corrosion resistance is being offered by a particular material.

So, now here I will summarize this presentation, in this presentation basically I have talked about the 3 types of the wear and their fundamental mechanisms, 1 was the cavitation erosion and the second one was the melting wear and third one was the corrosive wear and what are the different factors that affect these kind of the wear mechanisms, thank you for your attention.