Phase Diagrams in Material Science Engineering
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Lecture - 52
Solidification Behaviour of Ternary Alloy

Students, we are going to discuss today about the solidification behaviour for the three phase equilibrium, in the ternary system. In the last two lectures I have given a heavy description, of, the three phase equilibrium of the ternary systems and I choose specific case, in which, there are two eutectic, between the three binaries, and one isomorphous.

Then, followed by I discussed about the, isothermal sections and vertical sections. Today we are going to concentrate on solidification behaviour of these alloys. And I am going to take this lecture using different sketches on the board, so that you can understand nicely. First thing I am going to discuss is, to draw this phase model again, so that if you have forgotten you can again, you know, you can again revisit those things, and then I will discuss about solidification behaviour using these things.

So, let us go there. I am going to use these phase model for all our discussions.

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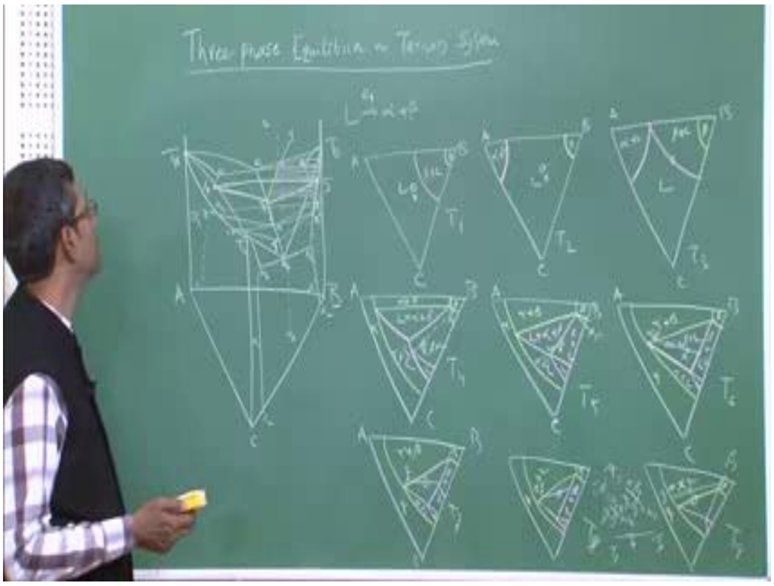

So, phase model which I told you in the last lecture, consisting of, 2 eutectic and 1 isomorphous system. So, isomorphous will be between A and C and eutectic will be between Ab and Bc. So, the isomorphous system between A and C is like this, this is your T.

Tc this is your Ta, and the eutectic is between C and B. So, this is the primary phase field of the C reach phase, and this is the primary phase field of B reach phase, and eutectic case, like this. I hope you can see clearly.

So, therefore, we termed this as a eutectic two e2 and these two points I termed as c2 and d2. There is another eutectic between A and B. So, that is little bit clumsy let me just draw it nicer, so that you can see it clearly. So, this is the two primary phase field regions between A and C, and these two are the primary phase field regions, of A region and B region, then I drawn the binary A eutectic like this e1. So, I termed this as a, this as b, c and d, and this is a1 b, b1 better a2 b2, and then I can connect, I know that I can connect these two eutectics, that is how this phase model will look like. And in fact, one can actually generate, this triangular region, between the three phases, alpha beta and the liquid, looking like this, correct? That is how I have drawn.

So, three phase region here looks like a triangle. Now I am going to discuss with you how the solidification will take place, right? So, let me just see where I have kept it because this is all, yeah. So, what I am going to do is, for you, let me remove this one, this is what I have drawn in last class, let me remove this one, and draw and composition x. Let us suppose the composition s given by this point x. This is your x, and we are going to discuss the solidification of these alloy. Now what is going to happen, first thing is that, this is a liquid, as you have seen, that this forms complete liquid, in altogether, complete liquid, at the above, complete means miscible liquid, and at low temperature only this forms this solids, those are different compositions.

Then similarly like, you can see here, the A reach of alpha phase will have this much of solid concentration, B reach will have this much, C reach will have this much concentration. Now, but in liquid it is all it miscible together. So, therefore, as you cool down the alloy, nothing should happen below point, suppose, 1. Let me just tell you, this point 1, 1 or let me just take this colour chalk so that is easier for you to understand.

So, point 1, this is a point one on which, I do not know whether you can see this is a point 1, on which this line will cut this liquidus surface. Because liquidus surface is a very complex one here, it goes like this, it goes down also so that is what, but when it cools down it hit's the liquidus surface as point 1, and at point 1, because it hits. So, therefore, this will be, liquid will be equilibrium with the solid, of a composition given by the point 2, point 2 will be this, this one on this surface, you see, this is the surface, this is the surface on which this will be in equilibrium correct?

So, as you go along, this is the alpha, this is the beta phase atom, because this is the beta, this is alpha, this is alpha alpha, this is alpha, this is beta. So, because of that, this is the beta concentration, or beta phase, which will form, at the, on the surface of the liquidus. When the, when you cool down at temperature, suppose, liquidus temperature, this is the concentration composition of the beta phase, which is B reach; obviously, at the liquid phase. Now as you cool it down, this is the way the liquid composition will change, correct? Similarly, this is the way solid composition will change, correct? That is how it will vary. So, one can actually draw varieties of tie lines, varieties of tie lines, you can see here, large number of tie lines you can draw, large number of tie lines you can draw correct?

So, this this is how the things will change, but things will, as you cool it down, at suppose, this is a point 3, let me I draw this is the point 3. At point 3, this line liquidus line, or this curve on the liquidus surface, will touch the surface on e1 e2. You can see here, this is going to touch that. And that means, that this will precipitate also alpha, because this is the eutectic between, eutectic reaction is what? Liquid going to alpha plus beta, this is the e1 reaction, e1. So, because of that, this is going to precipitate, this is going to precipitate, alpha also, and what about the alpha compositions? That we can get it, very easily; I will just draw this one, and show you. This is the alpha composition, I can connect. So, this is the alpha composition, and this is suppose let us (Refer Time: 8:23) this is 0.4.

So, you have equilibrium, and this is suppose 0.5. You have equilibrium between 0.3, 4 and 5. Let us be draw it, a colour chalks. This is a triangle actually which I have been referring you to always. So, the compositions of alpha, composition of beta, composition of liquid will be given by these 3 points. One is 0.4, other is 0.5, and the last one is 0.3 will tell the liquid composition, 0.4 will tell you the alpha composition, point 5 will tell you the beta compositions. And this is what will happen, this is, these all keep on happening and one can draw other triangles also at the bottom, like suppose I can draw a triangle between, 7 8, let me just show, this way. This is another triangle and this is suppose, this is, 6 7 and 8, and similarly, I can also draw another triangle below, you can clearly see this will be sitting here, like this it might be wandering that how I am drawing this triangles. These triangles are drawn basically connecting, points on the solidus surface, or the liquidus surface, here and these two are the solid compositions alpha and beta.

So, that is how the solidification will continue, and it will get over whenever it hit's this, alpha beta, there is alpha beta Plato here, between this, which I have shown you, last class solidification will get over; Obviously, from this phase 3D model it is very difficult to follow the solidification behaviour. So, what we will do? We can actually draw these isothermal sections. Isothermal sections at different temperatures that will be much easier, and how it will be changing, let us see that, then we will come back to this diagram.

So, let me just draw one by one. So, first I will draw, I am going to draw nine such things. So, this is at t1, suppose t1, means the temperature at (Refer time: 10:42) to point one and; obviously, at this at this temperature you have beta, and then you have a beta plus liquid, and liquid. A B C, that is obvious, and where is my composition alloy? Compositions alloy will be somewhat there. I am going to put a dot here like this. So, this is my x. So, at point 1, basically everything is almost fully liquid, there is no solid, because it is just touching the liquidus surface at t1. At t2 what will happen? At t2, the diagram will slightly change, you are going to have alpha plus liquid, beta, let me draw it this way, coloured, and this is here for you to follow. This is beta, all green things will be solid for me, and any solid plus liquid region or liquid, will be like this. So, this is alpha plus liquid, this is liquid.

Again my alloy composition is somewhere there, x sitting. It will just form little bit of beta, as you can see here, you can draw a line, it will form beta. But things will be much clearer, once you look at this one, at t3. At t3, what is happening? You have to go back to my liquid solid, the isothermal sections which I have drawn. At t3, this is very nice, very clearly you can see, this is my beta, and then you have two solid regions, alpha plus liquid, and beta liquid plus beta, and liquid ok? So, what you have you have? Liquid, alpha plus liquid, beta plus liquid, you have a clear distinct beta plus liquid zone, developed, that is what is here, beta plus liquid zone on the right side. And, in this, then it sit's on this, as it sit's on this will precipitate more and more beta.

Now at t4 it will be very interesting actually, t4 is very interesting case, let me see whether I can draw one more triangle here, because I have to draw 9 triangles. I can draw at t4, t4 is what you have fully developed alpha, fully developed beta, and fully developed also, alpha plus beta zone, and then you have a, you have a liquid, plus alpha plus beta, ok? So, this is what is my alpha, this is my beta, alpha plus beta, liquid plus alpha plus beta, liquid beta plus, beta plus liquid and alpha plus liquid, And what is my composition? Here, ok?

So, you can actually joint these two points, like this. This is my x, let us suppose this is L 4 and this is beta 4. So, volume fraction of this solid will be, L4 x divided by L4 beta 4 , because this is the tie line, you can draw a tie line to the two phase field. So, at t4 only we come in we are going, to we see basically the connection between 2 phase and 3 phase fields. Now it will be clear to you, until t3, basically t3 is the temperature at which the solid is just about to form. T2 it is not formed, t1 also it is not formed. T3 is temperature at which it is just connected, t3 is here, it is here 3 point 3. T4 it will be like this. So, at t5 it will be much clearer to you. At t5 what is happening? You have a larger alpha region beta also and alpha beta will be much larger, and then we have liquid plus alpha plus beta also, liquid. So, what are the regions, this is my alpha, beta, alpha alpha plus beta, and then you have liquid plus alpha plus beta, it is a liquid, alpha plus liquid, beta plus liquid correct?

So, what is you do here is that, yes all this temperature it will even, because if at at at this temperature, actually these composition will sit on the, (Refer Time: 12:00) sit on this on this line, between these 2 phase field. So, this is my x. So, therefore, this will be alpha will start precipitating right? Yes, alpha will start precipitating here, this will be L5, and this will be beta 5. Alpha will just start precipitating, not much alpha is formed, it will have larger amount of beta and liquid left over. Now at temperatures t6, this is t5, things will little bit change so; obviously, you will have larger alpha field, beta also, and then you have a, this, sorry let me draw, this one like this liquid will be very less. So, this is alpha plus beta, this is your alpha plus beta plus liquid, this is your alpha plus liquid, liquid, beta plus liquid.

And at this temperature actually the composition of the alloy will sit inside the 3 phase field, because it is it was sitting on this, boundary between 2 phase and 3 phase, but it will now sit inside the 3 phase fields. So, it will be somewhere sitting there, and it will precipitate more and more of alpha 5 and you can see this is the liquid.

So, thing which is clear to you is that, at temperature t4, it was precipitating only beta, and beta composition was B4, and these composition beta was in in in equilibrium with liquid composition L4. At t5 the temperatures drops so much that, the alloy composition is sitting on x, and x is basically sitting on this boundary, between the 2 phase field and 3 phase field, correct? So, therefore, it is precipitating still beta, is not expected to be static (Refer Time; 18:15). Basically it will just, you know, thermodynamically it can, it can start forming beta alpha.

Now, at t6 this alloy composition point moves inside 3 phase region, 3 phase region, triangular region, you can see here. There it can precipitate alpha. So, that means, what does it means? It means that, at this temperature, eutectic reaction is happening, eutectic reaction lead us to formation of alpha, and beta is; obviously, will precipitate, beta was precipitating early also. So, primarily, as compared to the binary phase diagrams, because binary phase diagram eutectic reaction or the 3 phase equilibrium takes place at a fixed temperature, so, it is basically a non variant reaction. Here you have a mono variant equilibrium.

So, because of that this eutectic reaction can takes place for larger temperature zone, and that is what you see here, although it is taking, it is started forming here, there, it will also start forming at low temperature. Here, I am going to draw it at t7, t7 is at a higher lower temperature than t6, beta, alpha, ok? And this is the, alpha plus beta phase field, and this is your, this. Slowly slowly liquid is, amount is also getting reduced, that is what you see here, and this is alpha plus beta plus liquid, this is beta plus liquid, alpha plus liquid, liquid ok?

So, what will happen now? Obviously, nothing will happen, except that this, this tie lines will keep on rotating. Why, which way it will rotate? It will rotate in anti clockwise direction, because B to A to C temperature is dropping. Melting temperature decreasing from B to A to C; this is tb which is the highest melting temperature. So, what do you, what is going to happen here, is like this, it will tell this way. So, this is my alpha 7, this is alpha 6, alpha 7, and L7 and the the alloy composition somewhat there. So, more and more alpha will precipitate; that means, more and more eutectic reaction will happen.

And now add temperature t8 and t9, things will happen almost similar. I am just drawing slowly so, that you can understand it, because this is something which requires, detailed understanding, otherwise. So, this is alpha plus beta plus L, I will remove it, this is beta plus L, L and alpha plus L, and this is your alpha plus beta.

So, where it will, where it will, it will be? This will again rotate, tie line, this will be somewhat like this, and x x will be here. So, alpha will be forming with the composition of alpha is 8, is this one, remember in all these diagrams beta is forming, because this is equilibrium between, alpha plus beta, and beta plus alpha, 2 phase fields surrounding the alpha plus beta plus L phase fields. So, therefore, alpha beta, both is precipitated. At t, t 8, t9 rather, the same thing will happen, there 3 phase region will slowly decrease, as you see here. I am not drawing everything. So, writing everything otherwise will be clumsy. So, here finally, this composition will sit on this point, and at this point basically, both alpha plus beta, because slowly this this composition point is going to enter into the alpha plus beta phase field, finally, (Refer time: 22:50) will consisting of primary beta crystals and alpha plus beta eutectic. That is what will happen.

And in that case you have a, basically one it moves here, the basically you can draw this, this is the triangle. So, this is your alpha 9, and beta 9. So, you can measure the alpha concentration is this, this divided by the whole, beta concentration is, beta percentage is this, divided by the whole length of the tie line, it is just like that.

So, I can alpha 9, beta 9 and x sitting over there, percentage of alpha is nothing, but suppose this is x. So, x beta 9 divided by alpha 9, beta 9, into hundred. So, percentage of beta is exactly same. Alpha 9 x divided by alpha 9 beta 9, into hundred, because of space I am just writing there. Basically, therefore, it might be difficult to follow you, for you to follow the solidification path ways in this, but you can follow this solidification path ways nicely here. Basically what, once you are able to draw the isothermal sections nicely, it is the matter of just putting the composition point there.

Remember the composition point is also, liquid composition is keep on changing right? As the more and more alpha and beta are forming, the liquid composition is also changing. So, because of that, this point is also moving, going away from it was initially here, then it moves there, then it moves there, then it moves there, you can see here how the things are changing. That is one point, second point is, you also must understand how the tie lines are rotating. Tie lines will think this alpha plus beta, alpha plus beta plus, liquid. So, beta plus liquid and alpha plus beta plus liquid, these 2 zones you have shown and also rotating, in the direction in which the melting temperature of the components are changing so, that means, anticlockwise B to A to C, that is anticlockwise direction.

So, I hope you have got little bit, I am not sure whether you have got a complete understanding of the solidification behaviour, but you have got a at least fair amount of understanding that how the solidification is talking place. Frankly speaking, if I have to tell you in one sentence; obviously, if I cool down initially beta will precipitate first because beta has a higher melting temperature; B is the higher melting temperature component and because of that beta has the higher melting temperature phase.

So, beta will precipitated first, beta will be equilibrium in liquid, till it reaches point 3, the liquid composition, which is again shifting from 1 to 3, till reaches 3, at 3, both alpha and beta will precipitate and; that means, what the eutectic reaction will happen, and as you go down more and more eutectic reaction will take place and more and more alpha plus beta phase which are phase will form.

And finally, this will end at a temperature at which your alpha plus beta, this this this thing, this three dimensional structure which I have drawn, alpha plus beta phase field, will this point 9 will sit on the surface of that. That is why the whole solidification will finish or get over. So, same thing is seen here, liquid initially, then liquid is in contact with beta. Finally, liquid and beta crystal will, more and more beta crystal will form, then it will move into alpha plus beta plus liquid zone, where alpha will precipitate, then it will move into there, at more alpha will precipitates, more alpha means more eutectic, and finally, more alpha and finally, it will move into alpha plus beta where the solidification will get over. That is how things will happen, and this is what you need to follow, correct?

In the next lecture, I am going to tell you a bit on this, and further, a phase diagram where, we have only one eutectic, and two binaries, two isomorphous systems, variation of that, because this is what we can do. Peritectic and monotectic systems are much more complex, so we are not going to discuss those. In the next class I am going to discuss that.