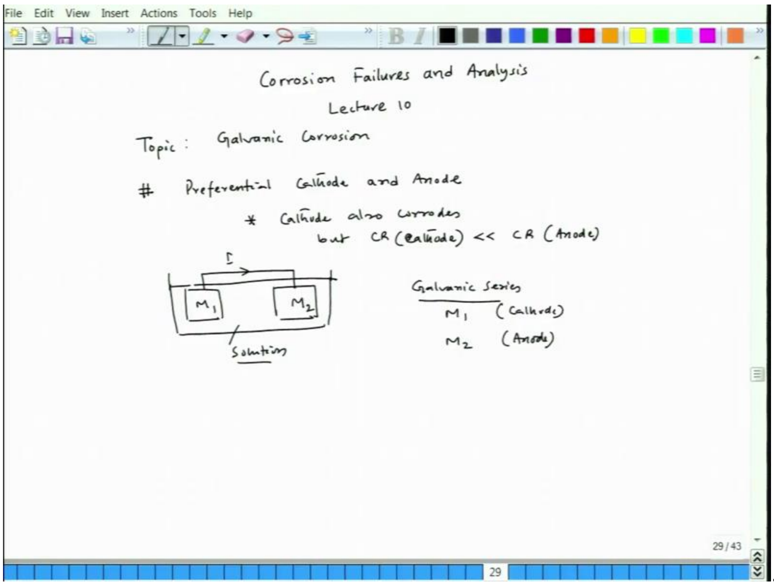
Corrosion Failures and Analysis
Prof. Kallol Mondal
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Lecture - 10
Importance of galvanic series

Welcome back to this course, Corrosion Failures and Analysis. And, today we have lecture 10 and our topic will be galvanic corrosion. And, today we will try to address the Importance of galvanic series and how it helps in designing structures. So, it actually helps you to choose materials so that the galvanic effect will be felt less by the structure and corrosion effect also will be minimized.

(Refer Slide Time: 00:57)



So, course is and lecture 10 Galvanic corrosion and before we move to galvanic series. So, let us put this most important factor in galvanic corrosion is the preferential cathode and anode. So, this is one of the most important factors. And, that is what we could we will see that it is not only two metals on a same metal or alloys galvanic effect can be felt, where some part will be cathode some part would be anode.

And, the anode part would go, would corrode and cathode part would get protected, but at the same time, which is a corollary we have seen with respect to zinc and iron case, that cathode also corrodes. But, corrosion rate of cathode is very very less compared to corrosion rate of anode ok. So, now, coming to galvanic series we could understand that how the galvanic series is made.

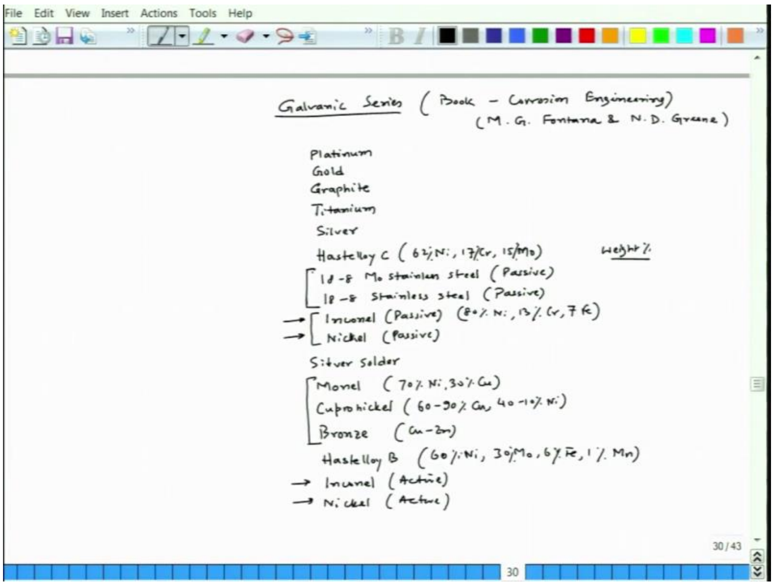
So, is basically comparing polarity of two components or two metals or alloys in a particular solution. And putting the metal, or alloy on top of another just by looking at the current flow in the external circuit or through the metallic conductor. And, if the current flows from metal 1 to metal 2 in that metallic conductor, definitely metal 1 will sit on top of metal 2 in the galvanic series and metal 1 would act as cathode and metal 2 would act as anode.

Now, this is basically just in short this is metal 1 this is metal 2 and they are connected by a conductor and they are dipped in a solution, dipped in solution if current flows from this way to this way is basically the electrical current will flow from metal 1 to metal 2. So, then in that series metal 1 will sit on top of metal 2 and this will be cathode and this will be anode in that particular solution.

So, this solution is specific to that solution also. Now, like that way you can have M1, M2, M3, M4 like that and then you just do that, permutation and those combinations, and then you will get this you can generate this series for that particular solution. So, you change the solution, you can generate another galvanic series.

Now, let us talk about the galvanic series. Now, if I try to look at a galvanic series as mentioned in the book by Mars G Fontana and N D Greene in that book you will find one galvanic series. And, there it interesting that they have clubbed some of the metals and alloys by putting a third bracket. So, we will see the importance of that third bracket.

(Refer Slide Time: 05:40)



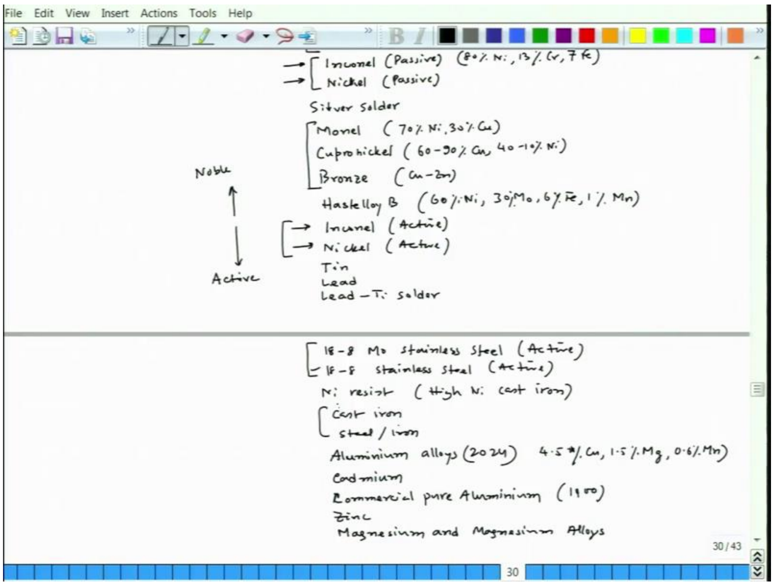
So, this is from the book Corrosion Engineering by M G Fontana and N D Greene. So, in this book you will find this particular series, it starts with Platinum, then Gold, Graphite, Titanium, Silver I will skip some of those alloys. So, then we can say Hastelloy, which is nothing but it is let us say Hastelloy C, which is 62 weight percent nickel, 17 weight percent chromium, and 15 weight percent molybdenum.

Then, we have 18-8 molybdenum steel, which is something is written like passive. Then, 18-8 stainless steel it is written passive. Now, there is one more it is Inconel it is written passive and it is nothing but 80 weight percent nickel, 13 weight percent chromium, and 7 weight percent iron. So, this is this percentage is all in weight percent. So, all are in weight percent. Now, we have nickel passive and interestingly, they have clubbed like this, they have clubbed like this.

In fact, they have clubbed this one, but this one they have kept separate ok. Then silver solder we have couple of nickel alloy monel, which is 70 percent nickel and 30 percent copper. Cupro nickel, which is 60 to 90 percent copper and 40 to 10 percent nickel, then we have bronzes bronze, which is also copper zinc alloy. And, then we have Hastelloy. So, now, they have actually clubbed these three alloys.

Then, they have Hastelloy B series, which is 60 weight percent nickel, 30 molybdenum, 30 weight percent molybdenum, 6 weight percent iron and 1 percent manganese, then we have Inconel and it is mentioned as active. And, then we have nickel which is mentioned as active. We will try to understand why for example, if you see this these two, and if you see these two their compositions are same, but one is active one is one part is passive. And, they are staying wide apart in the galvanic series.

(Refer Slide Time: 11:38)



Then, in fact, they have clubbed these two in one group, then tin, lead, lead tin, solder and in fact, now interesting set of alloys are coming. So, the next set of alloys is 18-8 molybdenum stainless steel and it is mentioned as active. And, similarly 18-8 stainless steel and this is nothing but austenitic stainless steel what you see. Active now they are also in a same group.

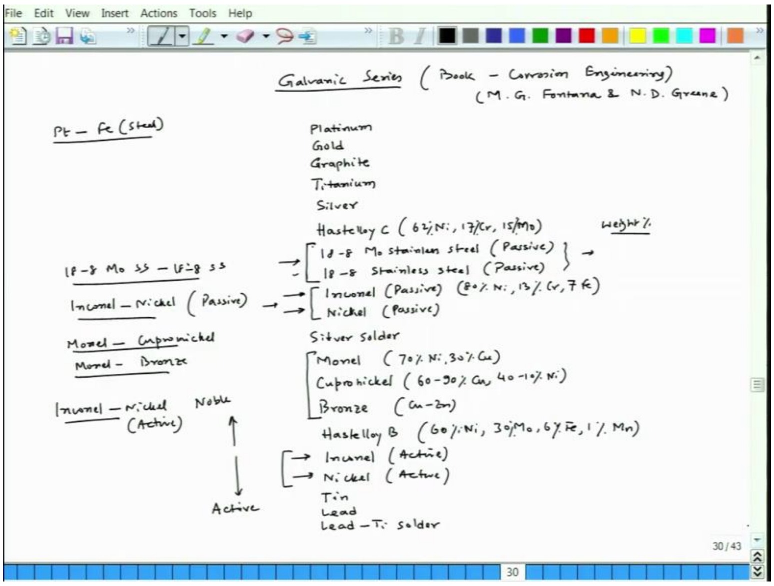
Now, we can have another set after certain few alloys they have mentioned some couple of alloys. For example, N i resist, which is high nickel cast iron, then after few things you can have cast iron as well as steel or iron.

So, they are also clubbed in a same group, then we have aluminium and in fact, you can have aluminium alloys, which is 2000 series let us say 2020 this is the series which is nothing but the copper aluminium alloys, which is which contain 4.5 weight percent copper, 1.5 percent magnesium and 0.6 percent manganese.

Then you have cadmium, commercial pure iron which is 1000 series pure aluminium sorry pure aluminium. And, it is basically 1000 series and then zinc and lastly they have put magnesium and magnesium alloys.

So, now interestingly they have and now another thing, they have mentioned that as you go down, they will become active as you go up they will become noble. Now, first let us understand this clubbed part, see if you see those clubbing.

(Refer Slide Time: 15:06)



This is one club, this is another club. Now, in that club if you have a connection between Inconel and nickel or 18-8 molybdenum stainless steel and 18-8 stainless steel so, this is another or you can have Monel or Cupro nickel or Monel or Bronze.

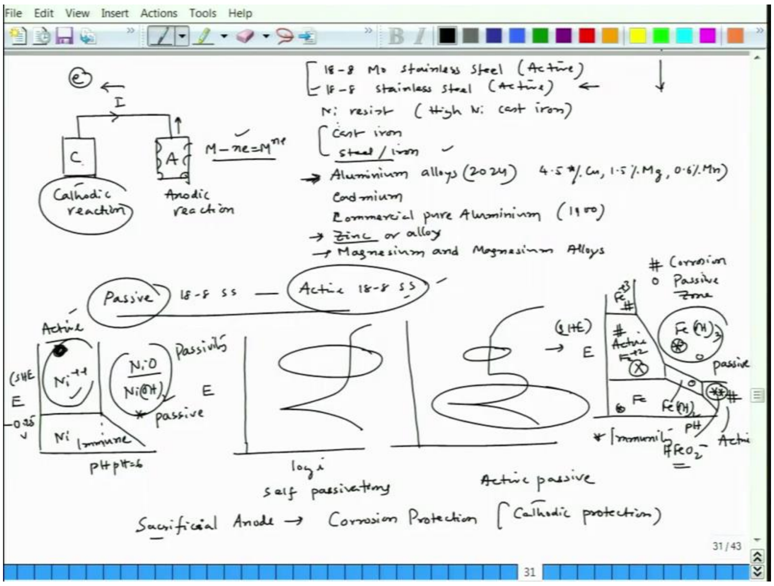
So, these are the couple you can form and here both are passive, but here if you consider inconel, nickel, active. So, if you have those kind of situations those are safe from the point of galvanic effect. Because they are lying so closely in the galvanic series and their character the electrochemical characters are so similar that they would not have any much effect of galvanic corrosion.

So, if you have two components; one is made of 18-8 molybdenum stainless steel, another one is 18-8 stainless steel. You do not face some problem of having preferential cathode and anode. So, galvanic effect can be minimized to a great extent.

Similarly inconel nickel which is passive both are passive, inconel nickel both are active no problem. Similarly, if we consider these two and these two are active still it is fine. Now, coming to so, that is what those clubbing has been done. Now, another part is if you have some something some joining like, platinum and then steel, iron, or steel. Now, if you see in the galvanic series platinum is sitting on top and steel is far below steel is here ok.

So; that means, the galvanic effect would be so high and platinum would act as cathode and steel will act as anode. And, another part is when they are wide apart so; that means, so, the voltage difference between these two electrodes will be so high that a lot of current will be drawn from the cathode part ok.

(Refer Slide Time: 17:58)



So, once that lot of current is drawn an interesting part is if I try to look at, what do I mean by lot of current is drawn, for example, let us say this is cathode and this is anode let us say, fine. Now, once you join and there are some we have cathode this electrochemical reactions are taking place.

And the cathode means, cathodic reaction and anode mean anodic reaction, and whenever we talk about anodic reaction this basically this one is dissolving. Anode is nothing but M minus n e equal to M n plus. So, this ion is forming which dissolves.

Now if it is drawing a huge current so; that means, backward huge electron will be passing from this end to this end. So, and then that huge electron; that means, it will be meeting those cathodic reactions and this electron will be released by this reaction. So; that means, lot of ions will be forming.

So, corrosion would be faster in this particular situation, when if these cathode and anode material are sitting wide apart in this galvanic series. So; that means, if we join platinum and if you join steel or cast iron; the cast iron or steel corrosion would be extremely high because they are wide apart in the galvanic series. And, the current drawn would be very high from the cathode by the anode.

Now, coming to few examples, like another interesting part in the galvanic series. If you have a joining like this one and then let us say we have a situation like passive 18-8 stainless steel and that you join with active 18-8 stainless steel interesting part is this passive and active stainless steel, if you see here this is staying here and here it is staying. So, they are also wide apart. So, this is the gap, this is the gap exist in their position in the galvanic series.

So, that time even though it is a stainless steel, but it is active then it will go for a huge corrosion. Now, what do you mean by active and passive? Now, 18-8 stainless steel is a self passivating metal ok. And, if we try to see their polarization behavior E and log i. It could be this or it could be this depending on solution. Now, this is self passivating and this is active passive ok. Now, when we have such situation.

Now, if the metal is existing in this region, the potential exist in this region, then that will act as active metal and if potential exist around this region, then it will be passive. Similarly, if the potential here exist here then it will be passive. Now, depends on where we have that potential. This also has a direct correlation with the probe diagram. If, we see iron probe diagram it is like this.

So, now, here it is Fe this is Fe plus 2 and this is Fe plus 3 and this is Fe OH whole 3 and this region is Fe OH whole 2 and this is H Fe O 2 minus. So, this is again the corrosion zone, this is immunity zone, this particular section immunity. So, these two sections are corrosion zone, this is also corrosion zone.

Now, if you consider this and this; this is passive zone. Now, one part you can passivate and make it in the use, and the another part you can make it active and then see, if you see this active and passive metal. Now, here this is potential and this is pH. Now, depending on the pH and potential the same iron can be active, same iron can be passive. For example, if the potential and pH stays here, then it will be active and if the potential and pH stays here, it will be passive ok.

So, in this case it will be passive, in this case it will be active. Similarly, once the pH and potential reaches here, in this case it will become again active. So, that way one metal can be passive, same metal can be passive, same metal can be active. Now another example let us take here, which is the nickel case ok.

In case of nickel, if I try to draw nickel probe diagram, I am just drawing schematically, I do not recall the values exact values ok. So, it looks like this. And, if I recall correctly so, this will be around pH 6 pH equal to 6 and this is minus 0.25 volt with respect to definitely standard hydrogen electrode. And, this is also standard hydrogen electrode fine.

Now, in case of nickel, nickel can be passive as well as active. This is nickel plus plus zone, this is nickel zone and this is nickel hydroxide zone fine or it is a nickel oxide zone. So, now, if nickel metal stays here it will be passive. And, if nickel stays here in this zone, in this zone, it will be active.

So, now, that is what if you see the galvanic series, somewhere I have mentioned nickel is active. So, this is active so; that means, it stays here in this zone, in this zone it stays here.

At some point I have written nickel passive if you see here. So, it stays here in this zone fine. So, they are passive means where as oxide layer has formed and that leads to the metal to achieve passivity, because this zone is passivity and this zone is active, this zone is immune fine. Here also this zone is passive, this zone is active, this zone is also active. Why? Because, these complex ions are forming where iron will dissolve in the form of complex ions, wherever in the probe diagram you see ions that is corrosion ok.

So, that way in this particular galvanic series we see same metal in one case it is active, another case it is passive. And, when you compare nickel let us say nickel and nickel passive and nickel active, this is here it is active and nickel passive is staying far above ok.

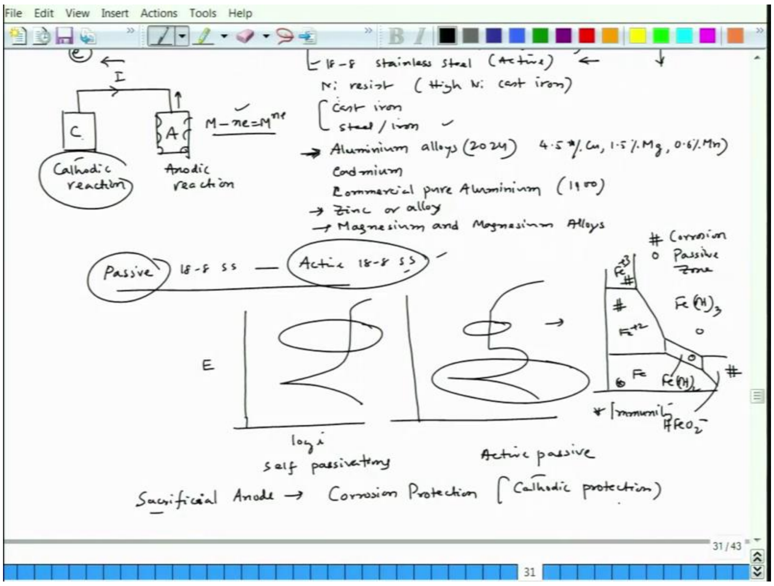
So, if you have nickel passive and nickel active this combination, the nickel active will corrode heavily, because they are staying quite away in that galvanic series. So, that is the importance of that is the implication of active and passive what is written in the bracket against some metals and alloys ok.

Same metal if it is active it will stay further below and if it is passive it will stay further above, and the further above one will act as cathode and it will act as a noble metal ok. So, that is the explanation for this correlation between active and passive thing what is written in the bracket in that galvanic series, what we have shown.

So, this passive means already passive layer has formed ok. And, active means it is not passive. So, it could be possible that some part in that operation is actually giving condition for passivation and some part it is not giving any condition for passivation.

So, then there could be a huge corrosion in the same sort of alloy, but one is passive another one is active and the active component will go for corrosion fine.

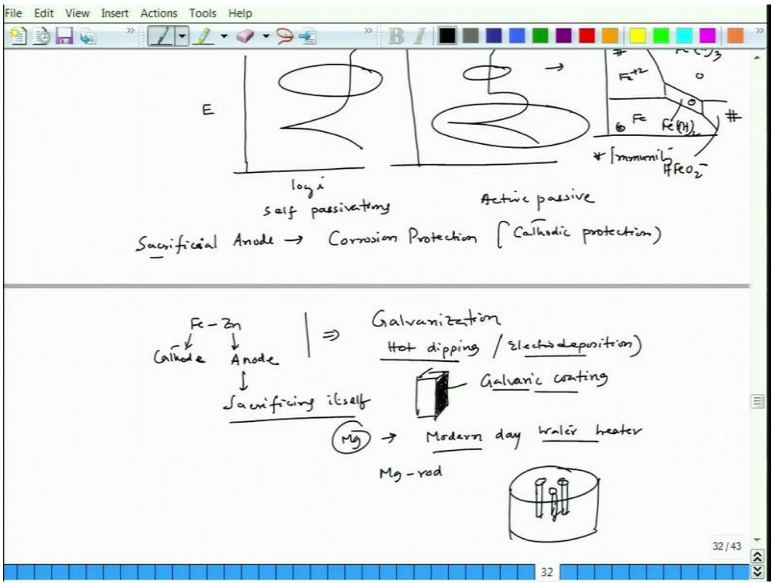
(Refer Slide Time: 28:01)



Now, if we consider three interesting alloys; one is aluminium and zinc or alloy, zinc alloy and these three. So, these three are extremely important, since they are used as sacrificial anode. And, sacrificial anode what it does? It gives corrosion protection and that protection process we call it cathodic protection.

What does it mean? It means that for example, if we consider, if you look at, if we look at position of zinc and steel. So, there in between there are lot of alloys are coming.

(Refer Slide Time: 29:01)



Now, if you have a contact between iron and zinc. Zinc will act as anode, and this will act as cathode, and iron would be protected. And, if you recall the mixed potential theory what we have drawn in the last lecture, last to last lecture, you can see that this exact this condition is holding.

And, there we are keeping one element for one alloy, little we are choosing one element or one alloy, from that galvanic series in such a way that; that metal which will act as anode, should be below the metal which we are going to protect, which will act as cathode. Now, this is one such example and practical example is a galvanization. We do hot dipping and there or electro deposition ok.

So, that time, we can have steel plate or sheet and on top of that, we can have zinc layer and that is nothing but galvanic coating. And, now this galvanic coating would give protection to iron, by self consuming or self sacrificing, what happens the zinc corrodes. And, during that corrosion, because of that corrosion of zinc iron is protected or steel is protected. So, that is what it is called sacrificial anode.

So, the zinc is anode, but it is also sacrificing itself so, that is what it is called sacrificing sacrificial anode. And, similarly it can be possible in case of magnesium. So, nowadays if you see the modern days, modern day geyser water heater. So, there we use magnesium rod, because modern day geyser is actually consisting of steel casing.

So, in the center you will see if you try to see the geyser like this on top you will find three holes and there you have those magnesium rods are dipped in the hot water. So, those magnesium corrodes and it protects the iron surface. So, that is what magnesium is also a very good sacrificial anode.

Similar way aluminum is also used as a sacrificial anode. So, we will talk about cathodic protection in detail and we do some calculation also. And, while we do calculation we will see that, what are the criteria of choosing different sacrificial anodes.

So, till then let us stop here. We will continue with this particular galvanic series for a while and then we will talk about some of the typical examples as well as a factors affecting galvanic corrosion in our next lecture.

Thank you.