Mechanical Behavior of Materials-1
Prof. Sudhanshu Shekhar Singh
Department of Materials Science and Engineering
Indian Institute of Technology-Kanpur

Lecture - 32
Precipitation Strengthening: Basic Criteria

So the basic criteria to obtain precipitation strengthening, let us talk about that, okay.

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Or obtain precipitates, okay. So what are the criteria to obtain precipitate in a given system, right? So the one of the basic criteria is that the solvus line should decrease with decrease in temperature, okay. I will explain this using phase diagram, okay. This also means that decreasing solid solubility as temperature decreases, okay. So let us understand this with phase diagram, okay.

So let me draw a phase diagram now. You have temperature here okay and let us see, let us say we have A and B is on the other side. So you are going to have weight percent of B okay, increasing in this direction, okay. Something like this and somewhere here say you have beta phase okay. And say you have liquid. This is alpha so this is say alpha plus beta. And then this is also going to be two phase which is alpha plus liquid, okay?

Now which one is the solvus line here? So this is your solvus line, okay. And see what I wrote before. It says the solvus line should decrease with decrease in temperature. So this is the solvus line here, okay. And you can see that this is decreasing with decrease in temperature, okay. And this also means that the solid solubility okay of B in A is decreasing as you decrease the temperature right, and you can clearly see here.

So if say if I take a temperature, let me change the color. So suppose I take the temperature of say T 1 here, okay? And then say T 2 here, okay. So T 2 is less than T 1, okay. And the solid solubility of B at a temperature of T 2 is less than the solid solubility of B at a temperature of T 1. That is what it means, okay.

So if you have a phase diagram like this or a part of the phase diagram like this on the say left side or say right side also whatever, okay. So then in that case you can form precipitates, okay. That is the one of the basic criteria to say whether a given system can form precipitates or not, okay? So the solvus line should decrease with the temperature, okay. Now let us talk about how do you form precipitate.

So this is the criteria, but what steps you need to take to form precipitates, okay? So say here in the phase diagram we have A is say aluminum and copper right and B is copper. So say A is aluminum and B is copper. And we are going to use this aluminum copper system to explain some of the phenomena in precipitation hardening in the subsequent you know lectures, okay. Okay, so let us talk about the steps now.

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So you have three steps to form precipitates. The first step is called solution treatment. The second is called quenching okay. And the third is aging, okay. So these are the three steps you have to follow to obtain precipitates in aluminum alloys, okay. So if I draw a heat treatment cycle it is going to look something like this. Say you have a temperature on the y axis, okay. Then you have time on the x axis, okay.

So for solution treatment, let us change the color. So it will be say something like this okay. Then you are going to quench it to some temperature. Then we are going to age it, something like this, okay. So this is your cycle, heat treatment cycle okay. Now, so this the top one so what you have to do, you have to take your sample, you have to go to high temperature say in this case T naught.

And I will use this nomenclature T naught T 1, T 2 and use phase diagram and then explain it to you, okay. So this process here we call it as solution treatment, okay. So you are going to a temperature T 1, sorry T naught and then you are going to leave your sample for long time there at that particular temperature T naught. Then you are going to quench it. So this second process here, so this process here is called quenching, okay.

So you are quenching it to say a temperature of T 1 okay. Now after quenching you are going to again take the sample and then heat it to a temperature which is much below the solution treatment temperature say here this one okay to T 2. And this process is called aging. And then you subsequently cool it down after you leave it there for some time, okay. So this is the overall process.

So we start with solution treatment then we go to quenching and then we age it okay, we call it aging. And thereby we are going to form precipitates in the give alloy system or given aluminum alloy, okay. So now let us understand this with respect to phase diagram okay and then I will also write the, what we typically do in solution treatment, quenching and aging, okay.

So let us, okay let us first write down and then we will use phase diagram to understand this concept, okay.

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So solution treatment. Okay, so what we are going to do we are heating the alloy okay to a single phase region to dissolve any soluble precipitate. I will explain all this okay, just wait. So we are heating the alloy to a single phase region so that we can dissolve the precipitates, okay. Now the next is quenching, okay. So after solution treatment you are going to cool the sample okay, very rapidly okay.

So cooling very rapidly to room temperature or lower, okay. So to room temperature or a slightly lower temperature so that we can obtain supersaturated solid solution, okay. And the last one is aging. So after you quench it you have to age it, okay. So here so when you do solution treatment I told you heating we are going to do it T naught right? I will use the phase diagram to explain this.

Then cooling we are going to do a certain temperature which is say T 1 and then aging again we are going to heat to a temperature of say T 2 to form precipitates, okay. In this case say T 2 to form precipitates, okay. So these are the three steps we have to follow to form precipitates in aluminum alloy, okay. So now let us use phase diagram and try to understand it, okay.

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So let me draw something like this, right? So you have temperature here and then we are talking about A and B previously so you have weight percent of B here and somewhere here you have beta, right? So this is going to be alpha plus beta and this is your single phase region here, right? So if you see this region is your single phase region, right? And that is what I meant when I wrote here if you remember, heating the alloy to a single phase region, okay.

So we have to heat it to single phase region which is shown here, just marked here right, this region. Okay, so the first step is solution treatment and what we are going to do, we are going to heat it to a single phase region which is alpha here, okay. So let us heat it to a temperature of T naught. And okay before that we have to choose some composition.

So let us choose this particular competition here okay, having a concentration of C naught okay and then we are heating it to a temperature of say T naught okay, which lies here in the single phase region. So you had a sample which contained you know two phase region, beta also, beta was also there right? So what you are going to do, you are going to heat the sample to a temperature of T naught.

And the composition of this alloy is this right? So at that particular temperature and for this particular composition you are going to obtain a single phase region which is alpha, okay. And you have dissolved all the precipitates. That is what I wrote also before right, for solution treatment. So if you talk about the microstructure, you are going to see a microstructure at a temperature T naught, which will not have any precipitates, okay.

So if it is a polycrystalline material you are going to have a microstructure like this. This is your microstructure okay, where you can see the grain boundaries and this all these are alpha, right? It is a single phase, there is no other phase. There is no beta phase. We have dissolved all the precipitates in the alpha matrix to form a single phase alpha here and that is the purpose of doing solution treatment, okay.

Now the second, so this is your solution treatment, after solution treatment. So I can write this is after solution treatment, okay right? Now since you have dissolved all the precipitates the next step was to quench it, right? So you are going to quench to some temperature say here T 1 right, T 1 okay. So you have quenched it. So you are now, this is my composition line, let me change the color okay.

So this is your composition line, okay. Now ideally if I am using this composition right and we are at a temperature of say T 1, you should form precipitates right, because this lies in two phase region, alpha plus beta, is it not? But since we are quenching it we are not allowing this solute atoms, B atoms to go out. We have not given sufficient amount of time for these B atoms to go out from the matrix to form beta phase, okay?

So all the B, almost all the B atoms are going to stay in the matrix and that is why we call it supersaturated solid solution, okay. Remember, alpha is also a solid solution, right. So when we do solution heat treatment, solution treatment we are going to form alpha which is a solid solution. Now when you quench it we are going to form supersaturated solid solution, which I also mentioned here, okay.

So all the B atoms are inside the matrix and it is supersaturated and that super saturation is given by this difference, okay. Now it is not in equilibrium condition because equilibrium condition is or based on the phase diagram I can say at equilibrium you are going to have alpha plus beta, is it not? So B atoms would like to come out from the matrix, okay. So let me draw the microstructure.

So microstructure as such will remain same if we are in T 1, okay. So microstructure does not change much. We are going to observe the same microstructure. The only difference here would be that this is not going to be an equilibrium structure and B atoms will try to come out from the matrix to form beta phase because that is the equilibrium structure. So this microstructure is after quenching, okay.

Now if I leave the sample at room temperature and give sufficient amount of time like years, right? So what will happen, these B atoms will come out and they are going to form beta phase, okay. But since you know we want to do everything faster and suppose we are working in industry we cannot give years to form some you know precipitates, right? So what we do we heat it to a slightly higher temperature say T 2.

So what we are here T 2, let me draw T 2 here, so this is your T 2, okay. So suppose we are heating to this particular temperature T 2. So we heat the sample to a temperature T 2 okay and then we are giving some driving force right, at higher temperature. These atoms then quickly come out and start forming precipitates in the matrix because the equilibrium structure suggest the microstructure should be having alpha plus beta, okay.

So when we heat it what we are going to form is called precipitates. So these are your grain boundaries what I am drawing now. And then you start forming precipitates, is something like this. All these are schematics right? Okay, so this is the microstructure at T 2 after say aging, okay. And these blue ones what I have drawn are precipitates okay and the remaining matrices obviously is going to be alpha, right?

So here we also have alpha. So the microstructure here is alpha plus beta, okay. Alpha is a solid solution of B in A right? And even after quenching your microstructure is going to have only alpha but it is supersaturated, okay. And this after solution treatment it is going to have only alpha, I told you already, okay. So this is how we do aging treatment, right? So we start with solution treatment, we dissolve all the precipitates prior precipitates and we form a single phase right, alpha.

So in this case alpha right, single phase, so this region okay, this. Then we quench it and we form supersaturated solid solution where given a chance if you give sufficient driving force B atoms will come out from the matrix and they will form precipitates because the equilibrium diagram or phase diagram suggests the microstructure should be alpha plus beta, right? So what we do, we do aging treatment okay.

So we go to a sufficiently higher temperature, slightly higher temperature and then we heat it there to form precipitates okay which is beta here in this particular phase diagram, okay. Now the aging treatment I mentioned right before that you can, after quenching you can leave it at room temperature and give you know sufficient amount of months and years, right. So and when this happens and you form precipitates the process is called natural aging, okay.

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So naturally your material, your aluminum alloy is going to age. So we call it natural aging. You are not going to put your sample in the furnace. You are not going to apply external heat to it, okay. So that is called natural aging. That means no external heat. It is going to happen or formation of precipitates is going to happen naturally. But when we heat it in the furnace, we are applying some external heat.

We call it artificial aging. That means we are supplying some external heat okay, so that precipitates then come out from the matrix much faster, okay. So giving external heat. That means say heating in the furnace, okay. Okay? So this is how we do aging treatment okay and this is the process by which we form precipitates in the matrix. Now these precipitates are going to interact with dislocations.

Also these precipitates you know are going to change its characteristic in terms of size and interfacial boundaries as we age it or we give more time, okay. So with respect to time, the nature of the boundary of precipitates and size, they change. So we will discuss that now, okay.