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

Lecture - 02
Various forms of corrosion

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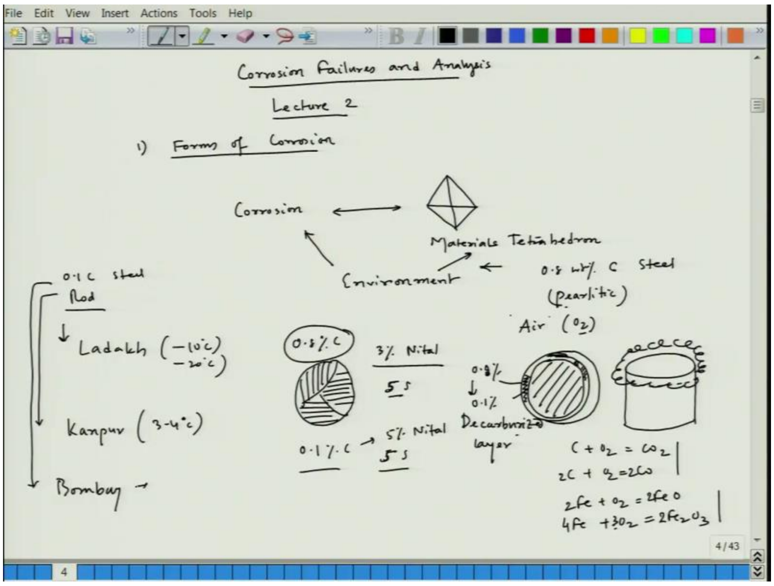

Hello, everyone. This is the course Corrosion Failures and Analysis and lecture 2. And, in the 1st lecture we could complete the first topic; the second topic is Forms of Corrosion. So, we will take this particular topic, forms of corrosion, fine. Now, as we see in the last lecture that there is a relation between corrosion and materials tetrahedron, fine and, this is related.

We have taken examples like 18-8 stainless steel and we should see that there is a there is a strong relation between corrosion and material tetrahedron. It is not only that, we have also mentioned that there is a also interplay about interplay of environment on corrosion as well as environment also has interplay with materials tetrahedron. For example, I am just one example I can give you here.

Let us say you have taken a 0.8 weight percent carbon steel ok which is pearlitic in nature pearlitic 100 percent pearlitic. Now, if you heat this particular steel in air ok where we have oxygen, you would see that if we consider a steel cylindrical steel let us say this is a small disc you have cut through. So, that means, so, you have taken a small disc and this is that disc ok.

And, if you do the microstructure after heating this particular 0.8 percent carbon steel at around let us say 600 degree Celsius for a long duration you will see after you etch that particular microstructure around that particular periphery you will get a white layer. So, that white layer is nothing but decarburized layer. Why? Because the carbon reacts with oxygen it form CO_2 or CO, you can balance, ok.

$$C + O_2 \rightarrow CO_2$$
$$2C + O_2 \rightarrow 2CO$$

So, these two reactions can happen and when these two of course, there will be reactions between iron FeO, then Fe plus O_2 equal to Fe_2O_3 where I can 3 by 3 here I can put 4 and here I can put 2. So, these are balanced.

$$2Fe + O_2 \rightarrow 2FeO$$
$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

Those reactions also can happen. So, those will be like rust that is forming on the top layer with the oxide layer, but the major observation would be if you would see the microstructure, you will see that the white layer has formed.

The internal section we will see pearlite ok, but outer section there will be a white decarburized layer. This is a typical problem. In case of cast iron for example, grey cast iron there the carbon content is of the order about 3 weight percent. So, there also we could see that kind of decarburized layer which looks like a white section.

Why white section? Because when you etch, the higher the carbon higher would be the etching tendency it would get grayish in color. So, now, if you take 0.8 percent carbon, so, there we have if we see the microstructure these are pearlite these are pearlite and these are pre austenitic grains. Now, if you etch it if we let us say 3 percent nital solution which is a common etchant for carbon steel.

And, if you hold it long duration in that particular steel if and if you do immersion etching there is a possibility that the surface might get burnt you would see some strange color appearing on the surface. So, those are actually burned surface and; that means, you have to hold it for a lesser duration.

But, if you take 0.1 percent carbon steel let us say here you have held it for 5 seconds and here you have held it for 5 seconds, fine both are 5 seconds, but in this case the burning tendency of the surface by the nital would be much higher compared to this section.

So, in fact, if you hold it for 5 seconds in case of 0.1 percent carbon you will not be able to see the micro structure under the optical microscope because it will not get etch properly. So, that means, it is always advised that 0.1 percent carbon you always use mostly use nitals 5 percent nital solution. So, there that etching would be much better.

Now, why this difference in reactivity coming? Because of the higher carbon. Now, here also since you have dipped it the same solution and this is the carburized layer because here the carbon content has gone down let us say 0.8 percent it might go down to 0.1 percent.

So, that means, it is obvious that the pearlite content as we you have seen last lecture that if we have a 0.1 percent carbon steel the it is mostly ferritic and pearlitic could be along the grain boundary only so, that time it will look like a whitish in nature because the pearlite since there are ferrite and cementite it looks a grayish color rather than ferrite the ferrite would look like a very bright color under the optical microscope. So, that is what it looks like a white layer.

Same happens with graphite because there we have in case of gray caster and where the microstructure is either in case of grey caster either it will have graphite flakes in a pearlite or there could be possibility of graphite flakes in ferrite pearlitic microstructure.

So, again wherever the graphite flakes are there after etching it will look like a gray color and if there the carbon content is less the graphite formation would be less and the ferrite formation would be more then the surface would look like a white color.

So, this is basically a kind of effect one small effect I have just narrated that environment can have a huge effect on materials tetrahedron that composition can change, microstructure can change and of course, if these two things change there will be a possibility of change in properties, ok.

Now, there is one more example you instead of O_2 you can have let us say a carbon environment let us say in a graphite for example, this particular thing this slice you put it in a carbon environment, ok or let us say coal or charcoal you can put it. You will see that this segment that time would be much darker in color compared to the inside part.

And, one example is if you see the normal blacksmith the usual blacksmith who makes those axes and all those thing you will see that they after making that particular iron object they push it in the coal environment, ok. So, that actually helps to do carburized form carburized layer.

So, that means, the carbon content in that particular layer would go up and that would give you extra strength or extra wear resistance of that surface because higher the carbon content higher would be the hardness this is a kind of thumb rule, ok. So, this is the effect of environment on materials tetrahedron, but if I consider the effect of environment and corrosion, it is also extremely critical why I am saying environment effect.

For example, if you take 0.1 percent carbon steel rod you keep it in Ladakh and another one which is in winter the temperature goes sub 0 minus 10 degree Celsius or minus 5 degree depending on that day winter periods some places it might also go to 20 degrees minus 20 degree Celsius. Now, another the same processing you take it to Kanpur where the winter temperature around 3 to 4 degree Celsius. Now, the same one you take it to Bombay winter time or maybe Chennai.

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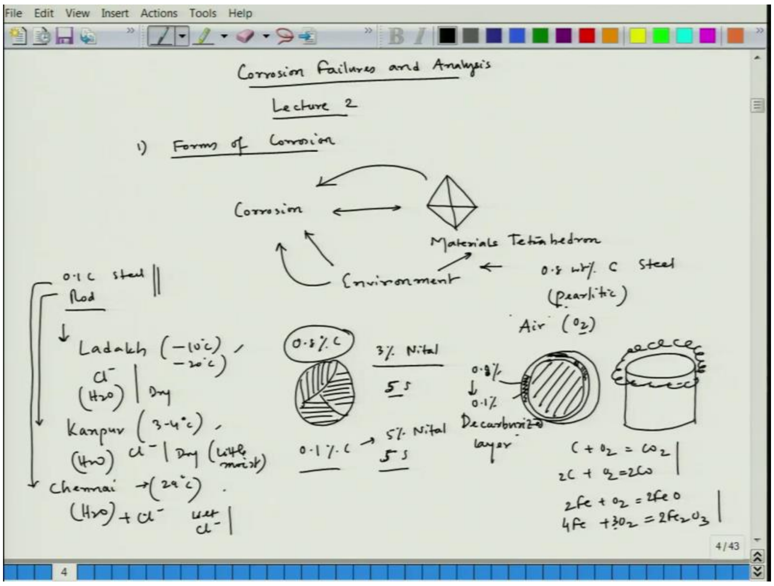

So, these are different cities in India ok. So, Chennai winter temperature could be around 29 degree Celsius in addition to that in Ladakh if we consider the chlorine percentage the chloride content would be minimal and in Kanpur the chloride content there would be chloride content in the environment and Chennai of course, you will see lot of chloride content.

Why? Because it is basically a sea facing city, ok. So, there you have the chlorine ion presence huge amount of chloride ion presence and the temperature is also high. And, if you see the corrosion of this particular steel in three different cities you would see that here the corrosion would be less; Kanpur the corrosion would go up little up, but in Chennai the corrosion would be maximum because it is not only temperature at the same time there is a presence of chlorine.

And, another thing we have to consider that moisture content, H_2O. Moisture content contained in Ladakh would be minimal because it is a very dry city very very dry city. It rains very little, but Kanpur it is not that dry compared to Ladakh. So, there will be moisture presence in the environment, but Chennai it is full of moisture. So, that means, these two factors those are the two huge culprits which induce corrosion, ok.

So, these two factors those are actually you can say demons if we consider the corrosion of metals and alloys. So, these two demons would try to damage the steel to a great extent, fine. So, that means, you could see that the environment plays a huge role in inducing corrosion, ok.

Now, so, that means, here I have less chlorine almost negligible chloride content, but at the same time dry there will be presence of chloride content chloride as well as moisture, but not that moist in the winter Kanpur becomes very dry. So, this is dry little dry I would say I had little moist I would say; sometimes in Kanpur in winter it rains.

So, that means, the moisture content goes up, but Chennai is wet environment. It is very patchy because in the winter also people sweat over there, ok wet as well as chloride content. So, these two factors would induce corrosion to a great extent into that particular 0.1 percent carbon steel. So, that means, environment has effect on corrosion.

Now, this materials tetrahedron has effect on has a relation with corrosion environment has relation with corrosion. Now, that means, we must find a kind of synergy between materials tetrahedron and environment to understand corrosion and if we understand corrosion we can definitely check for corrosion routes the protection routes which can minimize corrosion.

So, that is the sole purpose I have brought in materials tetrahedron factor and you will see the influence of that material tetrahedron as we go ahead when we talk about protection process. Now, coming to the different forms if we have environment if we have corrosion in that metals that corrosion might look different, ok and in fact, it looks different.

For example, if we check my introduction video which is almost about current 6 to 7 minutes video I have shown you different corrosion in the day to day observations. For example, one corrosion if you go there you can see that in Kanpur that one particular house roof, the railings are made of iron pipes and those pipes have got heavily corroded, the portion which is inside the concrete that inside the concrete it is so much corroded that the concrete has actually broken apart.

So, there one form of corrosion. And, you would see one clock I have shown you if you recall the clock there also around that key portion the corrosion is more prevalent rather than other parts of the clock.

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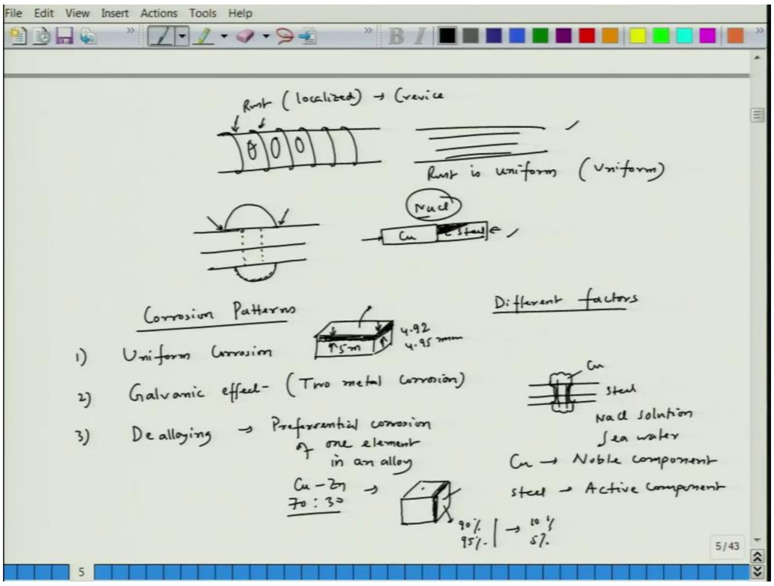

Corrosion Patterns

1) Uniform Corrosion

2) Galvanic effect (Two metal Corrosion)

3) De alloying → Preferential corrosion of one element in an alloy

Cu – Zn → 70 : 30

Different factors

NaCl solution
Sea water

Cu → Noble component

steel → Active component

Ok, so even for example, if you see rebar on the road just go by and if you see the rebar on the road you just take a small piece of rebar you will see that the rebar if we just take a example of rebar these are basically ribbed rebar. And, you will see you just closely observe this segment this section the rib portion and the foot of that rib portion you will see that the rust the red rust is prevalent over there rather than the entire section of the rebar.

So, these portion you would say you would see very little rust which is red color, but if you see the root of that particular rebar you will see the rust is forming predominantly over there. So, here around those segments the rust is less, but here the rust is more. But, if you take a plane bar if you take a plane bar with without rib you will see the rust is more or less uniform over the entire segments more or less uniform.

So, that means, all the places you will see rust, but here the rust is here and here rust is uniform, but here rust is localized. It is very clear if it is a plane bar and if it is a ribbed bar the rust position changes. So, that means, the form is different. So, this is more or less crevice pattern, we will learn later and this is uniform.

Now, let us say I give an example like let us say a rivet. So, this is a rivet, two plates are joined together. You will see that this portion where crevice is forming there the corrosion tendency would be more rather than the other parts. Now, let us say you have a copper plate and steel plate or carbon steel they are joined together, ok or let us say they are closely met and tighten it and leave it to NaCl solution.

You will see that this portion will be highly corroded; the portion which is in contact with copper. Here also the form is actually changing the corrosion form or the corrosion pattern is changing. Now, on the basis of this corrosion pattern we can define different corrosion, ok and as you see the corrosion pattern is arriving as we go ahead we will see that there are different factors which lead to such corrosion patterns, ok.

So, let us check what are the corrosion patterns let us check corrosion patterns and let us see different factors, ok. Now, one part is the first corrosion pattern you would see for example, here the plane rebar where the corrosion is more or less uniform over the red rust forms over the entire surface of the rod. So, when the corrosion happens uniformly over the entire section we call it uniform corrosion.

So, now if you see a 3D picture you will see the corrosion will be if you say the top part is exposed to the an electrolyte to the electrolyte you would see the corrosion is uniformly happening through the body section through the depth direction; if the distance here is 5 millimeter here it would be 4.92 or 4.95 millimeter. So, almost same sort of depth attack, ok.

So, those are we can call it uniform corrosion. So, then the second one we have say galvanic effect and here if you see the galvanic means we also call it two metal corrosion fine. So, in the case of two metal corrosion if one metal is joined to another metal and if this both metals have got difference in their activity in that particular electrolyte we have difference in corrosion of those two metals. For example, this is a classic example copper and steel.

So, if let us say steel let us say these two steel plates are fastened with a copper bolt ok, this is copper and this is steel you will see that these portion if they are under electrochemical attack these portion will get more corrosion. And mainly the steel corrodes not the copper because and if this is let us say NaCl solution or sea water solution. So, because in sea water copper act as a noble component and steel act as an active component, fine.

So, that is what copper does not corrode much. It does not mean that the copper will not corrode, copper would also corrode. But, if we see the corrosion rate of both the steel and copper steel corrosion rate would be much much higher than the copper corrosion rate, fine. So, this is called two metal corrosion and, remember, this is very important.

In some of the cases there is a kind of misconception that a galvanic effect if we have two metals one metal does not corrode another metal corrodes. It is not true. Both metals corrode, but the corrosion rate of one active metal would be much higher than the other metal, ok.

Please remember two metal corrosion does not mean the corrosion rate of both the metals would be as. So, one metal would be 0, another metal is maximum or the it is taking place, it is not that. Corrosion happens in both the cases, fine. Now, third part third is basically we have another corrosion pattern which is called de alloying.

So, de alloying I have mentioned this de alloying just after galvanic effect. It is basically the preferential corrosion of one element in an alloy. For example, copper – zinc. Copper – zinc let us say this is 70:30 copper and if you expose this one to even portable water, zinc if we see a 3D picture. So, let us say this surface is exposed to the portable solution.

So, around this part zinc would all mostly zinc would go into the solution and it will leave copper behind. So, this particular segment will look a very red like compared to the orange color what we see in case of normal brass color, ok. Here it will be very red, red like because the copper content goes up to around 90 percent even 95 percent and the zinc content decreases to 10 to 5 percent from 30 percent zinc.

So, that means, zinc is preferentially going into the solution and copper stays back. This is de alloying. So, we will have other examples also in case of de alloying.

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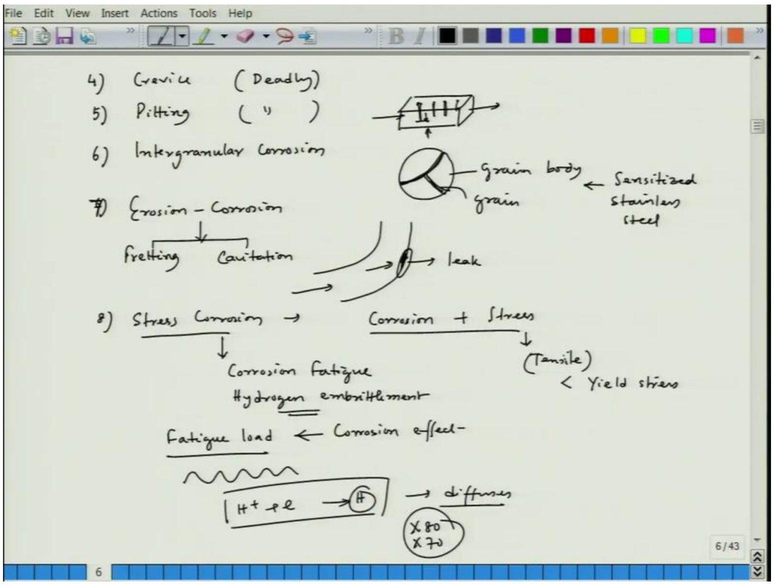

4) Crevice (Deadly)
5) Pitting (")
6) Intergranular Corrosion
7) Erosion - Corrosion
↓
Fretting Cavitation
8) Stress Corrosion → Corrosion + Stress
↓ (Tensile) < Yield stress
Corrosion fatigue
Hydrogen embrittlement
Fatigue load ← Corrosion effect
H⁺ + e → H → diffuses
X 80
X 70

Now, 4th we have crevice. Crevice for example, here wherever there is a crevice or sharp corner that portion can experience this kind of crevice corrosion which is very I would say deteriorating or I would term this word called deadly corrosion. This is very bad type of corrosion.

Then 5th we have pitting. This is also extremely bad corrosion deadly and if we see a 3D picture on the flat surface you might see the small small black dots and if we see the under cross-section that particular segment can go deep into the material; deep into the material.

What exactly happens there? Actually if this is the load carrying body the actual load is carried by the smaller smallest cross-section. So, you are not able to see how far that pit has moved in, but you would see that the solidly the material breaks down ok. So, this is what happens in case of pitting. Pitting can happen on the flat surface also, ok.

Even if it is a microscopically smooth surface also pit can happen. So, that pitting is also extremely important corrosion form. Then 6th we have intergranular corrosion. In case of intergranular corrosion if we see a microstructure these are the grains and this is the grain body. So, this is grain body this is grain corrosion happens along the grains.

So, that is what it is called intergranular corrosion this happens in case of sensitized stainless steel, fine. Now, 6th is 7th is erosion corrosion wherever there is a erosion factor which is a mechanical in nature in addition to that we have electrochemical components.

For example, if we see an example of pipe corrosion, let us say this is a pipe and emulsion is going through that emulsion will have the strongest effect around this zone and this portion can leak and there will be possibility that emulsion will leak out.

So, this example this is a particular example where it gives a mechanical erosion at the same time corrosion factor is coming into picture, that is what it is called corrosion erosion corrosion and it has two variants; one is fretting, another one is cavitation. We will talk detail about these two particular forms of erosion corrosion.

And, finally, we have stress corrosion and in case of stress corrosion as the name suggest corrosion plus stress. When these two things combine we can have catastrophe thus entire bridge can fall down because of the stress corrosion, ok. Entire component of a particular holding structure can break down because of stress corrosion and this stress corrosion has to be looked at very carefully because many of the catastrophic corrosion failures happened due to stress corrosion.

So, I would request you to go to a site called corrosion doctors. There is a section called failures of components failures industrial failures. So, that portion I would request you to look through or otherwise I will bring it in and then show it to you in the next class, ok and the stress corrosion there are two sections one is there are two other variants one is corrosion fatigue, another one is hydrogen embrittlement, fine.

So, this stress corrosion if we consider the normal stress corrosion you should make sure that the stress which is there which is mainly tensile stress that stress is below the yield stress of that material. So, that time we call it stress corrosion. Now, if it is a corrosion fatigue then definitely as you see the fatigue term coming into picture there is an alternate stress variation and corrosion is also party to it. So, this kind of corrosion happens when there is a rotating object.

So, now if we keep come to stress corrosion whenever we talk about stress corrosion normal stress corrosion where the stress is tensile in nature tensile and it should be below yield stress of the material. So, that time we call it stress corrosion. Now, corrosion fatigue as the name suggests that fatigue load is coming in and also there is a corrosion effect, fine.

Now, fatigue load means there is a variation in load one time the load goes down one time load goes up. It could be all tensile and there could be compression-tension, compression-tension kind of thing. So, the fatigue itself is a very deteriorating effect to the material failure ok, but if you have corrosion also then it actually gets enhanced to a great extent; that means, it fails much quicker than a normal fatigue. So, this is one factor corrosion fatigue.

And, hydrogen embrittlement if you consider this is also very important in the sense that wherever there is a chance of atomic hydrogen H and that can form from this reaction.

$$H^+ + e^- \rightarrow H$$

This reaction this hydrogen forms and hydrogen gets into this material diffuses and when it diffuses it reduces the cohesive force ok between the atoms. So, that means, it actually reduces the load carrying activity. So, that is what it is called embrittlement.

And, this hydrogen can induce embrittlement in different ways. One is it reduces the cohesive force between the atoms of that particular metal or it can react with some of the elements of the metal for example, zirconium if there is a zirconium hydride can form. So, those hydrides are very brittle in nature and those brittle hydrides can break when there is a load effect.

So, this particular hydrogen embrittlement. For example, pipeline steel X 80, X 70 those are line pipe variations of variants of steel. So, their hydrogen embrittlement should be studied very carefully because those steels are used for pipeline making and those pipelines migrates or the takes oil from one country to another the cross country pipelines.

So, those pipelines if there is a hydrogen embrittlement effect you never know the oil is leaking somewhere in between and before you could tap it by that time there is lot of oil loss. So, that is what you have to test its hydrogen embrittlement behavior in order to prevent oil leakage because that hydrogen embrittlement can lead to failure of that particular pipeline or the breaking of the particular pipeline and once the pipeline breaks oil spills out, ok.

So, that is what you have to be very careful in that stress corrosion part, we have to concentrate on that how it happens. So, those things will be discussed in greater details. Now, coming to the factors different factors and different factors if I have to name those factors I just name those factors discussion will happen in the next lecture.

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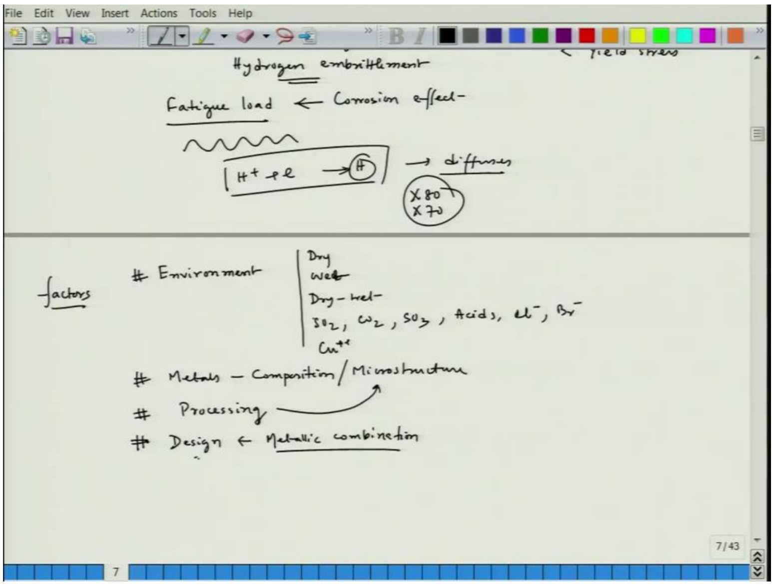

So, for example, environment: environment it could be dry, it could be wet, it could be dry wet, it could be SO_2, CO_2, SO_3, acids, chlorine ion, bromine ion or halides there would be possibility of deleterious metallic ions for example, copper plus plus.

Copper plus plus if it stays with the potable water and if you are carrying that potable water through a metallic steel pipeline there is a possibility of leakage. We will discuss why that leakage happens ok. So, those are the different environments you can come across.

Then there is a possibility of metals composition microstructure, ok. Then processing so, this processing changes microstructures then there will be possibility of design. Faulty design is even if the corrosion effect is there if it is a faulty design that magnitude of corrosion failure would be extremely high, ok, it can be multiplied if there is a design failure ok. So, we will talk about that, fine.

So, then whenever we are talking about design we are talking about how those metallic combinations are chosen metallic combination is chosen. So, it is impossible to develop a structure with the same metal; if it is a big structure you have to use different metals so, but the combination is very important. So, that comes under design. So, we will talk about that also. So, roughly these are the different factors, we will talk around this.

So, let us stop here. We will continue our discussion on corrosion failures and analysis in our subsequent lectures.

Thank you.