Indian Institute of Technology Kanpur

Present

NPTEL

NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

Environmental Degradation of Materials

Lecture 31

Broad Subject: Cavitation, Fretting corrosion, Corrosion cracking

Prof. Kallol Mondal

Dept. of Materials Science and Engineering

So we see that whenever pressure drops during operation at some portion of a moving object which is handling high pressure, high velocity fluid there bubble forms and when the system during that motion when it goes to a high pressure zone the bubble collapse, and during collapse there is a huge shock wave which is being exerted on the material surface and that shock wave can deform the material locally or it can erode away some portion of the passive film or the film that has formed during because of the exposure of the metal to the solution. Now we have to see that some example, for example, the impeller corrosion due to cavitation when in case of end suction centrifugal pump. So in the case of instructions end suction centrifugal pump we have seen that it looks like this and you have a section which is called eye and in the eye part and if you draw the – and this is basically the section, this is the discharge part and this is the eye part eye part and now in that eye part you have impellers, impeller blade, and it's rotating like this and water is moving this way and the water is getting sucked through this eye zone. Now you have three zones then. If you draw this way. So this is my eye part. This is my eye and this is my discharge. So in the eye section and this is suction zone, this is eye. Now if you see the pressure temperature relation, pressure zone relation let's say this is the pressure and this is different zones. Okay. So during that period if you see the pressure at the suction zone let's say this is pressure at the suction zone, this zone the pressure is very low and the pressure at the eye zone is still further low. E. And this is the, let us say this is the pressure at the suction zone. This is the pressure at the eye zone and then the discharge zone the pressure increases so the pressure goes to this place. This is discharge. So the pressure distribution is like this. Pressure distribution is like this. Now during that period and we have seen that these section we have low pressure and this section we have bubble formation. Now if the pressure line for the formation of vapor if you compare the phase diagram, temperature pressure for water. It's basically like this. This is liquid. This is vapor. This is solid, and this is one atmosphere and this is 100 degree Celsius. This is 0 degree Celsius, and this is 0.01 degree Celsius which is the triple point and corresponding pressure is 0.006 atmosphere.

Now during that period let us say the operational temperature is this. This is T operational. T operational and that time at the high pressure zone the pressure is this and the low pressure zone the pressure is this. So that high pressure zone there will be liquid and low pressure zone there will be solid during that operation. This is just a somatic. So let's say this point, let us say the high pressure – low pressure zone, the pressure drops here, high pressure, pressure is there. So if it comes to low pressure zone bubble forms and the bubble if it goes to high pressure zone the bubble will collapse.

Now if this is the pressure that is needed let's say this is the pressure which is needed for bubble to form at equilibrium at that operational temperature and if that pressure line is this so above that it would be liquid and below it would be vapor. Now this is my pressure, let's say this pressure is V, this is PT. So this is PT. If the pressure which is needed at that temperature for evaporation that is basically this one, and if that pressure is below the pressure what the water is experiencing during this suction operation and centrifugal operation if it is below that then we should not have any cavitation problem because all the time the pressure which is needed for vapor formation is higher than basically the pressure which is needed for vapor formation at that operational temperature is lower than the pressure what the water is experiencing during this suction and centrifugal process and if the pressure is lower than what is there in the atmosphere – in the system and then there should not be any problem of cavitation because the vapor will not form. Now if the situation is like this, if the PT line is this one that case I will have some problem because during that process this is one junction, this is another junction that means from the suction zone if you start the water is starting there the pressure is this. As it goes to the eye zone the pressure is down, pressure is less gradually it is – pressure is decreasing and once it reaches to eye zone and then once is it goes to the discharge zone pressure is gradually increasing and during that process the pressure at this point is equal to the equilibrium pressure which is needed for evaporation at that operational temperature.

So this point evaporation or the boiling would start. Boiling or vaporization start. So that means at this zone the boils or the vapor or the droplet or the cavitation would start on the impeller wall. Now as you keep going down in the pressure line there will be more and more boiling and more and more vapor formation or bubble formation. Now during this increased cycle once it reaches to this level, this is basically the boiling start level this point. Once it reaches to this level so there I have the reverse operation, because there the pressure is – the water pressure is going above the equilibrium pressure. At this point it is equal. So above that once it goes to this level then the boils or the bubble will try to collapse because this had this position equilibrium condition is a liquid would be stable, vapor will be unstable and the vapor would try to go to the liquid phase. Now there we have collapse. The collapse would start from here and gradually as we go up in the pressure cycle there will be more and more collapse on the walls of the impeller wall, impeller blade wall and there would be shock wave creation due to the water column is falling suddenly onto the surface of the metal and the cavitation damage would start. So that means here cavitation starts that means bubble starts forming because the pressure is going down and it is less than the equilibrium pressure what is needed at that temperature to form bubble and the boiling would start and the boiling would keep going on and finally when it reaches to this place the reverse cycle would start. The boiling would – all the bubbles would try to collapse and when it goes to this level in equilibrium there should not be any boil or it should not be any vapor so all the bubbles would try to collapse and the shock wave generation and cavitation damage. This is basically the actual thing that is happening on the impeller metal surface and that leads to cavitation damage on the impeller metal surface. So this is one classical example how the cavitation damage happens and the pressure-temperature relation and that relates to the situation what is being experienced by impeller in case of end suction centrifugal pump.

So this is about cavitation damage. Now before we end cavitation damage we need to know what are the protection mechanism for the cavitation damage the protection mechanisms are followings; this is control of cavitation. Somehow we need to reduce pressure differences, and also we need to make sure that the pressure what is being experienced by the water in the system, in the operation should be above the pressure level that is needed for evaporation. So we can that time the boiling phenomena would not be observed. Then second case is smooth finish of the surface. Why? Because if you have on the surface let us say this is my surface there are some scratches, these are some scratches. Those scratches are primary position for bubble nucleation. So if you have a scratch there will be bubble formation. There would be bubble formation. There will be bubble formation and wherever you don't have any scratch the bubble formation tendency would be less. So if you can make the surface very smooth because why bubble forms because those have basically – basically acts as nucleating site. That means a smooth surface when you should prevent bubble formation or would minimize bubble formation and then we can have coating. Very good coatings where we can have water resilient coating and we can also make the coating very very strong so that the cavitation pressure what is being exerted on the coating and that coating can withstand that much of pressure. We can also go for cathodic protection.

Now during cathodic protection in case of water system sometime we can generate H2 cathodic product, cathodic reaction product and that H2 let us say this is the metal surface that H2 can form a thin gas layer on the metal surface and that gas layer can act as cushion so that the gas surface that is being that is basically there because of this hydrogen gas generation on the metal surface that actually takes care of the shock wave to a great extent. So that way we can protect the metal surface.

So these are the common control mechanism in order to minimize cavitation damage. Now this is about the cavitation damage.

Now we will talk about another corrosion form which is also a part of erosion corrosion. That is fretting corrosion. Fretting corrosion is another example of erosion corrosion and here what happens if you have two metal surface, this is one metal, metal one. This is metal two and those two metal surface are in contact and they are under pressure, under pressure and this two metal may be the same material or could be different material that does not matter but the when these two metal object which are in close contact and when they are under pressure that time if there is a relative movement and that pressure and relative movement if that create slip or deformation that could lead to a sort of corrosion in this zone, the contact zone and that corrosion form would be in the form of pits or grooves. So that forms in this zone due to this slip or deformation when these two metal objects or blocks are in contact and when there are a relative movement and this movement are basically depicting a sort of fretting action and then we have this sort of deformation and this is called the fretting corrosion, and during fretting corrosion and if we see the pits or grooves we will see the corrosion products and mostly they are oxides. Mostly they are oxide and this oxide products are basically a small small particles that are deposited in the pits or groves in this zone, and what is the consequence of or what is the impact of this fretting corrosion now they are under pressure so that's what we want them to be in close contact all the time and since there are grooves formation let's say we have a groove formation here we have a groove formation here. Now this is my groove which is being formed or this is the groove which is being formed on the metal surface and that groove or pit could be a serious – that could lead to a serious damage because they can act as stress raiser and when it forms that time that can experience a lot of extra strain and there could be fatigue damage, fatigue could be possible because this load is always there at the same time you have slip as well as you have a stress raiser in the form of groove or pits. So there would be a fatigue action and due to fatigue there could be a complete crack in the system.

Now so this is and all the – another consequence would be, this is one effect. Second effect would be the system would become loose because as you have this constant wear constant slip and deformation and constant oxide product formation and there would be also wear action so it will become loose because you are not during operation you are not constantly tightening the entire system, the loose as well as there could be problem of tolerances. So there's a lose and the tolerance would go. Now third case there could be seizing action because of this phenomena loosening or loosening effect the share could be seizing in the system. Now where this can happen and another thing is because this oxide particles are forming and which is making it loose and that's what fretting corrosion can be also termed as friction oxidation. Friction oxidation or oxidation wear oxidation. So these are different names of fretting corrosion and these are the consequence. Now where this could happen? This could happen whenever we have some sort of metallic - two metallic surfaces which are under pressure and there is a relative movement and also this relative movement should be very small and if it is a continuous movement the problem of fretting would not be that severe. For example in case of railway components let's say this is one rail and this is another rail. This is the end part of the rail and you have tie plates. Two tie plates, basically they are bolted. They are bolted. They are tightened. So now during this expansion contraction of this rail section there would always be a small relative movement in this section and due to this relative movement there could be fretting corrosion. Let us say this is my rail part. Now in this part let us say these are the bolts and this is the tie plate, so this section we have fretting attack this section. We have fretting attack. This section we have fretting attack and that's why this tie plates are time-to-time tightened because of this wear effect on that fretting effect these tie plates become very loose. So time to time these tie plates are to be tightened just to keep these two blocks under pressure all the time. So this is one common example. There could be other parts for example this is tie plates railroad okay. Now this is one example. Second example engine components. Engine components we can have fretting corrosion. Automobile parts. So there we can have fretting corrosion because there we have the fretting action because of the constant vibration. Now we have to understand one of the mechanism of fretting corrosion. There are two broad mechanism and actually both the things simultaneously works -- simultaneously work.

Now let us come to mechanism. Now one mechanism the first mechanism it says that wear oxidation and in this process since we have written wear and then oxidation so first wear would happen due to this fretting action and then due to this wear there are small small particle formation and the locally the temperature is so much those particles will get oxidized and then oxidation would be the second phenomena that can happen in this particular mechanism. So if you see this two surfaces. Let's say these are the two surfaces. Another surfaces like this. This is my two surfaces. So these two sections you see this part, this part, and this part they're at - they are under huge pressure because both the plates are stress plate, pressure is exerted just to make them very tight. Now if these part if you have a very large pressure there could be possibility of cold welding. So if these zones are getting cold welded due to this pressure now what happens and now if there is a relative movement after that, after cold welding so if there is a relative movement so these part would get dislocated. There would be break in these parts. These are basically a fine fins. Those are getting cold welded. So those fin part will be removed and there would be discontinuity in those system, in those sections and during discontinuity during the process of this relative movement there will be small small particles which are being chipped out from this section, from this section and if there is a chipping off then a small part let us say this part is removed and those small small particles will form. So during chipping operation so this part would come to this place. So chipping is done and there will be small small particle formation and these particles initially those were metal particles and because of this relative movement as well as because of this pressure that local temperature goes up, local temperature goes up which will oxidize those metal particles and those oxide particles will be the debris in the groove section, in the groove.

Now this is where oxidation which is basically the cold welding, then relative movement, then dislocation of -- dislocating those joint part, small small metal particles will be chipped off from this sections, and those metal particles will oxidize because the local temperature goes up because of this friction action and this oxidized metal particle would deposit in the groove. This is wear oxidation.

The second mechanism it says oxidation wear. So the second mechanism here oxidation is written first so first the metal surface would get oxidized and due to this friction action and the pressure, application of pressure the oxide layer would be chipped off and the fresh metal surface would be exposed to the medium environment and that time those oxide – those environment exposed fresh metal surface would get oxidized again. So the oxidation is occurring first and the wear is actually wear effect actually removing the oxide layer.

Now here the wear is happening and then due to this fretting effect the oxidation happens in the next stage but here already there is oxide layer. So wear actually, wear effect actually removing that oxide layer and the fresh metal surface is exposed to the environment and that would get oxidized. So here let's say the surface is like this. It's already getting oxidized. This is the metal surface, one metal surface. The another metal surface is like this and always there is oxide layer. So the situation was like this and that is under pressure and due to this and then if we have this relative movement, small movement what would happen this section is getting the friction effect to the highest extent in this particular situation. So there this locally this part this section if you see the other section also would happen like that. So like that it would happen because of this relative movement. The oxide layer is getting removed chipped off. That oxide layer when it is getting chipped off that time those are basically staying in the groove part and now you have the phrase oxide, fresh metal surface which is exposed to the medium or environment and that's what that fresh metal oxides or metal surface would get oxidized further. So if the situation was like this, so this is the fresh surface. So those are getting oxidized again, and now again pressure you apply so they will come into contact again and their relative movement. The oxide surface would get again dislodged, fresh metal is exposed into the environment and then this fresh metal surface would get further oxidized. So that means oxidation is happening and the wear is basically removing the oxide layer at the contact point because of this relative movement and all is the system is under pressure. And this is I have said that this is example of erosion corrosion. In the erosion corrosion we see that the solution that is being handled is basically a liquid medium but our aqueous medium but here there is no aqueous medium it can happen in environment or the gaseous medium. Gaseous medium it can happen. So that is the only difference with fretting corrosion and erosion corrosion but the situation is same. Here also you have the relative movement between the medium and the metal surface and these two mechanism are there to explain the oxidation – explain the fretting corrosion and now there is – and these two mechanism generally work together in order to give fretting corrosion.

Now what are the protection route. Now the protection, if you want to see the protection route or the control route. Control. First case would be if we somehow lubricate this section, okay. This section or this section if we can lubricate well with some oil then the lubrication can reduce the friction effect. So lubrication is one method. Sufficient lubrication can lead to decrease the friction effect. Friction effect would go down. Second case would be quoting, proper coating, to improve the friction effect – to resistance this friction force to by – resistance the friction force. Then we can also go for hardening between these two surfaces contact surfaces so that we can't have better wear resistance. We can also go for gasket. Introduction of gasket which actually absorbs the vibration. So these are the common method where by which we can protect fretting corrosion.

Now we talk about stress corrosion, cracking corrosion, fatigue and hydrogen embrittlement. All three of it – all three are falling under corrosion cracking. So let us talk about corrosion cracking. As the name suggests it basically involves corrosion plus cracking. These two and this cracking can happen due to the application of stress and that stress is tensile in nature. Now there could be two type of stress. One is this. This is tensile. When the object is pulled like this you are pulling it, pulling it apart so it's basically the tensile and there could be one more situation where you have compressive. Compressive. So compressive loading or compressive stress if you divide the load divide by the cross-sectional area over which the load is on. So that time it is compressive stress and this time it's a tensile stress. So we have combination of corrosion plus the cracking due to tensile stress on the component which is exposed to a corrosive and the corrosion action is also going on simultaneously.

So there – it's a combined action of stress plus corrosion that will lead to corrosion cracking and it has three divisions. First division we call it SCC or Stress Corrosion Cracking and there we take the first part first letter so that becomes SCC which is Stress Corrosion Cracking. Here the load or the stress is the load or - basically it involves static tensile stress and now the second case is fatigue, Corrosion Fatigue where you have this is called CF which is basically Corrosion and Fatigue. It involves corrosion plus alternate or the cyclic stress, cyclic component of a tensile, cyclic stresses or alternate stresses and mainly this is coming from the tensile component of in that cyclic load cycle – cyclic stress cycle. So this also involve tensile component where the fatigue for example you have the fatigue action. This is zero loading so if you have a loading like this and if positive one is considered to be the compressive, this is compressive, and the negative one is to be considered as negative stress which is this is stress. So negative component is tensile and that time due to this tensile part we have the corrosion fatigue and component is exposed to corrosive solution. Now this is the corrosion fatigue.

Then we have one more variety of corrosion cracking that is called Hydrogen Induced Cracking or hydrogen IC, HIC and this is related to again tensile stress. It involves tensile stress as well as it involves hydrogen and this hydrogen is the product of the cathodic reaction that happens on the metal surface. There could be hydrogen embrittlement phenomena, hydrogen embrittlement or we call it as HE here the atomic hydrogen can go into the metal and that can introduce embrittlement effect into the metal and due to the tensile stress is always on in the system and that tensile stress can lead to cracking of the metal or alloy object. So that means we have three condition, three parts of corrosion cracking. One is SCC. Another one is Corrosion Fatigue and another one is Hydrogen Induced Cracking.

Now first let us talk about SCC. So SCC or Stress Corrosion Cracking. It's actually a delayed failure of metals and alloys by cracking when exposed to environment in the presence of static tensile stress. If you need to define this is a failure of metals and alloys and the failure form is cracking and when the metals and alloys this metals and alloy expose to corrosive solution or environment, it could be aqueous or even it could be gaseous environment. So when it is exposed to corrosive solution and environment and when this is under static tensile stress. This is basically definition.

Now in this case if you see that the tensile stress should be static and at the same time the stress at which stress corrosion happens that will be always less than the stress for the mechanical failure without the action of corrosive solution. So these stress value if you consider the value of this stress will be always less than the stress required for mechanical failure. This is one condition for stress corrosion cracking. So let's say if the yield stress is the design stress then the stress value where stress corrosion can happen that could be 60% of yield stress. So this is the – let's say the stress bracket SCC that means the stress at which stress corrosion happens in a particular alloy that is around 60% of yield stress. So that means the failure is happening below the stress required for mechanical failure. Now another point is if you see the corrosive solution only the corrosive solution cannot lead to the cracking phenomena or stress corrosion cracking. So only corrosive solution does not lead to SCC. So that means you must have the combination of corrosive solution as well as static tensile stress.

Now the question is what would be the action of this corrosive solution? It can initiate the cracking either it can initiate the cracking or it can act during the propagation. Okay. So that means during initiation the corrosive solution can act or the propagation process of the corrosion crack or the crack that time corrosive solution can act and actually they are all the time there would be a dissolution or the anodic reaction that would lead to initiation of cracking or propagation of cracking or it – so this to process can happen during stress corrosive solution and what would be the action of stress and in this case the stress always try to let's say you have metal surface where I have a crack formation. Now these stress and this crack formation is due to this corrosion effect or the local dissolution and that time the stress is active, the tensile stress that would try to open up this crack. Once you have the opening up of the crack the solution can further getting.

So that means it's a combination action of stress as well as corrosion. So this is the definition part of stress corrosion cracking. If we come to see some of the characteristics of stress corrosion cracking then we would understand better why stress corrosion cracking happens and how to protect materials from stress corrosion cracking.

Now one is tensile stress, the static tensile stress could be the stress which is being applied on the material or it could be built in stress. So it could be the stress could be applied or built in. now applied we understand that if from external source we are applying the loading and there the tensile component is leading to stress corrosion. Now built in stress is nothing. Many of the cases it's basically a residual stress. So the residual stress is very much detrimental if the stress is tensile in nature. Now it could be advantageous or it could be disadvantage. So the advantage definitely when you have compressive component that time it would be always advantageous. For example if you have a sort of fatigue related issue in the material then the compressive stress can avoid or can protect the material from fatigue damage for a longer period because that would act negatively towards the tensile component in the fatigue cycle.

Now disadvantage is definitely this would be disadvantageous if it is tensile. Now if the material it doesn't have any load but during processing for example casting, heat treatment that time it could develop residual stress and that residual stress can act in the presence of corrosive solution and there could be insidious or sudden cracking of the metal object due to stress corrosion cracking.

So that means we need to see that whether the material contains lot of residual stress and if it contains residual stress then we need to go for some sort of handling operation in order to remove that residual stress that for the low-temperature stress reliving operation is done. The stress relieving operation is done in order to avoid residual stress related issue and which act in the presence of corrosive solution in combination of these two can result stress corrosion cracking.

So residual stress as well as the applied stress that is important issue in case of stress corrosion cracking.

Acknowledgment

Ministry of Human Resource & Development

Prof. Phalguni Gupta

Co-orindator, NPTEL IIT Kanpur

Prof. Satyaki Roy

CO Co-ordinator, NPTEL, IIT Kanpur

Camera

Ram Chandra

Dilip Tripathi

Padam Shukla

Manjor Shirvastava

Sanjay Mishra

Editing

Ashish Singh

Badal Pradhan

Tapobrata Das

Shubham Rawat

Shikha Gupta

K.K Mishra

Jai Singh

Sweety Kanaujia

Aradhana Singh

Sweta

Preeti Sachan

Ashutosh Gairola

Dilip Katiyar

Ashutosh Kumar

Light & Sound

Sharwan

Hari Ram

Production Crew

Bhadra Rao

Puneet Kumar Bajpai

Priyanka Singh

Office

Lalty Dutta

Ajay Kanaujia

Shivendra Kumar Tiwari

Saurabh Shukla

Direction

Sanjay Pal

Production Manager

Bharat Lal

an IIT Kanpur Production