Aqueous Corrosion and its Control
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Lecture – 31
Forms of corrosion: Stress corrosion cracking (Part-III)

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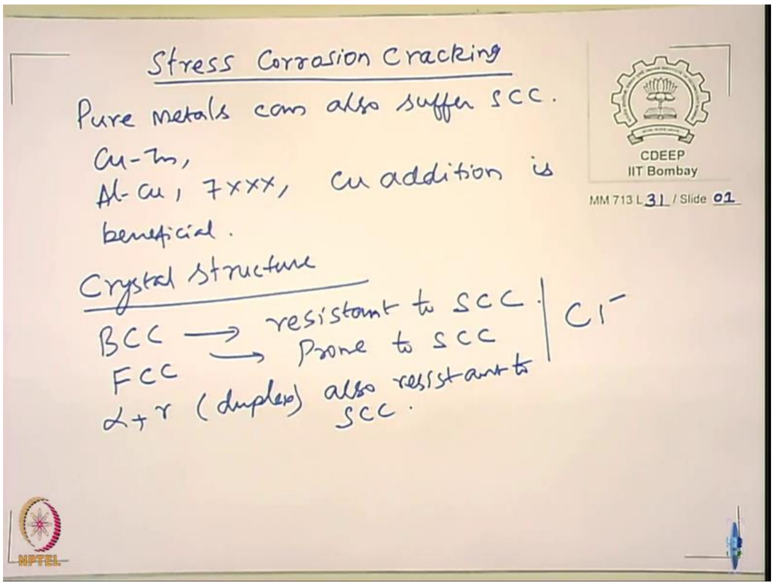

Stress Corrosion Cracking

Pure metals can also suffer SCC.

Cu-Zn,

Al-Cu, 7xxx, Cu addition is beneficial.

Crystal structure

BCC → resistant to SCC.

FCC → Prone to SCC

$\alpha+\gamma$ (duplex) also resistant to SCC.

Cl^-

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Welcome back to this discussion on Stress Corrosion Cracking and we have been talking about the factors affecting stress corrosion cracking. In that we saw two aspects in reasonable details; the tensile loading conditions, tensile stresses. Then, we talked about the environment, the nature of environment, how it can affect the stress corrosion cracking.

Towards, the end of the previous class, we discussed about the metallurgy and there are several factors in the metallurgy that affect that influence the stress corrosion cracking and one of that we saw was on the alloy composition and we just took an illustration of how the nickel can affect the stress corrosion cracking of a stainless steels.

We also see similar kind of things happening in the copper base alloys as it is. You know the copper, pure copper is relatively resistance against stress corrosion cracking. By the way, earlier there was a kind of understanding that hence pure metals do not undergo SCC, now that as metals can also undergo and also, suffer SCC.

So, earlier, you know they were considering that the pure metals are not prone to SCC. It has been shown that pure copper, pure aluminum, they do suffer stress corrosion cracking; but yes, the susceptibility index you call right. I think this not that severe compared to the alloys.

So, even the copper system, when you add copper you know talk about copper zinc alloy system, add more zinc; as zinc content increases, the stress corrosion cracking increases. On the contrary, if you take aluminum copper alloy systems, especially we talk about 7000 series aluminum alloys, addition of copper addition is beneficial.

So, it is always useful to understand how the chemical composition of an alloy can affect the stress corrosion cracking. The other important thing in the metallurgy is the crystal structure. We make illustration only related to ferrous system.

You take a stainless steel, the stainless steel you know we have seen the classification of stainless steel, when we talked about the sensitization of stainless steels and you have a BCC, they are resistant to SCC; whereas, face centered cubic that is your austenitic grade stainless steels are prone to.

See when I say SCC, you always have to associate with the environment right like a chlorides. So, even in the case of austenitic grade stainless steels chlorides in a sea water per say, it is not proned SCC, it undergoes pitting no doubt. But you lower the pH in acidic range, then I think the chlorides promote SCC or raise the temperature, then when the temperature goes beyond 50-60 degree Celsius, the chlorides are prone to SCC.

And whereas, the ferritic stainless steel is not prone to stress corrosion cracking and again you have a duplex stainless steel and you have alpha plus the gamma that is your duplex stainless steels, also resistant to SCC. So, the crystal structure, they do play a role in terms of a offering the SCC resistance. Then, I will highlight the importance of the microstructure. I will take an example of aluminum alloys ok.

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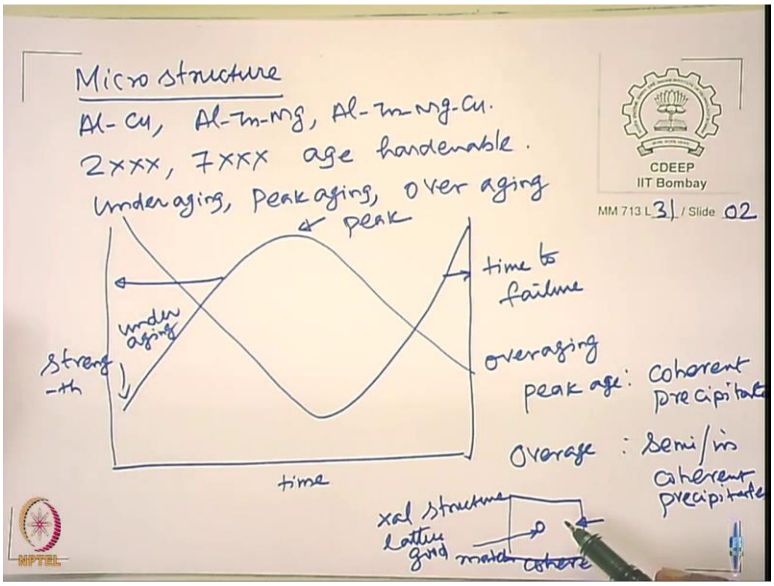

Micro structure

Al-Cu, Al-Zn-Mg, Al-Zn-Mg-Cu.

2xxx, 7xxx age hardenable.

Underaging, Peak aging, Over aging

peak age : Coherent precipitate

Overage : Semi/in coherent precipitate

Aluminum copper or aluminum zinc magnesium, aluminum zinc magnesium copper systems. This aluminum you know alloys are known for one special properties you know and most of the aluminum alloys, the strength are derived from where? From the precipitation hardening, especially the 2000 series and the 7000 series alloys, they are all age hardenable. They are age hardenable alloys right.

You know through the precipitation, the strength increases. You all know that aluminum alloys when you talk about aging, we call them as what? We call them as under aging, peak aging and you also have called as over aging right. The strength of the aluminum alloy increases from the solutionized conditions to under aging.

The strength increases the maximum in the peak age condition and subsequent aging treatment, what happens? The strength drops down; over aging conditions the strength drops down. So, if you if one plots the time of aging versus the strength of the hardness, do that how do the strength lie? The strength go something like it goes like that and this is your peak aging, over aging, this is your under aging treatment right.

If somebody looks at the this is the strength, this curve belongs to this. If I look at the resistance of the alloy to stress corrosion cracking, what happens? You will find ok, the time to failure which also is indication of the stress corrosion cracking right. So, at the peak age condition, the alloy becomes the most susceptible right and again, when you do a over aging, the SCC resistance increases.

So, when you increase the SCC resistance by over aging, you are going to have a drop in the strength level. So, that is you know some compromise on the available strength for structural applications. Without going much into details, we can say that in the peak age conditions, conditions you have what is called as a coherent precipitate and in the over age conditions, we are going to have semi or incoherent precipitates.

Again, there lot of metallurgy is involved about coherency, semi coherence and all. So, when you have a coherent precipitate that means, you know to put in simple terms, when you have, when you have a precipitation, it is a matrix right. It is a matrix you have and you form a precipitate, if they precipitate the crystals the crystal you know if the crystal structure or the lattice parameters, it is a good match. We call as a coherent ok.

So, this that kind of I know you know coherency that happens in the system leads to more strength, you know you guys sort of you know and when you talked about the strengthening mechanisms, I think some of you might have read you know how the peak age condition, the strength increases right and because the precipitates are plenty and the space between the precipitates are less and you have coherence is strained is difficult for the dislocations to move through and so, the strength goes up.

But same can lead to stress corrosion cracking and because of the fact that this leads to more of the planar you know or see the planar you know dislocation formation in the system. The idea here is to show that microstructure plays a role, the same is the case when you talk about martensitic steel, when you quench it you form a martensite is more prone to stress corrosion cracking.

When you age it, you temperate the stress corrosion cracking resistance increases; of course, you are going to lose certain amount of strength. So, the microstructure in turn plays a role and that is to be should be considered in designing any alloys.

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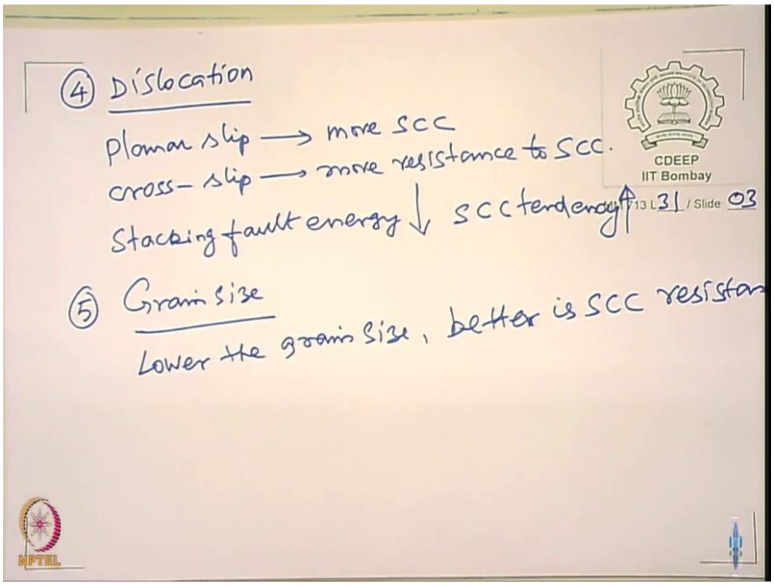

④ Dislocation

Planar slip → more SCC

cross-slip → more resistance to SCC.

Stacking fault energy ↓ SCC tendency ↑

⑤ Grain size

Lower the grain size, better is SCC resistan

Dislocation structure and again not going much in details. Planar slip more stress corrosion cracking; cross slip more resistant, more resistance to SCC takes place. Similarly, the stacking fault energy, it decreases, SCC tendency increases ok. Comes next to the grain size; lower the grain size, better is SCC resistance. So, fine grains are better. So, these are you know a kind of not in very detail, but a broad outlook about role of metallurgy on the stress corrosion cracking of alloys that we talked about.

I want to spend some time on the mechanism not in details. But broadly, we can look at the mechanism here. I think I given a reference to stress corrosion cracking book in the beginning right, on the class I think this edited by me and Tetsuo Shoji, there are two articles by Stan Lynch and you know he has given nice review article on corrosion mechanism, stress corrosion cracking mechanism and also, hydrogen embrittlement mechanism and those who are interested can go through that in details. Here, I am going to be very very brief.

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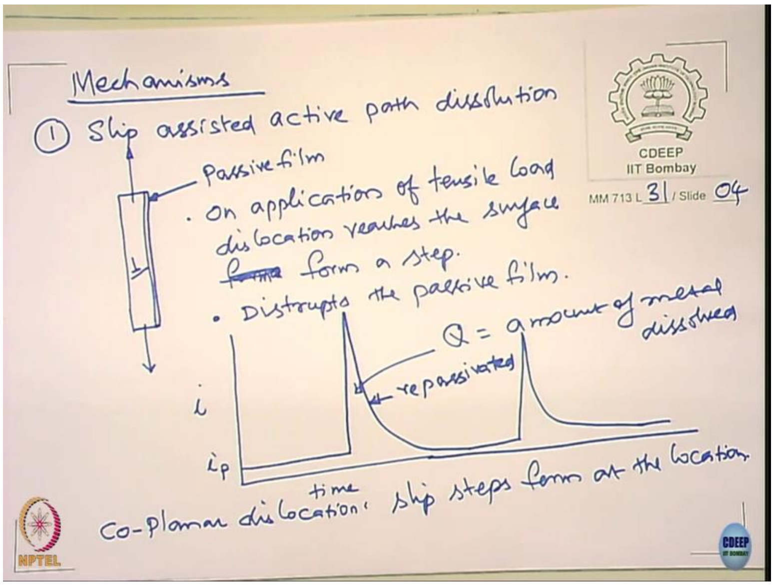

Mechanisms

① Slip assisted active path dissolution

- On application of tensile load dislocation reaches the surface form a step.
- Distrupts the passive film.

Q = amount of metal dissolved

Co-planar dislocation: slip steps form at the location

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The mechanisms there are of course, several mechanisms; slip assisted active path dissolution ok, the crack is assisted by the slip process. When you deform a material, you will have a slip plane right and you have dislocation on that. When you deform it, what happened to the dislocation?

The dislocation goes to the surface and form a step right. Now, if I have a film, a passive film, if I have a passive film, could I apply a tensile load, what happens? On application of tensile load or tensile stress, dislocation reaches the surface, then form a step right. This disrupts the passive film.

So, passive film on the surface at that level gets disrupted, then what happens now? The metal starts dissolving. If I plot the current versus the time, you have a current normally is equal to passive current density IP you are getting. If the dislocation disrupts the surface, current goes up and again, it gets repassivated. Now, the Q that you give the Q is equal to the amount of metal dissolved.

So, you can able to correlate to a faradic equation right. You can do that. You know the current, you know the area. So, you know how far the crack would advance in one step; re passivates. What it can happen again? This again can you can. So, every time the crack growth is assisted by the slip step, the tensile load, the tensile stress would assist the dislocation movement to the surface and so, the crack starts growing. So, this is one model.

Now, look at this; now, if I am going to have a co planar dislocation, what happens? The slip steps form at the same location. The crack growth, it becomes more advanced. What is coplanar dislocation? The dislocations lie on the same plane when you deform it; then one after another, the dislocation these surface and form steps.

I am not again going to talk about the too much details about the merits and demerits of this particular models. This is quite extensive or one you can say here is in this model, the crack is expected to do grow continuously, not the discontinuous manner ok. You would not see that because every time metal dissolves, it just moves at the atomic levels.

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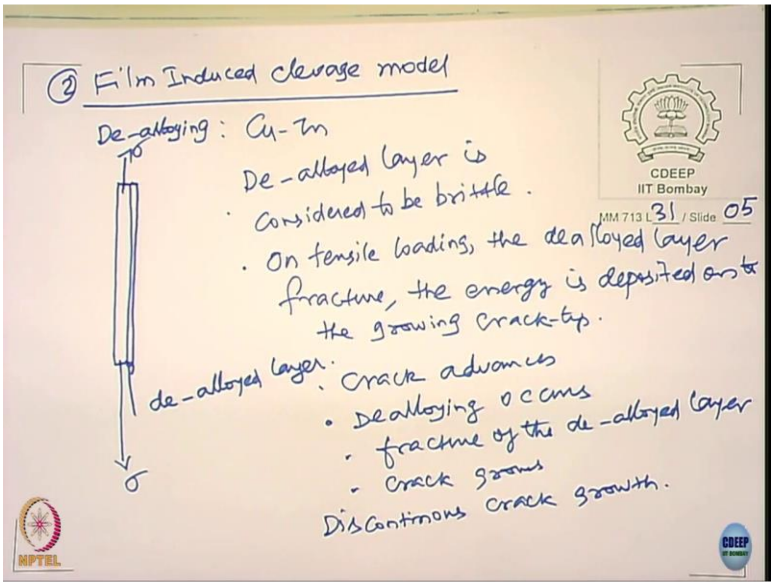

② Film Induced cleavage model

De-alloying : Cu-Zn

- De-alloyed layer is considered to be brittle.
- On tensile loading, the dealloyed layer fracture, the energy is deposited onto the growing crack-tip.
- Crack advances
- Dealloying occurs
- fracture of the de-alloyed layer
- Crack grows

Discontinuous crack growth.

Next is called film induced cleavage model. The film induced cleavage model primarily hinges on de-alloying like you have copper zinc alloy systems right. The copper zinc de-alloy system, what happens? The zinc dissolves and copper gets deposited onto the metal surface. So, you would expect this is the de alloyed layer and you apply a tensile stress. Now, the de-alloyed layer is considered as de-alloyed layer is considered to be brittle.

So, when you stretch this sample, when apply tensile stress and if this de-alloyed layer is brittle, when it fractures, what happens? On tensile loading, the de-alloyed layer fracture and what happen? The energy is the energy is deposited onto the growing crack tip. So, what happens now?

The crack now see when you have a; when you have a brittle film, it fractures and you deposit the energies is so fast, even the ductile material will turn into a brittle material right. It depends upon how fast how what is the strain rate. So, the high strain rate the even the so called ductile materials will behave as a brittle material.

So, now, what happens? Now, the crack advances; but again, what happens? De-alloying occurs and again, fracture of the de alloyed layer. Again, what happens? Crack grows ok. So, the crack growth here is discontinuous.

So, when you observe the brittle surfaces, you when you observe the metallic surfaces which suffers stress corrosion cracking, you normally see the cracks are not continuous. It just advances stops, advances stops. So, this model explains how you have a discontinuous crack growth happening in the ductile materials because of stress corrosion cracking.

So, the event the precursor event here is a de-alloying enrichment of the noble metal which of course is brittle in nature. On tensile loading, the fracture because they brittle and the energy that is released in the fracture process is deposited onto the crack front the crack advances. So, every time, the sequence repeats and the crack propagates. So, that is why it is called as film induced cleavage model. I think this two model, I think is good enough for us.

I think I will stop discussing more on the stress corrosion cracking models. If you want more, you can refer that particular review article for details. Any of you have any questions? Now, let us go to the next important topic of how do we control the stress corrosion cracking; how do you do that? So, what you do? Can you give some ideas?

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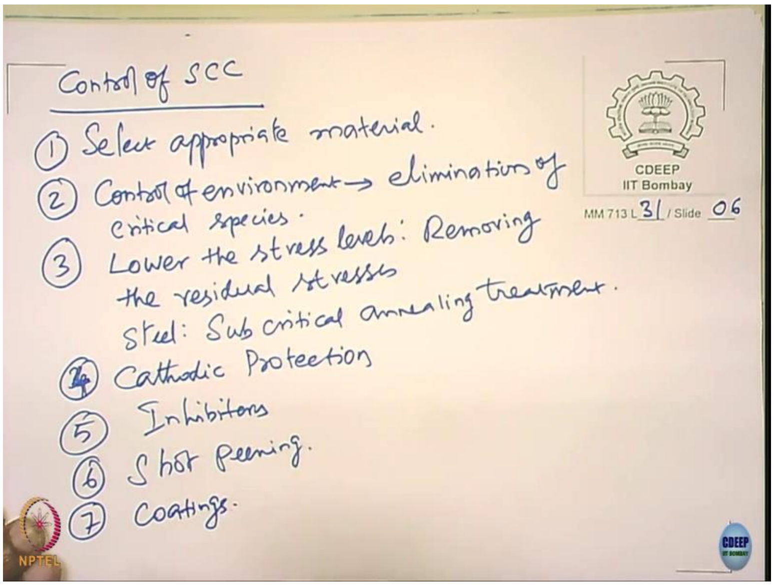

Control of SCC

① Select appropriate material.

② Control of environment → elimination of critical species.

③ Lower the stress levels: Removing the residual stresses
steel: Sub critical annealing treatment.

④ Cathodic Protection

⑤ Inhibitors

⑥ Shot peening.

⑦ Coatings.

Student: We can choose the right material, that is electrode material.

Choose right materials right; select appropriate material, then (Refer Time: 28:00).

Student: Control of environment.

Yes, control of environment. That means, elimination of critical species. One more? Lower the stress levels. We talk about removing the residual stresses, how people do this one?

Student: (Refer Time: 29:03).

That is not removing the residual stresses, what do you do in a steel; in steel what you do?

Student: (Refer Time: 29:11).

Is called as?

Yes?

Student: Subcritical.

Subcritical annealing treatment, below the eutectoid transmission temperature right. What else we can do?

Student: (Refer Time: 29:35).

Of course, I mean in the alloy development, you can reduce the grain size or probably, we will come into alloys, this things. Anything more you can do? We can do cathodic protection, add inhibitors right. We can also do you said shot peening right; shot peening in fact is practiced that will gives the compressive.

Student: Stresses.

Stresses, what more you can do? You can also apply coatings were possible. So, that brings us to the end of the discussion on Stress Corrosion Cracking and any questions? In aluminum copper system, especially in the 7000 series alloys ok, the copper containing seven thousand series alloys, if you look at the crack growth rate, the crack growth rate very significantly get reduced by increasing the copper content ok. Of course, there are I mean I quite a bit work on it and people have been you know discussed in detail about that ok.

So, I do not know what I mean just subject by itself. We need to see what really happens you know because the see the copper essentially makes the precipitates also noble actually, which are otherwise you know assist the stress corrosion cracking of the aluminum alloys.

So, then we get into mechanism of SCC hydrogen embrittlement in aluminum alloy itself. So, we have done some quite a bit of work on this alloy, this system and you know we can discuss probably offline, you know this is more details actually.

Any questions?