Phase Diagrams in Material Science Engineering
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Lecture – 47
Ternary Phase Diagram and Tie Line Construction – III

Students we have been discussing about ternary phase diagrams, and I just started discussing about the basics. The last time I have discussed about of the isothermal sections, and also the tie lines, rules and regulations of the tie lines for the ternary sections. Today I am going to talk about vertical sections, and as well also Polythermal sections. And we are taking examples of ternary Isomorphous system, in which all the binaries are forming simplize Isomorphous type phase diagrams. So, therefore, the phase diagram in the ternary space, is basically like a two curve surfaces, bounding the liquid plus solid region. So, now, let us took at the, again little bit recap of the isothermal sections. So, that you do not forget it.

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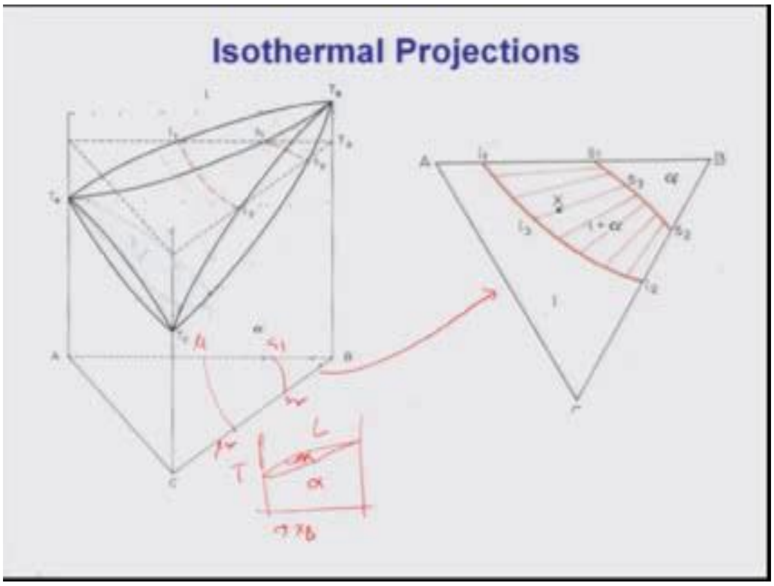

As you know this is what is these by ternary Isomorphous phase diagram, bounded by the two surfaces; liquidus, and the solidus, and there top is above the liquidus surface you have liquid, below the solidus surface you have solid alpha, in between you have liquid plus alpha, just like a binary section. And I have been drawing this 1 again and again, to make use sure that you understand it very clearly. So, this is the binary space diagram, and corresponding with ternaries like that.

So, now, the as you have seen that, this is a very simple ternary phase diagram, and we can actually look at the three dimensional model, and understand, but there may be (Refer Time: 01:55) where the three dimensional model is very complex, and because of that we need to look at the positions, and one of the best way of taking position is taking sections at some constant temperature. Suppose if I take the section at temperature, different temperature is call isothermal sections. And isothermal section is shown here. If I take isothermal section at temperature t 3 it will look like this. Basically if I take the way I do it I take a plane parallel to the horizontal, a Gibbs triangle, or Gibbs triangle at the bottom. I take a parallel triangle and cut the three dimensional model, using that triangle.

And if you look at carefully this triangle will cut the liquidus surface at l1 and l 2 solidus surfaces at l s1 and s 2. Now, if I project these two curves, these two curves here to here, and these two curves there, and I can actually right down l1 l 2 and s1 s 2, and this is exactly shown you here. So, therefore, this is basically projections of the ternary section, at temperature t 3, plotted on to the Gibbs triangle, and is looks like what is shown on the right side picture. Again l1 l 2 is the position of a liquidus, which is projected liquidus projection at temperature t1 t 3, sorry and s1 s 2 are the projection at temperature t 3. And these basically demarket the different regions, just like a binary liquid solid and liquid plus solid. And as I told you here actually you can draw tie lines between these two surf due to curves l1 l 2 and s1 s 2, and all this tie lines as I discuss will follow certain rules and regulations; that is what you have done. Now I am going to go forward, today I am going to discuss about the vertical sections.

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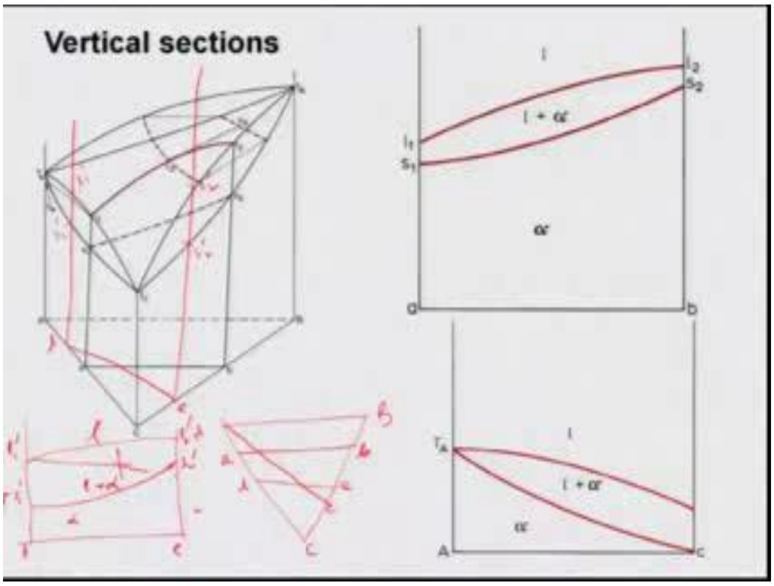

The second important section which is used in a ternary phase diagram is called vertical sections. So, those are isothermal and horizontal sections; the one I just discussed. Vertical sections are different types. You know vertical sections taken (Refer Time: 04:20) to the temperature, they are taken parallel to the temperature axis. So, I can take vertical sections at different, you know ways, in different ways. I going show you that suppose this is my Gibbs triangle and I can take a vertical sections parallel to the (Refer Time: 04:37) sides like this. this is suppose a b. I can also take a vertical sections starting one of the corners like this, a capital a small c. also I can take a vertical sections little bit angle, there are three important vertical sections normally we take. The first 1 along a b is shown here. Suppose if I draw a vertical plane, this is the vertical plane, let me just draw it for you. This is the vertical plane right. So, this vertical planes moves directly up, and if it moves it cuts; obviously, put the liquidus and solidus surfaces.

As you see it cuts the liquidus surfaces l 1 and l 2; l 1 is here l 2 is there, it cuts it moves vertically. Similarly it it also cuts the solidus surfaces as s 1 and s 2. Now I just plot this section along a b, a is starting at a composition b is starting at. You can see a is basically a binary compositions along a c and b is a binary composition along b c. So, they are all not pure, they actually alloys this 2 point indicates binary alloys. So, I have plot it the way it will look like is like this there will be two open ends on the both sides as you see here this is these are two open ends, this is the two open ends on the both sides, but it looks like a binary Isomorphous phase diagram; why, because it will have a liquid above solid below, and between the two curves you have solid plus liquid, liquid plus alpha what I have marked here, but remember this is not the case.

What I mean and to say is that, it is not like as binary I somorphous phase diagram. I cannot draw tie lines like this, I cannot draw. These are all wrong, this is wrong, complete wrong, you cannot draw a tie lines here. It is very clear why I cannot draw. See if I, suppose this is my section if I draw a tie line what does it go. It go and hits somebody else it does not meet this 1 liquidus surface to other solidus surface, it does not.

So, if you look carefully that is what you have to think yourself in the perspectives of the three dimensional diagrams, and if you look carefully you will see that is not possible here. I cannot draw tie lines between the two solidus and liquidus solid, the surfaces which is plotted here. That is the most important lesson you have to remember. Then on the vertical sections it is not possible to draw tie lines. Only on the horizontal sections I can draw tie lines, and then I can actually formulate the rules and regulations for tie lines. Now let us move on to the other thing; that is for the first thing, let us move from the other things.

So, therefore, another section we can draw is along a c; a is basically on the ends of the of the composition triangle Gibbs triangle and c is like that is. So, that way I will draw is let me just give erase this part, that you can see it nicely. So, the way it is drawn is that I can (Refer Time: 08:10) vertical section like this, and draw like that. So, if a draw a vertical section like that is again rectangle again a basically as a rectangle; obviously. So, it will s here liquidus surface there. So, if we see carefully the way this can be drawn is like this, this is basically like this, exactly like this. So, again this will also demark it regions, the liquid plus alpha and alpha. Just like the previous 1.

So, thus the basically it is possible to show this different. Regions just like a binary phase diagrams, but here you see; one and of these curves are joint other end is open. So, there is; that means, that, because its start from a reach end and it ends at the or the alloys which is b c on the b c side, or that is alloy consisting of b and c element it does not have any a, because as I have told you the composition sitting on this lines of the sides of the triangle, will demark it, will tell you that they are binaries.

So, as very clearly I cannot draw these tie lines here also, and do calculations that these are wrong not allowed at all. So, thus that is another way of drawing it, the diagrams. So, I again erase, and I tell you how to do the next 1. Next 1 is what. Next 1 is along d e. So, d e will not be like a parallel to a a b is parallel to capital a b small a b, d will be like this at an angle. So, if I do that then I take a vertical like this you can see here this is l 1 star l 1 dot s 1 prime.

Again this is s 2 prime, and this is l 2 prime. So, if I draw it, it will look like exactly the way I have drawn for a b. So, I am drawing it for your purpose here, so that you can understand it nicely. So, let me draw it properly. So, that you understand it properly. So, this is d this is e temperature, and this is my l 1, this is my l 1 prime, s 1 prime, l 2 prime, s 2 prime, liquid alpha liquid plus alpha. So, is exactly looks like, is little bit not same because temperature increasing that is that way. So, it will be higher I am sorry it will be higher. So, these points will change, sorry why it is moving I do not know anyway. This is l 2 prime s 2 prime. So, that is what it will look like, but here also I cannot draw the tie lines, because this tie lines if I draw they are in wrong.

So, the message is that vertical sections can be of three types; one which is like a b along a b, a lie, it can be a line parallel to on the sides of the Gibbs triangle. other one it is starts from one end a end and it go or b end or c end it goes through the opposite side, and third one is an triangle at line which is not parallel to on sides, but an at an angle like d e, but all of these will not allow to draw the tie lines; that is the very important thing you have to understand. Anything else and I need to talk let me see. I am just reading the book which is there.

So, it says the same thing iterating, it is general it is not possible to draw horizontal line tie lines, across the two phase regions in the vertical sections, to indicate the compositions of the (Refer Time: 12:49) phases at the given temperature. The only time, let me just read it out because that is very important you should remember that. Only time it is permissible is when a section occurs in a diagram which is a truly binary section. Yes that is possible; like if I take a binary section, suppose let me just erase let me just erase this part, if I take a binary section, why this is moving.

So, if I take a binary section along. this is a binary section will take like that, this is what it is, then I can draw then what I am getting. I am getting like this then I can draw this tie lines. So, what is mean to say is that. It mean to say is that, let me erase this is the problem, or let me just do one thing. I will I try to go get back to you just a moment. It is creating problem (Refer Time: 13:52) Let me introduce a slide take a moment please.

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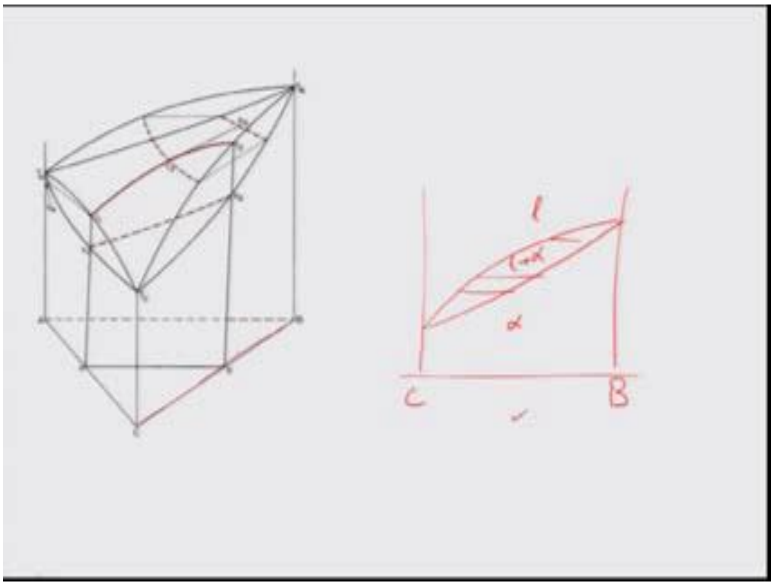

So, what is mean to say is that, if I take a section along this line, it will look like this, it will be looking like this and there I can draw? So, it is only possible when a section occurs in a binary section. If section occurs in a diagram which is a binary section, this case arise when a congruently melting compound occurs in one of the binary system, there is possible yes.

This is 1 way; otherwise if a congruently compound (Refer Time: 14:51) compound occurs in the binary section then also you can do that. The section from a third component to the compound can then be a binary section. Usually curve issued the binary section entire line can be draw on such a vertical section to present the composition to (Refer Time: 15:06) phases. So, this is 1 way, another way is that if one of the ends of the section is a corner point, and other end is corresponding to a congruently melting compound.

On the way if I when I am teaching it, if I finds as a diagram I am going to come back and discuss with you. So, that is then only you can allow you can draw this tie lines otherwise you cannot draw the tie lines. So, that is about the vertical sections. Now we are going to look at the last thing, is the horizontal or the polythomal sections. What is polythomal section let us look at it. So, before that let me just go back to you and discuss about the phase diagram here, what is the three dimensional plot yes. Three dimensional plot is here. So, I erase this part (Refer Time: 16:03) anyhow.

So, this is the three dimensional model, as you see here. So, in the three dimensional model, we have two surfaces; one is liquidus, other one is solidus. Now we can use these things, to understand the solidification path ways how alloy will solidify please remember I have done it for binary. So, I will also do it from binary again first, and then discuss the ternary.

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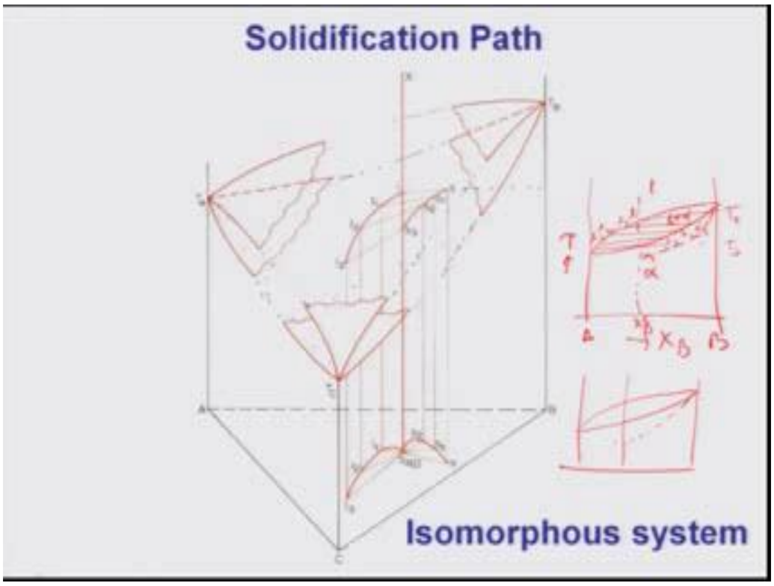

So, what happen to a binary let me just draw? Suppose I want to discuss in alloy, solidification of alloy x p zero; obviously, I have draw vertical line is like this. Now please concentrate here. now what will happen only this will liquidus top surface will liquidus bottom surface solidus is bottom (Refer Time: 17:04) solidus, so what will happen, below only this liquidus solid will start forming and I can draw a tie lines, and follow the things, and finally, whole liquid will solidify at this temperature.

This is t l this is t s right; that is what happens and you know that if I cool it very slowly like equilibrium manner, then the solid will have uniform composition, but when I change the cooling rate, or when I go for non equilibrium manner, then it will lead to coring that I have discussed. Now let us do that for ternary sections. To show you clearly what I have done is that, I have cut the middle part out. As you see here these are my solidus and liquidus surfaces. You can clearly see this is liquidus top one, or bit (Refer Time: 17:56) solidus surfaces. And I am going to follow solidification of the alloy composition x.

So, as you know as this cool down it will first hit the liquidus surface at l 1. So, as he hits the liquid subs l 1, l 1 as l, not l 1 l will be in equilibrium with the solid composition s which is sitting on the solidus, that you clearly see the right you can clearly see. Now as you cool down the temperature, the new equilibrium will exist between is, just like this suppose if I have this is what this is s this is l l 1 s 1 l 2 s 2 l 3 s 3 a like that is goes like then this is the (Refer Time: 18:50). Now, similarly as you cool down the nuclear will develop between a liquid l 1 a solid s 1.

So, these are the tie lines, or these are the things which you will connect on the not tie lines as on the solidus a liquidus surfaces. There has a cool down there will nuclear is between l 2 s 2 l 3 s 3, and finally, at s 3 it will solidify. Now question is this it is not always possible to track through the solidification path is from the three dimensional model, what I should do? Basically is to project the whole think on to the two dimensional a b c Gibbs triangle. So, what we project.

We project both the liquidus surface, and the solidus surface, and draw these lines. So, as you see here this is the x line which is meeting at point s 3. s 3 is where the solidification ends, and there from the s 3 the curve originates, move up to s, another one originates move up to l 3. So, what does it mean? This 1 which is originating from l or s 3 whatever, there are (Refer Time: 20:05) each other and moves along li l 1 and l 2 three is the position of the liquidus surface. On the other hand, the curve which you see here moving from s 3 moving, going to s 2 s 1 and s is a position of solidus surface there (Refer Time: 20:20).

So, if I have that in my view on the two dimensional position, then I can explain the solidification path is much easily, we will see how. So, I can see here s and l they are connected by a tie line, can you see that. Similarly s 1 l 1 is connected by that s 2 l 2 connected, s 3 l 3 is connected. So, now, I can actually, because this points are lying on the Gibbs triangle, I know their compositions very easily, because each of this point corresponding to a ternary composition, because they sitting on the inside the triangle.

So, as I know their compositions, I can easily explain, how does solidification is proceeding. I can actually calculate volume fraction of phase is very easily, which is not possible using the three dimensional model. In three dimensional models you cannot use and these composition data points and calculate, the volume fraction of phases. Or how the solidification is progressing, what are the solid compositions of solid product I mean you cannot do that, whether you can do easily if you project these things very easily.

That is the idea; that is why actually most of the cases we project even the thing on to the triangle, and this is what you known as polythermal sections, they are actually known as polythermal section. Why they are called polythermal sections, because they are actually at different temperatures. See l and s, they are meeting temperature suppose t, l 1 s 1 is t 1 l 2 s 2 at t 2 l 3 s 3 at t 3, because they are at different temperatures, and all of them we are projecting on these triangle; that is why it is call a polythermal section.

So, therefore, the message which you get very important message is that, we can use this polythermal sections nicely, to demark it how the composition is, how the solidification is taking place. In fact, how the composition with solid and liquid are changing. Now this is at equilibrium. Imaging what will happen if you do non equilibrium. In a binary we can do that, we can draw a dotted line like this , you have seen right dotted line like this, or let me draw it better because you have able to see it, a dotted line like that, sorry it should be dotted.

So, like this, that how you can explain the effect of non equilibrium solidification, but can I do it here. well that is possible here, and in fact we will discuss little bit in the next class about that, but for the time being just try to considered on these polythermal section and understand, in a national, before I move on to the non equilibrium and eutectic phase diagram. So, you know I am going to discuss about the eutectics solidification path eutectic systems, and different other polythermal sections, you can see here I am going to discuss all this step with you.

So, before I do that, I just request you to try to understand this particular aspect. Especially the isothermal sections vertical sections and polythermal projections. Please try to spend more time to understand these. Otherwise next all these things eutectic and other three phase or four phase equilibria in ternary sections will not be understandable to you. And these all is things cannot be even known discuss in a detail manner, in the sense that because these requires understand in three dimensional sections and the projection under the Gibbs triangle.

And therefore, it is important that you have to visualize it in the sense, that you can draw this projection yourself, and in your mind and then draw it on to another paper. So, that is what that is what my request you please try to spent time on these, that you can understand them very nicely. So, next class we are going to discuss little bit about these non equilibrium effect, and the finally, we will move into the eutectic phase diagrams.