Indian Institute of Technology Kanpur

NP-TEL
National Programme
On
Technology Enhanced Learning

<u>Course Title</u>

Environmental Degradation of Materials

Lecture – 35
Broad Subject: Corrosion protection, Change of materials, effect of Design of component

By
Prof. Kallol Mondal

Dept. of Materials Science & Engineering

Today we'll talk about corrosion protection mechanism by material selection and by changing the design of the equipment, we have already talked about the electrochemical ways by which corrosion protection can be employed, you know, in a particular metallic structure or equipment or the object. Now today we will talk about two more ways and we also know that there are five different categories by which corrosion protection can be done, one is design equipment, change of metals or change of materials or the selection of materials, then we have change of environment or changing the potential of metal object or by introduction of coating.

So let us start with change of metal, it also incorporates a material selection, material selection from the perspective of corrosion behavior in a particular environment. Now the material selection or the change of metal, there are four different ways by which we can incorporate a better corrosion resistance in a particular metallic object, one is change of composition, then we can think of changing the microstructure by suitable heat treatment, by suitable heat treatment or mechanical working or combination of both, then we can also employ, for example in a particular material if we have stress which can be in the form of residual stress, that stress we can get rid of by doing low temperature stress relief annealing operation, so then if we remove that part residual stress we can get rid of stress corrosion cracking, so removal of residual stress, residual stress or sometime we can introduce compressive stress on a particular structure on the surface, so if we introduce compressive stress we can get rid of, we can reduce the fatigue corrosion or even sometimes the stress corrosion cracking can be reduced, the fatigue corrosion mainly the issue, so introduction of compressive stress on the surface and this we can do on process, particular process that is called shot peening, shot peening we can introduce.

Now let us check the change of composition so if we see the composition part, composition part one way is we can increase the corrosion resistance either by making it more pure or removing some impurity from the system or by suitable alloying. Now one is either by refining or suitable alloying, now for example if we remove sulfur phosphorus from steel we can reduce the corrosion tendency of that steel or we can improve the corrosion resistance of steel, even we can reduce, this is steel if we reduce these two elements corrosion resistance CR, I am putting corrosion resistance, so corrosion resistance improves even if we get rid of carbon from stainless steel, in case of stainless steel we can increase the corrosion resistance.

Now we can also introduce, we can also have think of alloying, the corrosion resistance can be improved, the alloying addition for example one example is let's say we can have, we have already seen that SB that is antimony or arsenic, small amount of arsenic or antimony addition in brass it improves the corrosion resistance of brass or it can protect the brass from dealloying or dezincification so this sort of alloying, they act as inhibitor, so this is brass resistance improves again we can also think of alloying with chromium, if we have chromium around more than 12% in steel along with nickel, we can improve the corrosion resistance of steel and we can make it stainless, so this is stainless steel or even we can think of adding molybdenum into it, if we add molybdenum we can further improve the stainless property of the steel. Now we can also add carbon stabilizer, carbide stabilizer for example titanium, niobium if we add to stainless steel they are acting as carbon stabilizer, once we add this carbon stabilizer we have already observed that if we add carbon stabilizer in stainless steel they will form carbide preferentially and so the chromium carbide precipitation along the grain boundary in case of austenitic stainless steel would not be possible, so it can prevent sensitization, it can prevent sensitization, sensitization in case of stainless steel, so these are common effects of alloying.

And let us also see one more important effect, that is if we alloy titanium with palladium or titanium, palladium or platinum those are the noble metals, so this is, noble metal for example titanium in case of titanium if we add palladium or platinum we can see that the corrosion resistance of titanium improves actually they act as cathodic sites and the cathodic reaction, the exchange current density for the cathodic reaction increases so it takes it, takes the alloy to the passive layer, so we have already seen this graph which is log I versus potential curve the titanium is like this, now on the titanium is like this, this is my corrosion rate, this is I Corr and this is I0, let's say hydrogen on titanium surface and this is I Corr, I0 of titanium on titanium surface, now if we put platinum so initially the corrosion would happen uniformly and then on the surface of the platinum you have, surface of the titanium you have those platinum enriched zone where you have a higher exchange current density for the same hydrogen evolution reaction so the curve can become like this, so the corrosion rate would become here which is at the passive layer passive zone so the passivity is enhanced, so these alloying titanium with palladium and platinum can improve the corrosion resistance of titanium so the corrosion resistance of titanium increases, so this is another example.

Now let us also check what we can do by changing the microstructure, so the microstructure effect if we see the microstructure effect, so if we see the microstructure one excellent example is desensitizing stainless steel, so desensitizing stainless steel so there by changing the microstructure let’s say in a stainless steel you have the carbide precipitators along the grain boundary, along the grain boundary you have carbide precipitates, now what you can do, you take it to 1000 degree Celsius all the carbides will dissolve and there would be uniform chromium percentage all over the places and so there could, will not be any chromium depleted zone around the grain boundary, around the grain boundary there will not be any depleted zone and then we can employ rapid cooling just to avoid chromium carbide precipitation, so by changing the microstructure we can desensitize the stainless steel or the sensitizing stainless steel can be made into a normal stainless steel where this intergranular corrosion can be avoided, so this is one excellent example of microstructure variation or change of microstructure can lead to improved corrosion resistance here because of this heat treatment we change the microstructure where initially they are worse chromium carbide precipitates, now after taking it 1000 degree Celsius and quenching we avoid this chromium carbide precipitation as well as chromium carbide dissolves in the material so we have a uniform chromium distribution so microstructure is changing so, by because of this change in microstructure we abort intergranular corrosion, intergranular corrosion is avoided, so the change in microstructure, then there is one example for residual stress, one another way, this is second way, third way residual stress of course we have seen that the residual stress can lead to stress corrosion cracking in a material, so if we do low temperature annealing, low temperature annealing we can avoid residual stress induced stress corrosion cracking, so one example is see the point is in case of season cracking of, season cracking of bullets, brass bullets, so season cracking can be avoided, if we can take care of this low temperature annealing, just to removing residual stress.

Now fourth one is compressive stress, of course if we introduce, if we do shot peening we can improve the fatigue property to a great extent, fatigue resistance can be improved and also the fatigue corrosion resistance can also be improved. Now let us see, now these are basically the four different ways by which you can have a better corrosion resistance in a particular material, now this is regarding the change of metals and different ways how we can get, how we can introduce the change in the metal. Now we have to see, now second part is this material selections, what would guide the material selection or metal or alloy selection particularly in a particular, in a corrosive environment, now material selection or metals and alloys, how would you, what are the guiding factor? One is from equilibrium potential of that particular metal or alloy we can choose what sort of metal we should use in a particular application and there is the guideline one is the potential of metal is actually from up to - 0.414 volt, so that case we generally experience corrosion of that metal in neutral as well as acid solution, acid solution without the presence of oxygen, without the presence of oxygen we can experience corrosion.

Second is this is basically the electrochemical equilibrium potential which can tell you what would be the corrosion behavior of that particular material from this if we know the equilibrium potential this is a general guideline so this is one, second is potential from - 0.414 to 0 volt those materials, those metals and alloys they corrode in acid solution without the presence of oxygen or neutral solution with oxygen, with the presence of oxygen we can have corrosion. So then a third one which is the corrosion range is or the potential range is 0 to 0.815 volt where those materials are generally stable in acid and neutral media if oxygen is absent so the corrosion happens here, corrosion, here also corrosion. Now in case of neutral and acid solution if there is no oxygen there will not be any corrosion but you can experience corrosion if oxygen is present, so oxygen is present then with the presence of oxygen we can have corrosion in acid solution or in neutral solution, so neutral solution there would be very less corrosion if the metal potential, equilibrium potential is within this range.

And the lastly you have potential that potential if it varies from 0.815 or more than 0.815 they are generally having very good corrosion resistance, but they can corrode in acid solution, acid solution if oxygen is present, so the corrosion can happen. Now the point is, this is the factor number one equilibrium potential, the factor number two which is passivity of the metal, passivity for example iron, titanium those are the elements with a much lower equilibrium potential if they are in active state but they have the tendency to passivate, so if it is passivating metal then the corrosion resistance would be better, for example if you have a mild steel, mild steel and stainless steel this would be active all the time, but these can go into passive state and corrosion resistance would improve. Now which will guide the passivity, there is one particular ratio or we call it coefficient of passivity, so the coefficient of passivity if we check coefficient of passivity, let's say this is my log I by potential and log I plot and this is basically the corrosion potential E corr and this is basically EA, this is EC, now this factor if we call, E corr – EA divided by EC – E corr, this ratio more would be this ratio, higher would be the tendency for the metal to passivate, so as it this ratio increases passivation tendency improves, so this is one particular way to judge whether the metal has the passivating tendency or not, and we can see that titanium has the maximum passivating tendency compared to aluminum, even aluminum has better compared to chromium like that, like that you can categorize different material or alloy as per their passivating tendency. Then we can also think of formation whether the material form some insoluble product when it is exposed to a particular environment, so ability to form, so this is third effect, third factor which is ability to form insoluble product on the surface, for example lead, pure lead has a very good resistance in dilute H2SO4 solution, because it forms lead sulfate which basically forms insoluble layer on the surface and which can protect the material lead from corrosion in dilute H2SO4, but the point is if this dilute is H2SO4 is made concentrated the corrosion rate of planar lead would be very high because if it is strong H2SO4 this layer would dissolve and then lead would be exposed to the solution, so ability to form insoluble product.

Then we can think of absence or presence of cathodic sites in a particular metal, so forth absence or presence of effective cathode, effective cathode so for example if it is high purity zinc, high purity zinc it will have a very good resistance in HCL solution but once we have iron impurity that iron actually acts as cathodic sites and which increases the, this will act as a couple, galvanic couple and there would be a current flow and for example if you have zinc which is connected to iron so this will be anode and this will be cathode, and so there would be electron flow and current flow would be like this, so depending on the amount of current flow you can have the rate of corrosion of zinc. Now if you add copper the corrosion rate of zinc will further increase, so rather corrosion resistance of zinc in HCL will decrease, and for example one there is one plot let's say if we consider the alloying effect of zinc, alloying effect of zinc if we add copper and iron and this is my corrosion rate and in the absence of copper and iron the corrosion rate would be a constant corrosion rate, but if we add copper so the corrosion rate would be like this in the place when we have copper addition, when we have iron addition corrosion rate would vary like this, so as we increase the amount of alloying with copper and as well as iron we can increase the corrosion rate of zinc, so highly pure zinc would be resistant in HCL, but if we have those elements, cathodic elements we see that the corrosion rate of zinc is increasing in acid solution.

Now in case of iron again, if we have more carbon we have Fe 3C which will again increase the corrosion rate of the metal, but sometimes we can also see there would be no effect of the cathodic impurity, for example if the corrosion is, concentration polarization control, let's say if the corrosion rate is concentration polarization control so this is my E versus log I, where I see that the corrosion is concentration polarization controlled then whether we have a cathodic side, we don't see much change in the corrosion rate, corrosion rate would be same as like this. Now there could be positive effect of those cathodic sites as we have seen in case of alloying titanium positive effect, this is no effect of cathodic, affective cathode or it's basically we can call it ineffective cathode, or in case of titanium we can see that if we add palladium or platinum we see that passivating nature or the passivation would be faster and the material can remain in passive state because of those cathodic, affective cathodes, so here the corrosion rate, here the corrosion rate, in this case the corrosion rate decreases or the corrosion resistance improves.

Then we can also have a few more examples let's say we can have the corrosion protection by alloying, let's say sometimes we add molybdenum in stainless steel in addition to chromium and nickel, that molybdenum improves the surface film adherence to the material as well as it makes the film very infovis and stable, same way it can also the copper addition is done in iron the copper improves the passive film the rust which is forming, for example in case of iron, so forth effect would be, fifth effect would be we can think of improvement of corrosion resistance by alloying, let's say molybdenum, we have already explained this where the explanation is molybdenum is added or the carbide stabilizer is added in the material, also we can add copper in the steel which improves rust, adherence of the rust on the surface of the steel, now the allowing effect can definitely improve the corrosion resistance one particular example is addition of cadmium, alloying of cadmium in zinc, if we add cadmium in zinc then we can see that corrosion resistance of zinc improves here the reason is different, is actually cadmium what it does it increases the polarization of the cathodic reaction, so here you have, without the presence of cadmium this is my polarization, this is anodic, and this is cathodic polarization.

Now in the, this is without presence, without cadmium and if we have cadmium then the cadmium increases the polarization of the cathodic reaction so the corrosion rate is here now, previously it was here so this is with cadmium, so the corrosion resistance has improved from here to this place, so the corrosion rate has reduced. So this is the effect of cadmium in zinc which increases the polarization of cathodic reaction. Same thing happens in case of magnesium where we, in case of NACL see if we see the effect of addition of manganese, if we add manganese in case of magnesium, if we add manganese in magnesium let's say the corrosion rate of magnesium, in case of NACL, solution 3% NACL solution the magnesium corrosion in 3% NACL solution if we see the corrosion rate manganese can improve the corrosion rate, corrosion resistance of magnesium, but if we have iron than this situation would be different, because let's say this is the corrosion rate, this is the corrosion rate and if we have iron the corrosion rate varies like this, this is the percentage of iron, now if we add 1% manganese so the corrosion rate of manganese, this is 1% manganese so it overcomes, this is with iron only and if we add 1% manganese it improves the corrosion resistance of the material, so corrosion rate reduces from this to this if we have 1% manganese it basically covers up the negative effect of iron, what it does? This manganese also increases the hydrogen over voltage or hydrogen polarization increases due to the presence of manganese. And this is overall the effect of different metals and alloys on the corrosion rate and how we can select different materials and how we can improve the corrosion resistance of a particular metal or alloy, this is overall the change of material this is falling under change of material or material selection.

Now let me get into the another ways, another way by which we can control the corrosion or we can prevent the corrosion that is basically the corrosion control by design, corrosion by design, so many cases without changing the material by simply changing the design, mechanical design of the material we can avoid a lot of corrosion related effects and broadly the design consider, design considerations should include five different consideration we need to consider, one is appropriate selection, site selection, then for example if somebody wants to set up a factory he should choose the site properly depending on the product of the factory, then we can think of plant layout, then third factor which we should consider that is selection of material, then we can also think of design of material, design of components, then we can also think of choice of corrosion protection measure. So these are the five factors we should consider while thinking about setting up a plant so that we can get rid of corrosion to a great extent. Now for example the location of plant we should think about direction of winds, wind direction, we can think of wind direction, we can think of weather the location contains lot of saline particle, saline weather the salinity of the environment is more or not salinity, then we can think of proper stacking, so we can think of this many issues while choosing a proper site, then we can also think of plant layout, which way the plant should station whether it is in the wind direction or whether hot sort of cover it should have those are the issues we should consider in case of plant layout. Selection of material of course we have already talked about it, then coming the design of components, so let us discuss some general rules which relates to, which are basically relate to geometrical design and that can also minimize corrosion, so rule number one, there is general rules, which basically related to design. Rule number one is you can think of, one can think of adding increasing the thickness, increasing the thickness of the component and that thickness would be decided by the rate of corrosion into year of function of that particular component, so that would decide what should be the thickness I should choose while designing a particular component, and of course it involves a little extra cost because we are increasing the thickness of the material but that extra cost can be minimized if we have a proper control or proper protection mechanism employed in that particular system or proper monitoring of corrosion, so this is rule number one which is increasing thickness.

Rule number two avoid galvanic contact, wherever if there are possibilities in order to avoid galvanic contact we should go for it, for example one case if we have not, which basically if we have a bolt, bolt system if we have a bolt system which basically, this is the bolt system which is basically a fastener and in that system if we somehow this material of course would be different than the base material which is basically, which are basically getting fastened, so that time somehow we can think of something which prevents that metallic contact between the bolt material and the base material, even here also we can think of some sort of nonmetallic sleeves which can prevent the metallic contact that's what sometime we use teflon tape and here also we can introduce a rubber collar, but we have to take care of the fact that there should not be any crevice generation for example if the rubber collar is little bigger or the washer that can't have a bend like this if it is a little bigger so this is basically the crevice where corrosion can happen, so we can think of avoiding galvanic contact at the same time we should also understand that if we do not put that cover properly from the galvanic contact there could be the effect from other corrosion form, so this is avoid galvanic contact and that it can also be, for example if we have galvanic contact for example this one example, the another process could be if we can paint, if we can cover up on the cathodic area, but cathodic area then the corrosion rate would be different because the larger and there should be a minimum effect from the unfavorable area fact, area issue or area related corrosion, so the cathodic area if we can paint it or cover with some organic material or sometimes if we would like to go for painting let us paint all the places, so that is one way, so the avoiding galvanic contact is one important issue, a rule which can prevent the corrosion rate which can minimize the corrosion rate to a great extent.

Then third rule is crevice sites, avoid a crevice, if there is crevice corrosion possibility of crevice corrosion we should cover up that crevice part with some material in order to avoid that crevice and that way we can definitely get rid of corrosion to a great extent. For example, if we have two material if they are joined like this, they are joined like this, this is a crevice. So in order to avoid the corrosion at this place we can think of covering this or for filling this particular section with some material so that the crevice is out.

Now another example is, for example if we have a gasket let's say this is one particular section, this is one particular section you have a gasket like this rubber gasket down, now this is another material this is rubber gasket, now if in the bottom material there is one wavy pattern and if the gasket is loosely, the gasket is pretty big and if there is improper trimming of the gasket so gasket material would be like this so that case the gasket will be hanging like this, this is my gasket material, so here also we can see crevice so the proper design would be, proper design would be if we can trim it like this without extending it I can trim it like this, so now we avoid the crevice part, now we can also have crevice related issues like this, if you have a tank, metallic tank which is stationed on let's say a concrete base this is also a crevice, here also corrosion can happen so instead of making the tank station base this big we can make the base like this, so and here also we can put some material so filling up this crevice part so we can avoid crevice, so crevice related corrosion can be avoided. Then, so this is crevice corrosion which can be prevented by just changing the design, then the fourth one would be proper drainage, proper drainage sometimes we can have a design like this, let's say we have a tank, we have a tank and where is the, outlet is here this is my tank, this is my tank, now this is my outlet, now even if there is, let's say we would like to empty out this tank for maintenance we just tilt it like this and then take out the water as far as possible but still there could be a little more water which is been left out, which will be left out and it is basically a liquid trap where liquid cans can stay and the corrosion can happen in this zone, so the proper drainage so design, this design instead of this if we can make design like this if we can change the design like this, okay, and this is my outlet now so there would not be any possibility of liquid trap all the liquid can go out if we would like to go for some maintenance now let's say for one month maintenance is needed so that time we can take out all the water like this and we can do the maintenance inside the tank.

Now proper drainage, then one more another example is let's say you have pipeline which is like this, this pipeline and this pipeline through that pipeline water is flowing, now here also you can have a liquid trap here so the liquid can stay here even we empty out this liquid from this tank still there would be a little more liquid which will be left out and this liquid can lead to corrosion at this zone, so the proper design would be you can think of having if we have a system like this we can think of something like that, there will be outlet like this so the water can flow out or mainly we should not have a bent pipe line like this always the pipe line should be like this or like this, so there should not be any, there should be a constant angle so that all the liquid can go out and the liquid cannot stay in the pipe line even if the plant is not working, so then so the design would be this one instead of this we can have a design like this always it would be having sloped downwards so the liquid always can flow out even if it is idle.

Now then we can also have avoid, we can also avoid proper we can avoid this is fifth effect which is basically avoiding sharp corner, sharp corner this can, if we can avoid for example if the pipe line is like this and water is flowing like this, so that time if the water contains lot of dust particle or the slurry is flowing at a high speed so in this zone we can experience erosion corrosion, so this can be avoided the design can be changed, it can be changed like this, okay, so this is one way, so that the impact of the turbulence created at this zone would be minimum and at the same time if we can introduce little extra material at this place, this is my extra material so that anyhow the turbulence, always liquid would be heating in this joint though the zone would be little bigger compared to this so this zone have a little extra material so even if there is a erosion corrosion that erosion corrosion it can withstand for a longer period because you have little extra material here, so the avoiding sharp corner is one way which can prevent corrosion or let say you have in the way of the water flow you have some protruded part that is also bad, liquid is flowing like this in this protruded red part you can have turbulence so here also the corrosion can take place, or if you have a draught or if you have a dent like this let's say this is my dent, this is the dent in the system here also the liquid can come and there would be turbulence here, so again the corrosion would be more here and which is due to erosion corrosion the avoiding sharp corner or avoiding protrusion or avoiding this sort of dent so that can avoid corrosion or it can improve the corrosion resistance of the material, then we can also think of mechanical stresses we somehow if we can take care of the mechanical stresses avoiding this is six, avoiding mechanical stress sometime improve the corrosion resistance or it can linger the corrosion process and for that if a material if we introduce there should not be any sharp corner like this sharp track like this, these are basically acting a stress raiser wherever needed the surface should be very smooth, for example impeller blade if that blade is very smooth then the cavitation damage can be avoided to a great extent, so that case the stress raiser or those set of dents are not good, they can add to the corrosion process that is going on, then we can also think of, we can also think of avoiding paper pocket we can think of vapor pocket, for example if a pipeline design is like this, if then the water is flowing or the solution is flowing and in this section there could be extra gas accumulation so this part we can have more corrosion because here we have the contact, at the contact you can have more corrosion with the gaseous system and this system, so in that case we can put a pump here, vacuum pump, vacuum pump, so pump if we can put a vacuum pump, that vacuum pump will remove this vapor part and the water can flow without having this discontinuity water can flow throughout the system, so there'll be all throughout the water can flow, this is one way to avoid vapor pocket.

Then also we can exclude air, we can think of this is eight excluding air, we can take care of the air, and oxygen is one major substance which lead to corrosion in many systems if we can take care of the air from the system by either parching nitrogen gas through the system so we can take care of the oxygen, or dissolve oxygen content will be reduced to a great extent and we can avoid corrosion.

And then of course we can also introduce, we can also introduce trap, for example water, this is my tank, this is my tank where water is coming through this, this is the inlet so in that Inlet if we can put a trap which take care of the dirt particle so the crevice corrosion that can happen due to dirt or the erosion corrosion that can happen due to dirt or dust particle that can be avoided, so the introduction of trap would be an excellent design criteria which can lead to improvement in corrosion resistance. So this are several, this are different rules which guides the corrosion control by changing the design or improving the design.

So now today we have seen the control of corrosion or corrosion controller corrosion prevention by changing the metal or by changing the design or improving the metal quality by alloying or by defining or by a change, a design modification we can get rid of corrosion to a great extent.

Acknowledgement

Ministry of Human Resource and Development

Prof. Phalguni Gupta
Co-ordinator, NPTEL IIT Kanpur

Prof. Satyaki Roy
Co Co-ordinator, NPTEL IIT Kanpur

Camera

Ram Chandra
Dilip Tripathi
Padam Shukla
Manoj Shrivastava
Sanjay Mishra

Editing

Ashish Singh
Badal Pradhan
Tapobrata Das
Shubham Rawat
Shikha Gupta
Pradeep Kumar
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