Corrosion - Part I

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Lecture – 04
Uniform and Galvanic Corrosion

Hello everyone. Let us start lecture 4. As we have seen from this particular slide, the slide what

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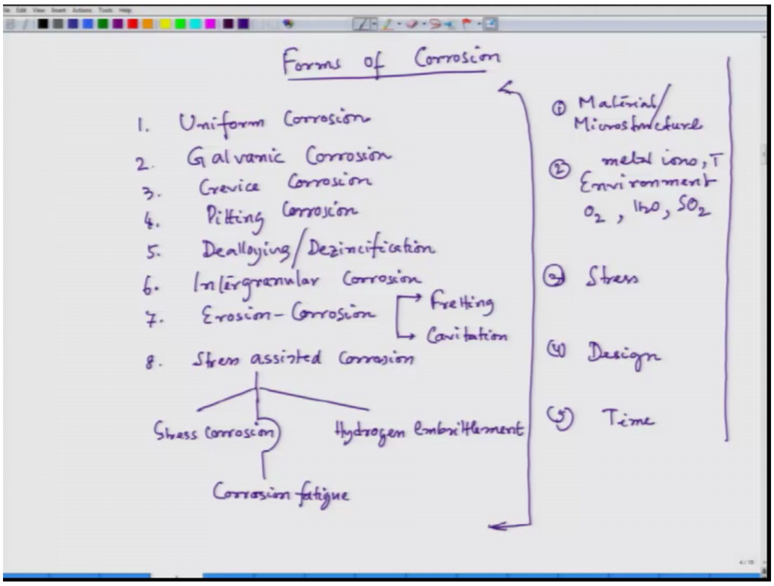

Forms of Corrosion

1. Uniform Corrosion
2. Galvanic Corrosion
3. Crevice Corrosion
4. Pitting Corrosion
5. Dealloying/Dezincification
6. Intergranular Corrosion
7. Erosion-Corrosion → Fretting → Cavitation
8. Stress assisted Corrosion

Stress Corrosion — Corrosion fatigue

Hydrogen Embrittlement

① Material/ Microstructure

② Environment metal ions, T O_2, H_2O, SO_2

③ Stress

④ Design

⑤ Time

We have discussed in our third lecture, forms of corrosion and we have said that it basically based on the appearance of corrosion. So, we will just briefly discuss on these eight forms and at the same time we would also discuss associated factors like composition, metals, materials, microstructure, then environment. Of course, there will be stress, design, design of components, and finally we have time, the time of exposure.

Now, when you talk about uniform corrosion, uniform corrosion

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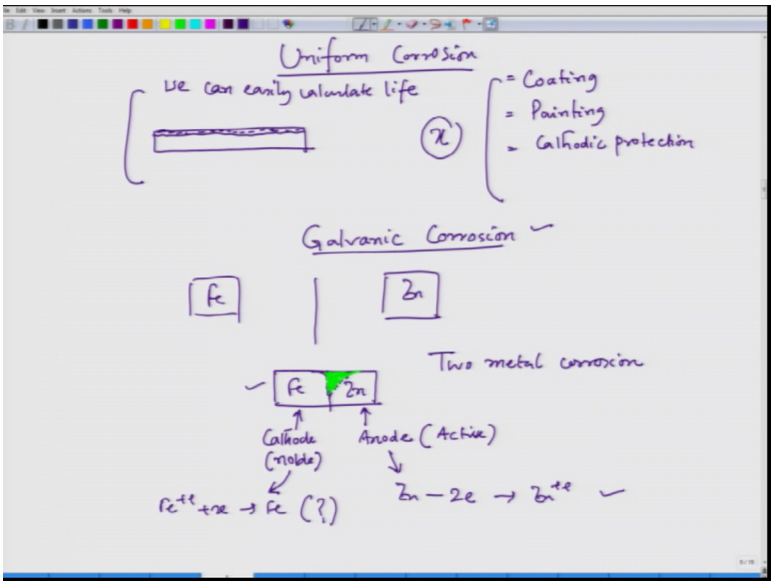

Uniform Corrosion

we can easily calculate life

x

= Coating
= Painting
- Cathodic protection

Galvanic Corrosion

Fe

Zn

Two metal corrosion

Fe Zn

Cathode (noble)

Anode (Active)

$Fe^{++} + 2e \rightarrow Fe$ (?)

$Zn - 2e \rightarrow Zn^{++}$

One example we have already discussed is basically the corrosion what we notice on the steel sheet roof, we call it corrugated roof that roof if we notice that the corrosion is uniform. For example, if this is my section the steel roof. And there if we call it uniform that means, the depth of corrosion is more or less uniform. So, this is my depth of corrosion is basically uniform throughout the cross section.

And this form of corrosion is in the sense good because we will see later that as well as we have noticed that a corrosion cannot be stopped. It can be controlled of course, it can be minimised, but we can never stop it because thermodynamically, corrosion is thermodynamically more probable feasible possibility. That is what we always get metal from metal ores. And then finally, we again return to metal ores due to corrosion. So, when we have this uniform mode of corrosion, as we have mentioned that the see this is good, because we do not have a preferential attack at any position. When we talk about crevice and pitting you would see that, why this preferential attack is not good to the structural integrity.

Now, if we have this, then we know that how long it would perform. Let us say we would like to have we know that the rate of this corrosion is x, if we know that rate of corrosion is x. Now if we want to work this particular structure for 10 years we can calculate what should be the thickness so that I can operate safely and considering this factor x thickness. So, we know that every year I have x amount of material loss and so, I can easily calculate what should be the total loss after 10 years.

And also in this case the protection is also easy because in this case we can simply put paints or a kind of organic coatings, it will work. And in this case, also the material choice would be cheaper for example, mild steel would be much better low carbon steel would be much better compared to the stainless steel, because if we want to protect it for a longer duration. Let us say somebody chooses stainless steel then we are getting into more and deadliest situations, because stainless steel has got a tendency of pitting or localised attack.

Now, also we can also have a kind of protection method called cathodic protection. So, in this uniform mode of corrosion, we have simple protection route, we have the material requirement is not that exotic. We can work with the low grade steel; low grade steel mean I mean to say that mild steel which is a very well commercially available cheaper steel. But if we consider other forms of corrosion, so what we say that protection route coating, then we can have painting, we can have cathodic protection, all those possibilities are there and the main advantage is we can easily calculate life.

Let us come to some of those forms which show, which show localised attack; if I come to galvanized, galvanic corrosion, in case of galvanic corrosion why this galvanic term comes up. Let us say, we have metal 1 and metal 2, and if we individually we dip them dip those particular metal pieces in acid dilute H Cl solution let us say.

Then, both of them will corrode heavily, but once we connect them rather we weld them let us say electrically we connect them. Then interestingly one metal does not corrode much rather corrosion is minimized to a great extent, but the other metal corrodes heavily and these happens when we have a joining between two metal parts and that time one metal is poorer another metal is superior. This poorer and superior term is coming from the point of activity in that particular solution. And when I talk about activity, we talk about electrode potential and that time we one which will corrode heavily in the joined condition, we call it anode or active part another part which will get less corrosion because of this joining we call it cathodic or noble part.

Let us have an example, example is let us say iron and zinc. And when we have iron and zinc, individually if we dip these pieces in dilute H Cl solution, we would see that the corrosion rate somewhat iron corrosion rate sometime it is more than zinc in H Cl dilute H Cl solution. But if we connect them, let us say iron and zinc is connected and then if we dip it, then we will see that the zinc part is corroding more and iron part is corroding less. So, this section this section of zinc is getting corroded. This section is zinc is corroded. So, this happens whenever this happens, we call this galvanic corrosion galvanic corrosion. And since this is due to the connection of or joining of two different metals, we also call it two metal corrosion.

Now, in this case, zinc is corroding that is what this becomes my Anode and, we also call it Active and this one we call it Cathode, we call it Noble. Such example is amply available in every corners of our day to day use. We will show some of those examples later, we will talk about mix potential theory. For the time being, let us understand few issues with this galvanic corrosion. This is very very important mode of corrosion.

Now, if we try to see this situation, this situation is also possible if we leave this particular joining in atmosphere. There also zinc part corrodes more and then the iron. In fact, iron gets protected due to the corrosion of zinc and we call it galvanic protection of iron and that is what the great example of galvanic protection is zinc coating on iron surface. So, zinc sacrifices itself, by corroding itself, by corroding and protects iron. So, that is what we also call it sacrificial protection due to the sacrificial effect of zinc on iron surface.

Now, here interestingly since we have talked about electrochemical reactions, there must be cathodic and anodic reactions. Now, whenever we talk about cathode and anode; that means, on the anode surface, anodic reaction should take place and cathode surface, cathodic reaction would take place. Now, the question is whether cathodic surface we have iron reduction, iron ion reduction. That is a crucial, crucial question. For example, on the surface it is very clear that anodic reaction that means, zinc would release two electron and form zinc plus plus ion.

Now, question is whether here we have iron plus plus plus 2 e, it will form iron. So, now, my question is this is right all the time, this would happen because if zinc has to act as anode, but here do you think that we would have this reaction?

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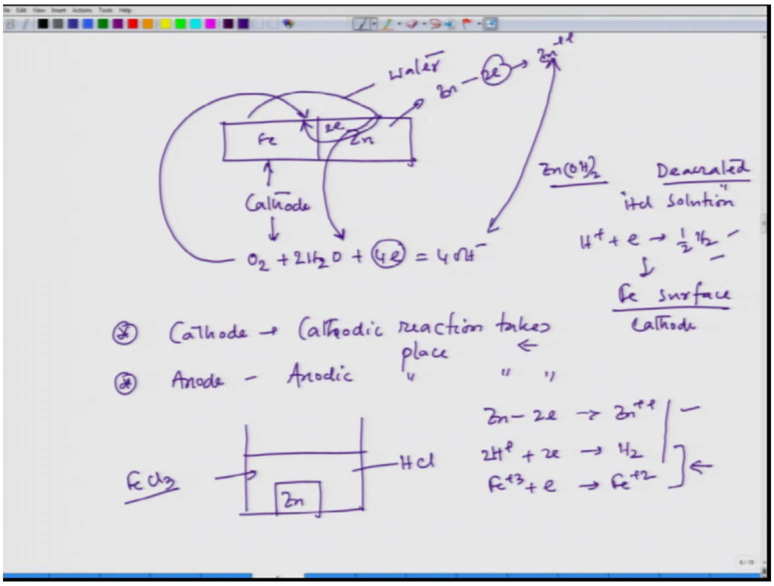

- Cathode → Cathodic reaction takes place
- Anode - Anodic " " "

$Zn - 2e \rightarrow Zn^{+2}$

$2H^+ + 2e \rightarrow H_2$

$Fe^{+3} + e \rightarrow Fe^{+2}$

Now, let us analyze it.

Whenever we have this particular situation, let us say iron and zinc and we have water pool let us say, this is a water pool or water droplet kind of thing. Now, when water droplet falls on this particular joining, that droplet does not contained iron ions. So, where would we get iron ions? So, the cathodic reaction is something different. It acts as cathode, but the cathodic reaction here in the atmosphere, we have it a mildly acidic generally, generally we considered to be neutral. And there the reaction, the cathodic reaction that happens on the iron surface is oxygen plus H 2 O plus 4 e equal to 4 O H minus. Now, zinc corrodes in the form of zinc plus plus and then for this two electron, these two electron will flow and it will come here.

So, in this particular metal object, this reaction happens on this surface and electron will go like this, electron will go like this. And this two will react and form zinc hydroxide. So, that way reaction is taking place. So, the cathode does not mean that that cathodic reaction of that particular metal ion, cathode means where cathodic reaction takes place and the cathodic reaction will be decided by the condition at this interface or the environmental species what we have there.

For example, in acidic medium the cathodic reaction would be H plus. This happens in H Cl solution and interestingly, in the H Cl solution, this reaction can happen if we have Dearated solution. Dearated means, the dissolved oxygen content is very small. So, then we have this reaction. So, that time cathodic reaction is this, but still it happens on the iron surface. So, iron surface acts as cathode. So, remember, cathode indicates cathodic reactions on that particular surface. Let us put for, write it down cathode, cathodic reaction take place and anode of course, anodic reaction.

Now, interesting part is in this case, cathodic reaction could be hydrogen evolution, could be oxygen reduction and could be metal ion reduction also but if some metal ion is already present. Now, classic example let us say, we have in a solution, let us say I have a zinc block and that case if it is containing H Cl, that time the reaction cathodic and anodic reaction would be H 2. These are the two cathodic and anodic reactions. But, if by chance if we have impurity like Fe Cl 3, then this there could be one more anodic reacts cathodic reaction that one more than cathodic reaction is plus 3 plus e equal to Fe plus 2.

Now interestingly, we have to see in a corrosion cell that the total number of electrons released and total number of electrons accepted, they should cancel out because charge cannot stay individually they have to be balanced and on that basis the mix potential theory will be derived or will be established.

Now, if we see that when we do not have Fe Cl 3, then we have one cathodic reaction, one anodic reaction. But once we have Fe Cl 3, we have two anodic cathodic reactions and one anodic reaction; so that case the corrosion rate of zinc would increase because these particular anodic reactions need to take place more to supply more electrons for the requirement of these two cathodic reactions.

So, here I am just giving example that metal ion can also reduce provided that particular solution contains metal ions. For example, this particular system is if it is dipped in H Cl solution where we have little bit of Fe Cl 3 contamination, then this reaction also can take place and of course, zinc dissolution would increase in that couple.

So, this is a galvanic corrosion and in the galvanic corrosion, there are factors. Of course, one factory is, important factor is distance effect.

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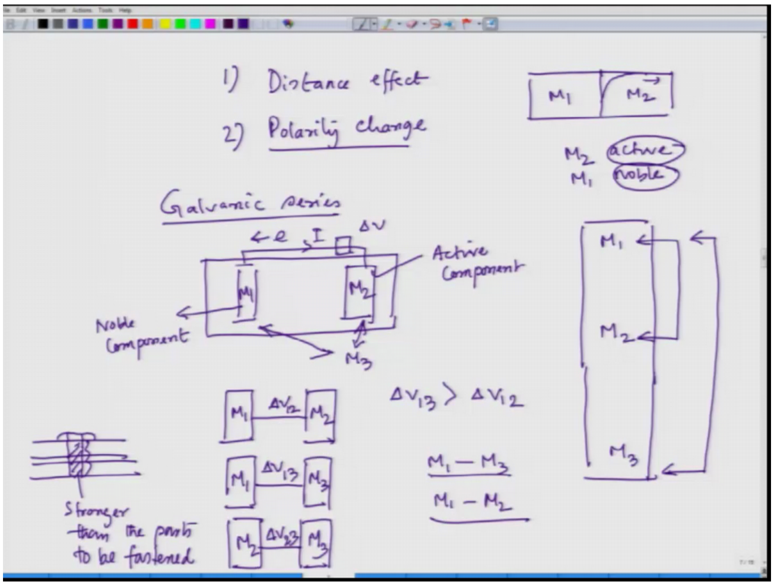

Distance effect, let us say I have this couple and in that couple, if this is metal 2, this is metal 1 and if metal 2 is active and metal 1 is noble. That time, the corrosion of metal 2 would take place preferentially, but the corrosion would be more at the interface rather than away from this a joint interface. Because as we have a more and more distance from this joint phase where the galvanic couple is joined couple that couple is formed, you have more resistance for the electron flow as well as charge flow. That is the reason that is where the corrosion rate reduces as we go away from the joint interface.

Now, in this regard, as we have mentioned that active and noble, this factor would come, this will be pronounced if we have a polarity change. This is another factor. The polarity change is serious. Sometimes, though we design the couple for galvanic protection of a metal, if we do not look at seriously at what happens with the change in condition. Sometimes the metal part which is active and which gives a sacrificial effect to protect the other metal part, if polarity changes, the metal part which we want to protect would corrode more than expected. So, how does it happen? And in order to know that, we have to know another important factor, another important a issue which is called Galvanic series.

Galvanic series is a kind of we will talk more about this galvanic series, we will talk when we talk about electrochemical series. This galvanic series is designed on the basis of the current flow. Now, if we have a metal object M 1, if we have a metal object M 2 and if we connect them and then put up this one in electrolyte, a particular electrolyte let us say a H Cl solution, then we simply notice which way current is flowing in the external circuit. In the external circuit, if current flows this way; that means, this is current flow that means, electron is flowing this way. So then, this particular component becomes active component and this particular component becomes noble components. And that time, this one will be protected and this one will corrode. So that means, in the galvanic series if I try to put them in a kind of sequence, then if I put the noble one at the top and the active one at the bottom like this, I can put them in a series.

Similarly, I have M 2, M 3. Let us say this becomes my M 3 component and M 3 can have a couple between these two or it can have couple between this two. Now, if M 3 lies and then of course, you will have a voltage difference also because whenever we have this there will be voltage difference.

Now, this voltage if it is more that means, they are widely apart in that series and if this voltage del v is less in that couple, they are closely plused. For example, if we have M 1, M 2, then M 1, M 3 and then another couple we can have M 2, M 3. So, we need to see the voltage difference between these two in that particular solution. This voltage is 1 2; this is del v at 1 3, this is del v 2 3.

Now, if we see that del v 1 2 is greater than del v 1 3; sorry let us say del v 1 3 is greater than del v 1 2. Then, this two would be lying close to this M 1. So, the series becomes like this M 1, M 2, M 3. So, now, that time M if I connect these two or if I connect this two, galvanic effect will be more in case of M 1, M 3 rather than M 1, M 2. So, if I have a connection between M 1 and M 3, M 1 would be better protected, because M 3 would corrode more. And if I have this couple M 1 and M 2, the protection mode would be little less than M 1 and M 3. But in both cases M 1 and M M 2 as well as M 3 individually, they will corrode. So, like that so, if I have to design a better protection system for galvanic protection, I would always tried to choose M 1 and M 3 rather than M 1 and M 2.

Now, question is sometimes in order to design a component, we have to choose different metal combinations, that time we have to be careful. So, that time we have to choose those different metals in such a fashion that in that series, they should be closely spaced; means for example, I can have a kind of component design where M 1 and M 2 would be better because that time the galvanic effect is less. For protection of M 1, I should choose go for M 3, but making a better ragged deign for a component that time I should where the corrosion should be less for both the components that time I should go for M 1 and M 2 because. In fact, many times we should we will not be able to make the same that component entire component with the same material like nuts and bolts.

In the nuts and bolts, the primary design criteria is the bolt should be stronger than this nut, sorry the nut should be stronger than the metal parts which are being joined. For example, if I have a metal joined this plate and another plate, this three plates are joined or the fastened I would say fastened by a bolt nuts and bolts, this is a bolt and this is become my this becomes my nut. So, that time this should be this material should be stronger than the parts to be fastened. So, that time we should choose material, so that in that galvanic series they are closely spaced.

Now, once we discuss this. Now we would understand the polarity change.

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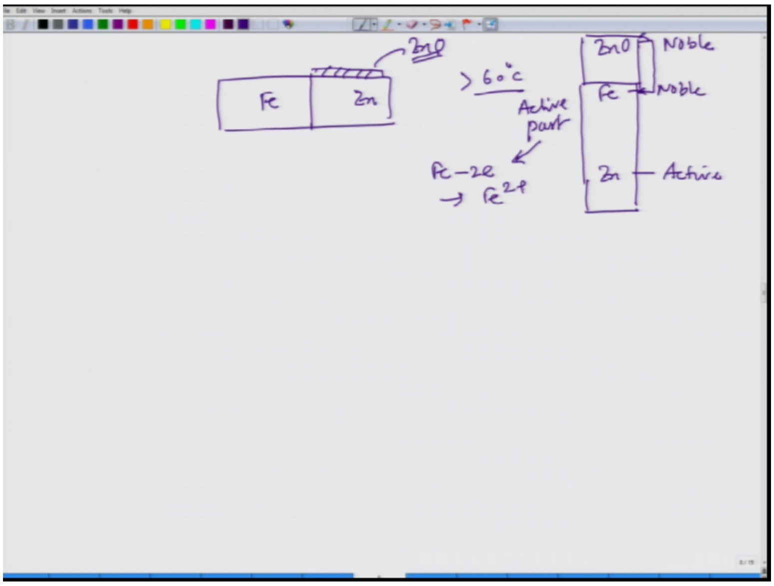

Let us talk about zinc and iron. In case of zinc and iron, if the temperature goes beyond 60 degree Celsius that time on the zinc surface, there could be a formation of zinc oxide and once there is a formation of zinc oxide, it becomes a deadly combination. Why because in the beginning, in the galvanic series in that particular temperature and solution that particular couple is exposed to, iron is on top, zinc is at bottom so; that means, zinc is active and iron is noble. But once zinc oxide forms, zinc oxide has got position which is above iron and ones that zinc oxide forms, zinc oxide becomes noble part and iron becomes active part. So, that time iron would corrode and the zinc surface will be protected because of the presence of zinc oxide. So, in that particular series, zinc oxide stays above iron. So, zinc oxide would act as cathode and iron surface would act as anode and that time iron would leave electron and they will form iron 2 plus ion. So, the corrosion of iron would increase.

So, that is the deadly part of considering materials for galvanic protection, in case of zinc, in case of galvanization. The galvanization is the process where zinc coating is done on the metal surface iron surface. So, we should not operate beyond 60 degree. And that time, zinc will not protect iron rather zinc surface metal oxide the zinc oxide would form that would corrode iron, then my purpose is lost.

So, let us stop here. We will continue our discussion in our next lecture.

Thank you.