Phase Equilibria in Materials (Nature and Properties of Materials - II)
Prof. Ashish Garg
Department of Materials and Metallurgical Engineering
Indian Institute of Technology, Kanpur

Lecture - 38
Ternary phase diagram with 4 phases

So, welcome again to this lecture number 38 of Phase Equlibria course. So, what we did in the last lecture was to discuss the Ternary Phase Diagram. We have been discussing the ternary phase diagram for a few lectures now.

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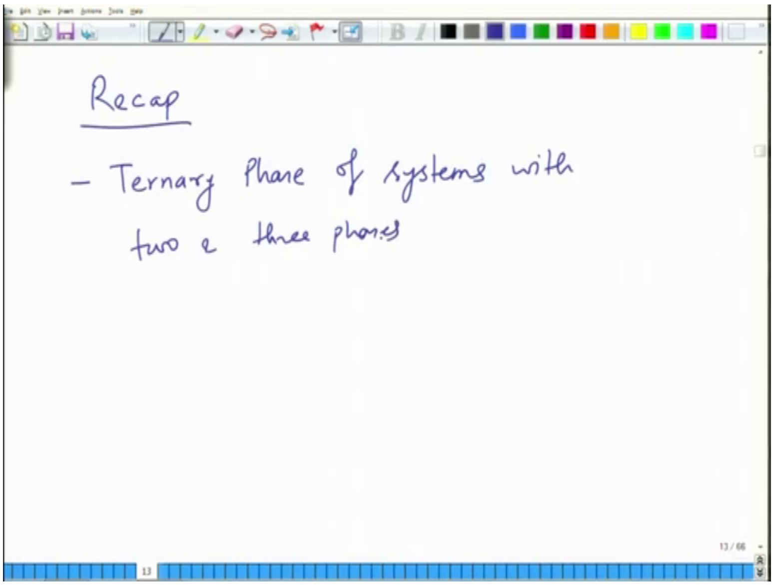

In the last lecture, we looked at ternary phase diagram of systems with 2 and 3 phases. So, we looked at how the phase diagram looks like what are the liquidus surface, what are the solidus surfaces, what a solver surfaces, how do these different phase regions are separated from each other, and how do these phase fields evolved as a function of temperature as you do the cooling.

So, we will just go through that a little bit before we go on to finish this part.

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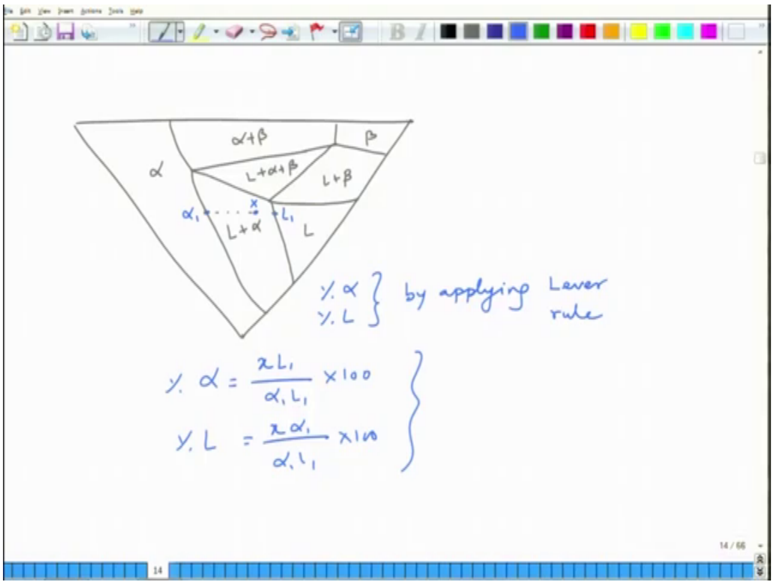

So, for example, let me give you one example of how do you determine the composition. So, let us say you have a phase field something like this, ok. So, let us say you have an alpha phase, you have a this is liquid phase, this is beta phase. So, here in between you have liquids beta you have liquid plus alpha, this is alpha plus beta and this is liquid plus alpha plus beta. And let us say you have certain composition and this composition. So, you are in this composition. So, you can draw the tie lines to determine the composition of alpha and composition of liquid.

So, this is the x alloy composition or and the ends of the tie line will give you the compositions of liquid and alpha and from this, you can determine the percentage alpha percentage liquid by applying lever rule ok. So, this would be for instance; so first integer alpha in this case would be if you have this x. So, this is let us say I do not know this is alpha 1, this is l 1. So, percentage alpha would be x l 1 divided by alpha 1 l 1 in 200 and percentage liquid would be x alpha 1 divided by alpha 1 l 1 into 100. So, this is how you can determine the composition of the phase phases as well as the proportions of these phases.

And this exercise can be extended to other temperatures as well. So, now, this is about the 3 phase equilibrium in ternary phase diagrams. There are systems with 4 phase equilibrium as well just draw that without getting into details.

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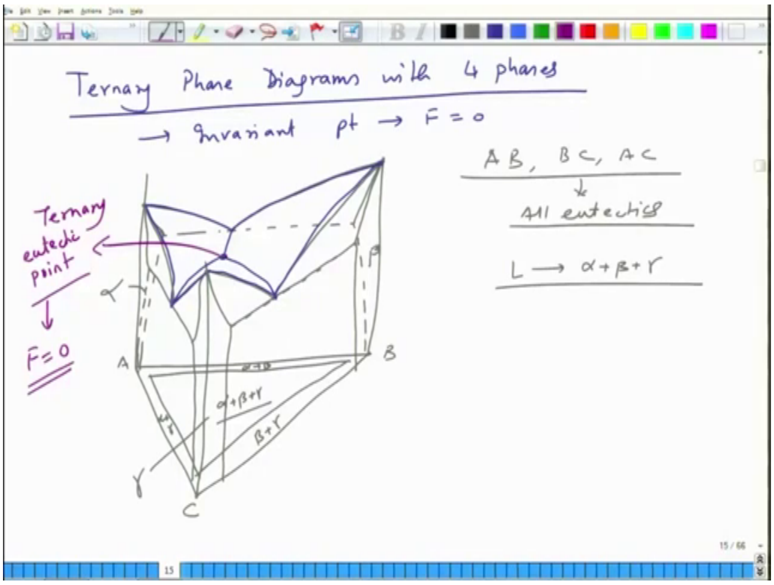

So, ternary phase diagrams with the thing about 4 phases is that you get an invariant point at which degree of freedom is equal to 0 and that is generally the you can say the eutectic point in these alloys. So, for example, your scenarios your scenario could be like this. So, I am going to draw a slightly oblique diagram just for the sake of illustration right. The first phase diagram is on the back.

And another phase diagram that you have is on the side. Somewhere here you have a phase diagram, this will have another and then in between you will have these are the two terminal points that you have and in between you will have another place boundary. So, let us say you have this system A B C. So, basically what you have is you have A B, B C, A C all three, all eutectics. So, what you are going to have here is basically you have a ternary reaction in this case where you have liquid giving rise to alpha plus beta plus gamma.

So, you have 3 phase fields here somewhere at the bottom. So, depending upon the solid solubility is you will have a 3 phase region something like this. So, this region for example, would be beta plus gamma, this region would be alpha plus gamma, this is alpha plus beta and in between you have alpha plus beta plus gamma and then of course, on the sides you have single phase region. So, you have single phase region beta here, you have single phase region alpha on this side and you have single phase region gamma on this side. So, alpha is nothing but your A rich phase, beta is B rich phase and C gamma is C rich phase or 3 terminal solid solutions and somewhere in between the intermingle.

So, the liquidus in this case is this. So, this is your liquidus and there are three eutectic temperatures for 3 binary phase diagrams, but somewhere in between they have a they have a eutectic which on which these three lines merge, so somewhere here or depending upon the phase diagram. So this will be a ternary eutectic point at which liquid will transform into liquid plus alpha plus beta and this at this point your degree of freedom will be equal to 0. So, you will not have any independent variable.

So, generally this is how it is going to look like and so essentially then again you can draw the phase diagrams which will vary in a space.

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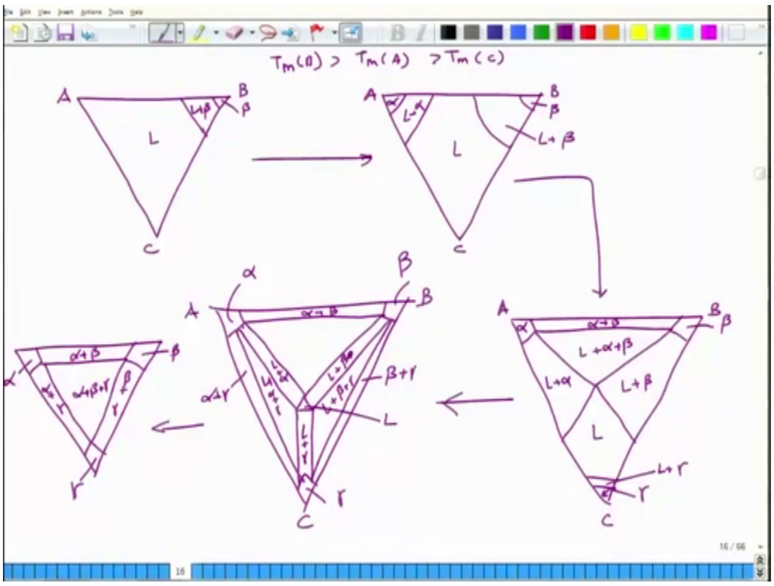

So, for instance you may start with something like this. So, to begin with you will have let us say something like this depending on the melting point. So, let us say B has the high melting points. So, if B has high melting point, then this region is beta, then you have a liquid plus beta then liquid.

As you go down to temperature further, we evolved into something like this. So, you have A B C. So, alpha has a has as T m of B is higher than T m of A which is higher than T m of C. So, first beta phase appears and then you have some alpha region.

So, you have liquid plus alpha, you have beta then you have some region of liquid plus beta which has broadened and then you have liquid. As you further decrease the temperature, you come across something like you start looking at some C, the C phase. So, this would be so it will look fairly simple actually. So, you will have this beta corner, you will have this gamma corner and somewhere in between you will have this liquid versus alpha plus beta and then you will have phase fields like this.

So, this would be beta, this would be alpha this is alpha plus beta this is liquid plus alpha plus beta this is you know in between you have liquid, this is liquid plus beta and this is liquid plus alpha and this is gamma. And sorry in between you will have liquid plus gamma as well. So, this would be liquid plus gamma and here you will have gamma. So, this is again decrease in temperature.

Now, if you further decrease the temperature, you will you might encounter at some point not a very equilateral triangle, but nevertheless for the sake of representation; you might encounter something like this. So, you have a beta phase field, you have gamma phase field, then in between you will have some tiny liquid phase field here. This liquid phase field is connected somewhere here like this is. So, let us say this is alpha, this is beta, this is gamma and alpha plus gamma make a face field alpha plus beta make a tiny face beat up as gamma make a tiny.

So, this is alpha plus beta, this is alpha plus gamma. Here, you can have beta plus gamma and this tiny area anything but liquid and then in between you will have and this alpha plus gamma phase field sorry liquid plus gamma and in between you will have two phase fields you will have for instance liquid plus alpha plus gamma and then you will have here liquid plus alpha.

Similarly, here you can have liquid plus beta and then you can have liquid plus beta plus gamma. This is liquid plus beta then liquid plus beta plus gamma. So, you can have a complicated phase diagram like that and when you come down in temperature further, you do not have too much space left, but we do not need too much as well.

So, you will have something like this. So, here you have beta. You have alpha, you have gamma. This is alpha plus gamma, this is beta plus gamma this is alpha plus beta and in between you will have alpha plus beta plus gamma. So, this is how a phase diagram the phase evolution will happen in a ternary phase diagram consisting of four phases. You can have similar situation in the peritectic systems as well.

But we will not discuss those for the sake of because it is out of purview of this course. The objective of this course was just to introduce ternary phase diagrams. So, what we have done in ternary phase diagrams, we have briefly introduced ternary phase diagrams looking at how do you define it on a 2 phase diagram.

So, ternary phase diagram is basically a triangular prism it has three sides of compositions and then vertical axis of temperature, but imagining this ternary phase diagram is rather difficult that is why there are some things which are evolved to understand this phase diagram a little better. So, there are some rules regarding drawing a tie line drawing a line of constant composition.

So, you have a vertical constant composition line starting from apex to the base or you can have a horizontal composition line which is essentially parallel to the side of a triangle and both have different definitions for that; the vertical line is all the alloy that fall on that line.

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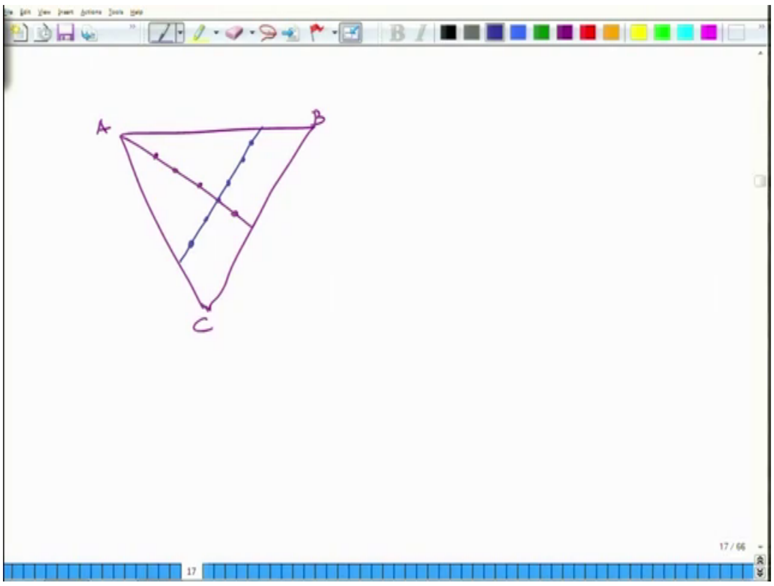

So, so, if you have this line for instance. So, all the alloy it is A, B, C; all the alloys that fall on this line will have fixed B to C ratio irrespective of composition of A. Similarly, if you have something like this and all the alloys that fall on this line will have fixed amount of A, but varying amounts of B and C. So, these are certain things that discussed we also discussed how do you apply a tie line which is similar in binary system except that tie lines are not parallel unlike in 2 D binary system. They variate, they vary at in the orientation at different temperatures.

Then, we also looked at how do you draw isotherms how do you draw vertical sections which are iso plates to understand the phase evolution and so on and so forth. So, this is a brief primer on ternary phase diagrams. For details as I suggested go through the book by Darren western and Saunders, ternary phase diagrams in material science, it is a very good book. It has examples of lots of ternary phase diagrams and now why ternary phase diagrams is useful, because most materials are not binary especially when it comes to the refractory systems refractory systems. For example, alumina, silica, magnesia the together they form a ternary eutectic and this is useful in determining compositions at which the melting point of the for example, that system is minimum.

So, that way because ceramics are generally high temperature systems, we do you want so for certain applications you want to define this design compositions which have low melting point and that low melting point, you can determine that low melting point compositions using the ternary phase diagrams. So, it is something which is very important to understand but it is also complicated. So, that is why a lot of practice is needed to understand it, alright.

So, we have sort of had a brief discussion on ternary phase diagram, what we will. So, ternary phase diagrams are useful.

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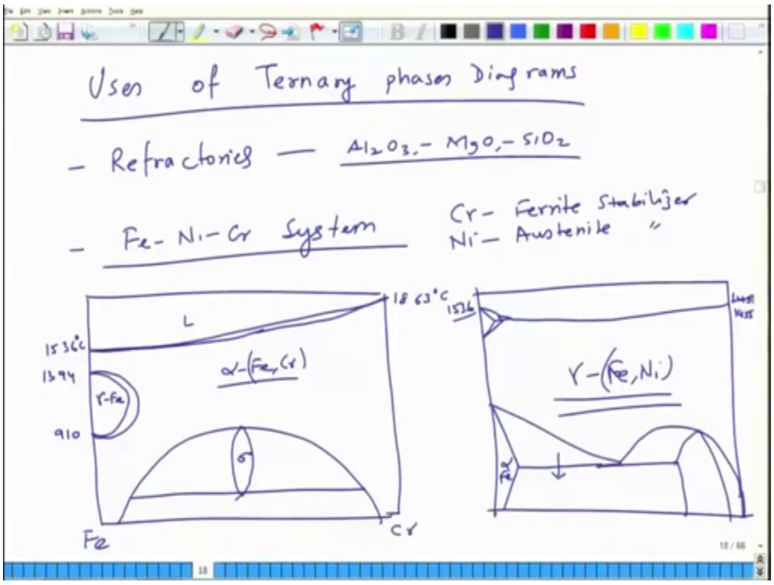

So, uses of ternary phase diagrams. So, for example: as I say refactories, so, you have you may have Al 2 O 3 M G O S I O 2 system. This is a well known system which has it is utility in lot of applications. So, if you understand the phase diagram of this composition, you can determine the compositions for which the melting point of eutectic will be minimum and then you can determine design that, will that system easily. Similarly, for iron nickel chromium system, this is the design of steels.

So, iron nickel chromium compositions are quite useful systems as far as both because nickel is a austenite stabilizer, chromium is a ferrite stabilizer, nickel provides toughness to steel, chromium provides corrosion resistance to steel. So, you want to, so you want to understand the phase diagram of these multiple elements phase diagrams by putting in multiple elements in and you cannot do that by understanding only the binary phase diagram.

So, for example, if you look at the phase diagram of binary phase diagram of iron, so if you draw Fe Cr phase diagram the Fe Cr phase diagram has shaped something like this. It is a very thin line. This is about 1863 degree centigrade, this is 1536 degree centigrade. So, you have a liquid region and then in between somewhere here you have a very narrow gamma region. This is 1394, this is at about 910 degree centigrade pure iron.

So, it see it squashes this region and this region then and it forms a broad sort of region in between and this phase field is basically alpha Fe. So, it basically broadens the phase field of alpha Fe and for iron with a small amounts of chromium you can have very broad alpha Fe region and in between somewhere you have a sigma phase and then you have a two phase regions. So, this is essentially your iron chromium phase diagram.

When you draw iron nickel phase diagram. So basically in this case chromium is a ferrite stabilizer and nickel is a austenite stabilizer and nickel what it does is it tends to. So, you have a peritectic reaction here, you have unconnected. So, this is 1455 degree centigrade and this is 14, 1536. So, and what it does is that it tends to modify this region. So, it lowers the it lowers the stabilized lowers, this temperature the eutectoid temperature tends to increase this particular point and then something like that you can go to a higher percentage of nickel what is in between is actually gamma Fe or nickel and this is alpha Fe Cr, ok.

So, this phase field austenite phase field is broadened and the ferrite phase field is lowered. So, this is your alpha Fe and this temperature the eutectoid temperature which is quite high in a 727 it gets lowered. So, the nickel stabilizes the, austenite phase field chromium stabilize the graph ferrites phase field, but if you draw both of them together, then you can draw a phase field of iron nickel chromium.

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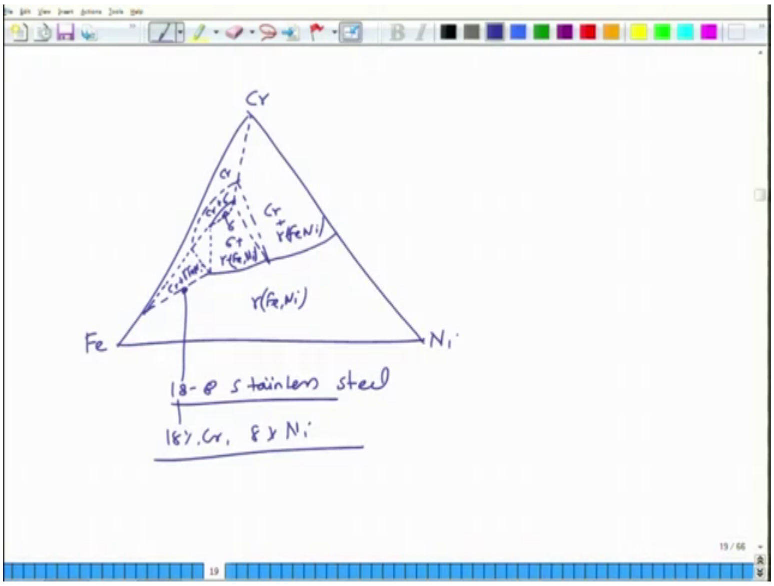

So, this is iron nickel and chromium. So, in the iron nickel chromium system, you have a something like ok, alright.

So, you have different phase regions here, you have this chromium phase and you have chromium plus sigma phase. This is your sigma phase, this is your sigma plus gamma Fe nickel, this is your chromium plus gamma Fe nickel, this is gamma Fe nickel and this is your chromium plus gamma Fe nickel and somewhere here, we form a 18, 8 stainless steel which is corrosion resistant as well as. So, it has basically 18, 8 is 18 percent chromium and 8 percent nickel.

So, it has high history, it is a austenitic, it is a steel which is a stainless steel or austenitic steel which is high corrosion resistance and high toughness and it is very useful for lot of practical applications. So, if you want to design such a system which has you know opposite characteristics of ferrite stabilizer and austenite stabilizer, you need to get into the ternary phase diagram.

So, binary phase diagram show you that you can stabilize alpha phase and gamma phase, the ferrite phase and the austenite phase and to have both of them in the same alloy you need to get to ternary system where you have you know a chromium rich region then you have so, this is your you can say your chromium rich region. On this side, somewhere here you will have iron chromium system; somewhere here you will have when you are an iron nickel rich region then you will have basically gamma iron nickel region.

And so, by interplaying the compositions, you come to you can design alloys for example, as I said for 18, 8 this is 18, 8 stainless steel which contains 18 percent chromium 8 percent nickel well which is a very famous stainless steel alloy. So, these are certain examples of a ternary systems that we have. Perhaps, let me just see if I have another picture of a ternary phase diagram in alloy in ceramics, just one second.

So, we can probably I can probably show you that in next lectures some picture of a ceramics system this is sort of the end of this particular content on ternary phase diagram in which we have looked at ternary phase diagrams with four phases. So, we drew three eutectics and by putting the three eutectics together, there is a point which is a ternary eutectic point at which degree of freedom is equal to 0. And what that basically implies is that it is invariant point at which 4 phases coexist. And this is a peculiarity of ternary system, as against a binary system where for invariant reaction you need to have, you can have maximum of 3 phases with no degree of freedom.

And this is how the phase evolution takes place where you start from formation of beta phase. Then eventually formation of alpha phase formation of gamma phase and then 2 phase fields broaden in the size whereas, you also have a 3 phase field and somewhere in between you will have. So, somewhere as you go from this somewhere in between you have this liquid phase shrinking and you have more and more 3 phase regions and 2 phase regions

As you go down, just before the eutectic you will have a 4 phase equilibrium which will be at the eutectic temperature ternary eutectic temperature. And then you will have a final phase distribution where you have alpha beta gamma terminal solid solutions which are bound by in between these two; these three terminal solid solution you will have 2 phase fields of alpha beta, beta gamma and gamma alpha.

And these will bind these will surround a 3 phase region that will be alpha plus beta plus gamma 3 phase equilibrium. So, again by drawing the tie lines, by drawing the vertical lines horizontal lines, by taking the I S O plates you can again look at. So, if you take for example, the ISO Pleth at particular point starting sorry from B, you can look at the evolution of phases as a function of temperature for fixed B and let us say 50 percent, a 50 percent C and this you can do for various temperatures to understand the phase evolution. And then, we looked at certain applications uses of ternary phase diagrams. They are useful for refractory applications and they use forests and a steel application.

So, we are now done with ternary phase diagrams pretty much. And next two lectures would basically be spent on reviewing some more things like 2 phase diagrams, and finally summarizing the whole list of content.

Thank you very much.