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

Lecture - 40
Stress corrosion cracking: Mechanism (Part 2)

Let us start lecture 40 and we talk about Stress corrosion cracking. And mainly we will concentrate on mechanisms of stress corrosion cracking. In the way we will talk about hydrogen embrittlement or hydrogen assisted cracking and later on we will touch upon corrosion fatigue. And then finally we will talk about protection routes or mitigation routes, if some material is experiencing SCC or stress corrosion cracking or corrosion fatigue or hydrogen embrittlement.

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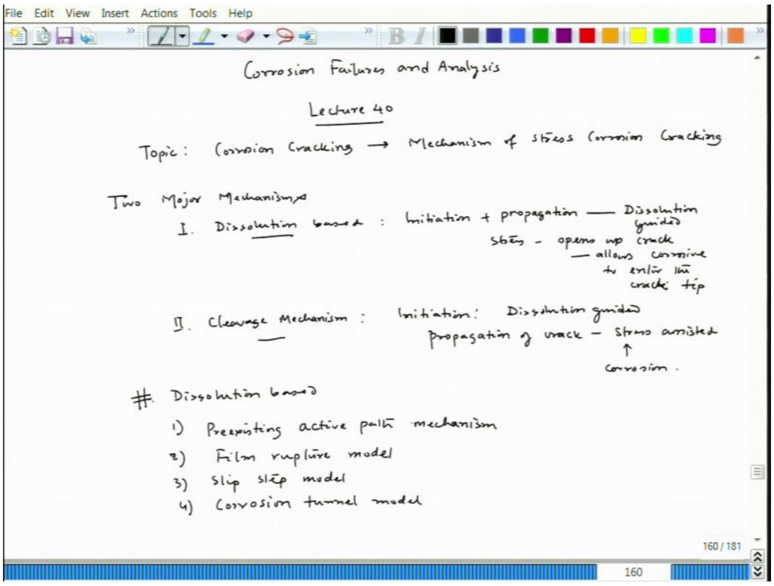

The course is Corrosion Failures and Analysis. This is lecture 40, topic is corrosion cracking or environmental assisted cracking or stress assisted corrosion cracking and we are talking about mechanism of SCC or stress corrosion cracking. Now we talked about two major mechanism; one is dissolution based, where initiation plus propagation a dissolution guided and stress. What does stress do? Stress opens up crack and allows corrosive to enter the crack tip.

Now there is other mechanism which is cleavage mechanism, where initiation is dissolution guided and growth or propagation of crack a stress assisted. Now, here also corrosion can play a role, but that is a second fiddle to the propagation of crack, but the stress is the main reason for the propagation of crack.

So, there are several other mechanism within those major mechanisms. One is dissolution based, if we try to find out what are the several mechanisms that are there in under dissolution based. If we try to find out then 1st thing that comes preexisting this is one of the oldest proposed mechanism for SCC; preexisting active path mechanism. And 2nd is one can have film rupture model, 3rd is slip step model and 4th one can talk about corrosion tunnel model.

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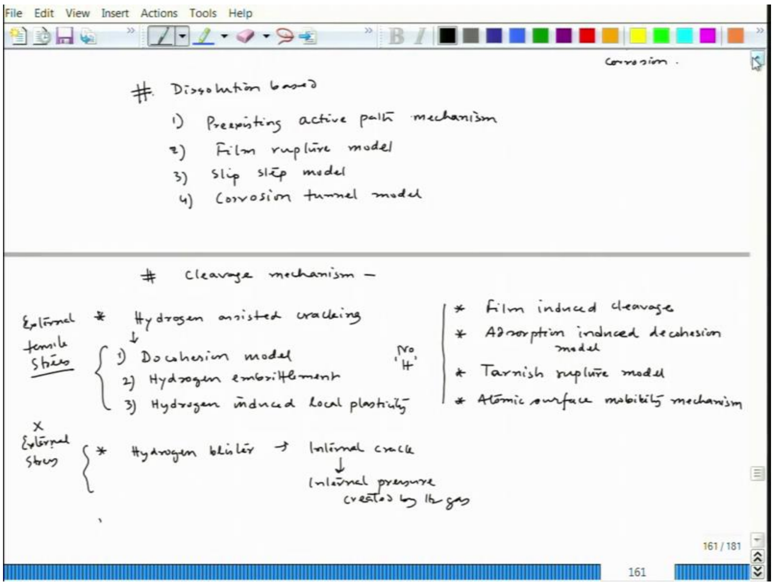

And interestingly if we talk about on the other hand if we talk about cleavage mechanism there are several other variations and out of that there are two segments; one is you can say one part is hydrogen assisted cracking and the other one is other variations are like film induced cleavage.

Then adsorption induced look adsorption induced decohesion model, then one can think of tarnish rupture model, then atomic surface mobility plasticity sorry surface mobility mechanism ok. Where we do not involve hydrogen ok; like there is one more mechanism in this particular section what is called I think this is fine.

So, there are other sub division of those models, but we can only discuss this four major variations then we can in case of hydrogen assisted cracking. So, there hydrogen is not involved no hydrogen. But in this case we have hydrogen involvement. Now one is definitely within this there are variations like one is decohesion model, second is hydrogen embrittlement one can also think of hydrogen induced local plasticity. And finally, there is one more now in this all those cases we involve stress ok, there we involve stress and those stress is tensile mode.

Now, there is one more which is little different, but still it is a basically hydrogen related failure we call it Hydrogen blister ok. So, this is there it is not involving stress rather i would say external stress ok. So, here of course, this material must be having a stress component external stress component ok, but here you do not have external stress component.

So, that time so if this blister also leads to failure or maybe delamination or kind of internal crack, so that internal crack would be due to the internal pressure created by hydrogen gas. Now, why it happens that will talk in a little while, now coming to decohesion based not decohesion it is a dissolution based model.

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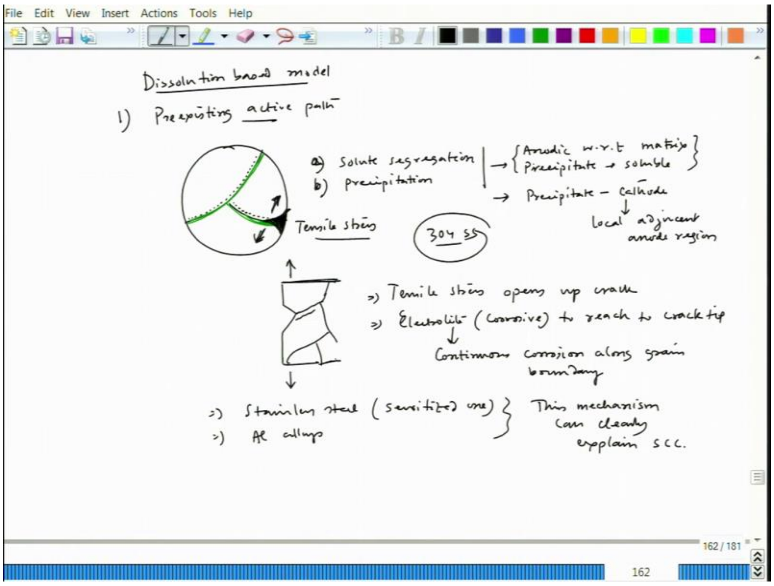

See, if we talk about dissolution based model, now there the first is preexisting active path. Now many metals and alloys if this is the metal microstructures, if these are the grains. There could be either solute segregation along the grain boundary along the grain boundary I 1 is solute segregation just hold on for a is solid segregation there could be precipitation ok.

So, now these two things can make a grain boundary either anodic with respect to matrix or those solute and anodic to that means, those solute segregation leads to a local region which is thin anode region compared to the matrix part. This precipitate could act as a soluble precipitate ok so this is one.

And other option would be this precipitate itself is cathode ok and then that leads to a local adjacent anode region. In both the cases you could see that the grain boundary area this grain boundary area is vulnerable for dissolution ok. Now, let us say there is a crack, so that crack is growing like this. So, this is the crack within this material ok.

So, let me just put it in this fashion, so here with the crack is growing ok. So, this is the crack this crack is going growing and this crack would be quite sharp now ok, so this crack is growing. Now here we have tensile property sorry tensile stress. So this tensile stress tries to open up the crack and this particular effects depending on the situation of that particular alloy system.

For example if it is a 304 ss stainless steel where it is sensitized then chromium carbide would happen along the grain boundary and then surrounding region will be anode. So, the thin strip will have intergranular corrosion, so that intergranular corrosion will progress at the same time tensile stress will keep on opening the crack. So, that way the crack grows within the body.

So, is basically you have a crack. So, this is the crack and now let us say this is the grain boundary this is the grain boundary. So, this is the grain boundary this is the crack, so the progress of the crack tip happen like this and this is under stress. So, this tensile stress opens up.

So, tensile stress opens up crack, so this allows electrolyte or corrosive solution to reach to crack tip and this will actually this will actually enhance continuous corrosion along grain boundary right. So that means, so the crack opens solution goes in little bit of dissolution happens along the grain boundary and then because that because of the dissolution the crack can have can have a possibility to grow into that crack grain boundary portions and then solution again ingresses in and then continuous dissolution happens.

So, the dissolution all the time is helping the crack to grow. So, this is preexisting active path, so that means in the beginning of the crack growth we already have a situation in this particular alloy system that some portion of the grain some portion of the particular alloy is vulnerable to dissolution here it is a grain boundary solutes or grain boundary precipitates. Now this can clearly explain intergranular failure of stainless sensitized stainless steel, in case of aluminum alloys also this can explain.

For example if you recall 8090 system where we could see that copper rich precipitates are forming along the grain boundary and that is actually leading to grainer intergranular failure. And you I have shown you how intergranular failure or fracture service looks like. So, depending that can explain so in case of stainless steel that too sensitized one aluminium alloys. So, there this particular mechanism can clearly explain the SCC fracture ok. So, SCC this mechanism can clearly explained SCC.

Now, question is in spite of the fact though it majorly could explain SCC in many alloy systems, but this mechanism only tells that if that particular fracture surface would be intergranular in nature, but it does not happen. So, sometimes trans granularity also comes into picture in order to address that, so the other mechanism comes into play which is film rupture model.

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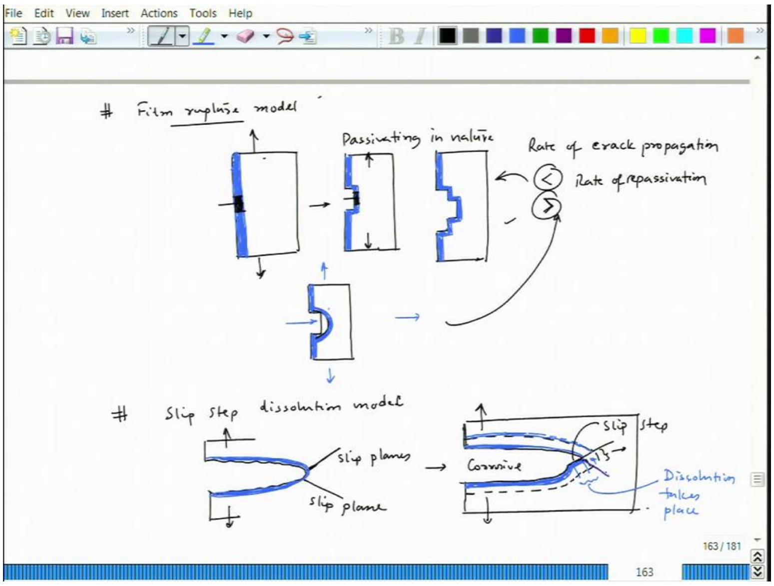

In the film rupture model let us say crack is there in the beginning let us say there is no crack and you have a load like this now this material is passivating in nature ok. So that means, in that particular corrosive it can passivate. So, once it passivates that means there will be a thin layer of oxides or hydroxides. So, this is the layer where oxides or hydroxide can form; so, it passivates.

And this particular passive layer could be brittle and because of its inherent brittleness a crack forms in that particular film. So, when the crack for example, here the crack forms and when crack forms a some part of this particular section might get chipped off. So, this portion chips off, so you have expose section ok; and it this is under tensile stress. Now since this material is passivating in nature, so then immediately the passive layer would form.

So, this initial passive layer is there and the next passive layer would form ok and then again this crack can break it like this, so then a small portion is chipped off. So, then second time you have a situation like this this is schematically drawn. So, like that way the crack propagates.

Now question is whether during crack propagation the crack stops for a while, because it passivates quickly and then that passivating layer is broken due to the tensile strain; strain stress action. Or this particular portion where the material is chipped off that will keep exposed to the material solution and the dissolution would take place and before the passivation happens.

So, that depends on the rate of crack propagation and the rate of passivation repassivation rather. So, that particular factor would be decided, if this is greater than this ok so that means, rate of repassivation is more than the rate of crack propagation. So, definitely the way this schematic has been drawn the mechanism would follow like this, the crack breaks the brittle surface layer and then again that another surface layer forms and accordingly the crack propagates. So that means, crack is only is trying to break the surface film and then dissolution takes over.

But if this is greater than this that the rate of crack propagation is more than the rate of repassivation, then definitely once this crack happens once this crack happens; so this portion is exposed to the corrosive and that continuous dissolution happens before repassivation takes place. So, some dissolution would happen and then the passive layer would form, because the rate of passive layer formation is less than the rate of crack propagation.

So, in this case like that then second level of course, this particular film will again be broken and sometime this particular bare metal surface will exposed will be exposed to the solution and dissolution would take place till the next passive layer forms. So, like that way it goes on if the rate of crack propagation is more than the rate of repassivation.

So, this is the mechanism where the rate of where the rate of crack propagation is more than the rate of repassivation and so this is this one ok and this is for this particular thing ok.

So, like that way so immediately the passive layer does not form. So, this is film rupture model that actually explains some of the transgranular mode of fracture. So now, in these cases it is not specific to the grain boundary it can happen at any location. So, inter granular failure if it is not happening due to pre existing active path, then if it is not happening that way then this could be the mechanism that could be followed ok. So, this is film rupture model where the system which one does not which does not show any inter intergranular failure there you can experience this kind of failure.

Now, interesting part is you could see you could see that why this is coming under dissolution mode, because this film formation is basically action of dissolution. At the same time the growth is also action of dissolution. Only the crack is only trying to break the film that is it the crack is actually opening if opening the particular crack point and then allow the solution to enter into the crack tip.

So, that is why the crack is basically the second fiddle, but you are actually dissolution is the main action here in case of film rupture as well as in case of active path process preexisting active path mechanism. Now, there is one more mechanism which is basically slip step mechanism slip step dissolution model.

So, let us say we have a crack this is the crack let us say and this is the tensile stress that is active. Now that crack tip because it is a so there is a tensile stress and there is a triaxiality here and there are slip planes here. So, let us say these are the slip planes, these are the slip planes and now because of the deformation of the crack tip there could be a small deformation here. So, then it can be like this if deformation happens ok.

So, now you could see that the small part small part section of a this section has pushed into the material. So, this is the material part this is the material part and small deformation has got a slip in that into that material, now here you have corrosive. So, till this when this happens actually this particular and if it is a film forming.

So now, there is a film also there is a film also this film is also existing there is a passivating metal. So now, this film is there here also we have film and you could see that the this segment this is a small portion which does not have film ok. So that means, this is the bare metal surface which actually this part is dissolution takes place fine and then passive layer forms ok.

So, then second step it will further go like this fine. So, then this part is open now and this is the passive part and then this part again dissolve and second time it can also take a different slip plane. So, instead of that it can deform this way so that time it will be ok. So, this part will be then so this portion will be exposed now.

So like that way the deformation takes the material into the takes the takes the deformation actually allows takes allows the bare metal to get exposed and then next step solution takes over and dissolution starts before the passive layer reforms. So that means, here also you could see that the stress here the stress at least doing something more to this it is not only opening up the crack, but at the same time it allows the deformation to happen along a slip plane at the crack tip and then dissolution takes place.

So, all the time the dissolution is coming into picture; that means, the deformation of course, is taking place here stress is actually not only opening up the crack at the same time it is allowing deformation in previous case the film capture model its only cracking the film, but here it also allows the deformation. So, that is what its little different than this particular model, but here also you could see all the time dissolution rapidly takes the material away of that exposed slip step and these are basically slip step.

So, this step are basically forming so this is a step slip step. So, this slip step is exposed to the environment or corrosive and dissolution happens and before re passivation happens. So, that way the crack goes into the material ok. So, this is the slip step dissolution model.

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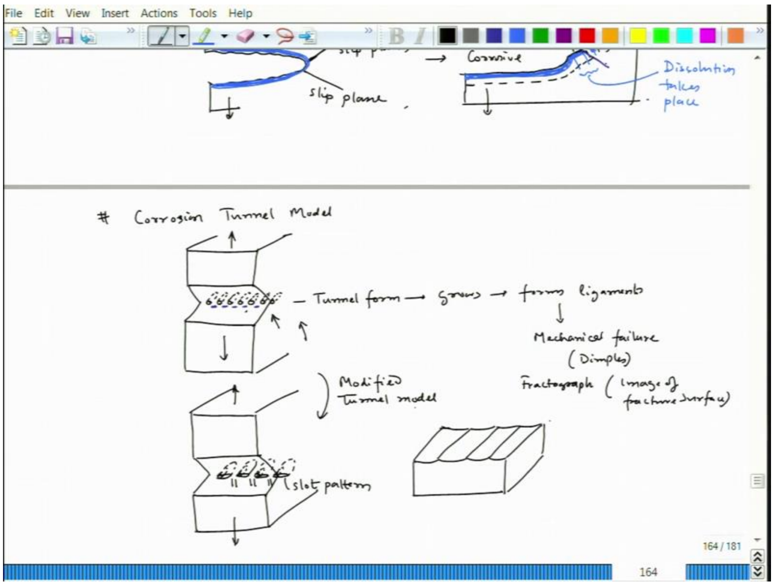

And the last one is corrosion tunnel model, in this case you have a crack tip let us say this is my crack tip and the tensile stress is acting like this. Now what happens the corrosion allows a small small tunnels to form. And those tunnels are actually that corrosion tunnels is basically taking the material away along those small tunnels ok. So, this is the tunnels and these small tunnels they grow tunnel forms grows forms ligaments.

So, these are the ligaments so this small portion is the ligament and those ligaments finally have ductile failure or mechanical failure you can say. And in case of ductile material there could be possibility of dimples. But question is if that dimples happens on that broken ligaments where the dissolution did not happen.

Now the fractograph should show that fractograph is basically the image of fracture surface should show that, but it is not same ok. So that means, there must be some issues with this particular model ok. Now in order to address that particular issue what happens it was modified the modification happens like this.

So, initially it starts with small tunnel, so this is going inside the material those dissolution dissolved tunnels. Now they take a form like this instead of maintaining that particular circular cross section they become a slot pattern and this slots are growing like this. And when this slot grows laterally also; so, then what happens this particular gap shortens ok. So that means they become a thin way thin section very thin section rather than this is that kind of ligament what we have in the previous case.

In this case we have ligaments, but here those ligament size dimension will be extremely small. So, that way to those ligaments will finally break and then we have a fracture surface like this. So, like this a grouped pattern can be noticed ok. So, it would be a kind of interface fracture surface you can notice and then it is a fantastic match between the two opposing fracture surface and then we can address this problem of not seeing any dimples or mechanical failure marks of those of those small ligaments what was what should be observed in this case.

But it should it has not been observed that is what this model has been modified. So, this is modified model modified tunnel model. So, it becomes slot previously it was tunnel and here it is second case it is slot pattern. So, that is the difference between these two, but here also you could see that the dissolution is actually initiating the SCC crack and then finally the growth is also taken by the SCC crack.

Growth of SCC crack is also helped by this dissolution of course the crack finally breaks open, because of the mechanical failure tensile stress that acts. But mostly it is a dissolution in the form of tunnels or slots that actually leads to SCC failure ok. So, this is the model what also falls under dissolution based model.

So now, this is about this is four major dissolution based model. So now, we will talk about cleavage based model in our next discussion or next lecture; till then.

Thank you.