Phase Equilibria in Materials (Nature and Properties of Materials - II)
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Lecture – 22
Microstructure evolution (contd.) Microstructure evolution (contd.)

So, welcome again to a new lecture, lecture number 22.

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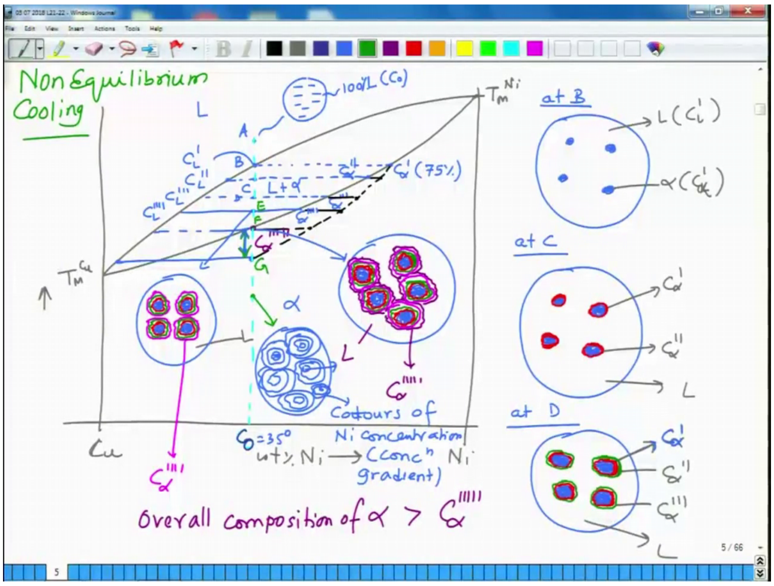

So, what we were doing in the last lecture is that we were looking at the Microstructure evolution in a copper nickel system.

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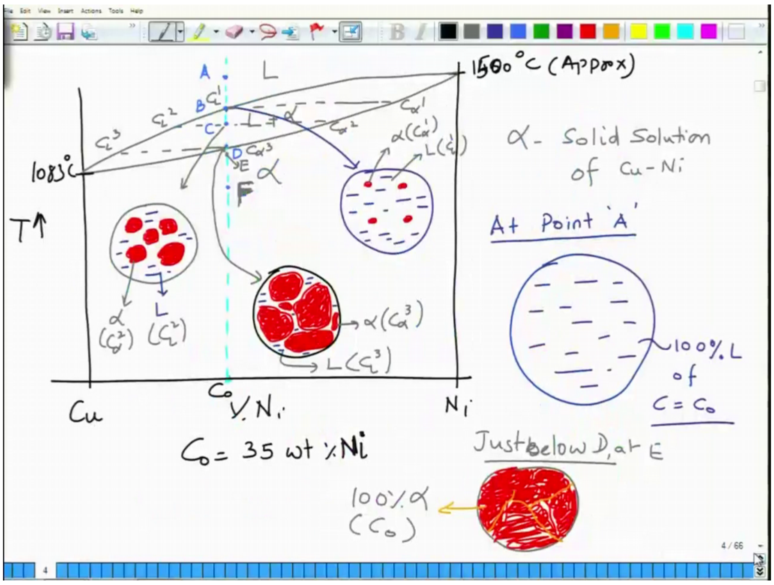

So, when you are cooling in a very slow manner so, that you are able to achieve solid equilibrium composition throughout the liquid and throughout the solid phase, what you form is you initially start with formation of small crystals of alpha of composition C naught, composition C alpha prime, and as the temperature decreases in the 2 phase region, the compositions of liquid and solid shift to C alpha 2 C L 2, the alpha grows bigger and bigger, and it is composition shifts towards C naught. And, liquid composition gets further away from C naught to pure copper, towards pure copper not necessarily pure copper.

But towards pure copper, and as you come to nearly the end of solidification that is at point D, you have nearly 100 percent alpha of composition C alpha 3 which is similar to C naught, and very little liquid is left whose composition is very thin in nickel. So, it has really small amount of nickel, and it is mostly copper. And at point D or E at point E or F, or even F you will have 100 percent alpha, whose composition will be equal to C naught. So, this is under conditions when cooling happens in very slow manner, where solid composition is able to equilibrate itself as a function of time and temperature. Now what happens under real conditions is that, under real conditions so, this is you can say non equilibrium cooling, ok.

Under real conditions what happens is that, under real conditions because the solid is not able to equilibrate itself with the next form solid. So, what happens is that, the first solid that will form will be of composition C alpha 1, but as the next solid form when the next solid forms at points 2, the next solid come that the first solid does not equilibrate in terms of composition with next solid formed, as a result the first solid remains at C alpha 1, and the next solid which is formed as C alpha 2. And this goes on gradually at point D, that the next solid forms is of composition C alpha 3; which is unable to equilibrate with C alpha 2 and C alpha 1 which had formed earlier, that C alpha 1 being greater than C alpha 2 being greater than C alpha 3. And this goes on until the solidification is about to end.

So, when you reach at point let us say what was this is this was point E and this was point F. As you reach point F which is the end of solidification as per the phase diagram, you have very small amount of liquid left and solid has various layers of alpha with different compositions. So, first alpha the blue one has highest amount of nickel in it, and the last solid which has formed has very lower amount of nickel in it. However, because of this composition gradient the overall composition of alpha is. So, what happens is that; so, what happens is that you have various layers of alpha of different composition, the first one forming of composition higher than the last one forming. As a result, the overall composition of alpha is higher than what it should have been at equilibrium. As a result, the solidus boundary shifts for the low because the overall alpha composition has to be alpha naught.

So, when the solidus boundary shifts lower as a result what happens is that, that the liquid is not finished. There is some amount of liquid that is left as a result you have to further cool down from F to G to complete the solidification. And this happens because of composition gradients. So, the liquidus so, the solidification point of the alloy is no longer F it shifts down to G because of shift of solidus of the phase diagram which happens because of non-uniform distribution of the solute within the alpha phase as a result of faster cooling which does not allow enough time for solid tool for a per nickel to redistribute and between different layers of alpha which form at different point of time. As a result, you will have a solid whose concentration will be different. So, what you will form eventually is something like this.

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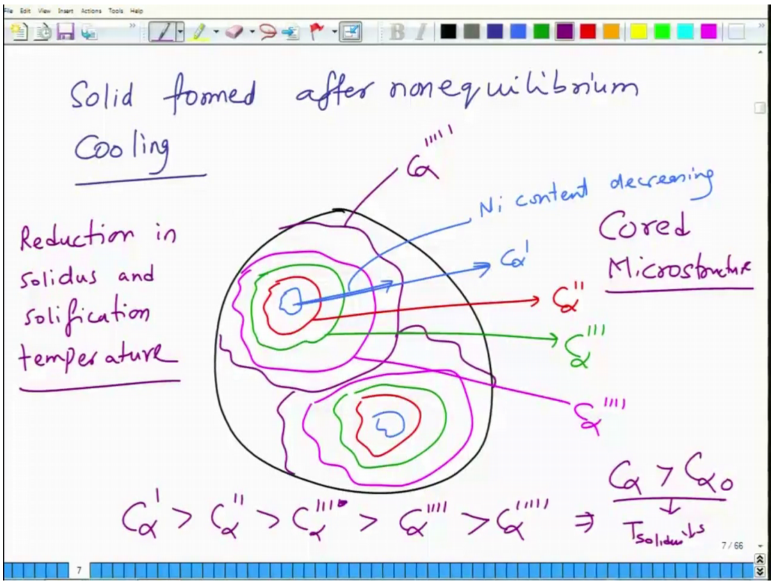

Solid formed after nonequilibrium Cooling

Reduction in solidus and solification temperature

Ni content decreasing

Cored Microstructure

$C_\alpha' > C_\alpha'' > C_\alpha''' > C_\alpha'''' > C_\alpha''''' \Rightarrow$

$C_\alpha > C_{\alpha 0}$
$\downarrow$
$T_{solidus} \downarrow$

So, you will have so, this is we draw a circle because in microscope when you look at the microstructure, you see that in a circular area generally, that is why we always draw a circle otherwise there is no need to draw a circle, ok. So, the first solid formed was this, the next solid would be like that, next one it would be like this. And then you will have like this and then right so, this is down. So, you will have different variations. So, you start from, start at so, your nickel content is basically decreasing. So, as it is so, you might have the same situations of where here. So, you another first alpha, second alpha, third alpha have fourth alpha, then you will have fifth alpha. This is how you will have various regions or alloys look like.

So, the first one will be so, this will be of composition C alpha 1, this will be of composition C alpha 2, and this will be of composition C alpha 3, this will be of composition C alpha 4, and then this will be of composition C alpha 5. With C alpha being prime being greater than C alpha double prime, ok. As a result, the overall composition of alpha will be greater than C alpha real, C alpha naught sorry, and hence this leads to decrease in the solidus temperature. So, as a result the T solidus decreases, and that reduces the solidification point of the alloy. So, this results in reduction in solidus and solidification temperature.

So, this kind of microstructure will be formed in real conditions in alloys, and this kind of microstructure is called as Cored Microstructure. Coring means composition fluctuations so, this is called a coring. So, you have at the center different composition as compare different what at the periphery, and this composition gradient is results in a microstructure called as core micro structure. So, this is what happens this is how the microstructure evolve in a binary system. So, we took the example of copper nickel system which is isomorphous system. Micro structures form differently in different alloy systems.

So, this is the very simple example of copper nickel system which is completely soluble in to each other, as a result you have either single phase liquid or single trade phase you at home temperature you will have single phase alpha or single phase solid. But what happens in a eutectic system is very different. And now I am not going to consider a non equivalent cooling or non-uniform cooling, or non uniformity in the composition, am just going to consider the microstructure that will form eventually. So, let me before I start that let me also point that out, now that you have compositional variations in that solid. It is going to affect the properties of the solid. As a result, this microstructure is generally heat treated.

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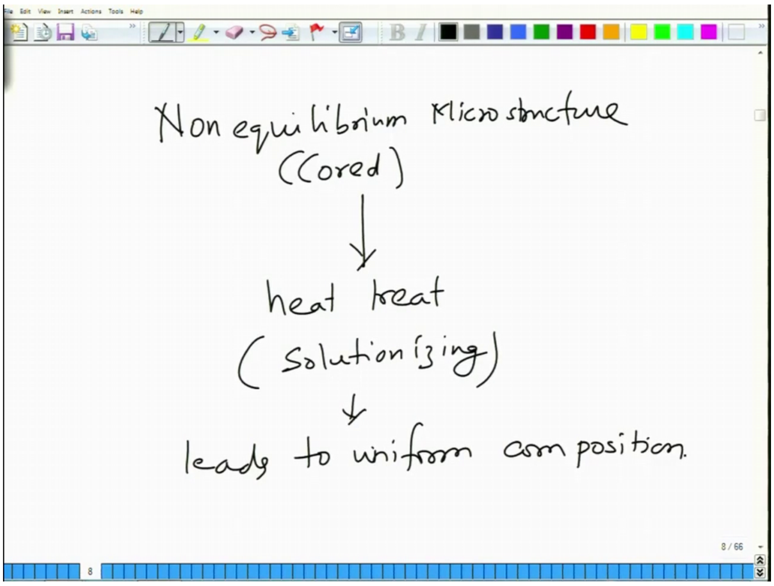

Non equilibrium Microstructure
(Cored)
↓
heat treat
(Solutionizing)
↓
leads to unifrom composition.

So, what we will do is that so, you have a non equilibrium microstructure; which is let us say cored microstructure, then you heat treat it, and this heat treatment is called a solutionizing, which is basically leads to uniform composition. So, you heat the temperature; such that you heat the temperature of the alloy such that you are in if you have this as a phase diagram.

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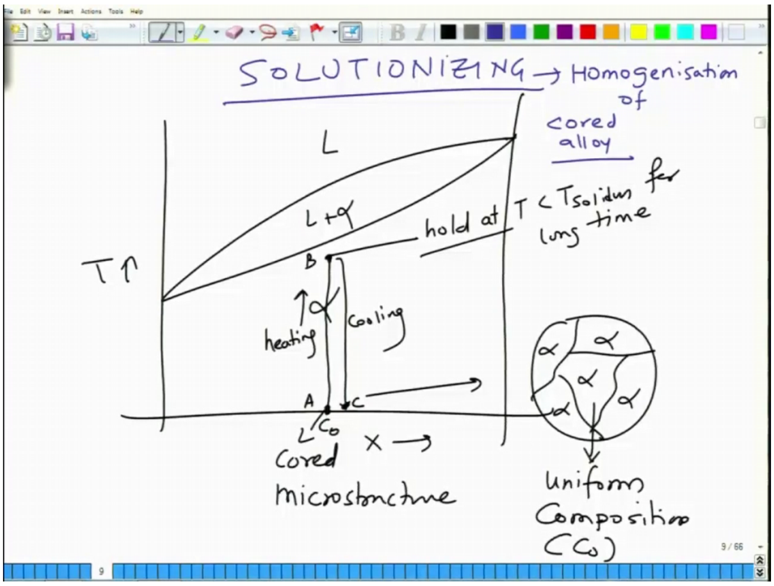

So, let us say you had a microstructure, which was cored microstructure. Again temperature and this is composition x. So, cored microstructure is heated to temperatures, which are just below solidus, there you do not cross the liquid region. So, you go from point A to B, hold at T less than T solidus for long time. You might have to hold it in vacuum, you might have to hold it in nitrogen depending upon the oxidation tendency. So, some alloys you can probably work them in air itself. So, depending upon the type of the alloy you might have to hold that in different ambient. And then hold it for a long time, and then cool it to see, you can cool it fast you can cool it.

So, this is heating, this is holding and then cooling. You can cool it fast or can cool it slow depending upon what kind of microstructure you want. But this is how you do the solutionizing treatment, you hold it at a high temperature which is high enough, but lower than the temperature at which liquid will form. So, you hold in the solid region at high enough temperature for long enough time so that all the solute is now able to homogenize itself across the solid. So, what will this give rise to is a microstructure, which will have 2 different grains of alpha.

So, this is alpha, this is alpha so, this will have uniform composition, same as that of what you had here C naught. So, this is called as solutionizing treatments, which is basically for homogeneous of cored alloy, ok. And this is a practice which is followed in industry to give rise to better components, now let us look at the microstructure development in eutectic systems, ok.

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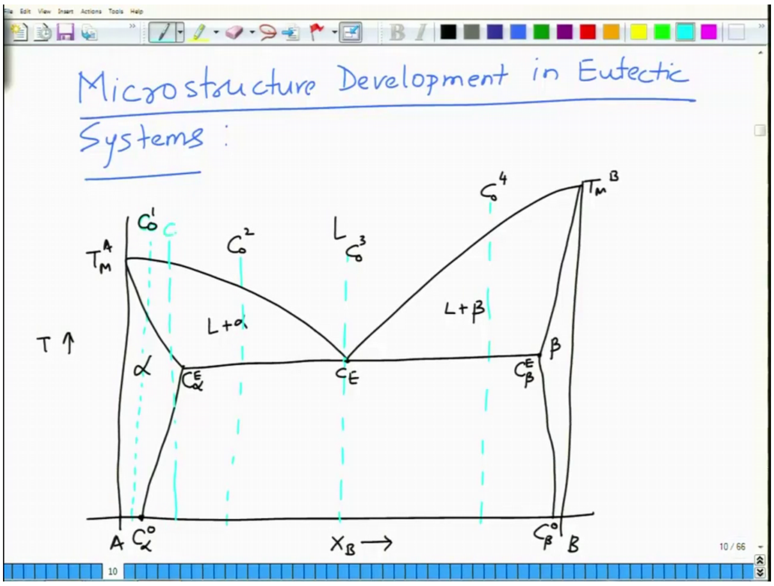

Microstructure Development in Eutectic Systems :

So, when we look at the microstructure development in eutectic systems is, first let us consider a eutectic phase diagram ok. So, A B this is temperature ok. So, let us say you have a phase diagram like this; generally eutectic diagrams will have as we know. So, this is A T m of A this is T m of B this is X B generally in 8 percent. This is the eutectic composition C E; this is the solid solubility of solubility limit of B in A. So, this is C alpha E, at eutectic temperature. And this is the solubility of A in B at eutectic temperature and beta phase.

So, this is C beta E these are single phase regions alpha and beta this is liquid, liquid plus alpha, liquid plus beta. And this is at lower temperature, let us say at room temperature. So, this is C alpha naught and this is C beta naught. So, this is the maximum amount of B that can be present in A at under ambient condition; say, this is the maximum amount of B that A that could be present in B at room temperature, this is the maximum amount of A that will represent in B; that is alpha phase with largest amount of B at eutectic temperature is C alpha. E this is the maximum amount of A in B that is in beta phase with single phase beta, at eutectic temperatures of composition C beta E, and as the temperature further increases the alpha solid solubility goes down, and beta solid solubility also goes down. And in between you will have liquid plus alpha and liquid plus beta, at eutectic temperature liquid of composition C E will directly convert into alpha plus beta mixture.

Now, let us see how does the microstructure evolve in such a system. So, we choose various points. We will first begin with a microstructure development for alloy whose composition is this, ok. Then we will choose alloy whose composition is this. Maybe not, maybe slightly, maybe the next one could be this. One composition that we will choose is that of eutectic composition. And this side will again be similar to the side on the left, but we can choose one composition at this point. So, we will take we will take 4 point. So, let us say we have an alloy C naught composition C naught 1, C naught 2, C naught 3 and C naught 4. Now, let us first begin with the alloy composition of C naught 1.

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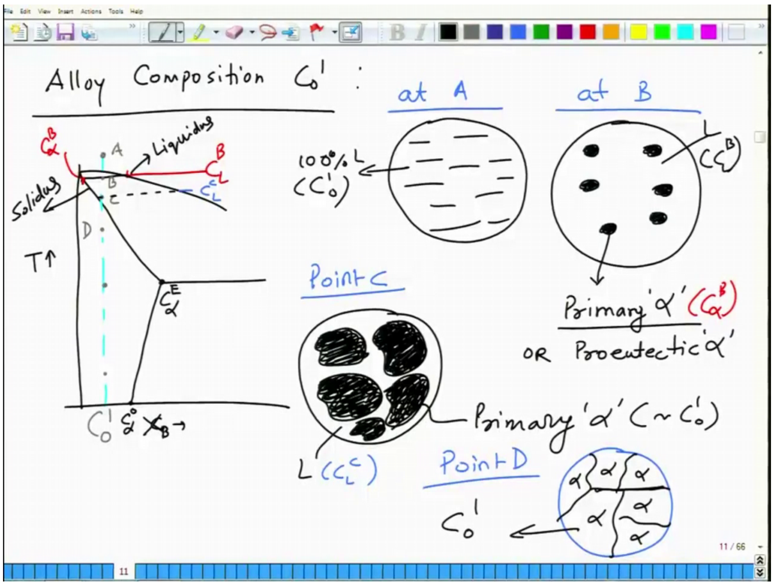

What we will do is that we will just zoom in the part of this part of the phase diagram, will not draw this part of phase diagram. So, we will just draw this part so, let us do that. So, this is X axis, Y axis temperature, X axis and X B. So, this was starting from this point to that point, sorry, I will just make it a little bit more wider ok. So, (Refer Time: 18:29), ok. So, we just look at this part. This is C naught 1 and we consider at this point, then at this point, at that point at this point and ok. So, we can consider any of these points. So, let us say we consider at A, B, C and let us say at D. So, at a we have 100 percent liquid. So, when we draw the microstructure, let me not draw that big, should not be drawn in one page; so, will be little smaller ok. So, at B what we have is 100 percent liquid. So, this is 100 percent liquid of composition C naught 1.

What we have at B is, some amount of alpha that is formed. So, this alpha which is formed and grown bigger, let us say I shade this alpha. So, this is alpha so, this is alpha phase which is the solid solution of B in a this is formed before the. So, this is liquidus and this is solidus, ok. It is formed after the liquidus, but before the solidus. So, this is called as primary alpha, and in the eutectic phase diagram you call it or pro eutectic alpha. But in this case since we are away from so, this is where the eutectic composition will end.

So, this is C alpha E alright, and this is C alpha what was it? C alpha naught; so, we just mostly we will call it primary alpha. So, we will have primary alpha of composition to disbelieve the composition. So, let us say this is the composition C alpha B and this is the composition C alpha C liquid B, C liquid B. So, you will have primary alpha of composition C alpha B, and you will have liquid of composition C liquid B, and whose fractions can be known by lever rule, alright. And then you come to point C, at point C, we have nearly ended the solidification. So, these alpha grains would have grown bigger so, this is alpha, ok.

So, this is basically alpha, primary alpha of composition nearly C naught of composition C naught 1 and remaining is liquid of composition. So, this will be C L C. So, this is the composition of C L C ok; which is higher than higher in solute. And at point D what will happen is that, point D you will have. So, this all of this will convert into 100 percent alpha. So, what you will have is basically, grains of these grains of alpha, alpha, alpha, alpha, alpha, alpha, alpha. And overall alpha would be of composition C naught 1.

So, you will have 100 percent alpha of composition C naught 1, ok. So, this is how the microstructure will develop in this alloy. Now let us take another slightly of composition. So now let us so, in the in this diagram, let me also draw a line which is this line. This line, so let us say we call it another. So, you have C naught 1, 2, 3, 4 we can take this as let C naught itself.

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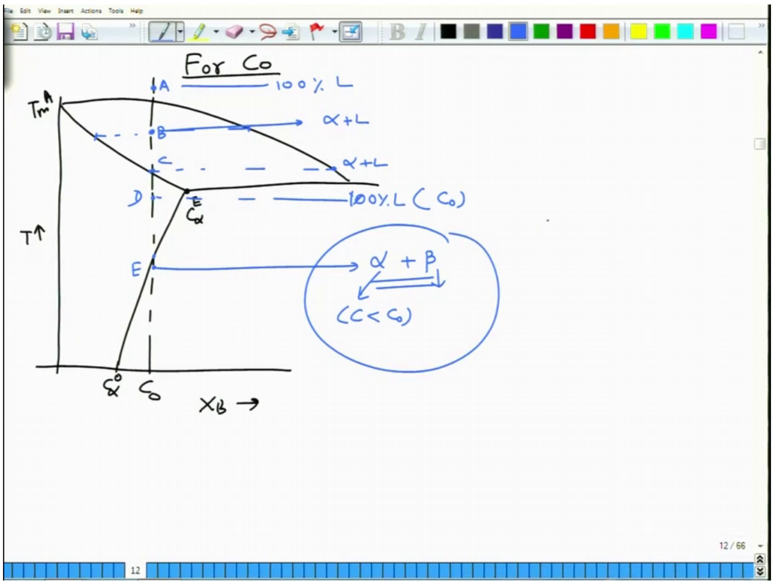

So, we take again we draw the zoomed up portion only. So, we only take this particular so, this is C naught C alpha E this is C alpha naught temperature. This is T m A that is let us not worry about this part, and this is X B. So, this is for C naught so, for C naught. So, this was earlier was it was for C naught 1 this is for C naught. So, again for this alloy also, if you have this point it is 100 percent liquid same as previously; if you are at this point, B point it will be alpha plus liquid; the composition is known by this line intersection, and proportion can be found out by the lever rule.

So, as long as I have took this point there is C. So, you will have the liquid composition by this point and solid composition nearly. So, this is again alpha plus liquid, and composition you know from the previous. Same as previous one; when you come to this point, then you are in single phase alpha point D 100 percent alpha of composition C naught.

The problem happened, now when you cross this line at this particular point, then what happens is that, the solid solubility of alpha starts decreasing, and you start forming some beta. Now this is where you will have at this point let us say point E, you will have alpha with some beta in it. And this alpha composition will be lower than C naught. And this beta will composition will be given by the tie line. So, we look at what this is in the next lecture ok.

So, this is what it will make a change in microstructure when you have different originally textual designer. We will further discuss more compositions of eutectic phase diagram in the next lecture. So, in this lecture we have looked at various microstructure evolutions and isomorphous on eutectic phase diagram, which will continue in the next lecture.

Thank you.