Corrosion Failures and Analysis

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Lecture - 37
Cavitation corrosion, Fretting corrosion and their preventive measures

Hello everyone. So, we will start lecture 37 and the course is Corrosion Failures and Analysis. We have been talking on erosion corrosion, then we started talking on cavitation damage and today we will talk about some of the protective measures one can take to prevent materials from cavitation damage and then we will start discussing on start discussing fretting corrosion which is also falling under erosion corrosion.

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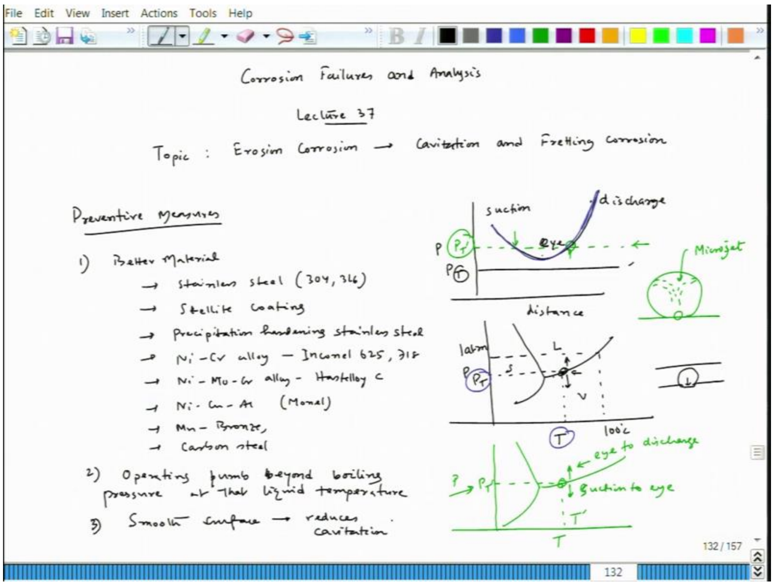

So the course is Corrosion Failures and Analysis and lecture 37 topic we will Erosion Corrosion with the spatial emphasis on cavitation and fretting corrosion. Now if we have we have seen that the cavitation damage happens when bubble collapses on top of a metal surface and that leads to micro jet impact on the metal surface and also the shock waves.

So, that lead to deformation on the material and that deformation can damage the passive film before it gets re-passivated or it can deform and then that deform surface can go through little bit of extra corrosion process or corrosion damage or corrosion degradation before another bubble forms. And this bubble is not air bubble this is happening due to boiling of fluid and if we consider water system then boiling of water and that happens because the decrease in pressure.

And if we could recall the phase diagram as well as the pressure line that is existing in the suction eye region as well as discharge region of an impeller of a centrifugal pump where the impeller motion gives rise to that pressure difference at different points; that means, suction eye as well as discharge zone and those pressure lines if it intersects the vapor pressure line of that particular liquid or that particular water at that temperature of the water then definitely boiling happens and bubble can collapse.

Now if we recall just so, if we could see that this is the pressure basis distance and this is a suction zone, this is the eye zone and this is discharge zone. So, now, this is suction of a pump. So, the pressure line means I am considering this and the vapor pressure line which is this one which is P T and correspondingly if I draw phase diagram pressure versus temperature of water.

So, this is the diagram, this is solid, this is liquid, this is vapor or steam and if we consider 1 atmosphere pressure then corresponding boiling temperature is 100 degree Celsius, but it can also boil let us say this is my temperature what I am considering here the temperature the fluid and that boiling temperature boiling pressure would be this. So, this is P T.

Now, if the pressure reaches P T then definitely and if that pressure go goes below this. So, at this point liquid and vapor they coexist because that is an equilibrium, now if the pressure goes down then steam forms goes up liquid form. So; that means, between suction eye and discharge points if this line the if the pressure drops below this particular point then definitely boiling happens and if pressure goes beyond that point this point then those bubbles that boiling happens and then bubble forms steam bubbles forms and that steam bubbles will collapse.

Now if this is the situation definitely no bubble will form because it is not able to reach to that equilibrium boiling pressure at that temperature of the liquid, but if it is like this is let us say P T prime, let us say if we draw another pressure temperature diagram. So, this is the diagram now if this is my T prime and this is my pressure P T prime.

So, now, if this is that condition pertaining to this then definitely at this point boiling happens when the pressure drops below this pressure and then bubble forms and that water when it goes to the discharge on pressure goes up and then at this point those boil bubbles that have formed containing steam they will collapse because the pressure is going above this.

Initially when suction to eye; suction to eye pressure drops boiling happens bubble forms and then this part is from eye to discharge pressure increases bubbles collapse. So, that way at this point actually the cavitation happens that impact happens and that impact happens because you have this bubble and that bubble collapses like this and then the micro jet hit the surface at this point at a very high speed.

And then that gives a huge pressure close to around 500 megapascal that can deform the surface and even if it is a passivating metal that can remove the passive layer and before the another bubble forms it can re-passivate if it is a strongly passivating metal. So, the by that time we have little bit of material loss.

So, that is the loss of metal through cavitation. So, now, if we have to find out ways to prevent it first of all if we try to look at some of the preventive measure. First is of course, better material because anyhow we cannot stop bubble formation if we try to create a negative pressure in order in case of pumps or in case of propellers where propellers move at a high speed so that the sheep moves in the forward direction.

So, we have with that that bubbles will be created so, in order to avoid that cavitation due to bubble collapse. So, we have to have a better material, better material in the sense that stainless steel; stainless steel has got a very good cavitation resistance compared to carbon steel ok, it has rather a very extremely high cavitation resistance compared to carbon steel.

Now, then we can use coating let us say a stellite coating, then an austenite stainless steel means even we can use precipitation hardened stainless steel this is normal one even 304 or 316. So, these kind of stainless steels one can use then precipitation hardening nickel chromium alloy like inconel 625 or 718, people can use hastelloy which is nickel molybdenum, chromium alloy hastelloy it is a hastelloy C, people can use monel, nickel, copper, aluminium. Even one can use manganese bronze and where cavitation is not that severe ok.

So, then in that case in the mild cases people can also use carbon steel. So, these are the kind of better materials one can think of. Second is operating pump beyond boiling pressure at that liquid temperature.

If we try to understand this statement so for example, in this case; in this case I have the boiling pressure which is cutting this suction eye and discharge lines in such a way that boiling and collapse of bubbles are both possible. But if the this line this entire this particular pressure line within the pump lies above the pressure where boiling happens at that temperature of the liquid. For example, if the temperature of the liquid so this is my boiling pressure now if all those pressure lines in the eye suction as well as discharge they are above that pressure line definitely boiling possibility is not there.

Now third point if you see if we recall that once deformation happens let us say it was a flat surface and after deformation there is a small dip ok and this dip can provide nucleating sites for bubble formation or bubble nucleation. So, here another bubble can form. So this particular dip is possible because there is a small deformation, but in the beginning if the surface is rough then definitely that formation nucleation of bubble will be much easier.

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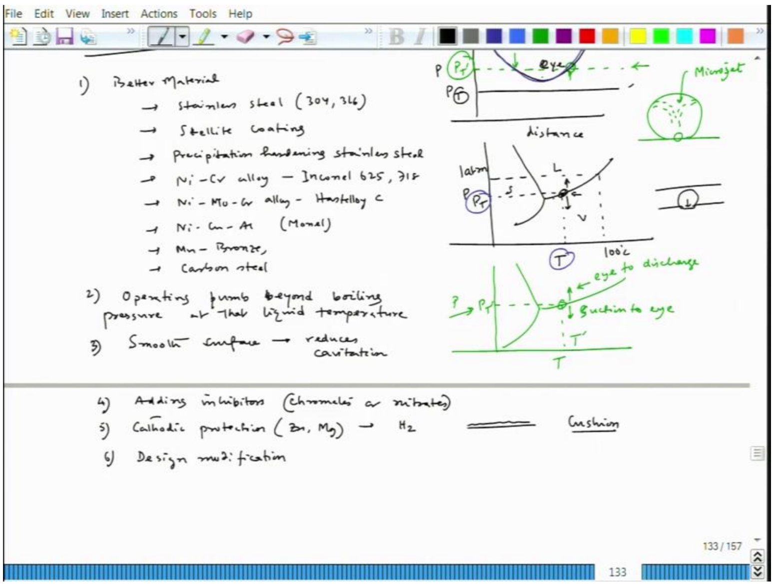

So, smooth surface that reduces cavitation, maintenance of smooth surface, adding inhibitors chemicals like nitrates, chromates those actually avoid cavitation. So, this kind of inhibitors which is chemical added to prevent corrosion. Cathodic protection is another way out in that regard sacrificial zinc or magnesium pieces can be used. Now here if the cathodic reaction product is hydrogen, that hydrogen gas on the surface this is the surface that hydrogen gas can create a cushion for those bubbles which are forming and if they burst.

So, that bursting due to bursting there is a shock wave. So, that shock waves can be absorbed to a great extent by the cushion of that hydrogen layer hydrogen gas layer that is forming due to the cathodic reaction product which is basically cathodic reaction product. So, this is one way to prevent.

So these are couple of methods people can think of and there are modern routes for example, there are reports like six design modification. Design modification means if we try to operate for example, propeller if we consider a propeller, that propeller when propeller moves there is a trail of bubbles that forms. In YouTube there are nice videos on this if one can go and look at it when propeller moves propeller rotates there is a trail of bubbles which are moving along with the along with the ship.

Now if we reduce the speed of that propeller definitely bubble formation would be less because that a pressure difference would be less, but if we reduce that speed of the rotation then definitely it will reduce that reduce the thrust which actually taking the ship forward, but in order to maintain that same thrust at the same time it can be reduced the speed can be reduced the rotation speed which actually avoids bubble formation or the pressure difference that can be done if number of blades can be increased.

So, there are reports that by increasing the number of blades and there are other design modifications which can actually reduce the speed of rotation which or in other way which reduces the pressure difference, but the thrust is maintained. So, that is one way of doing it is a basically a design modification of that particular propeller.

So, these are couple of ways one can think of reducing cavitation damage and if you want to see cavitation you can go to Google you just search cavitation damage you will find thousands of images and some of the images you would notice that even the blades of the impeller is completely washed off, because the dents those are formed because of this micro jet formation and the deformation as well as in parallel the corrosion is taking place.

So, that will actually take off the take away or the chip of that particular material and that if that material goes off definitely the thrust is reducing. So, the pump will reduce its efficiency the amount of water that it has to discharge will definitely be less at the expense of energy what we are consuming due to the running of that pump. Now so, those are the kind of serious defects that can be observed in case of cavitation damage.

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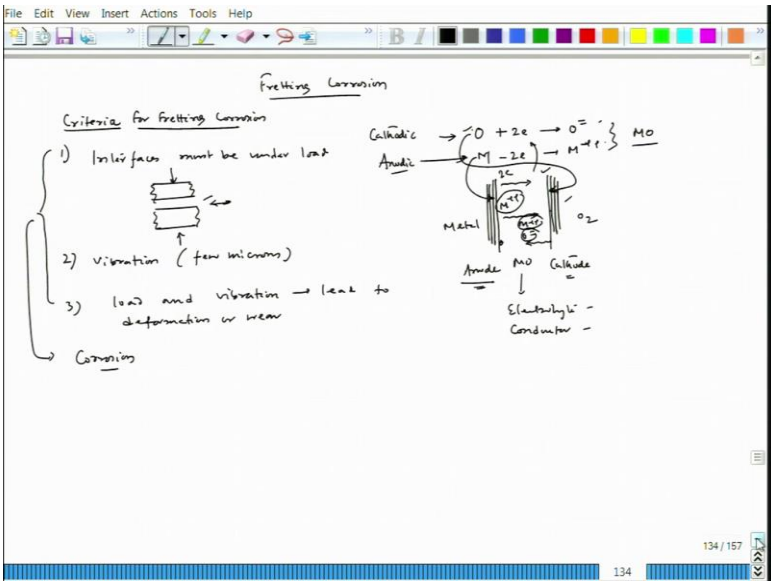

Now let us look at another form of erosion corrosion which is fretting corrosion see if we recall we have discussed in the beginning of erosion corrosion that fretting happens when two meeting surfaces are tight fitted ok and there is a small very small even few microns level of amplitude of vibration so that particularly led to a kind of fretting action between those interfaces.

Now, if we have corrosives then it can also lead to corrosion of that particular thing, now in this in the case of fretting attack it might happen in the dry condition also. So, dry condition definitely there will be a possibility of oxidation and oxidation is nothing but corrosion because when we check about oxidation, oxidation why we are saying oxidation is a corrosion; that means, we have oxygen removing two electron going to O minus minus and metal sorry this is accepting two electron and metal leaving two electron then metal plus plus and these two react and form metal oxide.

Now this can happen on the metal surface if we see the oxide layer this is M O layer and this reaction happens at this surface and this reaction happens at this surface. So, they are depending on the which one is diffusing in or out accordingly it will be decided where this reaction happens and where this reaction happens. Now in order to and that at particular thing had been talked in previous if we go to corrosion two lecture series corrosion two you will see that on oxidation this kind of mechanism has been explained.

But if we see that this particular; if we see that this particular if metal leaves two electron and metal plus plus ion is forming so; that means, this surface becomes anode because this one is anodic reaction. Now this is cathodic reaction it is a electron acceptance, accepting oxygen acceptance accepting two electron and forming O double minus. So, this is cathodic ok.

So, now, this particular part is anode and since cathodic reaction happens on this plane which is cathode and this is metal part, this is oxygen gas part. Now this metal can migrate and reach to this surface and then combine with O minus and form M O. So, that time this particular interface will grow other way around if this oxygen ion that can move. So, this is metal ion moving, this is oxygen ion moving. So, it can come to this surface and here metal ion and oxygen ion can combine and form metal oxide.

So that time this particular section will grow ok this particular oxide will grow into the metal and in this case oxide will grow into the oxygen gas layer. So, now, you see that there are four components here and for electrochemical reactions at the corrosion reactions we have must have four components one is cathode, anode, electrolyte and conductor. Now, if we see that this ions are moving through this metal oxide so, this is acting as electrolyte.

Now if this metal ion is forming. So, this is, but this reaction is taking place at two electron. So, that can go through that metal oxide and can reach to this section and then it combines with this oxygen atom forms oxygen to minus.

So; that means, it is also acting like acting as conductor so; that means, all four components are there this is 1, this is 2, this is 3, this is 4 so; that means, it is an electrochemical reaction and corrosion is nothing, but an electrochemical reaction. So, this is also degradation of metal, but it happens without the presence of hydro H_2O this is not taking place in aqueous medium.

Now this fretting action can happen when there are three criterias of course, one is the interfaces, this is criteria for fretting, interfaces must be under load so; that means, if we take this two surfaces. So this is two surfaces they are under load so, they are tightly fitted. Second is there should be a vibration there should be a vibration and that vibration could be very small few microns.

Now third part is when this vibration and load both are taking place that both the actions; that means, load as and vibration should create a situation of deformation or wear leads to lead to deformation or wear ok. So, that must be these three condition must be made. And then of course, you have these all three condition all three conditions are necessary for fretting. Now along with that if you add corrosion action then definitely we call it as a fretting corrosion.

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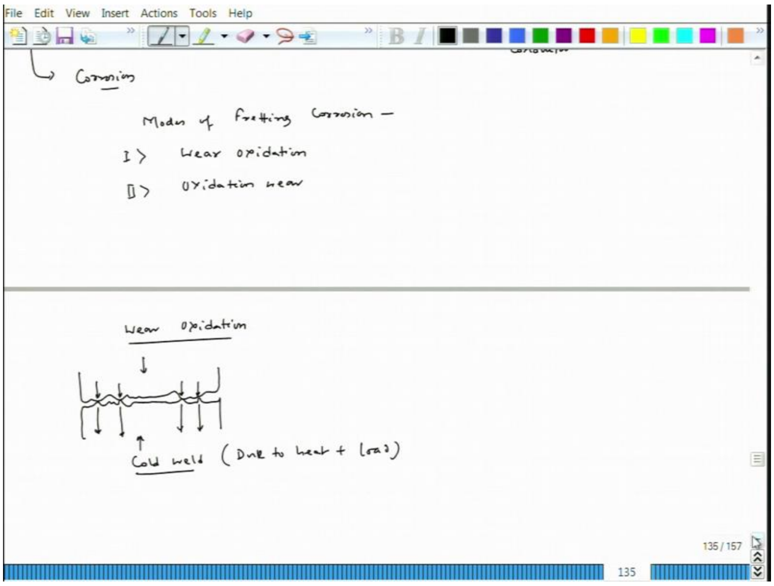

Now there are two modes of fretting attack one is if we try to see the modes fretting corrosion, one is wear oxidation and second is oxidation wear. Now if we try to look at two mechanism, this is wear oxidation if we try to look at two meeting surfaces that meeting surfaces we cannot make it there will be definitely some wavy nature on that meeting surfaces aspirations would be there.

Now if the surface is like this; this is one surface the other surface could be like this. So, these are the two surfaces and if you carefully notice that this is one point, this is another point, this is one point, this is one point where those metal surfaces are actually meeting at the point of reaches ok. Now since it is under load it is under load and there could be a small degree of friction that initial friction.

So, that will lead to a some sort of heat and that load as well as heat that can cold weld this section. So, this is sections are basically cold welded. Due to heat plus load and this heat is coming due to fretting action ok. Now once they are welded this is cold weld because the temperature may not go beyond that 0.5 Tm. Tm is the melting point ok. So, now, that time we have this welded portion.

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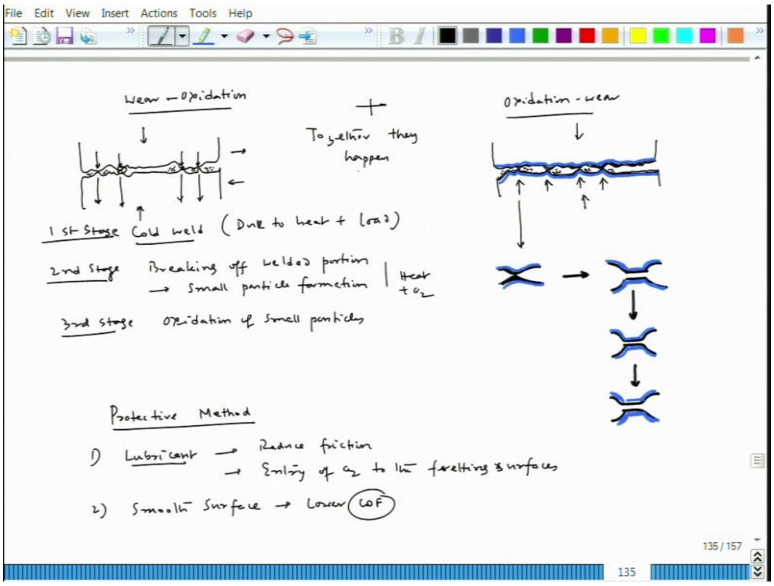

If the second stage this is the 1st stage let us say 1st stage and the 2nd stage if fretting action again occurs that cold welded portion may get chipped off ok. So, that particular action leads to a small debri formation. So, if this portion this portion actually breaks off. So, we have this moves little forward and this move little backward. So, this portion will break off and that break off will lead to small small particle formation. So, this is breaking off welded portion and that leads to small small particle formation.

Since this is exposed to atmosphere of course, there will be oxygen and the small particles when they are forming because of the fretting action there will be a lot of heat. So, this heat plus oxygen they will oxidize, the 3rd stage oxidation of small particle ok because of heat and oxygen and that is what at the feet at the foot of it there will be small small tiny oxide particles ok. So, here we have debris oxide debri and that debri is coming due to the breaking of that welded portion and particle formation and oxidation of small particles.

Now this particular thing continues so that means, this will continue. So, again the next cycle another ridge portion will have will be will get cold welded and the second fretting action they will get chipped off, small particle formation, oxidation of the small particles forming oxide debri.

So, like that way it keeps on removing the material and this is typically first oxidation first cold welding is taking place and then wear action is coming into picture. So, this wear action is coming into become then oxidation. So, that is what it is called wear oxidation ok, because wear action is coming first and then oxidation of those worn out particles this is about wear oxidation.

So there is one more which is oxidation wear, where oxidation happens first now if it is same thing the interface is rough ok those are micro roughness very small protrusions are possible on the surface now those protrusion are meeting. So, like that way this is the another interface. Now this is under load, now this happens this oxidation wear happens in case of passivating metal, now if we try to see the if we make it little thicker that interface.

So, this is a thick one. Now we have oxide layer. So, that oxide layer is forming just below that interfacing layer. So, this layer is forming because it is a highly passivating metal. So, this blue one is that oxide layer fine. Now, if the fretting action happens this region. So, where these are in contact they will chip off that oxide will chip off. So, now, if I try to look at this part and zoom it is actually like this and initially it was like this so, this is contact point.

Now this is the contact point and oxide layer is there, next section we have this flat portion is forming an oxide layer will stay here center part will not have any oxide layer because oxide layer got chipped off because of the fretting action. Now since this material is highly passivating nature and there is oxygen. So, it can react and that heat is there because it is a severe wear action.

So, fretting action which leads to little lot of heat and that oxygen can react and form passive layer or the oxide layer on top of it. And the second time again this if they are tightly fitted let us say if this is tightly fitted now tightly fitted now everywhere we have oxide layer after getting chipped off.

Now second time also this will again chip off like this is chip off like this and then again this oxide layer would form between two fretting action ok. So, like that way oxide particle will also form in the root of it, in this portion a lot of oxide debri will accumulate and this oxide debri is not the because of the oxidation of particles metal particles, it is basically the removal of oxide layer during the fretting action and then again the oxide layer re-forms.

So, that way the oxidation happens first and then the wear of that oxide layer happens. So, that is what it is called oxidation wear. Now its very difficult to isolate these two mechanism mostly both the mechanism happens together. So, together they happen ok, because its lot of heat due to fretting and there is oxygen. So, that is what that both the mechanism could be possible and cold welding is also possible. So, that is what these two mechanisms are is very difficult to isolate from each other. So, we better its basically combination of both the processes lead to a fretting corrosion ok.

Now if we try to find out ways to protective roots methods. Now if you see that both the cases both the mechanism wear oxidation or oxidation wear we have friction in friction coming into play. Now that is what if we use lubricant so then definitely the lubricant can reduce friction and that will definitely reduce fretting corrosion fretting damage.

Now it also gives you another advantage since you could see that after wear in case of wear oxidation, oxidation of tiny metal particles happen and whereas happens and whereas, in oxidation wear first oxide layer gets chipped off and then further oxidation of the metal surface exposed metal surface happens. So that way the fretting action continues. So, in this case also it reduces entry of oxygen to the fretting surfaces ok.

Now second is smooth surfaces smooth surface means definitely those ridges will not get number of ridges will be less and they will also get a much lesser load to get welded or to get that metal. If the oxide layer is covering that metal surface the oxide surface would not get a chance to get chipped off because the smooth surface will have less number aspirations. So now this smooth surface also avoid also leads to a lower coefficient of friction, so that is also possible. So, friction force will be less. So, the smooth surface can also prevent fretting.

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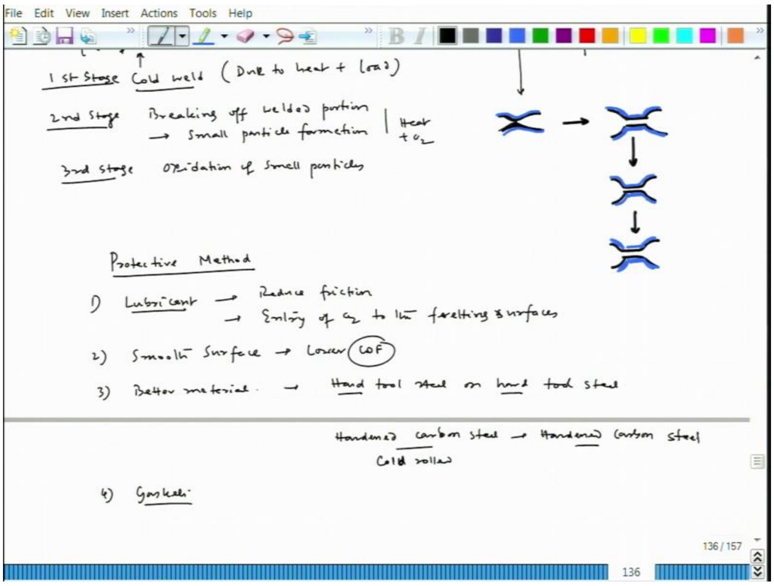

Now third is better material and here it is not about one material both the materials are to be considered because for example, in case of fish plates we have rail material as well as the fish plate itself. So, between that fish plate and the rail we have fretting surface, now better material we have to have a combination of those materials.

For example, if we try to see let us say one can use hard stool steel versus on hard tool steel and now you see this hard word is there so; that means, the harder the surface higher will be the wear resistance that is a kind of thumb rule, but its not always true, but at this moment if we only see that hard surface that harder the surface better would be the wear resistance which will be the fretting resistance, but that is not all the time true, but this is in general I am saying.

Now this is one better material means let us say hardened carbon steel and hardened carbon steel. Now when we talk about hardened carbon steel hardening can be possible if we do cold roll, cold rolling cold rolled steel or cold rolls cold rolling is one of the process to increase the hardness of a carbon steel. So, that is one sometimes it can be gaskets can be used rubber gaskets. So, what it helps what it does? It actually prevents oxygen to enter into the fretting surfaces. So, that is what oxidation is avoided.

So these are the couple of routes which way one can think of reducing fretting damage. So, let me stop here. So, we will continue our discussion on stress corrosion cracking from the next class onwards. So, on the fretting on the erosion corrosion we have talked about general erosion corrosion, then we talked about cavitation and then finally, a fretting corrosion. So, erosion is to some extent complete, let us move to move on to another topic which is stress corrosion from the next class onwards till then.

Thank you.