Mechanical Behavior of Materials-1

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Lecture - 33
Precipitation Strengthening: Precipitate Characteristics

Okay so now we know how to form precipitates, what are the different steps we have to take to form precipitates, right? One is solution treatment followed by quenching and then aging, right and then you are going to form precipitates, right?

So during aging I already mentioned that you heat it to a certain temperature, say T 2 and then you leave it there for sufficient amount of time so that beta phase can come out from the matrix okay and then that will lead to a strengthening, okay. So now depending upon the time right, so with respect to time the characteristics of the precipitate also changes. So we are going to discuss about that particular concept now, okay.

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So during aging the characteristic of precipitates change with aging time, okay. And to understand this let us take classical example of aluminum 4% copper. So I have already mentioned that aluminum copper system will give you precipitation strengthening, right? So we are talking about aluminum 4% copper, okay. So we will use this particular system.

So when we age this aluminum 4% copper alloy, it will go through a sequence of precipitation. And that precipitation sequence will be given by, so precipitation sequence will be alpha, so that is your supersaturated salt solution. So this is like supersaturated salt solution. So let us call it alpha SSS, right. So you are going to heat it to a temperature T 2 and then beta will come out, right?

But it will, in aluminum 4% copper there will be a sequence for precipitation and that sequence will be it will start with the formation of something called GP zones. Then it will form theta double dash precipitate, then theta dash and finally it will come to theta which is equilibrium precipitate, okay.

So in this particular system it is equilibrium precipitate like there we discussed about beta in aluminum copper system it will be theta okay Al2Cu. So it does not directly form theta precipitate, it goes through a sequence of precipitation. So it starts forming GP zones, which are clusters of copper atoms in aluminum matrix, okay. And the shape is typically disc type.

Then it goes to theta double prime, then theta prime and theta, okay. So there is a specification sequence in aluminum 4 weight percent copper if you age it, okay. And this happens with time okay this set sequence occurs with time. So what happens during this aging time, with respect to aging time a few things will happen, okay. And the first is the size of the precipitate increases, okay.

So as you increase the time okay, your size of the precipitate is going to increase, okay. Now the second, since you are increasing the size of the precipitate, your distance between the particles are also going to change, but it first decreases and then increases, okay. Because when you start you have to the volume fraction is slightly lower and subsequently the volume fraction is going to be increasing, okay.

So the distance between the particles is going to first decrease and then with respect to time it is going to increase. So distance between the precipitate it also changes, right? So eventually it is going to increase with respect to time, okay? And the last one is the interface between precipitate and matrix will also change, okay. And this is happening with respect to aging time, okay.

So with aging time, so these are the characteristics of your precipitates that will change with aging time. And what do you mean by interface is suppose you have a precipitate in the matrix, so I am talking about this particular interface, okay. So I will talk to you about it, okay. And why we are talking about it?

Again I am reiterating because of these changes right, the interaction, the nature of interaction with the precipitate of the dislocation is going to change. And that will lead to change in the strength of the material. That is why we are discussing this particular concept, okay.

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So here I have shown the precipitates in a aluminum alloy system and you can see with respect to aging time, so your time is in this direction, okay. And all these are your TEM images, transmission electron microscopy images, okay. And if you see the scale bar here, so this is 50 nanometer, this is 0.5 and this is also 0.5, right? So you can clearly see that the precipitates here, so all these small particles right, all these small particles these are your precipitates.

We have discussed this right? So the size of the precipitates that is increasing and the distance also increasing. So you can see if I talk about this particular thing, the distance is this much, but here your distance is pretty large right? So the size of the precipitates increases as well as the distance between the precipitates increases with aging time and that is what you clearly see here, okay.

So that is one of the changes you are going to observe in the precipitates with aging time, okay. Now the next is interface, right?

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So interface, okay? So there are different type of interfaces. Whenever we talk about two phases you can have coherent or semi-coherent or incoherent interfaces between the two phases, okay. So what are these? So let us talk about that because that is also going to affect the nature of interaction between the dislocation and the precipitate, okay? So the first one is say you have a, this is your precipitate.

So these are your say, so this should be equal, okay. The distance between these should be equal and say you have atoms here okay, something like this. So all these places I am having atom. So this is a rough schematic. So there will be slightly some mistakes, but try to understand the concept here, okay. So this is your precipitate and my interface is here. So this is your interface right, okay?

Now we are going to have okay, so let us change this because this becomes easier. So let me call this as matrix because I am going to change the spacing between the precipitate okay. So now let us, we are talking about the coherent one. We will take blue, okay. So if the interface between the precipitate and the matrix is perfectly coherent then there will be one-to-one matching, okay.

So you are going to have a situation like this. Again these are rough drawing, okay. So you have precipitates, atoms in the precipitates like this, something like this. So you are going to have one-to-one matching here, right. So this is called if this is the situation then this is called perfectly coherent condition right, perfectly coherent.

This also means that you are going to have one-to-one correspondence between precipitate lattice and the matrix, okay? Here this is your precipitate. So you are going to have one-to-one matching between the precipitate lattice as well as matrix lattice, right? And if this situation is there, this also means there is not going to be any strain because there is one-to-one matching, right? So no strain, okay?

So you are going to have any strain. So this is called, this situation is a perfectly coherent or this boundary interface is perfectly coherent interface. Now you are not going to find any two elements which are going to have one-to-one, perfectly one-to-one correspondence, right? It is like fingerprints, right? So each element is going to have different lattice parameters, right?

So you are not going to have this condition anywhere, okay. So there will be slight difference between the lattice parameters of the precipitate and the matrix okay, at least some difference will be there right? So the second case will be coherent boundary with some stream okay and the situation will be something like this. So you have this interface. So let me first draw for matrix, okay.

Now let me draw for precipitate, the lattice for precipitates. So it will be something like this. Again these are some rough drawing, okay. So there is you can see that there is you are not going to see a perfect match. So two lattice parameters are not going to match, right. So here again this is your precipitate, this is your matrix okay.

Now what is going to happen, since there is a difference between these two precipitates in terms of lattice parameters right, you are going to have strain associated with it right. So these two are going to match, something like this okay. So now compare with what you see here. There is a perfectly match condition right, one-to-one matching. Here also there is one-to-one matching between the top and the bottom lattices.

But the problem is since the lattice spacing is difference right, there is a difference in the lattice spacing, you are going to have some strain here in this particular region at the interface, correct? So you are going to have one-to-one match. So your surface, your interface is going to be coherent, but there will be some strain associated with it, which you did not observe in the perfectly coherent case, okay.

So this case is coherent interface with strain, right? So again you are going to have one-to-one correspondent. It is not going to be lost. So you are going to have one-to-one correspondence between precipitate lattice and the matrix. Same situation as the perfectly coherent here, right? But now you have strain associated with the interface.

And this particular strain because of the difference in the lattice parameter of the precipitate and the matrix, we call it this particular strain as coherency strain, okay. So you are going to, your interface is going to be coherent, but it will be associated with coherency strain okay or sometimes it is also called an elastic coherency strain, okay. So this is also a coherent interface.

Now when the size of the precipitate increases as we saw just now okay with respect to aging time, the interface is also going to change from coherent to semi-coherent, right? So your precipitate size was small and it had some coherency strain. Remember coherency strain is going to depend upon the difference in the lattice parameter of these two phases.

So if the difference is larger between the lattice parameters of precipitate and matrix, your coherency strain is going to be larger correct, okay? Now after certain time or after say certain size of the precipitate, the precipitates or this alloy system cannot sustain this much of coherency strain, okay. So there is certain amount of coherency strain which this alloy system can have, okay.

After that the interface cannot maintained coherency because of the higher amount of strain. Because remember strain is also going to be associated with strain energy, okay. So you cannot have large amount of strain energy. So this interface is going to change to semi-coherent from coherent interface, okay.

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So the third what we are going to talk about is semi-coherent interface. So in this case say you have an interface here, okay. Now let me use the same color. So what is going to happen? Let me draw first the matrix one. And remember these lines are actually associated with atoms, okay? For better understanding I am drawing this line, okay. Now let me draw the precipitate one. So you are going to have this thing.

And then this, then this is here and then you are going to have say this, something like this, like this, this so something like this, right? And it can continue. So this is your precipitate and this is your matrix, okay. And as usual, this is my interface here, okay. So now see here you have one-to-one match between these two. You have one-to-one match between these two, right? But then this guy is missing here.

So this plane there is no match, right? Then you have one-to-one match here also, one-to-one match here also. Then again you have match here, but again there is a missing one here, missing plane. Then you have one-to-one match and then one-to-one match and it goes like this, right. So what you are doing? You are not able to, remember this semi-coherent interface came into picture because of higher coherency strain, right?

So now you are going to have here a partial one-to-one correspondence between the precipitate lattice and the matrix lattice. And to take up the strain you are going to form dislocations and the interface. So these two here what you see right, these are your dislocations, is it not? So these two are half planes, right? So you have these two planes here corresponding to these two, correct?

So you are actually taking up the strain at the interface by forming the dislocations, okay. So in semi-coherent interface the first point will be partial one-to-one correspondence between the precipitate lattice and matrix lattice, okay. So you have partial one-to-one correspondence, like here these two are missing, right?

So if I say one and name one and two, right, so these two are missing planes, but rest of them have one-to-one correspondence, okay? And that is why we call it semi-coherent. So some of the planes are matching. And the second one is dislocations form at the interface to take up the strain, okay. So you are not going to have a very high amount of coherency strain. Instead you are going to strains associated with dislocations, okay.

So this is the characteristic of semi-coherent interface. Now if you increase the size of the precipitate much more this semi-coherent interface is going to change to completely incoherent interface, okay.

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So here you are not going to see any correspondence. So no one-to-one correspondence between the precipitate lattice okay and matrix lattice. So you are not going to have any correspondence. So let me draw, say this is your interface here. So you are going to have say something like this, okay. And the second one can be say this is your matrix as is your same coloring and then this is your precipitate.

So there is no correspondence right between the planes, okay. So again when you form precipitates right and you give time, so with respect to aging time, the characteristics of the precipitate changes. And what are those characteristics? Size, distance within the precipitate second, and the third is the interface between the precipitate and the matrix.

So with aging time the size of the precipitates increases and as size of the precipitates increases the interface between the precipitate and the matrix changes from coherent to semi-coherent to incoherent interface. And we are talking about remember the example is aluminum 4% copper. There will be other system where the sequence is not there, right. Alpha to GP zones to theta double prime to theta prime to theta.

You can directly from theta precipitate or equilibrium precipitate. But we are talking about a special case of or the classical example of aluminum 4% copper which you are going to find in most of the books. So it will also easy to understand for you guys, okay. So now we have understood the change in characteristics.

So now what we are going to do, we are going to next, we are going to try to understand how these changes in the characteristics will affect the interaction between the dislocation and the precipitate, okay. And thereby you are going to see the changes in the strength of the material also. Okay.