Corrosion - Part I
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Lecture – 02
Introduction to Corrosion –II

Welcome back to lecture number 2. We would continue where we have left in our lecture 1. We have started talking about material degradation, and where we have seen that we would look at the chemical or electrochemical route of material degradation where there could be combination of mechanical action, as well as a there could be combination of heat or radiation.

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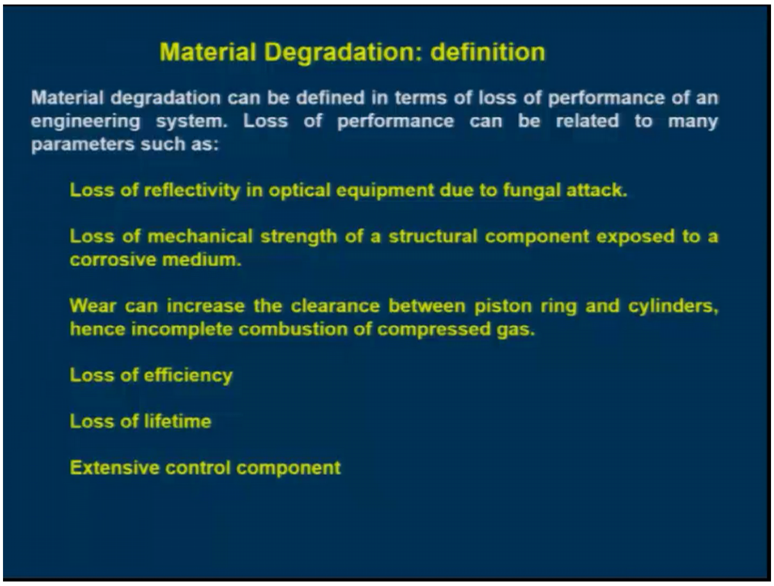

Material Degradation: definition

Material degradation can be defined in terms of loss of performance of an engineering system. Loss of performance can be related to many parameters such as:

- Loss of reflectivity in optical equipment due to fungal attack.
- Loss of mechanical strength of a structural component exposed to a corrosive medium.
- Wear can increase the clearance between piston ring and cylinders, hence incomplete combustion of compressed gas.
- Loss of efficiency
- Loss of lifetime
- Extensive control component

Now, if we come to this slide if you see this slide, here it says that the material degradation can be defined in terms of loss of performance of an engineering system. Of course, loss of performance; it can be due to material loss, due to loss of colour, due to loss of aesthetics many aspects.

Now, loss of performance can be related to many other parameters, such as loss of reflectivity in optical equipment due to fungal attack. This is also degradation and once it happens then of course, we have to throw that for example, camera lenses.

Loss of mechanical strength of a structural component exposed to corrosive medium. This of course, we will attack this particular situation in our next series of lectures. Wear can increase the clearance between piston ring and cylinder, hence incomplete combustion of compression gas; this is also loss of performance. Now we would not look at wear, but of course, the part of wear will be taken along with corrosion. In case of erosion corrosion, we will take wear plus corrosion. Loss of efficiency of course, once we have corrosion related damage, we do loose efficiency of that machine. Loss of lifetime this is natural, once we have a degradation in the form of corrosion; that means, a loss of materials then of course we have to replace that particular material prior to its usual time duration. And of course, lastly extensive control component: this adds to the cost of that particular corrosion.

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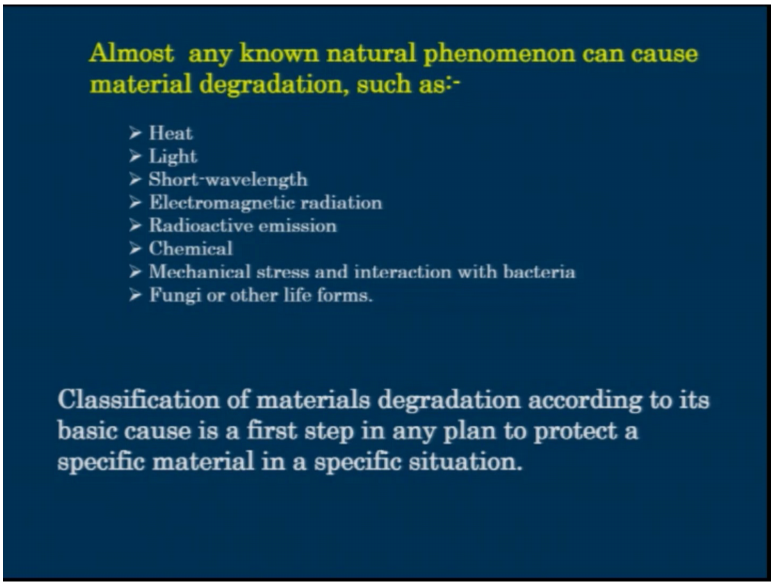

Almost any known natural phenomenon can cause material degradation, such as:-

- Heat
- Light
- Short-wavelength
- Electromagnetic radiation
- Radioactive emission
- Chemical
- Mechanical stress and interaction with bacteria
- Fungi or other life forms.

Classification of materials degradation according to its basic cause is a first step in any plan to protect a specific material in a specific situation.

Now, if we come to see the reasons or phenomena that can cause material degradation, there could be anything which are available in environment. Because every time any material we have to expose it to the environment for our purpose; like heat, light, short wavelength, electromagnetic radiation, radioactive emission, chemical, mechanical stress and interactions with bacteria, fungi or other life forms. So, all this factors they will be the reasons for someway or other a material degradation. Hence, the classification of material degradation according to its basic cause is it first step in any plan to protect a specific material in a specific situation that is what we have been talking about.

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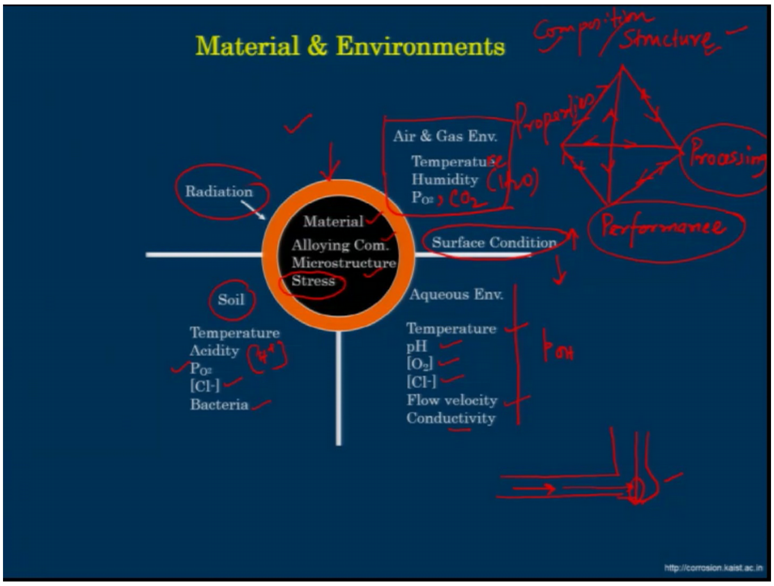

Material & Environments

Radiation

Material
Alloying Com.
Microstructure
Stress

Air & Gas Env.
Temperature
Humidity
P_{O_2}

Surface Condition

Soil
Temperature
Acidity
P_{O_2}
[Cl-]
Bacteria

Aqueous Env.
Temperature
pH
$[O_2]$
[Cl-]
Flow velocity
Conductivity

http://corrosion.kaist.ac.in

Now, coming to materials and environments interesting if I see materials, then first thing what it comes to a material scientist is basically the material tetrahedron. And in the material tetrahedron you will see for example; if I draw a material tetrahedron, this is a kind of material tetrahedron we see where structure is one side then processing, then performance and then properties. Now of course, when I talk about this material tetrahedron in the structure we can also have one other more criteria, which is called composition.

Now, for a particular composition the structure, properties, performances, processing all are interrelated. So, this is a classic material tetrahedron. Now if I come to this particular picture, this particular picture this material tetrahedron we have made some material for performing some duties. For example, some cases we need to hold a particular load, some cases we need to have a kind of a protection against a corrosion or we need to also prepare material where wear can be protected, wear can be resisted all sort of things.

Now, if I consider materials this is coming under this. Alloying compositions it is coming under compositions one particular field of material tetrahedron, microstructure which is coming under structure again. Now the stress is basically a kind of factor, which can come under processing or performance ok. So, processing sometimes we do use rolling forging. So, you need to put stress performance means we do need to hold some load, the stress part is coming up.

Now, when this particular structure so; that means, the structures is made out of this particular material, alloying composition, microstructure stress and with intended with some properties, which will be needed for performing some details. Now this particular material is exposed to the environment, and our environment is does have such things which can degrade the material.

For example if I consider this part, this part, this section you see we have air and gas environment, where temperature is a factor sorry for the spelling mistake. Temperature is a factor humidity which is nothing, but H 2 O content, P O 2 of course, oxygen concentration is there. Then of course, there could be another factor which is C O 2. C O 2 is also available. Now these kinds of gases and environments they have many a times have negative effect on that material performance like atmospheric corrosion of iron objects.

Now, coming to surface condition: yes, so I will come to that particular surface condition little later, now coming to aqueous environment, many a times that particular material or structure is either in the soil or in the water medium or in the chemicals so; that means, that aqueous environment comes into play. And whenever we come to aqueous environment we have temperature, we have of course, the H plus ion concentration or OH plus ion OH OH minus ion concentration that time it will be called p OH. So, p h p OH of course, dissolve oxygen content chlorine ion. So, we have just given an example of chlorine ion there could be halides. Other halides for example, fluoride all sort of halides they are deadly towards the corrosion of metallic objects.

Now, flow velocity, this is also coming in the form of a kind of corrosion aspects you might have heard of heard about cavitation. The cavitation is a serious kind of damage happens due to a change in pressure in during operation of impellers, pumps all those stuffs. So, their flow velocity also plays a role for example, a pipeline if the pipeline for example, I am just giving an example, if a pipeline is like this pipeline is like this that time if water is flowing like this and that water contains suspended particles this velocity can create lot of force on this particular section. And then gradually this particular section will get corroded in this corroded or eroded rather ok. Now this is a kind of factor, which also leads to material degradation this is coming due to flow velocity.

Conductivity of course, if something is placed in water and that water contains a very little amount of conducting ions apart from of course, a little hydrogen ion on OH ion that is present, because of the dissociation of H 2 O. Then that water the material would corrode could to little less compared to the if that particular water contains little bit of iron ion or chlorine ion there it will be a hugely corroded.

Now, coming to the soil, if we see the soil part there also moisture is important factor, acidity is important factor, which is h plus ion concentration h plus ion concentration P o 2 partial pressure of oxygen even chlorine ion content there could be a possibility of bacterial attack on the materials; so this surface condition. That means, now I am coming to the surface condition, surface condition means if something is exposed to the gaseous environment or air environment and below that if it is below the soil, with in the soil or in the water medium or any other chemicals liquid chemicals.

Now, coming to radiation this is also another factor, which can lead to problems on the materials. So, this is a kind of a relation between materials and environments which is not a kind of very friendly relations they are always trying to attack the materials.

Now, corrosion part.

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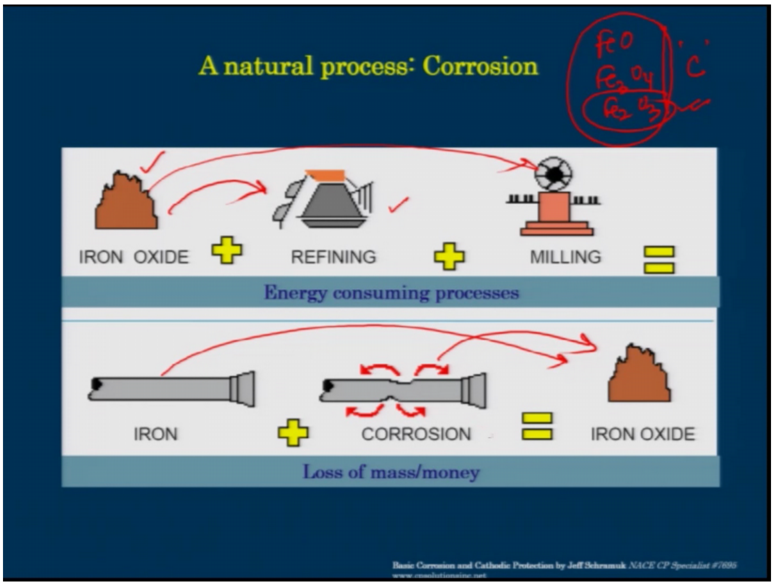

A natural process: Corrosion

Energy consuming processes

Loss of mass/money

Basic Corrosion and Cathodic Protection by Jeff Schramuk *NACE CP Specialist #7696*
www.cpsolutionsinc.net

So, if you see the corrosion before let us forget about corrosion for the time being, let us say how do we get iron. The iron the first general we make it iron in blast furnace, in the blast furnace what you do? Its a basically a reduction process, and in that reduction process we reduce iron ore which is in the form of F e O, F e 3 O 4 or F e 2 O 3, these kind three iron oxides are reduced by carbon that is what we always have iron containing iron containing sorry containing carbon.

That carbon presents if it is below 2 percent or 1.8 percent we call it steel, and then beyond 2 percent carbon of course, in weight percent it will be called as cast iron, but this is coming from the production route which is blast furnace.

Now, there we refine this reduction and then after reduction we send it to another plant which is called steel making plant where actually we do oxidation, because once we form iron from blast furnace its generally called p garden. That p garden contains many impurities and those impurities are to be taken care of or removed by oxidation. That means, by oxidizing those particular impurities, we take we remove them from the metal and then we get steel which contains low carbon. And then that steel is taken to a milling process means either rolling mill or forged products will they get lot of iron objects.

Now, that those iron objects are exposed to environment in the form of structures, in the form of utensils in the form of many other applications. And then we see that gradually that iron is again turning into red rust and interestingly the red rust are nothing, but this three oxides mainly these oxides F e 2 O 3.

So, what happening? It is basically coming from rust and then again we are turning to rust. So, it is a natural process, we cannot stop corrosion because this rust formation; that means, when the reaction happens with air moisture and oxygen then the rust forms, and these process is thermodynamically a feasible process. In fact, this process we need to spend lot of energy because thermodynamically this is stable phase. So, in order to get iron from iron oxide we need to spend energy, we need to reduce we need to have lot of other factors but from this to this is a natural process.

So, the corrosion is a natural process. So, natural process cannot be stopped it will happen. So, what we can do? We can control it. So, when we control what do you mean by control we mean control? That means, we can prevent corrosion, rather we can reduce corrosion to a great extent. So, that is the essence of studying corrosion. So, we have to reduce or we have to control corrosion, stopping corrosion is out of question.

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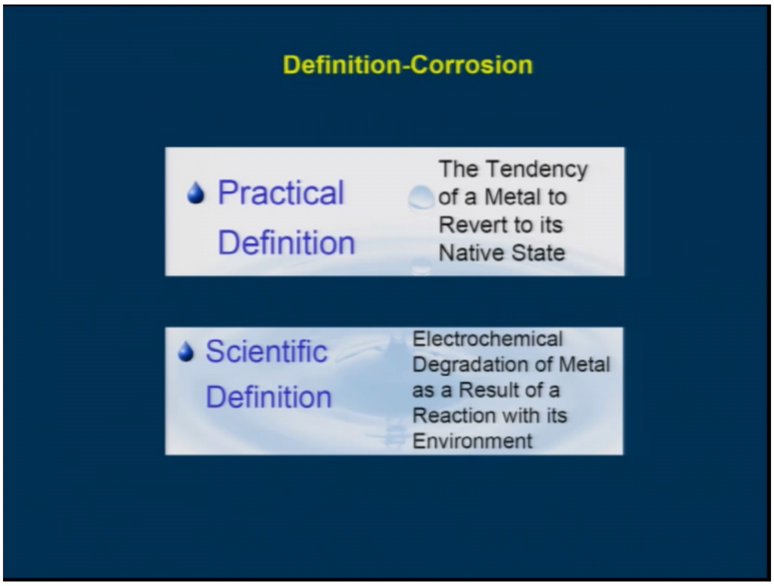

Definition-Corrosion

- Practical Definition: The Tendency of a Metal to Revert to its Native State
- Scientific Definition: Electrochemical Degradation of Metal as a Result of a Reaction with its Environment

Now, coming to definition there are two definition: one is practical definition. If we see the practical definition the tendency of a metal to revert to its natural state, which relates to if you see the previous slide. So, we are taking iron from iron oxide, now we are reverting iron to iron oxide. So, the second process is natural process, the first process is energy consuming process. So, this loss of and of course, when you do that when you have this of course, there will be loss of mass and loss of money.

So, this is a practicality in it the tendency of a metal to revert to its native state. Native state means what? Iron oxide or iron ions those are native states. Scientific definition yes when you talk about scientific definition we have attar this word in some cases, electrochemical degradation of metal as a result of reaction with its environment.

Now here interestingly, we are using electrochemical, we are not using chemical. Remember that whenever we talk about corrosion related corrosion kind of degradation corrosion is of course, a degradation wear is of course a degradation, but when we talk about corrosion that time we must consider that the metal is reacting with its environment electrochemically. That means, there is a formation of metal ions. So, metal from metallic from atom it will go into the ion that is the scientific definition of corrosion.

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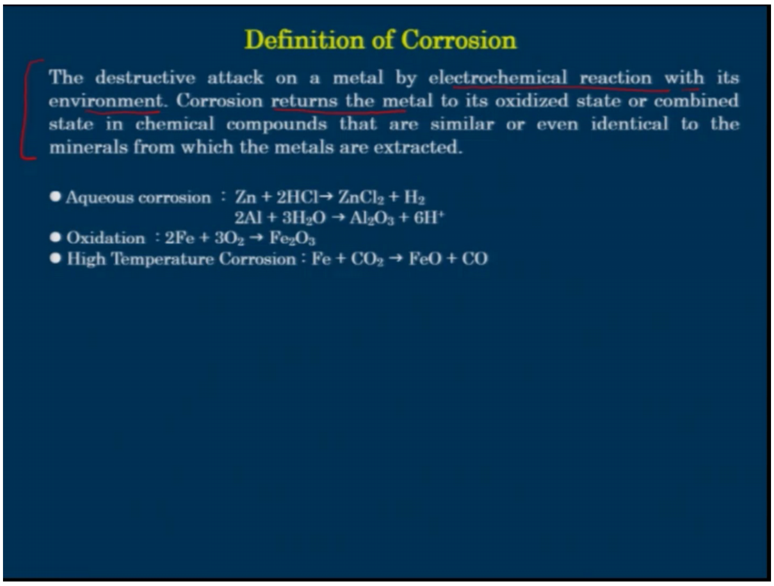

Definition of Corrosion

The destructive attack on a metal by electrochemical reaction with its environment. Corrosion returns the metal to its oxidized state or combined state in chemical compounds that are similar or even identical to the minerals from which the metals are extracted.

- Aqueous corrosion : $Zn + 2HCl \rightarrow ZnCl_2 + H_2$
  $2Al + 3H_2O \rightarrow Al_2O_3 + 6H^+$
- Oxidation : $2Fe + 3O_2 \rightarrow Fe_2O_3$
- High Temperature Corrosion : $Fe + CO_2 \rightarrow FeO + CO$

Now, coming to definition of corrosion still continue, the destructive attack on a metal by electrochemical reaction with its environment as we have mentioned. Corrosion returns the metal to its oxidized state or combined state in chemical compounds, that are similar or even identical to the materials from which the metals are extract. So, in this particular definition, we are combining both practicality as well as the scientific part of it. The first part which is the attack on a metal by electrochemical reaction, with its environment is the scientific part and the second part is basically the corrosion returns the metal to its native condition. So, this actually combines both.

Now, since we have started talking about electrochemical reaction, gradually we will see that we will getting into the electrochemistry.

So, now let us see this aqueous corrosion of zinc in 2 in HCl which is a dilute HCl.

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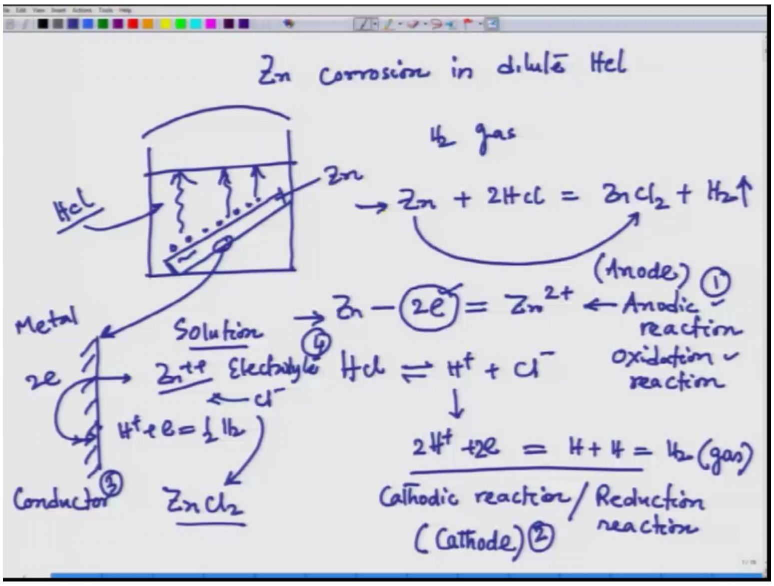

Now I would go to let us get to the aspect of zinc corrosion let us say we start with this particular thing, zinc corrosion in dilute HCl. Now if we have a kind of container and in that container if we put a bar of zinc, bar of zinc this is zinc and we have HCl here, this is dilute.

And once we put in zinc you will see that there are bubbles formation on the zinc surface. So, those bubbles are coming out and there will be vigorous bubble formation. And if we take this particular bubble for example, you encapsulate this particular section and then take this bubble. And then finally, you burn a matchstick, you will see that it gets burnt. So now, this particular gas which is coming out this gas is nothing, but H 2 O gas.

Now, if we see the reaction, the reaction is zinc plus HCl equal to zinc C l 2 plus H 2 and if we balance it this is the balanced one. Now we wonder that where this electrochemistry taking place. That means, we have said that electrochemical reaction might happen because zinc is this in metal condition metallic condition. And now it is going in the form of zinc chloride and this zinc chloride is actually zinc is dissolving in the form of zinc chloride, and zinc chloride will dissolve in that particular solution and hydrogen gas is coming out.

But if we break this particular reaction into 2 parts, you would definitely see that yes there are electrochemical reactions. Now if I look at zinc, now if we take 2 electron out of zinc it goes to zinc plus 2 2 plus ions.

And now since this 2 electron is coming out from zinc atom, this 2 electrons need to be taken up because charge cannot remain unbalanced. So, now, there are H C l in that HCl you have H plus plus C l minus if we dissociative HCl. So, these H plus will take up one electron and form H, and if we consider 2 h plus ion. So, it is plus H it is forming h 2. So, 2 atomic hydrogen will combine each other and then from h 2 gas. Now, if I see this reaction this reaction is nothing, but anodic reaction or we call it oxidation reaction. And this reaction we call it cathodic reaction and or reduction reaction.

Now, whenever there is anodic reaction or oxidation reaction it talks about material degradation so; that means, zinc atom is going into solution so; that means, this zinc rod is gradually losing zinc. So, it is a degradation and this degradation is happening because of this electrochemical reaction, because this reaction is electrochemical reaction. And these 2 electrons which have been released by zinc they are taken up by 2 hydrogen atom and forming hydrogen gas. So now, you see in this entire reaction we have 2 electrochemical reactions taking place, one is anodic another one is cathodic.

Now, question is these 2 electrons how would it move to the side of cathodic reaction. Electron must flow through a conductor. So, it is flowing. So, for example, let us say the small segment if I zoom it. So, this is the zoom part of this, and this side zinc plus plus ion is forming.

So, the 2 electron this is the metal side and this is the solution side, 2 electron is released to the metal. And now here let us say hydrogen is taking up electron and forming hydrogen gas. So, these 2 electrons is flowing through this conductor, and in this electrolyte which is also called solution we call it electrolyte. There zinc ion and there are chlorine ion, there if combining and forming zinc chloride.

So, now in order to have this entire reaction we have four components; what are those four components? One component is anodic reaction where anodic reaction happens we call it anode, where cathodic reaction happens we call it cathode. So, these are 2 components this is second component then where the electron transfer is taking place, we call it conductor, and of course there is one more component which is electrolyte. For example, if there is no electrolyte these reactions cannot take place. So, this electrolyte is this is third component, and this is fourth component.

So, now for this particular zinc corrosion through this electrochemical reactions, we must satisfy this condition that there must be four parts, one part is anode second part is cathode, these two are forming electrodes and then one part is third part is conductor and fourth part is electrolyte. So, this all four must be there.

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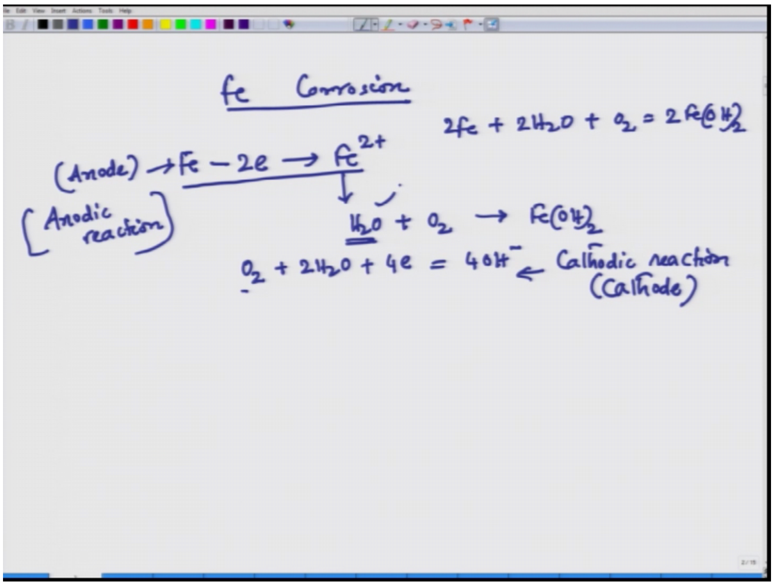

fe Corrosion

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

(Anode) → $Fe - 2e \rightarrow Fe^{2+}$

[Anodic reaction]

$H_2O + O_2 \rightarrow Fe(OH)_2$

$O_2 + 2H_2O + 4e = 4OH^-$ ← Cathodic reaction (Cathode)

Like that if I see the iron part now, iron corrosion, there iron of course, if it needs to corrode it has to form ions. So now, how can it form ions? It can lose 2 electrons and then go to plus 2 or 2 plus as we are putting this convention 2 plus.

So, this particular ion would then react with H 2 O and oxygen. So, now, then this will form F e OH whole 2 and if we try to write the complete reaction then it becomes 2 H O 2. Now question is this anodic reaction is of course there now where is cathodic reaction taking place we need to know that. And for that we need to also consider one more cathodic reaction is O 2 plus 2 H 2 O plus 4 e equal to 4 OH minus. So, this is anode or anodic reaction, this is cathodic reaction or cathode electrolyte is nothing but this moisture becomes electrolyte these happens when a metal object iron object is exposed to environment this H 2 O becomes electrolyte.

Now, question is this is cathodic reaction of course, the electron where it flows that electron flow would happen; these happens on the anode these happens on the cathode and electron flows through the iron object ok. That becomes conductor and this becomes electrolyte.

Now, in the previous case also, we could see that zinc itself act is acting as cathode as well as anode because the cathodic as well as anodic reactions are taking place on zinc surface. Here also the anodic surface as well as cathodic surface, iron is behaving in the same pattern if iron becomes cathode as well as anode. Now question is we will not be able to tell specifically this part is cathode and this part is anode, because in the beginning it will be all statistically distributed reactions. That means, cathode where only we can say where the cathodic reactions happens, anode where the anodic reactions happens

So, but if I try to see the formation of this, it also follows the same route; that means, electrochemistry. And iron is dissolving by forming iron ion, and there is a cathodic reaction which is oxygen reduction this oxygen is reducing and of course, cathodic reaction is nothing, but the reduction and in case of zinc zinc ion is forming anodic reaction, and hydrogen ion is getting reduced and forming hydrogen. So, that becomes my entire situation for iron corrosion as well as zinc corrosion we follow electrochemical roots.

We would continue with these particular aspects that cathode anode electrode as well as conductor and electrolyte this is the essence of or the backbone of corrosion subject. Now before we end this lecture 2, I would like to just tell you that of course, corrosion is deadly, but some cases corrosion of course, helps. Now let us give some examples you would be surprised to see that some of the cases yes, the corrosion actually helps one classic example is let us come to this battery.

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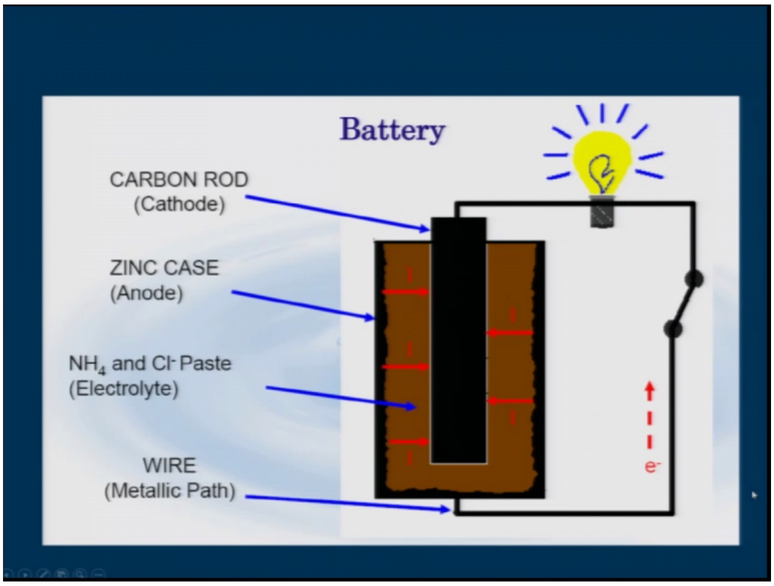

Battery

Now, in the battery we of course, have corrosive reactions. Now carbon rod which is acting as cathode zinc case casing is acting as anode. And then because zinc case is corroding it is releasing electron and that electron is flowing through this particular electro external circuit external conductor and that is what we are getting a glowing light. So, battery is designed on the basis of corrosion because zinc is corroding that is what we are getting electrons and that is available for glowing lights.

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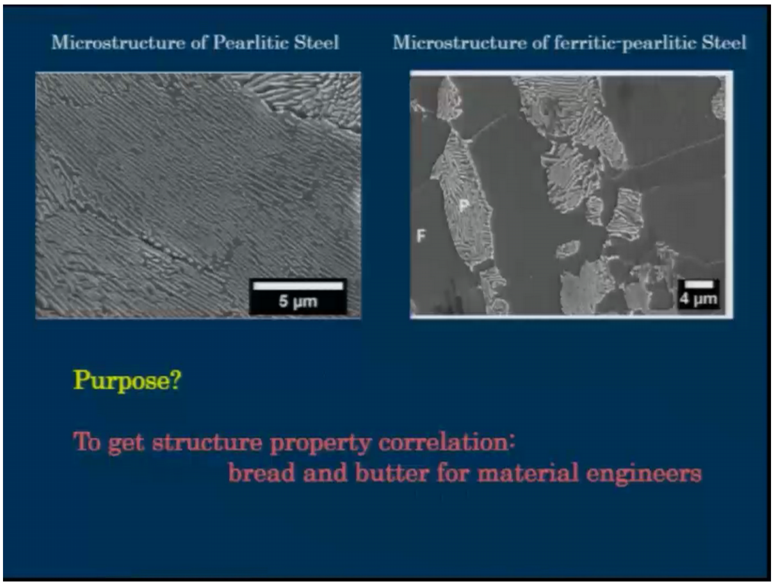

Microstructure of Pearlitic Steel

Microstructure of ferritic-pearlitic Steel

Purpose?

To get structure property correlation:
bread and butter for material engineers

Now this is another example the microstructures which is the bread and butter of material scientist, because this microstructures are needed to correlate property and structures.

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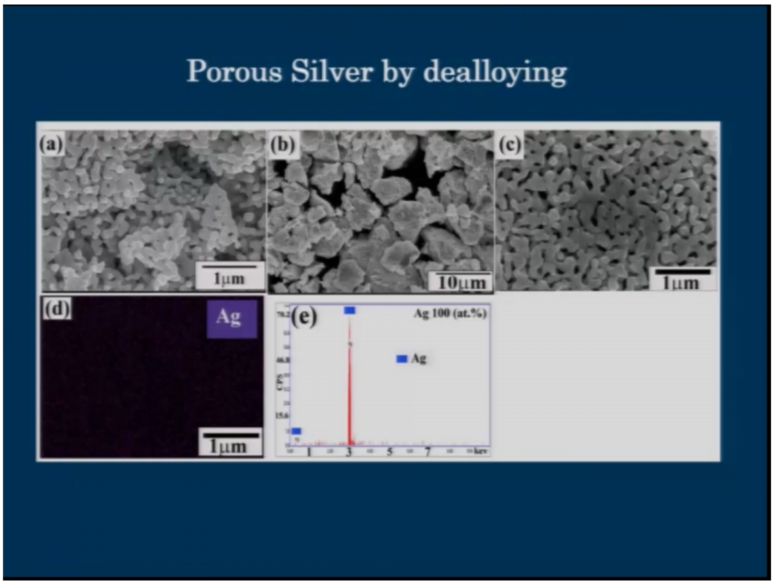

Porous Silver by dealloying

Now, another example is porous silver, there are porous gold which are very good catalyst they are they are formed by dealloying. For example, zinc silver or gold silver if we formalize then specifically, and then we can take out silver. In case of gold silver or in we can take out zinc in case of silver zinc alloy, and then form porous network like this.

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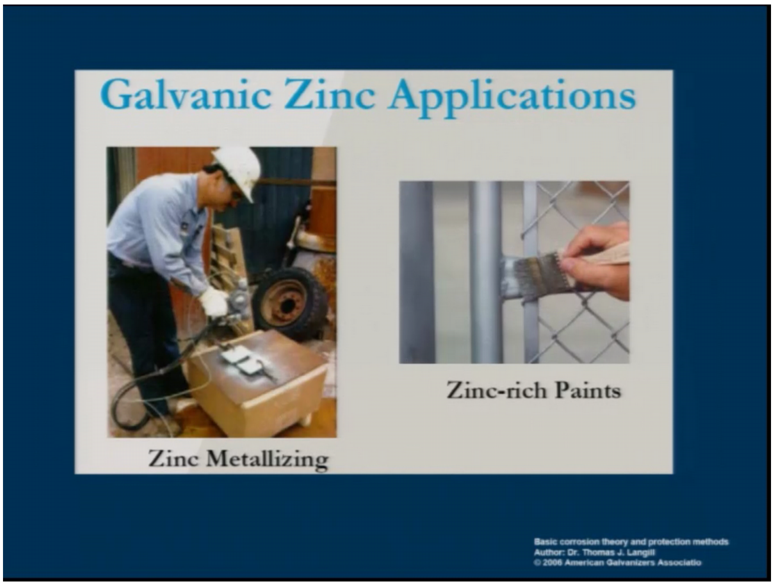

Galvanic Zinc Applications

Zinc Metallizing

Zinc-rich Paints

Basic corrosion theory and protection methods
Author: Dr. Thomas J. Langill
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And finally, I come to this example, which is called galvanic zinc application. Galvanization is a popular method where we protect iron structures, this also is the corrosion is the basis of galvanic corrosion galvanic galvanization or galvanic zinc application. Zinc corrodes and zinc becomes my sacrificial anode and then iron is protected iron becomes my cathode.

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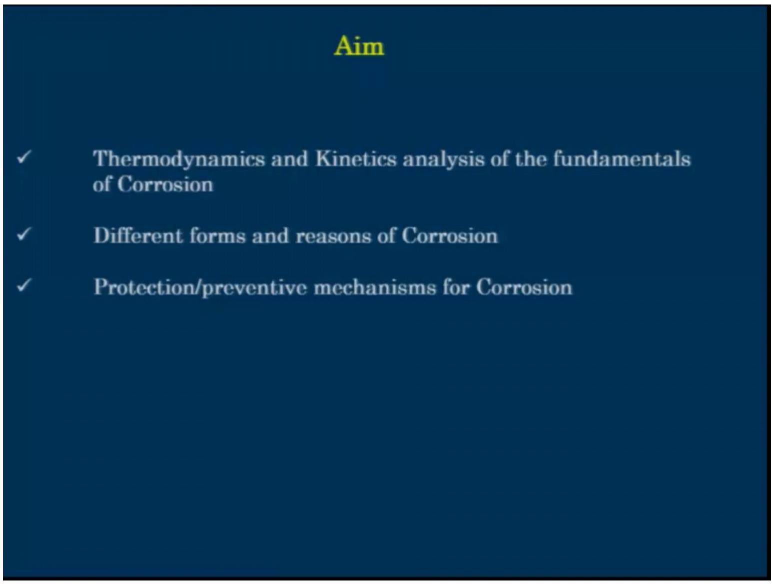

Aim

- ✓ Thermodynamics and Kinetics analysis of the fundamentals of Corrosion
- ✓ Different forms and reasons of Corrosion
- ✓ Protection/preventive mechanisms for Corrosion

So, at the end let me end this lecture by saying our aim is to understand thermodynamics and kinetics of corrosion, different forms and reasons of corrosion. And of course, finally, we would look at protection and preventive mechanisms for corrosion. Thank you very much let us stop today.

Thank you.