Aqueous Corrosion and its Control
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Lecture – 34
Effective corrosion management

Welcome to the last lecture on this course, MM 713 Aqueous Corrosion and its Control. Today, I thought I will just talk about in general how do you really you know manage corrosion, what are the broad guidelines that one would follow in controlling corrosion. Before we do that it is better to review what you have seen so far.

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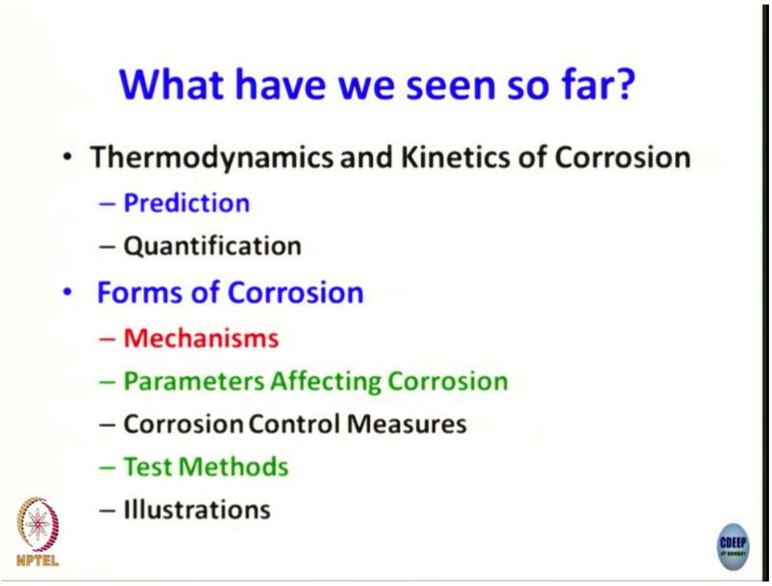

We said that we broadly categorized this course into two parts; the first part was on thermodynamics and kinetics of corrosion. The second part deals with the various forms of corrosion. And in the thermodynamics and kinetics primarily we focused on two questions; the first question was can we predict if a metal can undergo corrosion or not? And we used the electrochemical concepts to predict the corrosion, because that is much easier than using the free energy concept.

Then for quantification we looked at the kinetics of the corrosion. And wherein we started with the simple (Refer Time: 02:03)Tafel relationships the relation between the over voltage and the current as an electrochemical reaction would have. Then use that the

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And then we went on applying this to a complex systems of corrosion processes, wherein you can use the concepts to predict corrosion, in a complex situations where you have multiple cathodic reactions, where there are flow velocities, where there are some additives, where there are galvanic corrosions. In fact, we started applying this to all forms of corrosion we have been talking about when we talked about different forms of corrosion.

Having understood the how we can able to look at the prediction and the quantification of corrosion, we looked at the various forms of corrosion as applicable to industries we looked at the various forms of corrosion from the point of view of industrial applications only.

Student: Yeah.

And we thus classify them as various forms of corrosions primarily because the way you control corrosion would be different depending upon the mechanism of corrosion we talk about.

And so, we looked in details for various forms of corrosion, the mechanism of corrosion we looked at, we looked at the parameters affecting the corrosion, we looked at the corrosion control measures, test methods. In all these cases, we also saw the illustrations and to highlight how they are important and what are signatures that these failures leave behind. So, all this we looked at over the last 33 lectures, we saw that.

The one thing that we need to look at is the corrosion control is a major domain beyond understanding prediction, quantification of that and understanding the various forms of corrosion because it is occurring in industries, because it is a industrial problem. So, you must have a clarity in how do you approach the corrosion problem.

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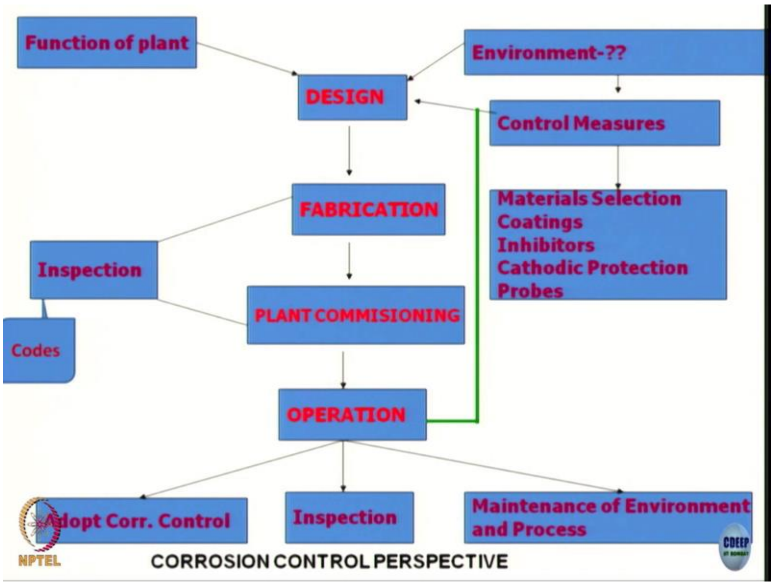

The corrosion problem I would like to see as a perspective as a control as a perspective. Anyone who talks about corrosion control, so start with the drawing board, right in the project stage. In the project stage it has to be integrated in the project stage. The no point in start worrying about corrosion control when you have you know commission the reactor and process is on because that is going to be very expensive process.

So, start with the design of system as you do you know as a mechanic engineer does for taking care of various other aspects of a reactor or a structure and so on, we should integrate this in the design itself.

How do you integrate; when you decide you integrate in the design the whole thing, then comes of course, the fabrication, right in the actual fabrication of the component. And I think now you must be aware of having understood various forms of corrosion, how the fabrication also can influence the corrosion, right; a welding problem could be one of the things, a dissimilar metals that you can come into contact with your problems you know. So, the fabrication also we should look at how the corrosion can influence we influenced by this fabrication.

The plant commissioning is the another one which is equally important in order to in order to reduce the corrosion process. There are cases where the people started the project by the time ended the several component got corroded actually, ok. So, it is important to look at the plant commissioning stages also, all right. And then comes the operation of the particular unit, a particular equipment, or particular industry for example, you know in here we should now take care of those aspects of that.

Now, I am going to now look at in each every case broadly. You know again its it is hard to go in much details, let us go little bit more broadly how you look at these 4 aspects of design, fabrication and you also talk about plant commissioning and operation of that.

When you talk about a design the first thing that comes is what is the function of that, right; what is the function, what function does it really do. That is the major things. Is it is it heat exchanger? Is it a pipeline? Is a conveyor belt; it could be simply a crusher it can happen in a cement factory what is the function of that.

Why it is important is please notice the material selection that you talk about does not primarily consider corrosion as the requirement many cases. So, material selection depends upon the functional requirement of particular industry component or all actually, ok. So, that is why you need to look at what is the function of the plant, you need going to be there. If you know the function then you can also start looking at the environment.

What is that environment? You should review the environment there; what kind of feed feedstock being used, ok; what are the input from there, ok; what are the pH of that and what is the chloride content and what is the water content in that; what are the organics present here; what are the temperatures, what are the pressure. All this we need to review and when you start reviewing this and you know what the function of the plant is then you can look at the control measures.

The control measures must sync with the main function of the plant, otherwise you know nobody is going to listen to you, right ok. Just because it is corrosion resistance you cannot use the particular material at all.

Now, corrosion control measures we have seen before I just want to just you know highlight to you what kind of corrosion control measures. It could be a material selection. You can talk about could be a coating, could be use of inhibitors, you can go for cathodic protection systems, in some cases even anodic protection systems you can use, and of course, when you talk about corrosion control monitoring is equally important, so you can use the corrosion control I mean corrosion monitoring probes for online monitoring probes are used actually, ok.

So, probes also can be because you know when I want to put probe you should have a provision in the reactor, right. If you have no provision in the reactor tomorrow you cannot just put a probe there, it does not happen. So, start the design stage. If you have this idea about it then they are incorporated into the design of the particular system actually.

So, the design stage you take care of them, then you of course, you talk about the fabrication and the things. Here inspection are a very important and people follow the codes (Refer Time: 10:26) codes are very important.

I think we are not dealing with this, right now. But as you go along and serve in the industry you know there are so many codes, API codes, for example, all petroleum things, ASME boiler codes we are going to be there. So, these codes would be enforced in all these stages even design stage, fabrication stage, commissioning stage, these codes will be a part of corrosion control exercise that you have.

Coming to operation, it is very important to adapt the corrosion control measures. You know you see in the design stage itself you decide know what you do, I am I going to go for cathodic protection or am I going to go for inhibitors or am I going to add I mean you know I am I going to you know go for a cathode protection for example, coatings. So, this whatever that you decide they are to be properly adapted in the practice, maintenance of the environment and process control.

See, I seen industries where people have designed for certain you know operations in terms of temperatures, pressure, feed, feed stock they use and tomorrow they change it because the feed stock they get are different. A refinery for example, they may get a crude maybe from somewhere middle east. There is certain amount of hydrogen sulfide present, certain amount of carbon dioxide present, they change the crude because the cost becomes low, but no more the constituents, the corrosion constituents are same. So, it changes.

So that means, you need to take care of that, you know if you; so, if you are going to do that then you should see how we are going to manage it otherwise the reactor is going to prematurely fail. I have seen cases where people want increase the production by rising temperature and pressure, just fails in a week. It worked for 20 years, just failed in one big time actually. So, the maintenance of the environment and process tool systems are very important. Look at the how much it can have excursion that is something very very essential, ok.

Codes inspection is a part of this actually, ok. Inspection and maintenance, they are all part of the systems. You need to look at the you know look at the inspection, inspection team should be aware of the corrosion issues how to do that.

Inspection itself is a big subject. Where do we inspect? Ok. It is a big issue. For example, I have a long pipeline of 1000 kilometer long, am I going to inspect every inch of the pipeline. So, people sometimes use models to look at risk based inspection.

We will see later, ok. Where you have more risk you focus on that location that is based on the models, based on the mechanisms and way you know how you predict where you think the corrosion becomes very severe. It happens in nuclear power plants, it happens in thermal power plants, it happens in many systems where the issues are very critical, they do that. So, it is a broad philosophy of corrosion control and we should really enforce that.

Now, what we are not seen, ok. So, when you when you what also you do is it is very interesting to see here when you do when you adapt corrosion control measures, you do inspection, you do maintenance, you learn new things. See the problem with the corrosion is it is a time dependent process; it is very difficult to have a test which can simulate exactly the operating conditions and get a data in short time.

So, many times you do an accelerated test either you over predict or you have underestimate the corrosion. So, when you do operations you know how the systems are working. So, what happens? You plough back, ok, you plough back what learned, what you learned from this from the operations and put it back into the designs. The next generation of design takes into account the experience. You also in fact, use it to refine your models, ok. So, that the predictive models becomes more useful at all.

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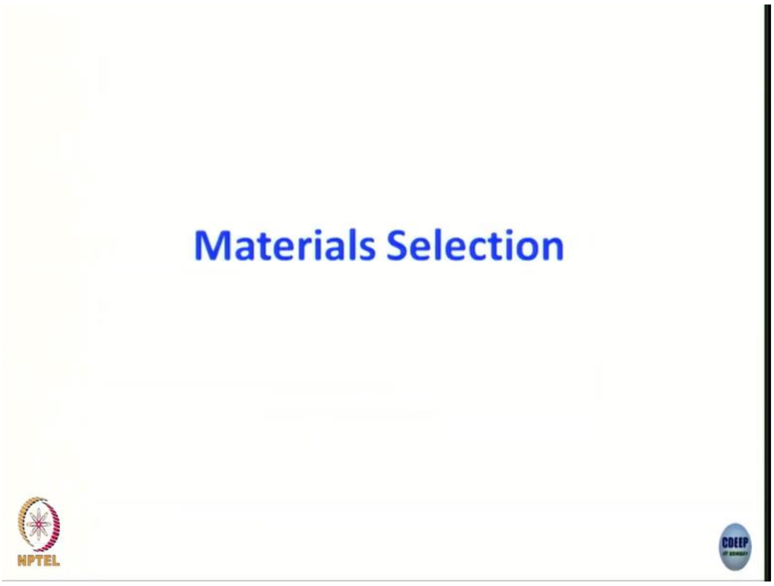

So, this is what I think is done. We will go to spend some time on material selection very some time ah. See material selection we have seen it under various forms of corrosion. So, when we say galvanic corrosion, pitting corrosion, crevice corrosion, all this you know erosion corrosion, even sensitization we have seen how we do a material selection for a given corrosion problem.

I am going to give a broad perspective here and you know, so that we save some time you know. If you take a FONTANA book it is a big chapter on material selection actually, ok. It deserves to be given, but it is introductory course and we do not have much time. So, I want to be a bit more brief in this.

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Somebody ask you as a corrosion engineer, what is the material, what is the basis of material selection. You simply jump into think that oh corrosion is the issue, so I want to choose a material which gives you a best corrosion assistance.

That is not the case, ok. That is not the case. There are so many factors that decide what material to be selected. I have given some of them here, but not it is not exhaustive list by no means. It makes to feel that how you look at material selection that is the reason why we have given this. But no way it is a comprehensive, ok.

So, first and foremost in material selection process as I have seen before you look at the operating conditions, you review the environment and you foresee possible failure mechanisms, will it suffer a stress corrosion cracking, will it undergo selective leaching, will it undergo sensitization because you have now expert. That should be much easier for you to do that, ok.

So, if you know the operating conditions and it is possible for you to predict what kind of corrosion mechanism, corrosion failure it can it can operate a given situations. So, the material selections that is the main hinge, and that is point. If it having a problem you have to search alternative material or you have to find some other way of overcoming the problem, ok. But you need to recognize what is the kind of corrosion problem even operating conditions can happen in a plant.

The second issue is the product requirement, right. Sometimes the engineering allows certain amount of corrosion. We have seen it also earlier you know when you select materials only the corrosion allowance we talked about, right. You can you can put a corrosion allowance. But then the product says no you cannot allow any corrosion to takes place, ok, because it may be a drinking water, it can be for a pharmaceutical industries or some kind of chemicals you make you do not want to be contaminated.

So, there is another requirement which is a product requirement. The product requirement demands a high purity, I think corrosion resistance becomes utmost important. You select the material properly, ok, so that you can bring down the corrosion rate. But sometimes what happens you bring down the corrosion rate by just employing a stainless steel, the stainless steel cracks because that environment that temperature content is such that it cracks.

So, you may bring down the overall corrosion you know rate by choosing stainless steel, but you are going to have a newer problem. In which case, what you do? You probably go for a carbon steel, you give a lining, you can give a glass lining can work actually, ok. So, that is how it works.

So, the material selection process is a evolution process. It has many dimension to that actually, ok. The one more issue, somebody in oil and gas industry they have offshore platform, there is a drilling, there is they are they are doing a drilling there, and then taking a oil and I want to choose the material. What is the problem there? The problem is the replacement becomes a problem, right even I say that I want to replace the replacement cost is much more than the cost of the component actually. So, which means you better go for better materials.

There is another rider comes over there, ok. So, where you cannot monitor, where you cannot inspect, where you cannot replace it quickly you have no choice, but to go for a better material with respect to corrosion actually, that is an another factor that comes into picture.

Design and fabrication or you choose even good material, but you cannot weld it. Very nice cast iron, ok. You have iron you know and 14 percent silicon based corrosion resistance. You know you can have it; you cannot weld it actually, right. So, there are other factor that comes into picture is can you really fabricate. What is the other requirement that you have, that comes into picture here residing this.

Maintenance, in some cases I can afford to inspect maintenance you know once in 6 months, some cases I cannot afford do it for 3 years, 4 years, ok. So, then what happens? Then obviously, the choice of material the cost is not going to be consideration there at all actually, ok.

If you are going to give additional production measures then you can reduce the cost. A ship hull is an example. Your carbon steel used, right it is not a great material, but it is used in seawater applications how you apply a coating; you carry out a cathodic protection it does work. So, you can also look at additional protection methods used and so, we can go for a cost effective material can happen at all, ok. Because all this we are doing because there is one factor many times you know you need to consider it can be overrating also is a cost of the material actually.

The cost is more then of course, you are nobody is going to listen to you. The cost again should be seen not in the cost of material the cost will be seen in a broader sense like life cycle cost. If I use a carbon steel will work for 2 years, if I use a stainless steel it can work for 20 years. I mean you cannot compare the cost in that manner. How do you compare it? You compare it as a life cycle cost, ok.

And of course, you know suppose you do a good painting, the painting very painting process is very expensive you know it can be equally casting as a paint itself, ok. So, then you go for better paints because it is not going to be easy. All are fine, I want to use materials there is a big embargo, right, you are not getting material India now, right. What do you do about it? Right. So, materials availability is equally important one.

Or, I come out of the fantastic design from mechanical engineering point of view or this gives you better efficiency, it does everything. But what happens? There is no material available to withstand that operating conditions. One is availability, the ability of the materials to function the way that you want it actually, right.

So, there is another dimension to the to the problem, ok, selection materials, from purely from mechanical engineering point of view, chemical engineering point of view does not work because that material may not. In fact, there are several applications. The critical thing is what material, right; you cannot withstand very high temperatures I want to have it 1500 degree Celsius. It does not happen, ok. So, material availability is one more thing, ok.

All of them I have fantastic low cost; I produced only yesterday I have only small data that I have. I want to fly tomorrow; I want to use it in the aircraft. I think they are think very much. The data availability, how robust this data can count a lot in terms of in terms of material selections. So, that is some way very cautious.

So, that is why people what the people do is they time that is developed a particular material and come to the production usages probably maybe 10 years, 5 years, it takes because the data becomes a problem. If the data is not available you have to be extremely careful, in terms of you know selecting materials or if you select it I have to have some way of monitoring that more properly, ok. So, these are some basis for material selection.

Please again they are not by any means all exhaustive, right. You can add more to it and because as you start practicing you know there are so many critical issues which decide which add to the material selection issues. So, that is what I think you should you should consider in this actually.

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Now, when you are talking about material selection we always you know you know see people look at differently at different people, material selection, in my experience like that. If you are going to talk about you know in heat exchanger, a mechanical engineer talks about because of the point of heat transfer, ok. He looks at heat transfer.

When a corrosion point of view, it is a different issue together. I can tell you suppose I use a copper based alloy and copper based alloys have high thermal conductivity as compared to carbon steels as compared to stainless steels.

But you know what happens to be the copper alloys, copper alloys with the time it may not corrode more, but it starts falling. It just falls. When it falls it forms a scale, and those scales are what? They are you know you can hinder the heat transfer. And so, what happens? Then heat becomes a problem.

So, the material selection when you talk about we had look at various properties not this is (Refer Time: 25:43) corrosion actually you know. In fact, I see in this happening more with the with the people like the people will not have background of metallurgy actually and would involved in design. They do happen and get into problems.

So, we have seen it also in you know the last about, so you know lectures we seen, ok. And in bits and pieces we seen you know how the material properties affect, but I give you a bit more a comprehensive manner.

Heat treatment. Can you give an example where heat treatment can be a problem in for corrosion? Yeah.

Student: Sensitization.

Yeah, sensitization. It could be a problem. We are going to use aluminum alloys (Refer Time: 26:33), aluminum alloys, heat treatment could be a problem because you would use it is going to get embedded in environment, right. So, heat treatment could be a problem. We are going to use a martensitic stainless steel or steel; if you do not temper it you are going to undergo stress corrosion cracking hydrogen embrittlement can happen, ok. So, heat treatment is something one really looks at it.

Hardness, macro and micro. Again macro in overall sense, micro means suppose you weld what happens to the weldment, does the hardness increase, you can affect stress corrosion cracking hydrogen embrittlement. Of course, tensile properties, toughness, ductile brittle transient temperatures.

Student: Ok.

Stability against temperatures, you know again corrosion is what we are looking at actually. So, these are the properties that you watch out for in overall you know you know in the overall aspect in designing a particular reactor, particular vessel and so on.

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Now, come to materials, ok, we generally I put here metals I am not covering the non-metals. Please understand that there is no way you can exclude other materials, for the construction purposes, ok.

There are plastics and there are ceramics we used, there are non-metals are being used actually, ok. And, but what I listed given list is kind of broad you know you know broadly they are used I would say and I have given you can see here the cast irons, steels, low alloy steels, stainless steels, nickel based alloys, copper based alloys, aluminium alloys, titanium alloys, zirconium alloys, tantalum; tantalum is not used as an alloy normally used as a element only, ok.

Now, these are the materials generally used and again the criteria for choosing any of this we have seen before. What does the kind of criteria that we talk about, ok. They should all apply over here, ok, so that you can optimize the material selection for a given application in this now, ok.

Let me just give you a broad thing about how materials are being used in the things now. I just touch upon first the ferrous group of metals based on iron, ok. How do we really use actually?

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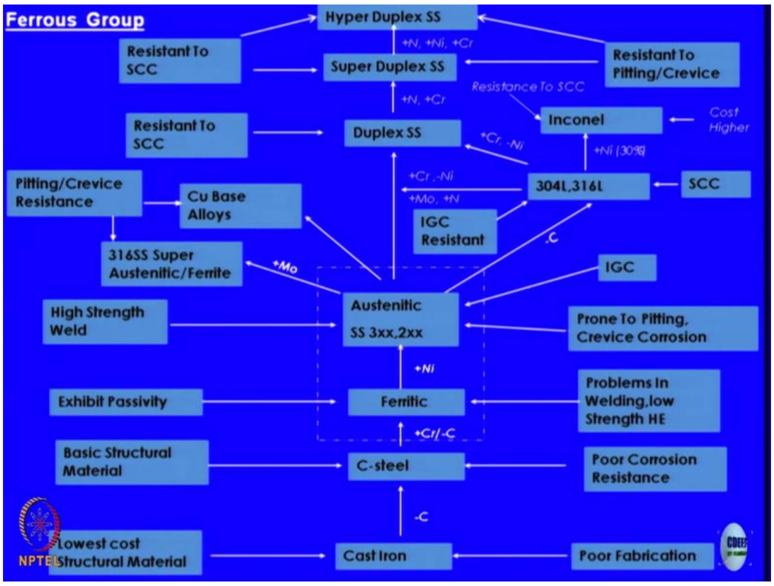

So, let me start with the ferrous group of the metals which I think ferrous groups are very widely used among all the alloys we listed now, ok. And in the ferrous group the basic material is a cast iron, and you know what a cast iron is it has a large amount of carbon in that and so, the cost is less and can be used as a structural material. But what are the limitation of this? What are the limitation using cast iron? Why cannot use everywhere cast iron? Yeah.

Student: It is brittle.

It is brittle, can be there are of course, some cast irons are ductile also. So, you cannot fabricate it very easily you know. The fabrication becomes a problem. When workability is a problem you cannot draw into a sheet, you cannot draw them into wire. So, that is a problem that you see in the case of the cast irons.

So, what you do is you remove the carbon in the cast iron, you get into the carbon steel. The carbon steel is a basic structural material even. If you look at many of the important industries, refineries, chemical process industries, power plants, the major constituents of materials is still the carbon steel. We may talk about stainless steel all this, here they are important, but the major structural material still is the carbon steel.

So, it is advantage you can fabricate you can weld lot of advantages of that, ok. What is the problem with that? The problem is it is a poor corrosion resistance. It is a basic material the corrosion resistance of that is it is not that great.

So, how do improve corrosion resistance? You add chromium, but you cannot add chromium when you have large amount of carbon. So, remove carbon you add chromium, you get into a stainless steel that is called as ferritic grade stainless steels.

It has got a reasonable corrosion resistance as it exhibits passivity, ok. But what is the problem? The problem that lies here is that it is difficult to weld you know you can weld, but the weldability is little bad, it has got you know poor resistance against hydrogen embrittlement. So, we want to improve upon this, what you do? Add to it a nickel, right, add to this nickel. When add nickel to it you get a different class of stainless steel which is an austenitic grade stainless steel.

There are 2 types here, 300 series 100 200 series, the 200 series is a is having more amount of manganese and the 300 series consist of nickel as the alloying element. You know nickel is required to stabilize the austenitic phase. When you use this one it has got high strength you can weld very easily I mean no doubt about weldability is very good. But what is the problem here? The problem with this stainless steel it is prone to pitting, it is prone to crevice corrosion, of course it is prone to stress corrosion cracking as well, ok.

Now, in order to minimize or lower the pitting tendency crevice corrosion tendency, what you do? Add to it molybdenum to this you get 316 stainless steel, you get a super austenitic grade stainless steels, you get a even super ferritic stainless steels. So, you get another variation of stainless steel they are reasonably resistance against pitting corrosion and crevice corrosion.

In order to avoid pitting corrosion, you have other alternative. Alternative is what? Copper based alloys, ok. So, we will not be covering here copper based alloys, but you have an option of going to copper based alloys. But this copper based alloys and high moly containing stainless steels are generally resistance against pitting and crevice corrosion actually.

Now, when you take a austenitic grade stainless steel generally they prone to sensitization we know about that, right. So, how do you control this? You minus carbon ah, right. You get a new variety of stainless steels which is 304 and 316 L, low carbon stainless steels. You know how we can reduce that. And this you know the one here the ferritic here and austenitic here, this is the two class of stainless steels are used. Between these two austenitic is very widely used. Ferritic of course, are used for limited applications. They do that.

So, low carbon stainless steels are of course, resistance to the sensitization and, but then you are not address the issue of stress corrosion cracking so far ok. So, how do you address this? You go into duplex grade stainless steels, right. Duplex grade stainless steel here means it consist of a ferrite phase and a austenitic phase.

How do you get it? If you go from austenite, you lower the nickel content, right you increase the chromium content, you get into duplex grade stainless steels, and. So, this how you develop this kind of stainless steel which is resistance against stress corrosion cracking (Refer Time: 35:40).

But nevertheless the alloy is still prone to what is called as the crevice corrosion. You can also go for high nickel alloy which is inconel actually. The inconel gives you high resistance against the SCC, but the inconel is expensive, ok. So, you can strike a balance between austenitic grade stainless steels and inconel alloy in terms of cast. So, you go into duplex stainless steel and you can have assist resistance offered by the duplex stainless steel actually.

It cost more as I told you and it is resistance to SCC, but if you look at the duplex stainless steels they are still prone to crevice corrosion and pitting corrosion because you remove nickel content in this actually, right.

So, add nickel, add more chromium, you go into what is called as super duplex stainless steels 2507 we talked about, this 25 chromium 7 nickel that we have, ok. And it has got resistance SCC, it is resistance to pitting corrosion, crevice corrosion, but it is not reel resistant, you cannot use the sea water application, still there are some issues with the duplex stainless steels.

So, recently they have come out with the a better grade of duplex stainless steel which is called as hyper duplex stainless steels, add further nickel, you have further nitrogen, you further chromium to it and again maintain the phase balance and this alloy is offering resistance again SCC and pitting and crevice corrosion resistance. So, they are being used in sea water applications, ok.

Of course, when you when I do all this happily like a tree going from cast iron to super duplex stainless steels to hyper duplex stainless steels on to I mean inconel alloys you have to keep in mind the cost also goes up from the bottom most to the topmost. So, the corrosion control also comes with the cost.

But the bottom line is what? Bottom line is lifecycle cost. The safety involved here. See, there are certain things as I told you when I talk about material selection I did not discuss about safety involved, environment involved. There are so many issues which we also talk about any when we deal with the material selection.

So, this is about the ferrous group of materials used you know in industries and lot of developments have taken place over the time period.

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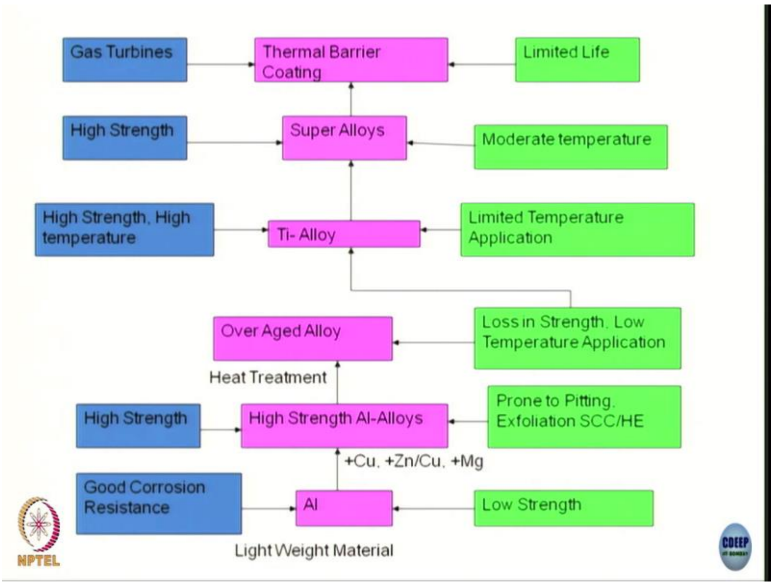

The next class of material which is called the aluminum light, light metals actually. Light metals from the corrosion point of view the not may used. As I told you that material selection depends upon what? Depends upon the functional requirement. Light means it is required for certain application like transportation application. I want to be light, ok. But otherwise some application you do not care it should be light at all.

So, aluminum is used in the transportation industries and it is also used where you do not want to spend too much money and you want to be corrosion resistance you know that is also possible to do that. So, let us look at this aluminum alloy aluminum, it is a light metal, and you have good corrosion resistance you know it forms a stable oxide film in the atmosphere, so it is resistance to corrosion, ok. That is really good thing, but it has a low strength.

You know very very pure aluminum, you know what is the strength of it. It can be 50 to 60 mega Pascals, so low, right. So, what increase the strength? Further, what you do? We add this alloying elements such as copper, zinc and copper, magnesium you know the various alloying elements are added and there are several different alloy systems have been developed. 2000 series and 7000 series aluminum alloys or high strength aluminum alloys.

When you add these elements, when you increase the strength, strength goes up, ok. We talked I think other day may reference to peak age and over aged kind of things. When you add the strength, you know when add these elements the strength goes up the problem is there the problem is it is prone to pitting, prone to exfoliation, prone to stress corrosion cracking, is prone to hydrogen embrittlement actually. Especially, exfoliation stress caution cracking and hydrogen embrittlement are related to the micro structures, and microstructure depend upon the alloying elements and the heat treatment.

So, if you have high strength, well the service life it is not going to be great because they are prone to this kind of corrosion problems. To overcome this you give a heat treatment and that heat treatment is called as over aging treatment and over aging treatment, ok, there is a loss in strength. That is one of the problems.

But it is resistance against SCC, resistance against exfoliation and embrittlement are all. It is good, but there is a loss in strength. But there is a problem. What is the problem? The aluminum alloys cannot be used for elevated temperature applications, right. Why?

It precipitates dissolves now the strength is lost. So, there is a limitation in using high strength aluminium alloys at elevated temperatures. I am not talking about high temperature I am talking about just elevated temperature itself it is not going to be, ok.

So, in order to overcome this people go for the titanium alloys. It is used in gas turbines, ok. Very very extensively used in gas turbines, in medium temperature range actually around 250 to 400 maximum people use a titanium alloys, ok.

Titanium alloys have high strength, at high temperatures. When it is high temperature please look at as medium temperature in the range of 250 to 400 degree Celsius you can use, ok. And, but again it is limited temperatures, ok. I cannot take it 600, 800, it is not possible, you cannot do that.

There is also some problems you will you will talk about titanium alloys, ok. What are the problems with titanium alloys? You cannot use it for storing dry chlorine gas you seen before, right, ok. It titanium alloys are very good as long as it is aqueous condition. If it is a non-aqueous condition the titanium alloys I think are not going to be great actually.

And you want to raise the temperature further you go to super alloys they have high strength and reasonably high temperatures you can go to 800 degree Celsius and all, ok. And again moderate 800, you can do. You want to go beyond that what happens? Super alloys are not having strength. And also what happens? They also suffer oxidation, hard corrosion. You studied the a course on high temperature corrosion, right. There you have a detailed idea about how the super alloys are vulnerable to various forms of corrosion at high temperatures.

In order to overcome this people give what is called a thermal barrier coatings. The thermal barrier coatings, it is a composite coating. It is right, you may also have a bond code and you can also have a ceramic code, it increases oxidation resistance, it also reduces the surface temperature of the super alloy component because thermal barrier means it offers a reduction in the temperature because of the insulation property of that.

So, it is used in gas turbine applications, ok. And what is the problem there? It is a limited life you know, right. Yes, limited life and we need to refurbish it actually, right.

There are some life for these blades and again you have to recoat it or nothing you needs to do that.

And nowadays people are looking at simply ceramic blades, they are not looking at, ceramic blades and where it is supposed to have good toughness. And of course, ceramic blades may have you know less problem, I mean there will be more problem of oxidation and chemical resistance attack you know that could be a problem, but they are things are going on in some direction of that.

In fact, GE is supposed to come with engines with the ceramics replacing some of this super alloys or high temperature applications. You need high temperature in order to make the turbine you know efficiency higher. So, that is about the light metals. Then, we can look at the other kind of alloy the major alloys are used or the copper based alloys, ok.

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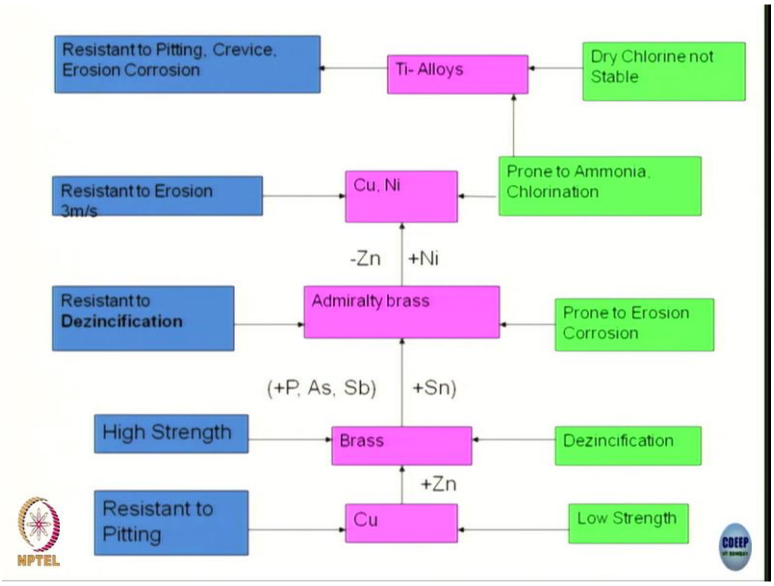

They are used in the applications, the copper base alloys are used and it is resistance to pitting, resistance to crevice corrosion, it is very good actually. But what is the problem with this? It is a low strength. You want to increase the strength of this, alloy with zinc. And alloy with zinc what happens? You get a brass. Now, brass has high strength.

Student: Ok.

What is the issue there? It undergoes dezincification, certain processes. So, how do you over come that? You add tin, antimony arsenic phosphorus, ok. These things are added to reduce dezincification and leads to admiralty brass. The admiralty brass you know it resists dezincification, but you want to increase the zinc mod it does not help, right. And so, it is prone to erosion corrosion.

You cannot withstand higher velocity in the pipelines. And you want increase zinc then what happens? You can have erosion corrosion resistance, but it is suffering dezincification problem. So, what you do? You go for you know you go for nickel addition to copper and you get cupronickel alloy here. And the cupronickel alloy is resistance to erosion you can go to 3 meters even, yeah 3 meter per second is the limited limit of which the material can resist.

See, again please look at when I say 3 meter per second, you are going to have a very corrosive liquid 3 meter per second is not I mean valid. We talked about normal water may be sea water, ok. So, these are to be seen in you know within with certain within qualification line, ok. You know otherwise you cannot blindly just use this these numbers everywhere actually. They are only indicative.

And cupronickel alloys are prone to ammonia and prone to chlorination, you cannot do every high chlorination actually in the systems. And so, you go for titanium alloys. So, if you have very high chlorides and ambient temperatures, if you go a titanium alloys, but titanium alloys have the problems the dry chlorine gas it cannot be stable and its resistance pitting crevice corrosion, erosion corrosion damage. All this can happen.

So, I have given broadly 3 class of materials and how it can be used and what are the issues involved here in a very brief manner, to get a feel for the materials properties and the selection criteria for them. Any of you have any questions here? So, hope things are clear.

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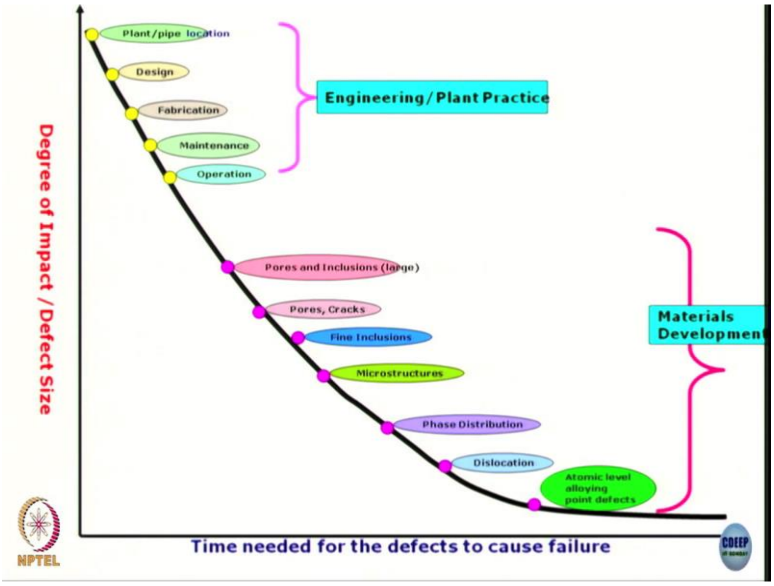

Now, I am going to go to the next aspect of this. Now, how do I look at material? How do I look at materials development actually? Ok. Now, I have given you an axis here, it is an x axis, time needed for the defects to cause the failures. Now, the time needed to cause the defect to failure has to be higher than the service life of a component, right. If I decide the service has to be 10 years, the defects should take maybe 11 years to cause the damage then the component integrity is fine, otherwise what happens the component will start failing, ok.

So, the time needed to cause the failure will depend upon the kind of defect that you have. The things that go without saying is the nature of environment stresses strain, I am not talking about it, ok. I am just comparing that the environmental behavior is similar and what will happen if I change the size of the defect.

Now, we look at the degree of the impact and the defect size, if I start, relating these two you get a very nice picture about the corrosion control on one side, materials development on the other side of it actually, ok. This is this thing.

Now, what could be the bigger defect? What could be a major problem? The problem is the plant itself the location of the plant itself you know. Suppose, you have you have established a plant, just at the seashore or a creek where the sea breeze all the time this knocks the plant, ok. You have huge amount of chlorides coming to and there can be frequent problems of one component or other component.

In fact, I have seen a case in one of the refinery over here. You guys know what is called a cooling tower, right, previous cooling tower. Cooling tower is used to run the heat exchangers, right. The they chill the water by counter current that water is now sent to the heat exchangers actually. How does the cooling tower work? Water goes from the top you know from the they can somewhat atomize it, on the bottom you blow the air, the air takes away the heat, and then water gets cooled down.

But when the when the when the air goes from the bottom like this, ok, it also carries moisture, it carries water. And when assume that that is in the center of the unit, center of the plant you can imagine that whatever the wind goes it going to carry and all the surrounding areas suffer huge upper corrosion.

So, plant location is a very important thing and wherever it is possible this to be considered. If you have a problem I think you are sure that the time for failure is very short. I given here the time to failure, time to failure is this, this much, it can happen quickly.

If you plug that particular problem, assume that that you work on the problem and you have a problem in the designs of that it can be catastrophic stress concentration happening, stress corrosion cracking can happen within 4 months within 3 months, ok. So, I think if there is a faulty design, you find then again you will see that the time to failure is less. If you fix the problem of design you got into problem of fabrication, you did not properly fabricate and I think again what happens then the time of failure is extended, but still is not too far.

If you fix the problem of fabrication, if you do not look at maintenance inspection all these kind of stuffs in the industry, again it is going to be premature failure, right. Again, its time is increasing failure, but then again it fails operation maintenance of that. All this are part of the engineering practice, there and the plant practice operating practices, ok. It is not related to metal alloy, just a guy who makes a material. You may get a better material, but you do not do things properly. I think it is going to make a failures in this case.

Assume that all these are taken care of in this case and the life of this can be extended further into that actually. Then what happens? Then you get into issues related to materials actually. If all I am doing this well, but you do not use the right material then it is going to cause the problem. The material can have a defect, it could be porosity, you are welded, weld as a porosity; you casted as a porosity, and it can big force inclusions can cause the problem it can fail this. You have seen, the time has improved from here to this, but again it is a premature failure.

But a taker of this large inclusions and all, but you let the small pores small cracks, p pin in the material then what happens? Then again, it is going to now fail prematurely, that, but you have travelled quite this quite a bit quite a far distance in terms of time. You done it actually.

But if you can get rid of that, but you can look at fine inclusion this is of course the manufacturing process; have; we talked about earlier what? We talked about the hydrogen blistering where the inclusions are part of it, right, the inclusions can be they are fine inclusions actually.

They are not very coarse inclusion they are fine inclusion. They can cause problems in the system, but you can take care of the fine inclusions and if you do not take care of micro structures, ok. The micro structure is at a next level of dimension wise, right. You do not take care a micro structure. I have not done a over aging, I done a peak aging, you finished, ok. It can fail much much earlier. It can happen.

So, if take all micro structures, but you have done some cold rolling, their dislocations present in the materials, it can cause test corrosion cracking. So, if you do not you know and phase distribution again you know this is another thing, whether it is whether your gray cast iron or white cast iron the phase distribution can be one problem, fix that, you get into dislocation other dimensions of that again the life is traveling like this here.

So, fix the problem of dislocations, then we look at elements at the atomic levels atomic level alloying elements, ok. Alloying elements point defects all of them going to be there. This add to be engineered now.

It is very important. It is very important when you talk about a long term implication. I give an example where long term means you never imagined actually. Can you imagine that I need to have a storage vessel lasting for 10000 years? Have you guys have ever imagined about it? You need it to store nuclear waste.

The nuclear waste takes long time to you know, it is where in this decay, right this radioactive decay it takes about 10000 years or so, in order to succeed all this decay and need to contain them in a vessel. Now, what happens now? Now, you have improved the life and all, but 10000 years is really a pretty long time and nobody is going to be here to see witness that actually, right.

But assume that I have taken very nice nickel based alloy or alloy of very high purity, I say sulphur is sulphur is reduced so much reduced 0.00 maybe put three 0s and let say about one sulphur, ok. You would very happy because input is a control atomic level everything is controlled now. But now imagine that the metal corrodes over a time period.

Now, when metal corrodes what happens now assume that nickel corrodes, iron corrodes, chromium corrodes everything comes may be very very low rate no problem. But what happens? The sulphur gets enriched in the surface. One atomic layer of sulphur on the surface is sufficient to simply depassivate all of them. It is possible for to calculate how much material is required to be corroded before I enrich the surface with sulphur, ok. So, that means, it could be a problem. We never anticipated that this surfer can be a problem because they are looking very good.

So, when you talk about life longer life I think what was counted so far is not that you know it is not enough, you need to count more than that. So, designing alloys at this level is very important in order to have a longer life of this component. And these are all we call them as material development, ok.

The material developments depends on in the life of the component that we expect from here. But again if you engineer materials at that level, then what happens the cost also goes up. But then there are situations where cost is not the just a criteria safety becomes very important.

So, the material development is ongoing process and the corrosion is also an ongoing process. The issue of corrosion was not that today, but you cannot say the issue of corrosion will not be there tomorrow because we talk about environmental issues, we talk about sustainability we talk about depleting resources and so, the corrosion becomes very critical in all these cases.

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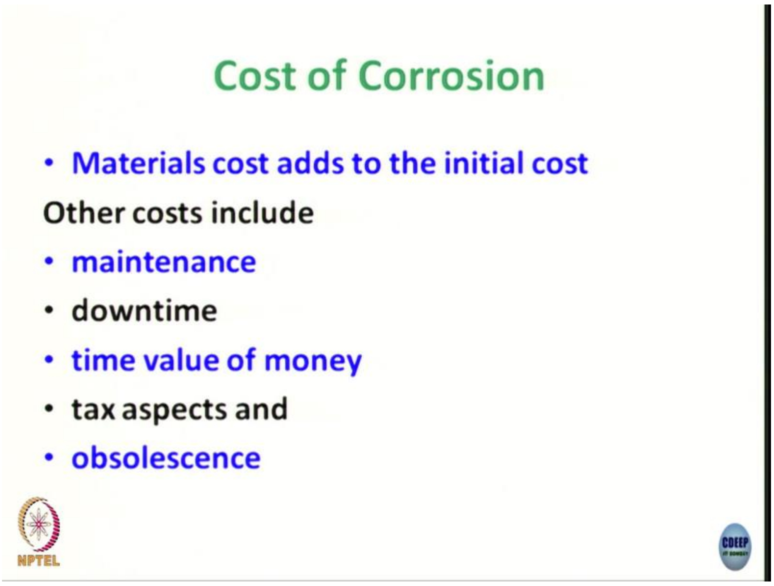

Now, coming to cost of corrosion, it is very important when you look at what the cost of corrosion means. Now, when you talk about material selection also, you know it starts from that you know, now when you talk about cost of corrosion I mean what is the how much it takes for me to reduce corrosion, right or what is the; so, if I am going to look at material is something very expensive material, or cost more, but that only adds to the initial cost of corrosion control, right.

But you look at what are the cost of corrosion you know that should be added to it, right. If you imagine that I am going to have a frequent maintenance, frequent shutdown, then the time for value of money is increases. I can say that I have now working on 2, 2 2 projects with industries.

The problem started sometime it start a problem in April or so I think, ok. And the person calls you and say this is a corrosion problem. Even today the investigation goes on, ok. It is almost now what from April to now, how many months are over? It is almost about 7 months are over. 7 months are over we are not got into root cost of the problem at all actually because so many constrains involved downtime.

So, we do not know what is cost of that, ok. And there is one more case, there is a its a pharma company is very well known internationally known pharma company which produces drugs, very very much actually, there are 3 reactors all shut down, and now is going on.

Now, it is, so, when you talk about cost of this it is not seen only in that perspective of it; what is the down time that is involved. And some cases you cannot afford downtime where it is for example, defense. Can I keep the readiness of the this? I have to keep them ready, right. I cannot have luxury, ok. I am just losing the profit fine, but here it is not the question. The question is it really readily ready for use. So, some cases you cannot really afford to that actually, ok.

So, when you talk about cost of corrosion I listed few of them, but again it is not only that I want you to think broad that is why I am just giving this here actually, ok. It is no way an indication of that I have added everything to the cost of this actually. Think more than materials more than fabrication and more than you know safety involved. There are several issues involved in defining what the cost of corrosion could be actually. So, it could be a problem.

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And so, people look at the corrosion control in many ways and you know and one is called as the asset integrity management, ok. You know see you know I have an asset now and I want to see it is this is functional, ok. So, this is a very important subject.

People nowadays are aware of it actually and they do it in a very periodically; see that the assets are you know are good or functional, ok, and how do I manage this. And again inspection becomes important part, and again inspection sometimes very difficult; in aircraft what portion what portion will you see that actually you know. So, that means, you go for what is called as a risk based inspection.

Now, when you talk about risk based inspection then becomes mechanism becomes important, then (Refer Time: 61:09)Tafel lines becomes important, right and thermalize becomes important, ok. If you can able to measure everything physically then they are not important, right. Because I can go and measure it and all, right.

So, where they are important is that when it comes to prediction when you want to see how I can able to manage things with you know for that I need models, I need understanding basic understanding of that, ok. So, that is a very important thing that happens in the you know in keeping the assets you know working actually. You know and then do all kind of inspection management and all.

Now, again this is a big job here you have inspection, you collect the data, how to analyze the data actually. I just measure potential, right. How do you analyze this? Unless you understand science of it, otherwise you say a potential it has gone from minus 500 to minus 400, oh, it is going to go like this. I mean what? Sometimes going from minus 400 to minus 500, minus 400 to minus 500 may be good, sometimes reverse may be good, depends upon what happens there at all actually, ok.

So, there are lot more in managing the corrosion control of any equipment, ok. And again important is the management how the particular management visualizes the corrosion as issue sometime you know you see that it is a pipeline failure 15 fellows died, gas got you know catch fire and corrosion everybody talks about it and then again substrates again till another failure occurs, again work up and then start looking at it, ok. But I think things are no more same because there are stricter environment regulations and controls as it goes I think the corrosion failures are not affordable anymore. So, that becomes very important.

So, with this I think I would like to stop my discussion on this particular course. I do hope you guys had some broad perspective about the basics of corrosion and you know and how do you really tackle at the introductory level actually, ok.

So, thank you very much. And I hope that you continue to work on the corrosion control thing and read, so that you get more and more enriched on this topic.

Thank you very much.