Corrosion Failures and Analysis
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Lecture - 13
Factors associated with galvanic corrosion: Case study 3

Welcome to the course Corrosion Failures and Analysis, we have lecture 13 and this will be the concluding lecture on galvanic corrosion. And next class onwards, we will can take up other forms of corrosion. Now, the course is galvanic corrosion.

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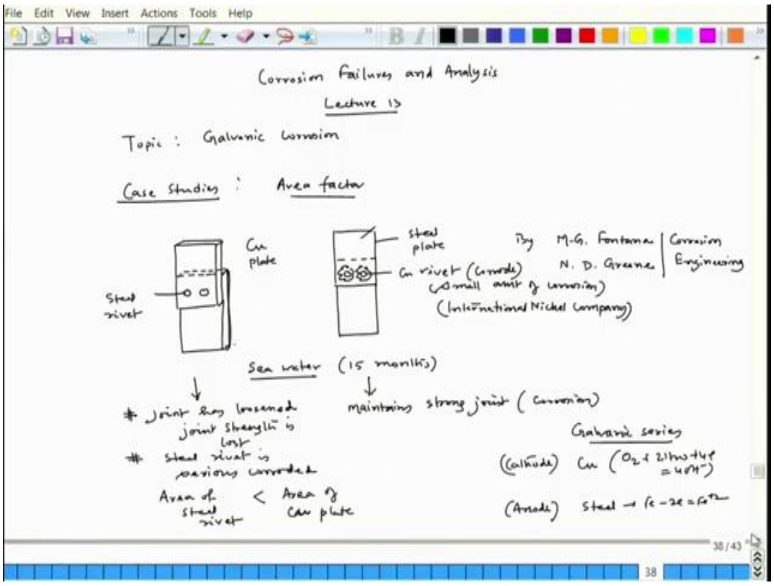

Now, we take up some case studies or examples, some I will take up from different books; on area issues, area factor the example what is given in the book written by Fontana and Greene, which is corrosion engineering, ok.

So, this two plates we have rivets. So, this is two plates which are copper and another situation if I drew only the top view; so this is copper plate and steel rivet. And in this case this is copper rivet and steel plate, both of them as per the book data, both of them is dipped in sea water sea water for 15 months, ok. And this was basically referred to just follow the book by M G Fontana and N D Greene, the book name is corrosion engineering, ok.

So, this is if you see that book, this is basically taken from International Nickel Company, fine. So, this entire thing I am projecting for education purpose. Now, in that case both are dipped in 15 months. Now, after sometime, after 15 months we would see that, the part which is steel plate and copper rivet, that maintains strong joint in spite of corrosion; because as we have seen that from the mixed potential theory that, corrosion of cathode, anode cannot be prevented at all, but corrosion of cathode also cannot be stopped completely.

So here this copper rivet would also corrode, but very small corrosion, small amount of corrosion, fine. But here and the steel of course, and the steel corrosion would be filled around this zone, around this zone, ok. So, other part would also get corroded, but the rust formation would be more around this area.

Now, it will maintain this strong joint; but on the in the case of copper plate and steel rivet, we will see that the joint has loosened up and it has lost strength also lost. And second observation is the steel rivet is seriously corroded; this is typical example of unfavorable area factor, unfavorable area ratio.

And in the sea water as per the galvanic series; copper stays on top of steel and here the oxidation reaction is. So, now, oxidation would be f e minus 2 equal to Fe plus 2 and in case of this is anode and if it is copper; so the oxidation, the cathodic reaction would be, this is cathode it will be O2 plus 2H2O plus 4e equal to 4OH minus.

Now, since in this case area of steel is less than area of copper plate; the unfavorable area factor would unfavor copper area, the unfavorable area factor will be experienced.

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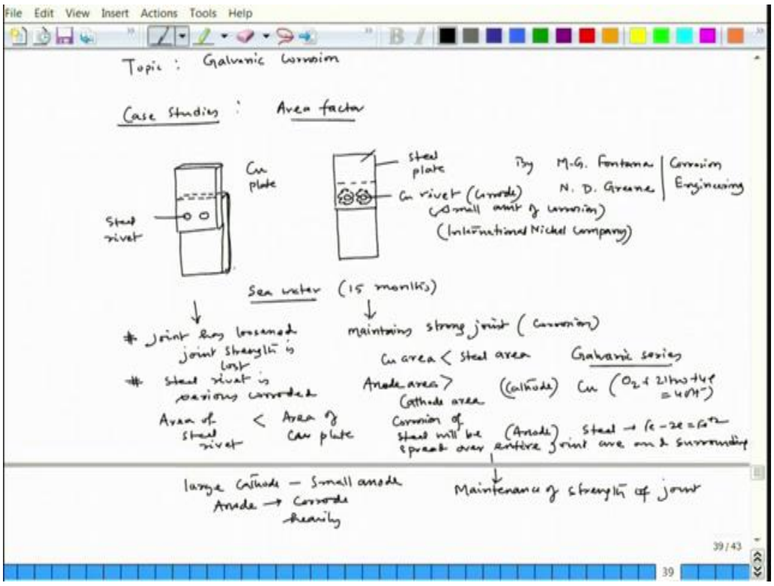

Topic : Galvanic Corrosion

Case Studies : Area factor

By M.G. Fontana | Corrosion Engineering
N. D. Greene

Sea water (15 months)

Joint has loosened
joint strength is lost
Steel rivet is serious corroded
Area of steel rivet < Area of Cu plate

maintains strong joint (corrosion)
Cu area < Steel area
Anode area > Cathode area

Galvanic series
(cathode) Cu ($O_2 + 2H_2O + 4e = 4OH^-$)
(Anode) Steel → $Fe - 2e = Fe^{+2}$

Corrosion of steel will be spread over entire joint area and surrounding
↓
Maintenance of strength of joint

large cathode – Small anode
Anode → Corrode heavily

So, here large cathode and small anode.

So, anode will corrode heavily and finally, the strength will be lost, the joint strength will be lost. But here copper area is less than steel area; so anode area is more than cathode area. So, hence the corrosion of steel will be spreaded over entire joint area and surrounding and that would lead to maintenance of strength of the joint. So, this is an example of, typical example of large cathode and small anode and large anode and small cathode, ok.

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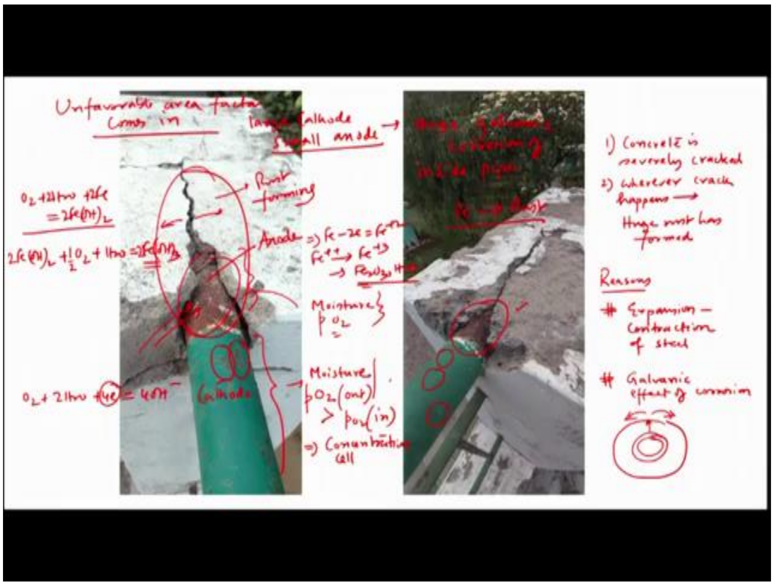

Now another example let me cite from my own experience. So, if I see this typical example. So, this is two pictures I have taken; the house wise I stay where I stay, the rooftop where there are pillars, concrete pillars and inside that pillars we have inserted that they have inserted this, while making this particular structure they inserted those pipelines into the pillars and then they have painted outside ok, outside they have painted.

Now interesting part is, you could see that pillar the top part where there is the pipeline is there; that pipeline around that pipeline, the concrete is heavily broken, ok. And this breaking happens, there are two factors; one is corrosion rust as from by the observation. So, observation it is very clear that, this particular pipeline, ok. So, let me analyze this particular failure. So, what are the observation? Observation is concrete is severely cracked, ok and second is wherever crack happen, huge rust has formed.

So, there are some pillars where the crack has just opened up; for example, in this case the crack has just opened up, but still you could see there is a huge amount of rust, here also huge amount of rust. So, these are two observations, ok. Now, let us see why this crack has formed. So, there are two reasons, one is which could be minor ok; let me tell you which could be minor, so that is expansion and contraction of steel.

Since the environment is heavy environment, day time the temperature can shoot up to 40 degree Celsius and the night time it will bring back to around 25, 30 degree Celsius. So, there could be change in expansion and contraction. So, that would lead to a kind of stress generation in the concrete; but the second part and that might lead to a failure of that particular concrete, but the second part which is leading to a kind of galvanic effect of corrosion.

Now, let us analyze why the galvanic effect? Now, if you see that outside is painted and the paint cannot; is not kind of a impervious in impervious thing; there are pores and it can also have mechanical damage over the years, it does not happen 1 month, 2 months, it will happen after 1 year or so.

So, those cracks or the breaking of paints, there we expose and in fact the entire paint segments are impervious and there we have moisture, there we have moisture as well as oxygen and that would lead to oxygen.

Now, the part which is inside, that would also have moisture, shift in moisture and oxygen inside this part and this part we have also moisture and oxygen. But here if you see, since it is covered the partial pressure of oxygen and here partial pressure of oxygen; so this factor would be, if we say this is out would be greater than p o 2 in. So, this lead to concentration cell. So, this would become cathode and this would become anode.

Now, since this cathode area is the exposed area of the pipe, so it is a huge area. So, the huge number of this reaction would take place, this reaction would take place. So, now, in order to meet, that electron that electron should be provided by the anode area.

So, the anode area is here, where we have Fe minus 2e Fe plus 2 and then Fe plus 2 would again convert to Fe plus 3 ok and it might go to Fe2O3 H2O. So, this is hydrated ferric oxide or you can simply write; so we have shown it previously that, you can have O2 plus H2O plus Fe2, it becomes FeOH whole 2, you can make 2, ok. So, this is the reaction, ok.

$$O_2 + 2H_2O + 4e = 4OH^-$$

$$O_2 + 2H_2O + 2Fe = 2Fe(OH)_2$$

$$2Fe(OH)_2 + 1/2O_2 + H_2O = 2Fe(OH)_3$$

So let us see oxygen 2, oxygen 4 ok fine that the balance is maintained. So, then again FeOH whole 2 plus oxygen plus H2O, it can go to FeOH whole 3 and that time I can make it would be, I can make it 2 here half. So, oxygen is 3. So, we can make 2. So, this 6 2, 2 ok; I think this is balanced, hydrogen is 4 plus 2 6 ok, it is balanced, ok.

So, this phase or this phase that would form; because there are always little bit of oxygen going in ok, though its partial pressure is not 0, ok. So, this phases are forming inside of it, ok. So, this is inside the rust is forming.

Outside also rust is forming, it is not that rust is not forming, that is very clear if you see this area. So, though there are little rust that has form; for example, if you see here it is just opening up, just opening up, ok. But in fact, the entire paint will be impervious, so that would allow; but even if that mechanical failure mechanical breakage of that paint does not happen, still you will have those reactions.

So, now, interestingly, now we know that which one is cathode and which one is anode. Now, the unfavorable area array factor comes in; why? Because if you see the entire pipe, so almost about close to 10 feet or I think 20 feet pipe is outside this concrete and inside may be hardly 1 feet pipe is inside the concrete.

So now inside that 1 feet area 1 feet distance, that much area is actually exposed to the are becoming, that much area is becoming anode; the rest 20 feet area 20 feet length area equivalent area is actually cathode. So, the large cathode and small anode and leading to huge galvanic corrosion of inside pipe, ok. Inside pipe means, the pipe which is inside the concrete structure. Now, why it fails now? Interestingly if we compare the density of this rust and the density of iron, the density of rust is lower than the density of iron.

So the iron is actually going to rust. So, there is the rust phase is forming; since the rust phase has a lower density, it has a higher specific volume.

And since that volume is entrapped into the concrete structure that would lead to a hoop stress on the concrete structure. And because of that hoop stress, if we have a concrete like this let us say this is the pipe, this is the pipe and around that we have concrete; so the hoop stress is basically it is leading to this, this kind of failure would happen, there will be splitting of concrete.

And this splitting of concrete is very much visible. So, there is a tensile stress, because the rust less volume let, the higher specific volume rust is actually pushing the concrete from inside to outside and that is what from top it is actually splitting. So, that is what that failure happens, ok.

So, the now question is, how do we prevent this? That prevention part I will discuss, but I will leave it to you today think about it, what could be the preventive part; because this is not there in any book, this is my photographs, I have taken this photograph and I am explaining this, this is the explanation what is true here. But now you have to suggest, how we would prevent it, ok?

So, the only thing is I can give you the hint; hint is somehow you have to avoid this differential aeration cell or concentration cell. In order to avoid that, because it is exposed to environment; you cannot take oxygen out, you cannot take moisture out, the only way you can do it, somehow you have to take oxygen inside, take moisture inside;

still corrosion would happen, but it will not happen the way it has happened, because of the unfavorable area factor, ok.

So, I am just given you the hint, you take it up and then find out a reason. So, this is open ended reason, I have, so you have to tell me what could be the reason; you can write to me in that in the YouTube video you can write, what could be the reason, ok fine. So, this is one example I just wanted to share with you, this is also typical galvanic corrosion, ok.

So, now let us coming back to our lecture.

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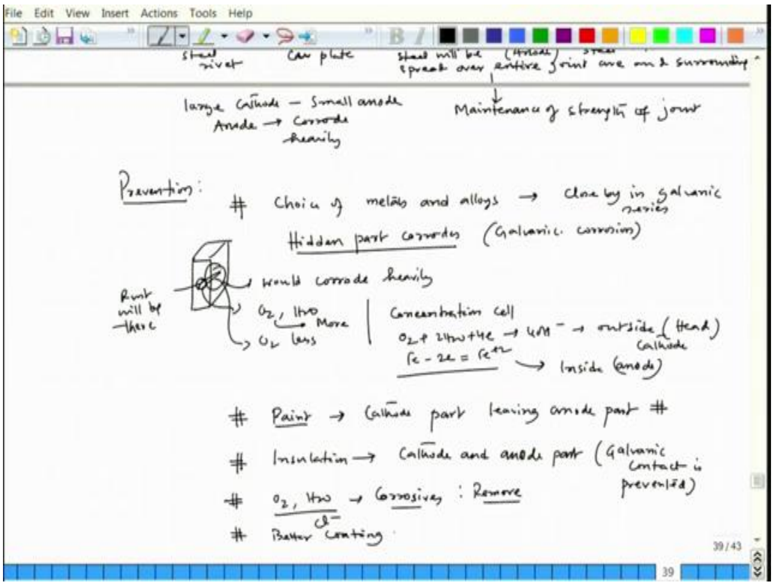

steel rivet Cu plate steel will be spread over entire joint area and surrounding

large cathode – Small anode
Anode → Corrode heavily

Maintenance of strength of joint

Prevention:

\# Choice of metals and alloys → Close by in galvanic series

Hidden part corrodes (Galvanic corrosion)

→ would corrode heavily

→ O_2, H_2O → More

→ O_2 less

Concentration cell

$O_2 + 2H_2O + 4e \rightarrow 4OH^- \rightarrow$ outside (Head) cathode

$Fe - 2e = Fe^{+2} \rightarrow$ Inside (anode)

\# Paint → Cathode part leaving anode part #

\# Insulation → Cathode and anode part (Galvanic contact is prevented)

\# O_2, H_2O, Cl^- → Corrosives : Remove

\# Better Coating

So, I have just given two examples, there are several such examples ok; you can go to book written by Zaki Ahmad, even in the book corrosion engineering by Fontana and Greene, there is a typical problem in Fontana and Greene which is the pipeline this tank corrosion, that tank corrosion also you can look at, ok fine. Once you have understood this, you should be able to understand that also, ok. So, now, let us come to what are the protection mechanisms.

Prevention ok, so first is choice of metals and alloys. When somebody chooses those metals and alloys for a bit a mini structure preparation, they should be close by in galvanic series. So, the galvanic effect will be less; there will be uniform corrosion which is fine, because I can design my, I can give over protection or little bit of extra thickness if it is a uniform correction.

So, no problem in that; but if it is a galvanic corrosion, the part which is hidden would get corroded. This is important aspect, the part which is hidden gets corroded during galvanic corrosion; this is typical example what I have shown that roof concrete corrosion, the part which is inside the concrete was getting corroded, ok.

So now this is important aspect; the hidden part corrodes in case of galvanic corrosion, fine. So, now, if you notice in your household, let us say you have a pin or nail ok; a nail let us say is fitted to wooden stuff and if it is staying there for long time, let us say more than 5, 6 years or more than that and if it is exposed to environment.

Interesting part is you will see that, on top of it rust will be there, rust will be there; but if we try to take it out, you will see it will break open and if it is wooden, if you can take it out very carefully, you will say that the inside part which has gone inside would corrode heavily.

Same logic, outside is getting oxygen H 2 O; inside also it is not possible to avoid oxygen access or moisture access, but the oxygen and moisture would be very low. So, oxygen inside less and here it is more, again concentration cell, ok. So, this concentration is basically cell is basically same as what we had in case of rain water example, ok. So, outside we will have this reaction; inside in oxygen partial pressure is less, this reaction would happen.

Sometimes you might see that those particular wooden stuff where the nail is there, you might see some cracks over there; that cracks is coming again because the same reason, if it is a hard wood that crack formation would be very much evident, because the rust is again having higher specific volume and that would lead to a kind of pushing stress and that particular stress would lead to a crack of the, splitting crack of the of the wooden stuff, ok.

So, this is; so that is what whenever you try to see if there in the galvanic effect, you try to look at the hidden part, because this is hidden, in case of concrete case, this was the pipe was hidden; the hidden part experiences galvanic corrosion, because it is always the collapse and the outside or head of the screw or the pin or the nail is actually cathode and inside is anode, fine.

Now, there could be one is paint and the while painting, one should paint cathode part leaving anode part. So, this is also important, I think it needs explanation, ok. So, we will take it up. So, ok we can also spend little time in your next lecture ok for the on the protection part. So, this part I will discuss in the next lecture, ok.

So, the why we are saying cathode part needs to be painted rather than anode part? If you see that the painting is not possible over the entire area, please paint cathode part; note you can leave the anode part open, ok. So, that will actually prevent corrosion effect.

Then we have insulation; insulation means somehow you insulate cathode and anode part, so that the galvanic contact is prevented, galvanic contact is prevented. So then also you will have lot of advantage. There could be issues like, if you can take out oxygen moisture; so those can be considered as corrosive or chlorine ion which is actually acting against the passivation.

So, this corrosive if you remove, you can prevent corrosion, galvanic corrosion. Like the example what I have narrated that, in case of packing of CRG cold roll grain oriented steel sheet, it is evacuated, the pack is evacuated, so that moisture and oxygen is less, the corrosion effect would be less, ok. Then there are things like better coating, ok.

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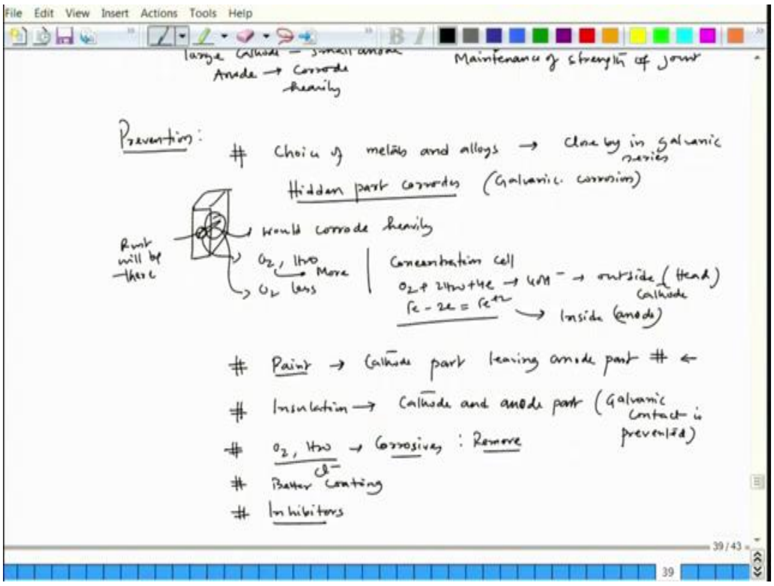

large cathode — small anode
Anode → Corrode heavily

Maintenance of strength of joint

Prevention:

Choice of metals and alloys → Close by in galvanic series

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Paint → Cathode part leaving anode part # ←

Insulation → Cathode and anode part (Galvanic contact is prevented)

O_2, H_2O, Cl^- → Corrosives : Remove

Better Coating

Inhibitors

And there could be examples of inhibitors. So, this coatings and inhibitors will explain later. So, inhibitor is basically inorganic or organic substance, which do not take part in actual corrosion event; but it actually leads to prevent some of the corrosion steps, so that way it protects.

Coating of course, it avoids contact of metal and the corrosives, ok. So, these are the some of the important aspects of preventions. And in our next lecture what I will do; I will try to explain this part that, why the painting of cathode area is important rather than painting of anode area, ok.

So, till then let us stop here; we will continue our discussion in next lecture. Next lecture I will start with some typical examples and then I will move to some other corrosion forms. Let us stop here.

Thank you.