Modern Construction Materials

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Module - 2
Lecture - 5
Part 2 of 2
Development of Microstructure

This is the second part of lecture five of modern construction materials, we have looked at different ways that microstructures forms in solids we started discussing phase diagrams. Now, we will go on to see binary phase diagrams and have a short discussion on then on synetnery.

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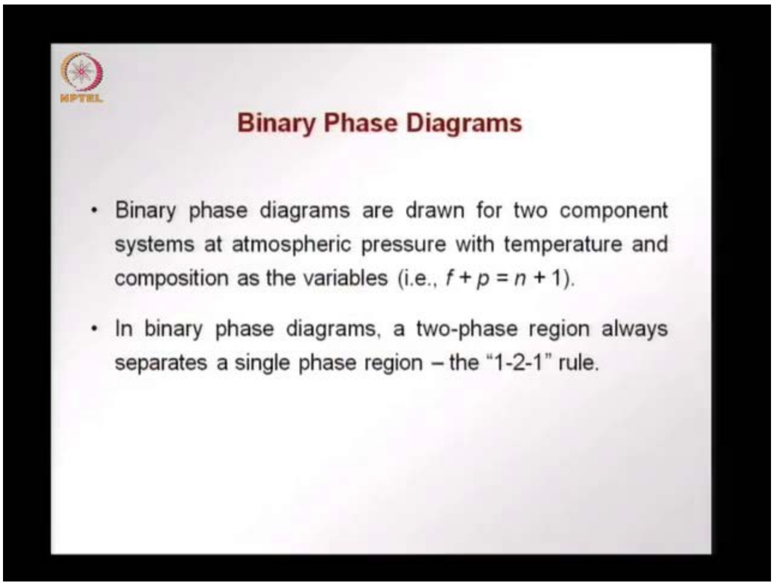

Binary Phase Diagrams

- Binary phase diagrams are drawn for two component systems at atmospheric pressure with temperature and composition as the variables (i.e., $f + p = n + 1$).
- In binary phase diagrams, a two-phase region always separates a single phase region – the "1-2-1" rule.

Now, we looked at the Gibbs phase rules when we started the discussion on phase diagrams when we have a binary phase diagrams drawn for two components systems. We have this diagrams at atmospheric pressure with temperature and the composition as the variables, that is the gives phase rules becomes f plus p equals to n plus 1, also we find that in binary phase diagrams two phase region always separates a single phase region. For another single phase region that is between two single phase regions there will be a region where two phases coexist this is called the 1-2-1 rule.

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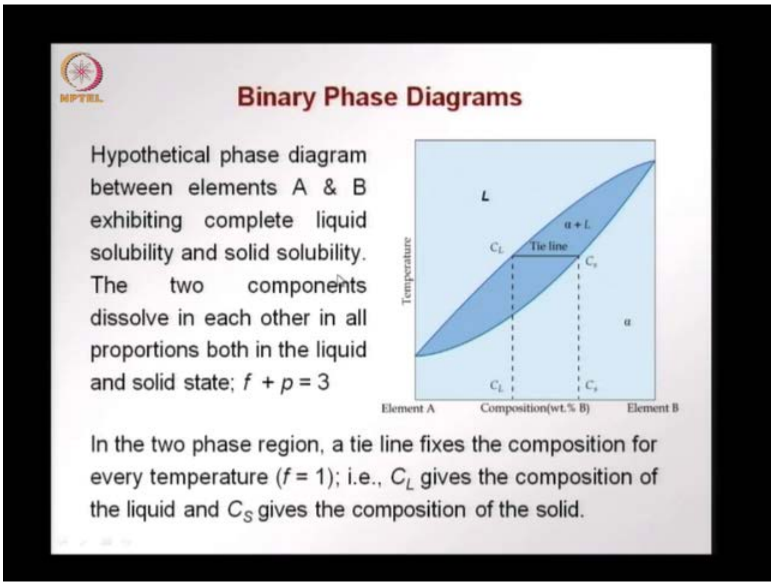

Binary Phase Diagrams

Hypothetical phase diagram between elements A & B exhibiting complete liquid solubility and solid solubility. The two components dissolve in each other in all proportions both in the liquid and solid state; $f + p = 3$

In the two phase region, a tie line fixes the composition for every temperature ($f = 1$); i.e., C_L gives the composition of the liquid and C_S gives the composition of the solid.

So, let us take this binary phase diagram it is a hypothetical phase diagram between two elements A and B, element A and element B we assume that these elements have complete liquid and solid solubility. That is in both the liquid form and solid form, they are completely soluble in each other and the solubility is in all proportion, both on liquid and solid states f plus p equal becomes 3. In the given phase root we have this part which corresponds to the liquid phase and this part corresponds to the solids phase and we call it here alpha.

So, this is the alpha solids phase and as I said before between different regions which single phases they will be a two phase region separating that. So, this is the dark blue region where you have the alpha solid phase and also the liquid phase, then we finds that within this region two phases have to coexist that is p is equal to 2. So, according to the gives phase rule f becomes 1 within this region there is only 1 degree of freedom that is if we change the temperature there is always a corresponding composition.

That means that there is a line which fixes the composition for each temperature this is called the tie line C L that is the composition corresponding to the edge of tie line gives the composition of the liquid. The other edge bordering the alpha phase region that is the solid phase region C S is the composition at the point, where the tie line needs the border between these two regions gives the composition of the solid phase. So, at this temperature within this region the composition of the liquid phase is given by C L and the solid phase is given by C S.

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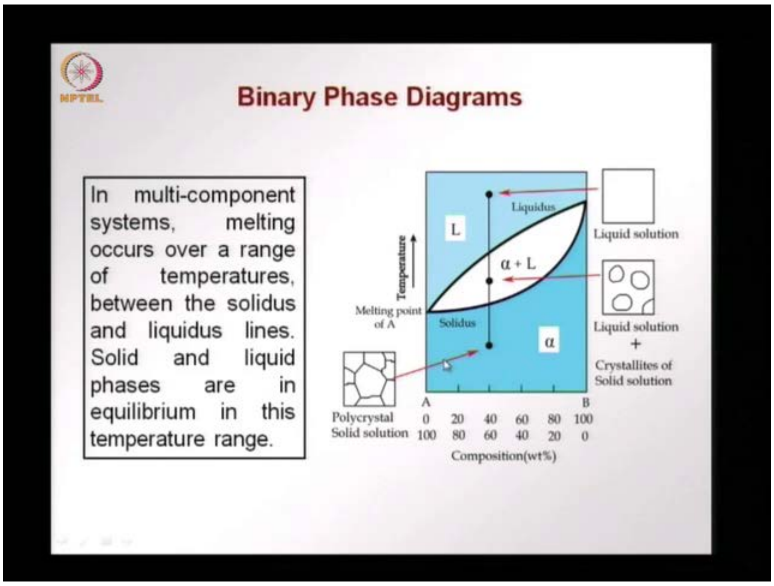

Binary Phase Diagrams

In multi-component systems, melting occurs over a range of temperatures, between the solidus and liquidus lines. Solid and liquid phases are in equilibrium in this temperature range.

Also we find that in multi component systems the melting of the material occurs over a range of temperatures it is not at a fixed melting point, but the melting occurs over range of temperatures between the solidus lines. This is the solidus line separating the region of the solid phase are alpha and the two phase region alpha plus l. Similarly, we have a liquidus line which is the upper bound of this region separating the region where we have the liquid phase. The region where we have the alpha plus l phase, that is the solid phase and the liquid phase co existing.

So, this is the liquidus line and what we find is melting occurs over the region between the liquidus line and the solidus line, within this temperature range the solid and liquid phase are in equilibrium. We can show this diagrammatically with these 3 diagrams, here you have the liquid solution you have a single liquid phase shown here. Now, as the temperature decreases shown by this vertical line, we have at this point the nucleation occurring, the alpha raise starts to form. This is representing the crystallize of the alpha phase as the temperature continuous to decrease the solid phase now uses of all the liquid and when we cross the solidus line and come into this alpha region.

We have now the poly crystal solid solution with this being the green boundaries that we have discussed in the previous lectures. So, we have two things that we have to remember in binary phase diagrams first is that there is a tie line for each temperature which defines what would be the composition of the solid phase and what would be the composition of the liquid phase. Secondly, we gave the solid defecation occurring over a range of temperature and later on we will see that this defines how the microstructure form as this solidification is occurring over a range of temperatures. We find that different types of microstructure can form the depending on which region across during the solidification process.

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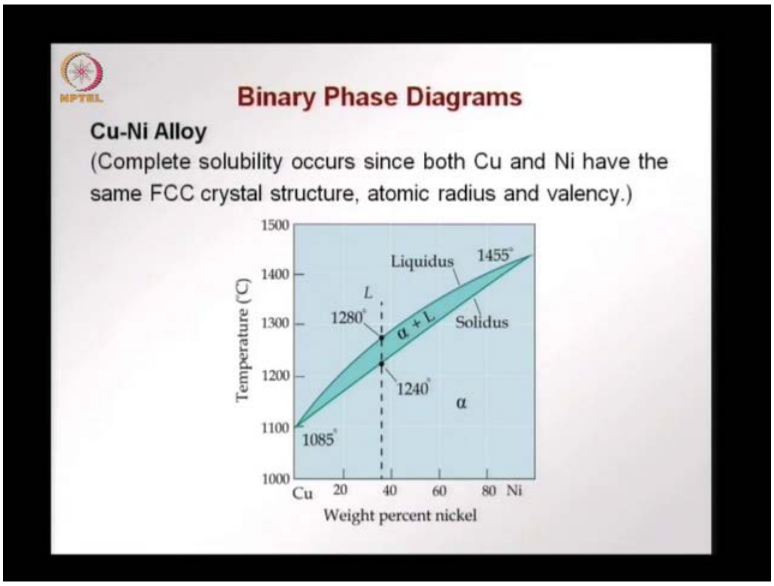

Binary Phase Diagrams

Cu-Ni Alloy

(Complete solubility occurs since both Cu and Ni have the same FCC crystal structure, atomic radius and valency.)

So, in the case of an alloy of copper and nickel this is an alloy where we have complete solubility in both the liquid phase and the solid phase of copper and nickel in each other. This is because both this elements copper and nickel have the same F C C crystal structure, they also have the same atomic radiation and balance it. So, the distortion of the lattice structure is not much when one of these elements is dissolved in the other. So, what we see below is the phase diagram or couple and nickel the top region is the liquid phase region.

The bottom region is the alpha solid phase region and as we said before between the single phase regions we should have a double phase, two phase region that is this, where the liquid melt can coexist with the alpha solid phase. We also see now that as temperature drops shall be taken a certain composition around 38 percent nickel and the rest being copper. Now, if the temperature of the melt drops, we will see that we reach the liquidus line for this particular composition at around 1280 degree Celsius.

So, that is where, now nucleation start alphas phase starts crystallizing as the temperature continuous to drop. This crystallization or solidification completes at a temperature, where we meet the solidus line at 1240 degrees, the other things that we see here is that now the melting point will depend on the composition. If we have pure copper the melting point of the solid is 1085 degrees, if it is pure nickel it is 1455 degrees in between, depending on the composition we will see different melting points for the alloys that form with different compositions.

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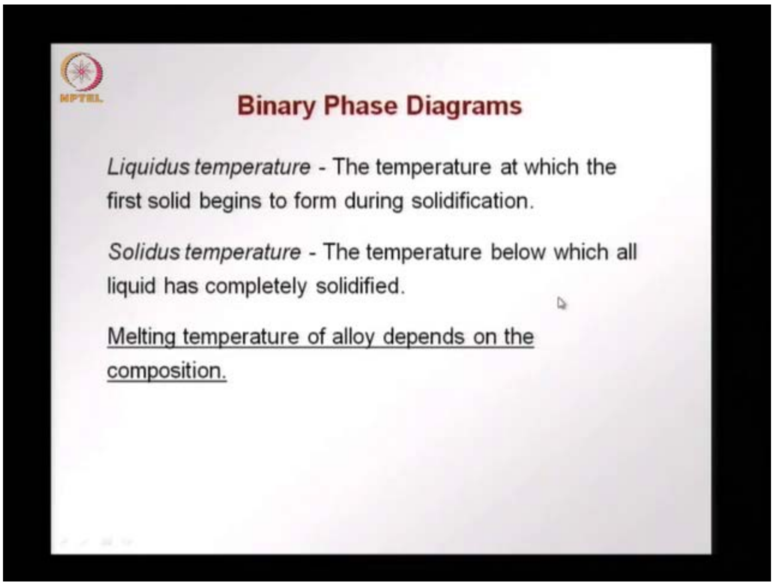

Binary Phase Diagrams

Liquidus temperature - The temperature at which the first solid begins to form during solidification.

Solidus temperature - The temperature below which all liquid has completely solidified.

Melting temperature of alloy depends on the composition.

So, some of the things that we have seen are the liquidus line or the liquidus temperature is that which the first solid begins to form during solidification nucleation starts, but does not finish immediately. The solidus temperature for the solidus line is below which all the liquid has completely solidify, this two bound the two phase region which has the liquid phase and the solid phase. It equilibrium with each other, we also saw that the melting temperature of the alloy depends on the composition.

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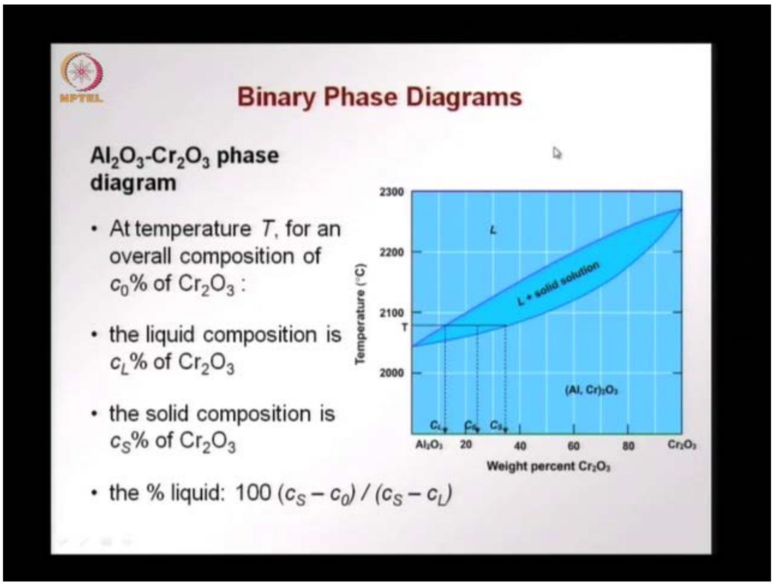

Binary Phase Diagrams

Al_2O_3-Cr_2O_3 phase diagram

- At temperature *T*, for an overall composition of c_0% of Cr_2O_3 :
- the liquid composition is c_L% of Cr_2O_3
- the solid composition is c_S% of Cr_2O_3
- the % liquid: 100 $(c_S - c_0) / (c_S - c_L)$

Now, let us see the phase diagram of aluminum oxide and chromium oxide, we will use this to illustrate how the tie line defines the composition of the liquid and the solid phases, and also tells us about how much would be the liquid phase within the material. So, we have, now L defining the liquid phase region here we have the solid phase consisting of the oxide aluminum and chromium. Between this two, we have two phase region which shows us the region where the liquid phase and the solid phase can coexist.

As it is said before for any particular temperature here given as T close to about 2100 degrees, if we draw a tie line at this temperature this point whether tie line meets the liquidus line, if we drop it down we get the composition of the liquid phase denoted as C sub L here. Now, the other end of the tie line when it needs the solidus line when we drop it down, we get the composition of the solid phase, now this holds good for any composition of the alloy in this region.

See we have a composition C 0 defining the amount of chromium oxide in the aluminum oxide, independent of this the composition of the liquid phase and the solid phase are always given by this tie line. The intersection with a liquidus and solidus line using this we can find out what is the percentage of liquid. So, if we take an alloy with C 0 percentage of chromium oxide in aluminum oxide at a particular temperature T, we draw this tie line the liquid composition is given by c L, the solid composition by c S percentage.

The percentage liquid is then given by this equation 100 times c S minus c 0, this part of the tie line divided by the entire tie line c S minus c L. So, this will give us the percentage of liquid, that is there in this material at this particular temperature T, so here we find that the values of tie lines has well as the composition entering.

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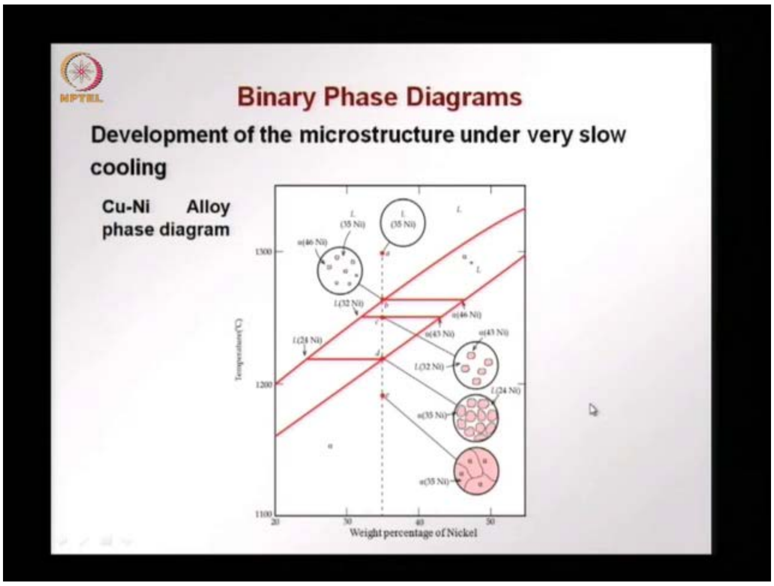

Binary Phase Diagrams

Development of the microstructure under very slow cooling

Cu-Ni Alloy phase diagram

Now, let us see how the binary phase diagram tells us that the microstructure develops, so we look at how microstructure develops under slope cooling by crystallization is allowed to occur and the structure to form without any rapid cooling. We look at the copper nickel allow a phase diagram, and if you remember we said that in the case of copper and nickel we have complete solubility in both liquid and the solid phases. Now, part of the phase diagram with a range of about 20 to 55 percent nickel this top region is the liquid phase region, here at the bottom we have the alpha solid phase region.

So, let us take the case of an alloy with 35 percent nickel 65 percent copper and we have a melt, we see how the microstructure develops in this case when the temperatures keep dropping very slowly. So, in the liquid we have the microstructure with uniform mixing of the liquid a nickel and the liquid copper, so we would have a composition with 35 percent nickel, corresponding to that of the alloy that say is the microstructure at this point A. Now, we decrease the temperature until we need the liquids line denoted by point B here.

Now, nucleation occurs at this point the composition of the liquid will be that of the intersection of tie line and the liquidus line that is 35 percent nickel. So, the nickel has 35 percent nickel, to know what is the composition of the nuclei that is forming we have to draw a tie line and we reach this point corresponding to 46 percent nickel. So, the nuclei are that formed at this particular point will have 46 percent nickel and 54 percent copper. Now, the temperature drops for the against slowly we reach say this point denoted by C, and to find out how the microstructure is developed when this point is reached, we draw another tie line on the left.

We have the tie line needing the liquids line at a liquid composition of 32 percent nickel and on the right we have the tie line meeting the solidus line at a point corresponding to 43 percent nickel. So, that means the liquid at this temperature has 32 percent nickel, the solid phase has 43 percent nickel, so we find that both the liquid and solid phase have decreased in there nickel contained from point B to point C. We drop the temperature further and we go down to the point D where, now we have the right end of the tie line corresponding with a solidus line at a value of 35 percent nickel.

So, that will be the solid contained, so the solid part, now has the 35 percent nickel corresponding to this point and the liquid has 24 percent nickel. So, this microstructure now looks like this with the liquid part having 24 percent nickel and the solid part having 35 percent nickel as the temperature drops we cross over to the single phase solid region here. Now, we have a poly crystalline solid with grain boundaries between the different crystal, and you have a completely solid material with 35 percent nickel in the alpha phase.

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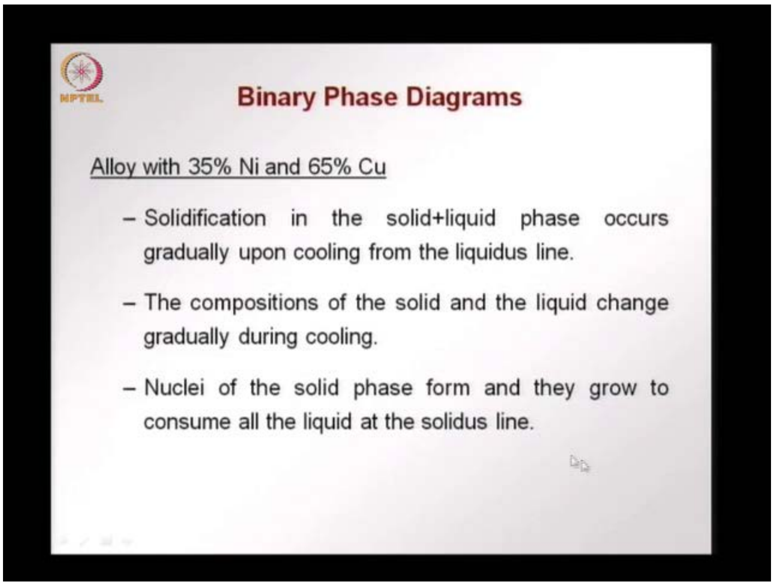

Binary Phase Diagrams

Alloy with 35% Ni and 65% Cu

- Solidification in the solid+liquid phase occurs gradually upon cooling from the liquidus line.
- The compositions of the solid and the liquid change gradually during cooling.
- Nuclei of the solid phase form and they grow to consume all the liquid at the solidus line.

So, what we saw is solidification occurs in the solid liquid phase region gradually upon cooling below the liquids line the composition of the solid and liquid change gradually. During cooling, the nuclei of the solid phase form just when the liquids line is crossed and when the solidus line is crossed all the liquid is consumed.

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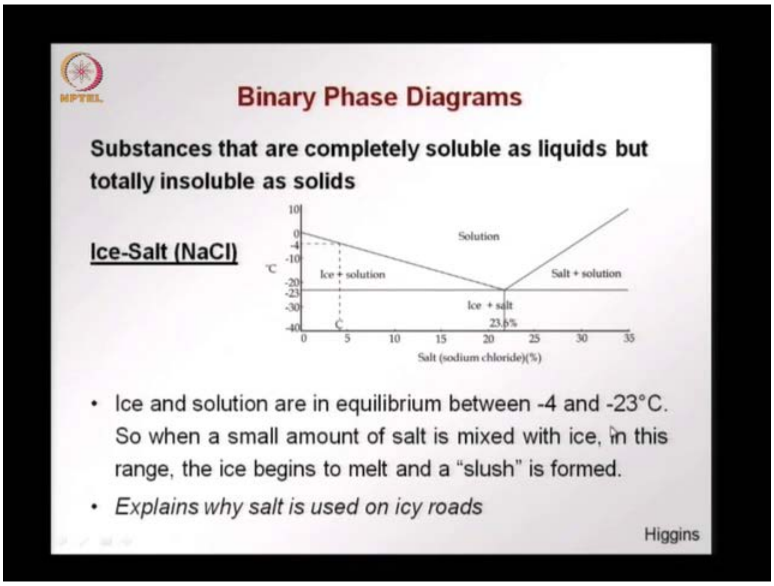

Binary Phase Diagrams

Substances that are completely soluble as liquids but totally insoluble as solids

Ice-Salt (NaCl)

- Ice and solution are in equilibrium between -4 and -23°C. So when a small amount of salt is mixed with ice, in this range, the ice begins to melt and a "slush" is formed.
- *Explains why salt is used on icy roads*

Higgins

Let us see what happens when we have a substances that is completely soluble and another as a liquid, but the two substances are totally insoluble as solids, that would be the case of the mixture of ice and salt, say sodium chloride.

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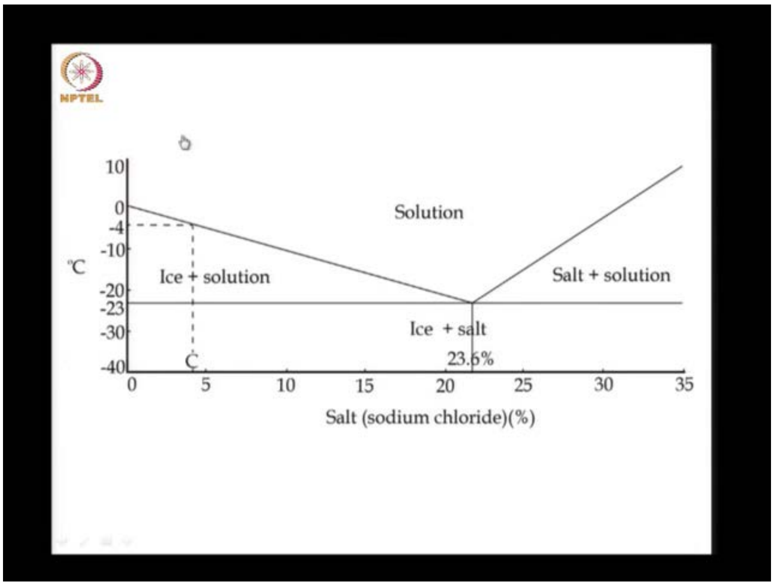

So, what we find is that there is a region where we have a solution of water and salt, this is this region, this region both ice and solution of water and sodium chloride can exist this region. We have more of salt with the salt water solution and below minus 23 degree, we have the 2 solids separate ice and salt separate, below minus 23 degrees what we find is that for small quantities of salt.

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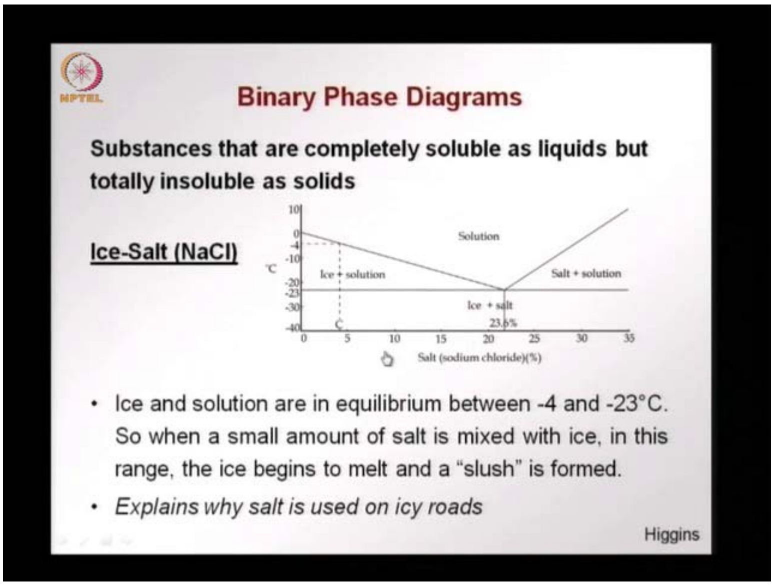

Binary Phase Diagrams

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Higgins

Next, in water we have a temperature range say minus 4 to minus 23 degrees, where ice and the salt solution coexist. So, this means that if we take ice and mixed a small quantity of salt that they will be some melting of the ice, the formation of a salt solution below minus 4 degrees above this line, the liquids line we will have a complete solution forming.

So, what we have said is ice and solution for small quantity of salt being mixed with ice are equilibrium between minus 4 and 23 degrees. So, when a small amount of salt is mixed with ice, in this range the ice begins to melt and a slush mixture of ice and salts solution is formed. This is the region why the salt is used to melt the ice on icy roads, the water frizzes and becomes ice, and to melt this ice some small amount of salt is spring salt. This salt now has to create a situation where we have some solution form to be equilibrium with the ice and the ice melts and the road becomes safer for travelling.

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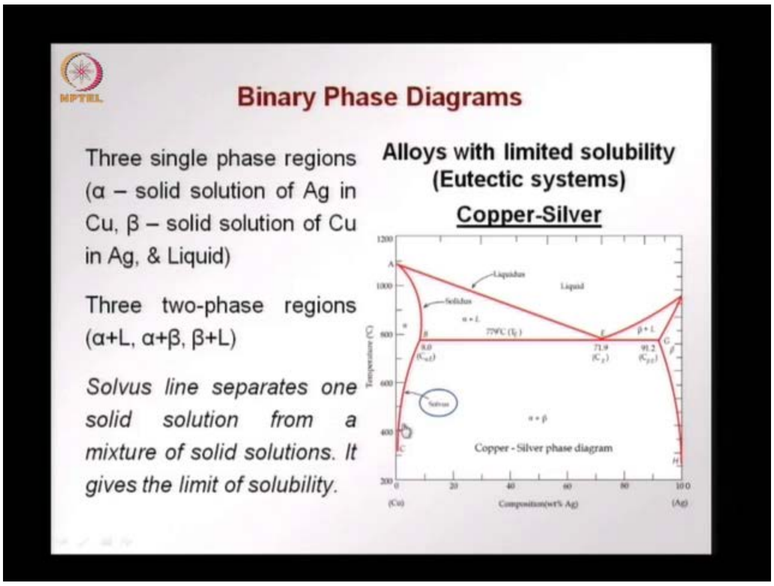

Binary Phase Diagrams

Three single phase regions (α – solid solution of Ag in Cu, β – solid solution of Cu in Ag, & Liquid)

Three two-phase regions (α+L, α+β, β+L)

Solvus line separates one solid solution from a mixture of solid solutions. It gives the limit of solubility.

Alloys with limited solubility (Eutectic systems)

Copper-Silver

Copper - Silver phase diagram

We can also have alloys with limited solubility this are called eutectic systems, like in the case of copper and silver.

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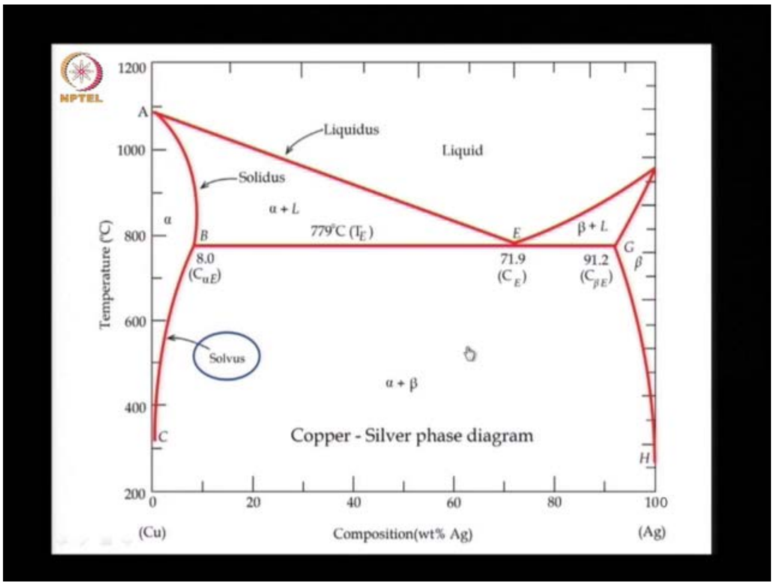

Here, we have 3 single phase regions we have the liquid phase, here over this region we have also alpha solid phase, over this region a beta solid phase. Here, within this region, here we have a two phase solid region, that we have the alpha phase and the beta phase coexisting over this region. So, this means that copper and silver are not completely soluble in the solid phase between this different region we have the alpha plus L region. That means we have a solid alpha phase coexisting with the liquid phase in this region, and then we have the beta the solid phase coexisting. Here, in the liquid region this is the liquidus line that we saw before, this is the solidus line also we saw this before. Now, what we see is there is only also another line called the silvers line separating the region, where we have complete solubility and incomplete solubility in both extremes. So, this is the solvers line and, here we have another solvers line, so again this is the phase diagram of cooper and silver. We see, here on the x axis pure copper on this end and with introduction of silver, we have different alloys that can form.

Here, you would have the K of 100 percent silver, this is 100 percent silver, this is 100 percent silver, here we have the region with alpha being the only solid phase beta. Here, being the only solid phase E this region there is mix of the two solid phase alpha and beta. So, we saw alpha which is a solid solution of silver and copper beta which is the solid solution of copper, silver and the liquid, these are the three single phase regions.

Then we have 3 two phase regions alpha plus l, beta plus l and alpha plus beta, we saw that the solvers lines separate the solid solution alpha and beta respectively. From a mixture of solid solutions, this gives the limit of solubility the solvers line gives the solubility of copper and silk.

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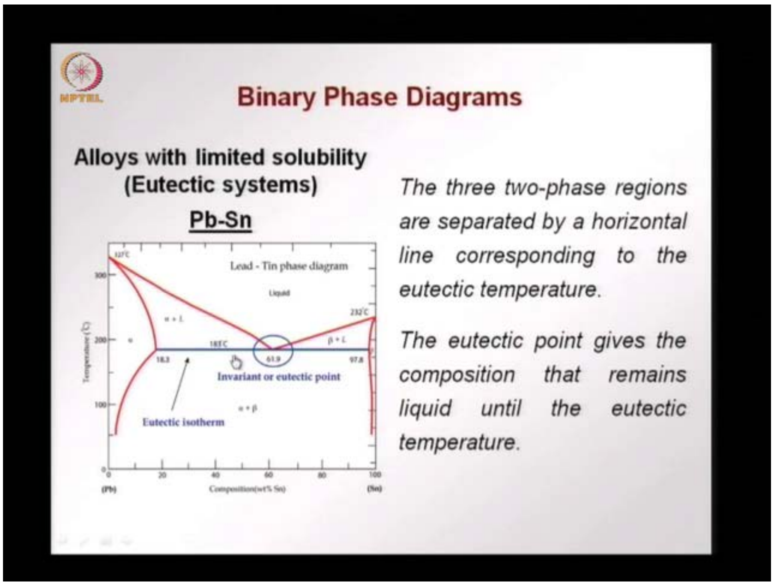

Binary Phase Diagrams

Alloys with limited solubility (Eutectic systems)

Pb-Sn

The three two-phase regions are separated by a horizontal line corresponding to the eutectic temperature.

The eutectic point gives the composition that remains liquid until the eutectic temperature.

Similarly, we can see the diagram the phase diagram for led and thin this is also eutectic system.

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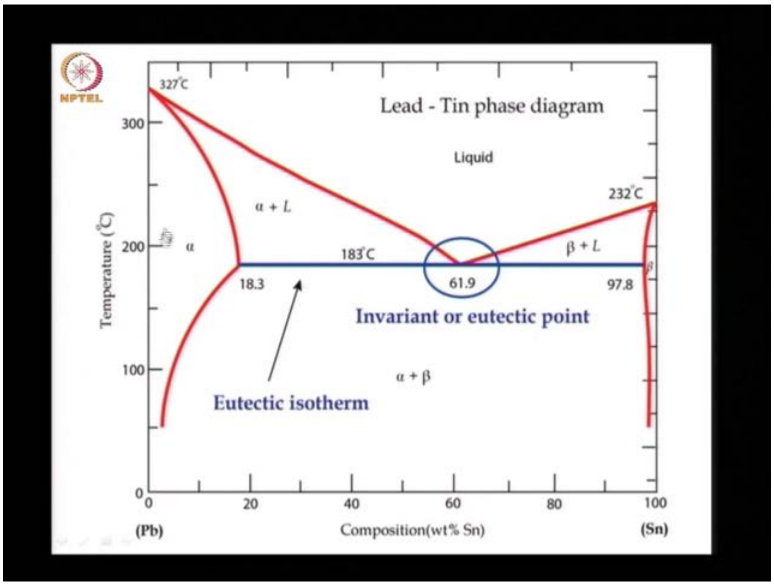

So, we have, here the phase alpha where we have complete solubility of thinned this is a led reach solid phase then we have beta, which is again a single phase region with more thin. Then let, here we have 2 solid phases coexisting with each other again the alpha and beta this is the solvers line, now this is the liquidus line and this is the solidus line. This temperature below which the materials exist as a two phase solid is called the eutectic isotherm. This defines a temperature below which the solid exist in two phases and this point, where the liquid completely changes into a solid without passing through an equilibrium region with both solid and liquid is called the invariant or eutectic point.

So, we have 3 two phase regions and this 3 two phase regions separated by a line corresponding to the eutectic temperature, and the eutectic point gives the composition that remains liquid until the eutectic temperature. So, you have a liquid which remain liquid until this point, then it becomes a solid after crossing the eutectic isotherm. When the temperature is below this particular point and this also happens only for certain composition, in this case see about 62 percent of tin and led.

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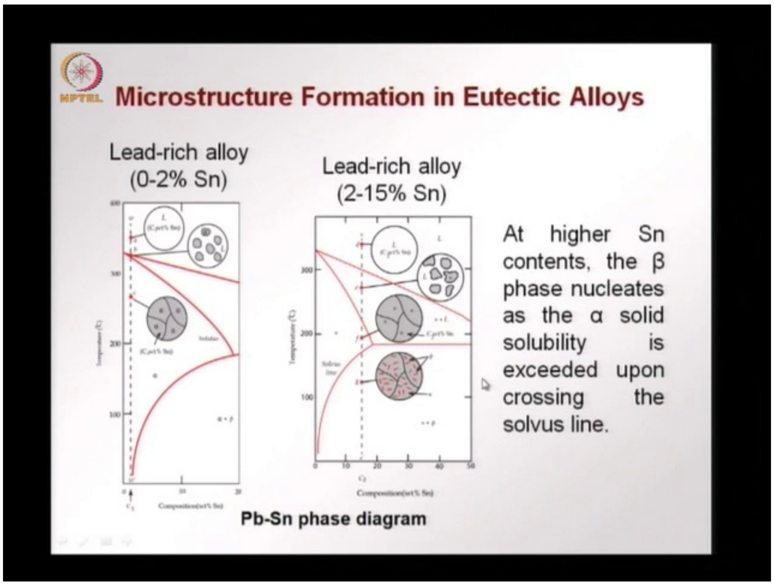

Microstructure Formation in Eutectic Alloys

Lead-rich alloy (0-2% Sn)

Lead-rich alloy (2-15% Sn)

At higher Sn contents, the β phase nucleates as the α solid solubility is exceeded upon crossing the solvus line.

Pb-Sn phase diagram

Now, as the composition changes the microstructure also will change, let us take case of the led rich alloy.

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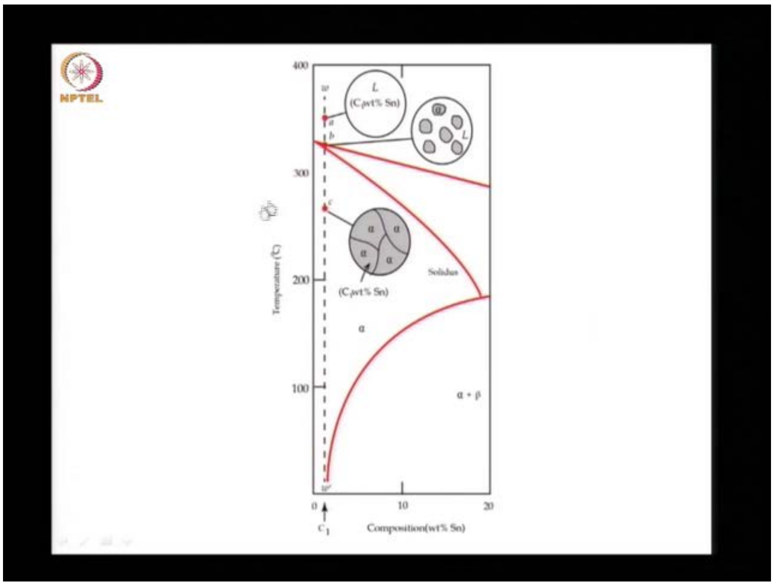

That is very little tin, tin percentage less than say about 2 percent, so you will have a melt, here with that particular composition in point A, you have a complete liquid phase. As the temperature drops, we hit the liquidus line nucleation starts and the alpha phase starts to form as we go down into this alpha region.

Now, we find that crystallization completes as in the previous cases you will have polycrystalline material with different alpha crystals or alpha gradients. Now, let see what happens when we have again alloy reach in led, but with the slightly higher percentage of thin in the range of 2 to 15 percent.

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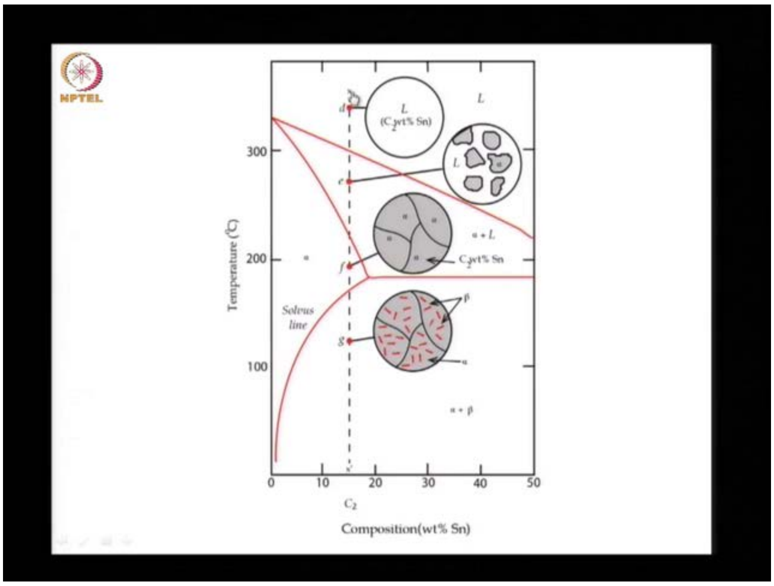

So, instead of the composition being here, now we are looking at a composition in this range, so we will see what happen when we go down this x, x bar are vertical line, showing how the melt changes into a solid is the temperature is slowly rubbed. So, we are twist at this first point which is the liquid solution of led and tin, we have a certain percentage of tin. In this alloy we now cross the liquidus line and going into the two phase region of alpha plus L, alpha starts crystallizing nucleation and crystallization start to occur.

We have a material which is partially liquid and partially solid at this point E and we will have to use the same concept of tie line to find out what is the composition of the liquid phase and the solid phase. Now, as we decrease the temperature we cross the solidus line and we giving to this region, where we have a single phase solid region. So, at this point F, at this temperature corresponding to F, we will have a solid a poly crystalline with different alpha gradients, making up the micro structure as the temperature is cooled further we crossed the solvers line.

Now, the solvers line divides with completes and incompletes solubility and as we cross this line, now we will be going to a region where both alpha and beta coexist. So, the beta phase starts to form within the alpha phase that is represented, here this red lines show the formation of the beta phase within the gray alpha phase regions. So, you see that as we go through the different region the microstructure changes, we saw previously in the case of led rich alloy with very little tin we had a microstructure and riches.

This we had only in the alpha phase, but now with the higher tin content as we cross through this region as we go into the alpha plus beta region, we have the microstructure changing from this to this. Here, we had only the alpha phase and, now we have a beta phase inside the alpha crystal forming. So, at higher thin contains the beta phase nucleates as the alpha solid solubility is exceeded they cross the solvers line. So, that means we are exceeded the solubility of thin in led and the beta phase forms within the alpha phase.

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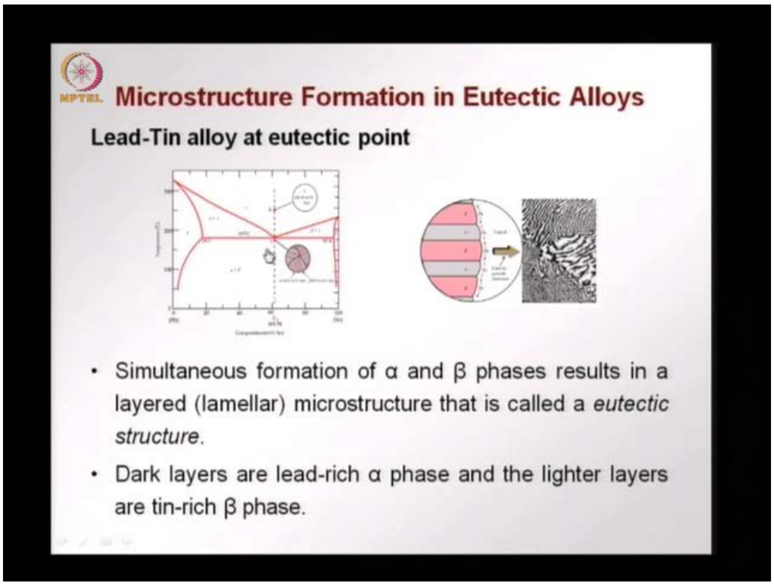

Microstructure Formation in Eutectic Alloys

Lead-Tin alloy at eutectic point

- Simultaneous formation of α and β phases results in a layered (lamellar) microstructure that is called a *eutectic structure*.
- Dark layers are lead-rich α phase and the lighter layers are tin-rich β phase.

Now, let us see what happens in the eutectic point.

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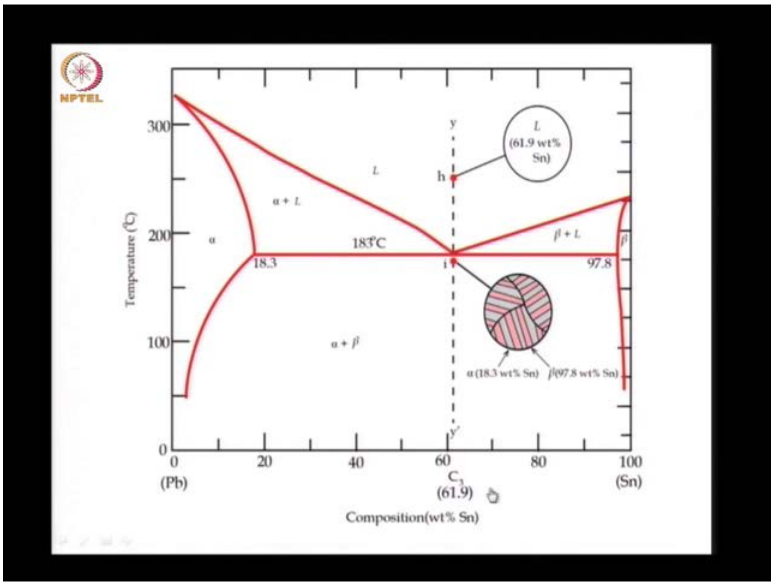

So, we take the composition with about 62 percent tin that corresponds to the eutectic composition, so we would have a liquid. Here, say in this region for example at h, at this point h, other corresponding temperature h, we will have a liquid with 61.9 percent. Now, we cool this liquid slowly and what we will see as at this point i, the liquid changes into solid without passing through any phase where the solid and liquid coexist. We have the structure that is form like this called the eutectic structure where we have layers of alpha and beta phases.

Alpha and beta phases have different composition given by the tie line, so here if we want to know what would be the composition of alpha phase we take as the tie line. We go to this point and see that alpha phase will have 18.3 percent thinon, the other side we will we see that the beta phase will have 97.8 percent tin, so this is tin rich beta phase.

We have a led rich alpha phase forming as layers and what we will also see is that as the temperature drops, further this composition will change because if we were going to tile line. Here, we will see that in the alpha phase they will be less thin it will become richer in led the alpha phase will become the richer in led. So, in the eutectic region, as the temperature drops further we will see change in the alpha and beta composition.

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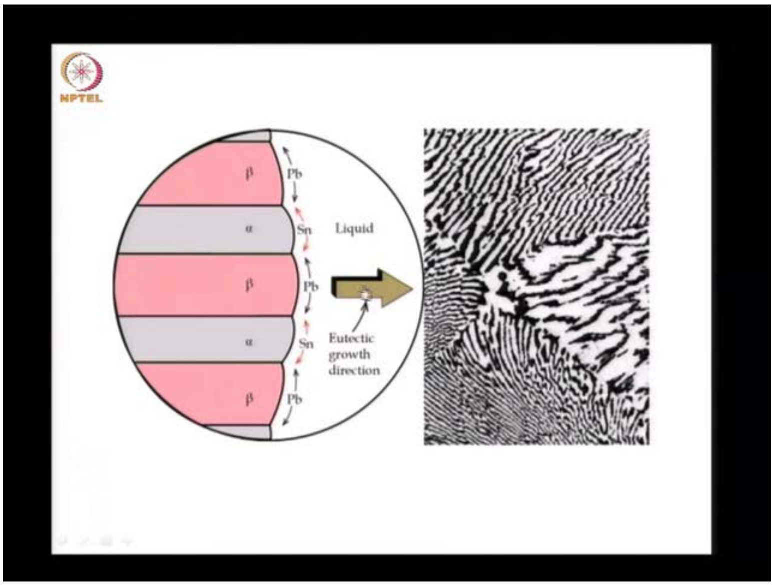

When we look closer into the eutectic structure we find these layers of alpha and beta and this is how microscope picture will show the difference region. As the eutectic structures grows, we find that beta phase will become poorer in led, the led will go to the alpha phase which is becoming poorer in thin as the temperature decreases. So, as growth occurs, as the eutectic structure grows we find a change in the composition of both the alpha and the beta phase. This simultaneous formation of the beta and alpha phases result in a layer microstructure, which is called the eutectic structure, the dark layers that we saw in this microscope image give the led rich alpha phase and the lighter layers at the tin rich beta phase.

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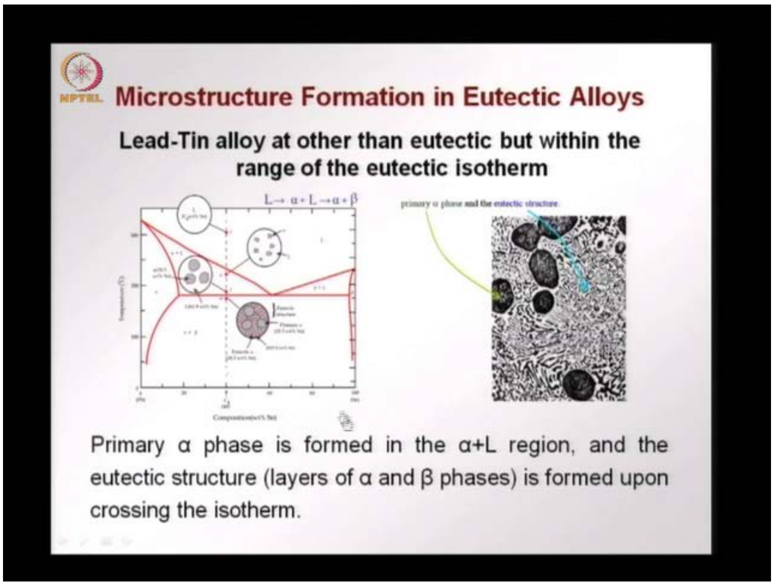

Microstructure Formation in Eutectic Alloys

Lead-Tin alloy at other than eutectic but within the range of the eutectic isotherm

Primary α phase is formed in the α+L region, and the eutectic structure (layers of α and β phases) is formed upon crossing the isotherm.

Now, let us see what happens at the region other than eutectic point, but within the range of the isotherm.

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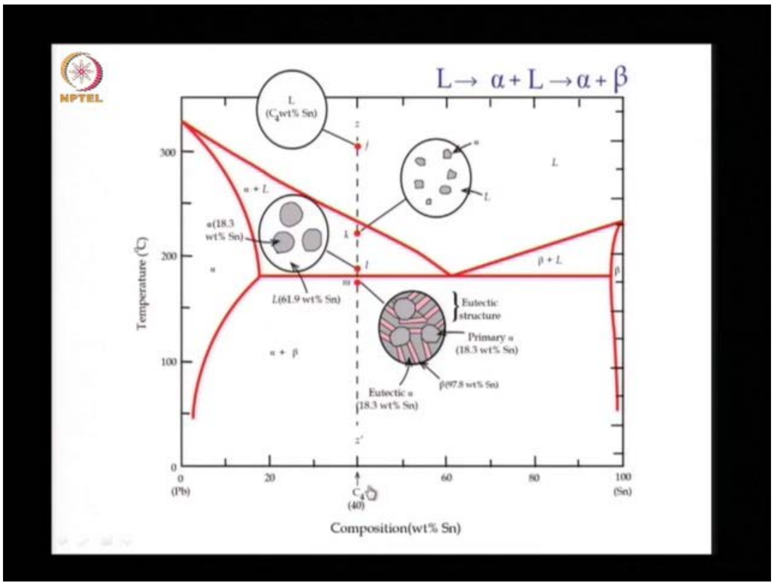

So, let us take the case of the composition of alloy with about 40 tin say C 4, so we will have a melt say in the point j, at the temperature j, we have a liquid with a complete mixed of tin and led. So, we have a complete liquid phase, then we cool this melt cross the liquids line and going to this region of alpha plus L and we will have, now alpha nucleating and starting to crystallize.

Again, if we want to know the composition of alpha and the liquid we have to go draw a tie line and we will know what the composition of the alpha motion is. Now, as we continue to cool the material, we will have a change in the alpha phase for example this point very close to the eutectic isotherm. We have an alpha phase with about 18.3 percent tin and the liquid phase with 61 percent of tin, which will be the other end of the tie line we cool further. Now, we cross the eutectic isotherm and what we see is outside these grains of alpha, we have the eutectic structures form this primary alpha which form in this region will have a tin contain of 18.3 percent.

But, outside we now have and alpha and beta phase mix together in the eutectic structure, in this case the eutectic alpha has an 18.3 percent tin given by this point. The beta phase of the eutectic structure has 97.8 percent tin corresponding to this point, so we have a microstructure like this, where we have the primary alpha phase. These are the primary alpha phases and then we have a eutectic structure around, so the primary alpha phase is formed in the alpha plus L region. The eutectic structure regions, which are the layers of alpha and beta phases is formed upon crossing the isotherm.

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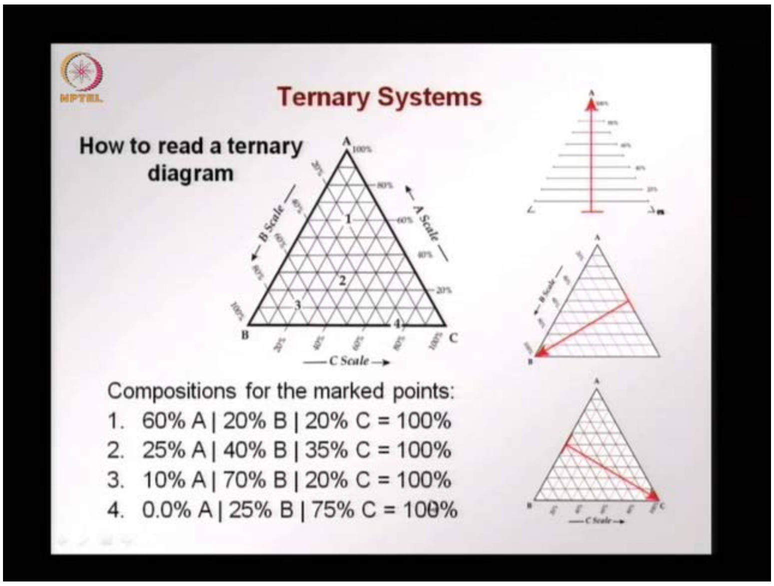

Ternary Systems

How to read a ternary diagram

Compositions for the marked points:

1. 60% A | 20% B | 20% C = 100%
2. 25% A | 40% B | 35% C = 100%
3. 10% A | 70% B | 20% C = 100%
4. 0.0% A | 25% B | 75% C = 100%

Now, we looked at binary phase diagram we will just spend the few minutes on ternary systems and before that we have to understand how to read the ternary diagram. So, in a ternary diagram we have three components A, B and C and A, we draw a chat with percentages represented in a triangle form, where this scale is like this.

Suppose we have to mark a point with a certain percentage of A in the composition, we look at the scale going from 0 to 100 along a line perpendicular to the base opposite this point A, which correspond to 100 percent A. Similarly, for B if we want to know what the percentage of B in the material is, we look at this line perpendicular to the base opposite to the apex corresponding to 100 percent B and, so with C. So to illustrate we have marked 4 points, we want to know what the composition is, at point 1 we start by seeing how much would be the percentage of A. So, we go to the base opposite to the apex corresponding to A and we see what would be the composition, this would be 0 percent A, 10, 20, 30, 40, 59, 60 percent A.

So, this point has 60 percent of A, its composition in terms of B again we go to the opposite side 0, 10, 20 percent B for C we again start. Here, 0, 10, 20 percent C, now what you can do is look at this diagram and C, if you can find out what the compositions of 2, 3 and 4. What you will see is that the composition has to add up 200 percent otherwise your result is wrong and you can do this exercise. Now, for 2, 3 and 4 or any other point, to check if you are able to read a ternary diagram properly, so I hope you done the checks and you got the results are given below for 2, 3 and 4.

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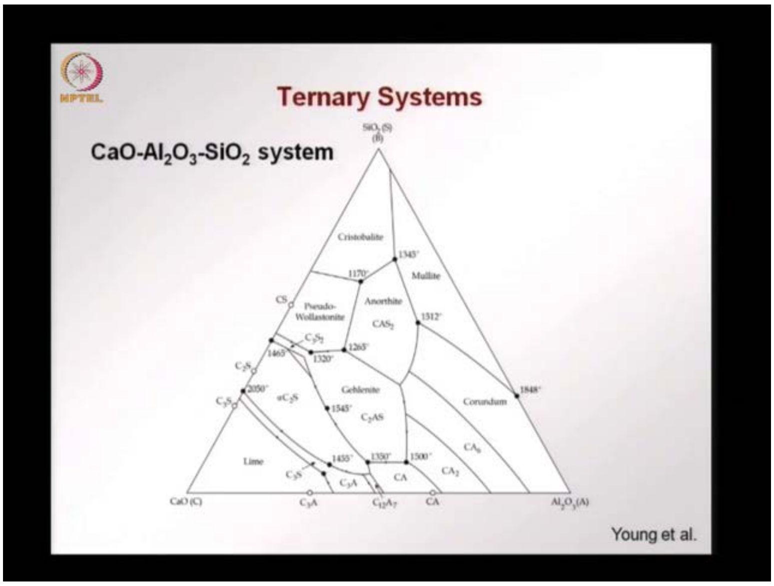

Ternary Systems

CaO-Al_2O_3-SiO_2 system

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So, the ternary diagram is used to the market materials with different properties for examples in this system, where we have the oxides of calcium aluminum and silica, we see that different regions have different properties and have been denoted as such. So, at this apexes we have a here aluminum oxide B which is silica and C calcium oxide, so we have different regions for example this region is the C, 3 S region which is the tri calcium silicate of cement. This would be completely line as calcium oxide we have C to S which is again a compound of symmetric and so on.

So, each of this regions have different properties and we use this like contra verse to demarcated different properties, so as a pose to the binary phase diagram, which had temperature on the y axis and composition on the x axis. Here, we have only composition represented in the ternary system and we have the ternary system, being used to demarked different regions corresponding to different properties.

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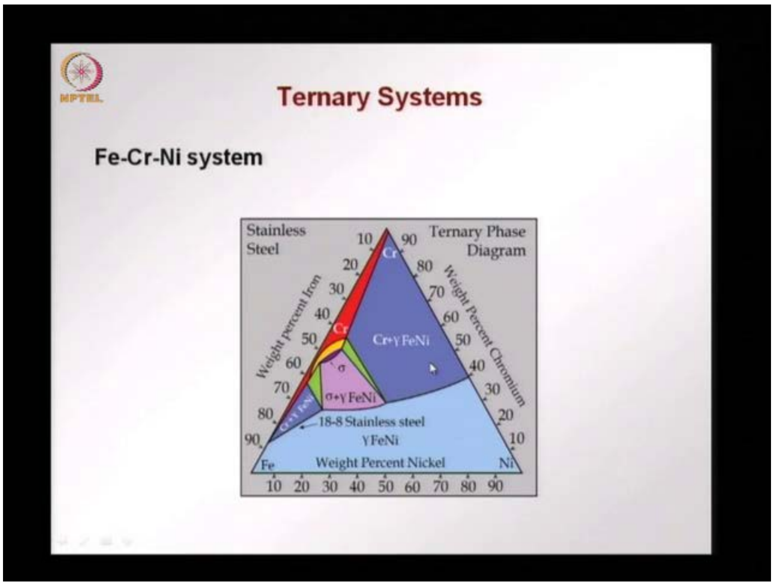

Ternary Systems

Fe-Cr-Ni system

We have a similar phase diagram which is used for the ion chromium nickel system, where again we have, now percentage of nickel chromium and ion put together to denote different materials and so on.

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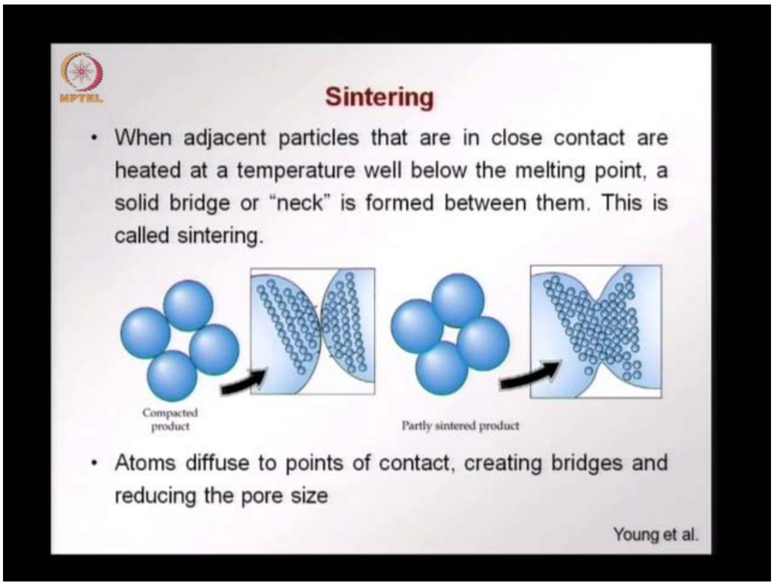

Sintering

- When adjacent particles that are in close contact are heated at a temperature well below the melting point, a solid bridge or “neck” is formed between them. This is called sintering.

Compacted product

Partly sintered product

- Atoms diffuse to points of contact, creating bridges and reducing the pore size

Young et al.

We will complete this lectures with the short discussion of sintering, we already saw that sintering occurs due to diffusion of atoms and molecules between particles when these particles are in close contact and our heated. Now, we should remember that we are below the melting point, we are not heating to above the melting point, however there is a diffusion of particles and a solid bridge or neck is formed, this is called sintering. Here, the atoms diffuse to the point of context, three bridges and therefore reduce also the pour size, the pour between the particles are reduced because of this necking and sintering occurring.

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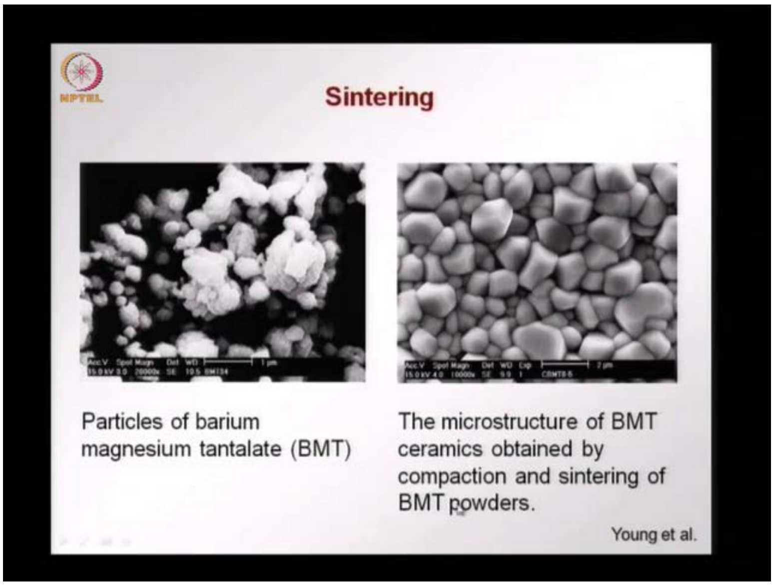

Sintering

Particles of barium magnesium tantalate (BMT)

The microstructure of BMT ceramics obtained by compaction and sintering of BMT powders.

Young et al.

This is an example from young where they see particles of barium magnesium tantalite B M T sintering and forming a compacts structure of particles, I have seen here. These are the particles of B M T with temperature and pressure, a compacts structure forms in this ceramic, the B M T ceramic after compaction and sintering.

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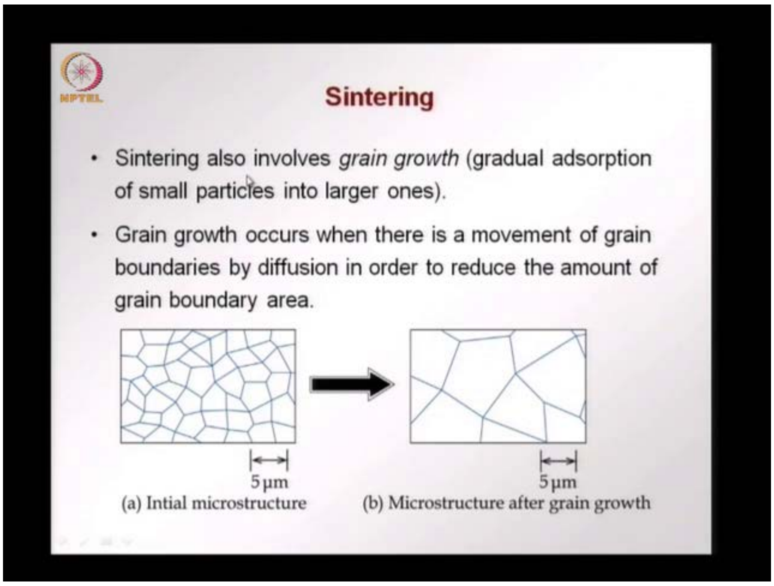

Sintering

- Sintering also involves *grain growth* (gradual adsorption of small particles into larger ones).
- Grain growth occurs when there is a movement of grain boundaries by diffusion in order to reduce the amount of grain boundary area.

(a) Intial microstructure (b) Microstructure after grain growth

We also see that sintering will involves grain growth, so the microstructure changes in sintering, this is because there is the gradual adsorption of small particles into larger once and this fills up the green boundaries. The surface defect now is removed and we have a continuous solid, so green growth occurs when there is the movement of green boundaries by diffusion. If you remember when we discussed green boundaries, we said that green boundaries are regions of high defects and there the energy is high and when you go back to the concept of condensation diagram.

We discuss and understood that we want to decrease the energy, we want to minimize the potential energy or the lattice energy in order to have a stable microstructure. Therefore, this diffusion in sintering tense to do away with some of the grain boundaries and the grain grow in size. So, if you have an initial microstructure with small grains or less than 5 microns, say 2, 3 microns with some temperature and pressure, there is diffusion across these grain boundaries. The grain boundaries fill up to have finally a structure with larger grains, say in the order of 10 microns, so the grain seizes and the microstructures changes due to diffusion during sintering.

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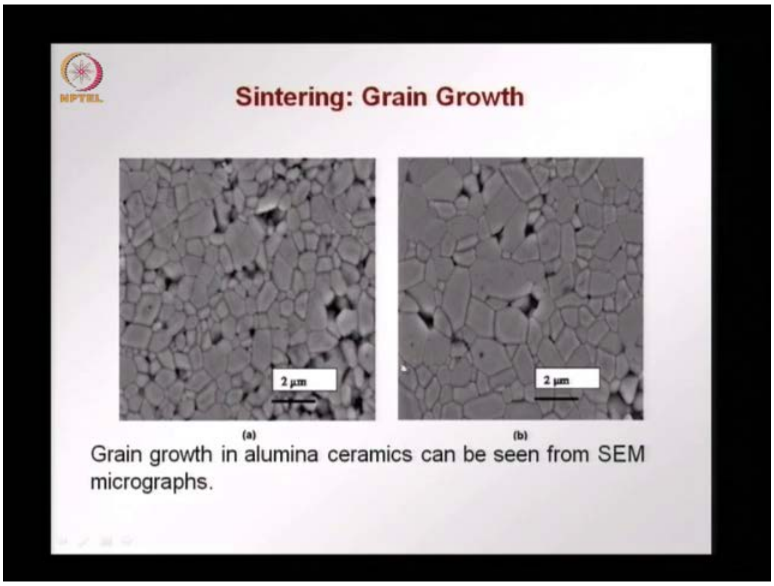

Sintering: Grain Growth

Grain growth in alumina ceramics can be seen from SEM micrographs.

This is the picture of alumina ceramics seen in S E M micrographs, you see here before sintering how the grains are smellers grains. After the application of temperature and pressure, we have the same ceramic, now with larger grains.

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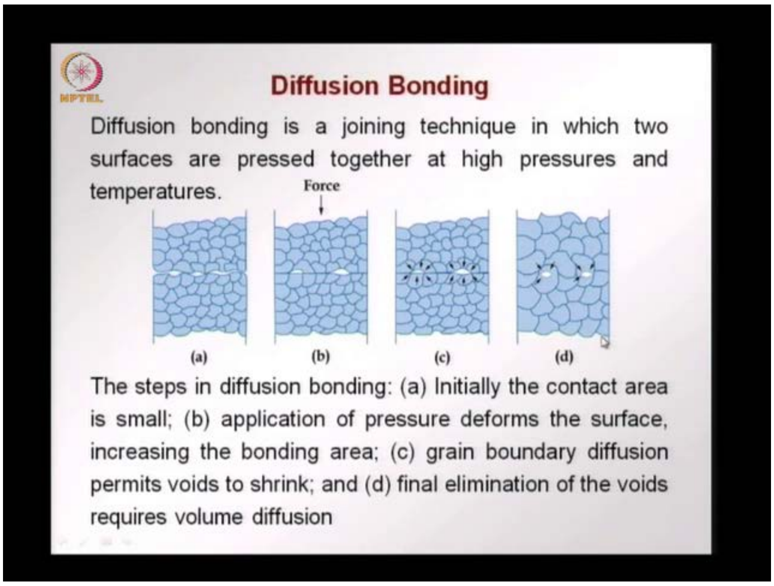

Diffusion Bonding

Diffusion bonding is a joining technique in which two surfaces are pressed together at high pressures and temperatures.

The steps in diffusion bonding: (a) Initially the contact area is small; (b) application of pressure deforms the surface, increasing the bonding area; (c) grain boundary diffusion permits voids to shrink; and (d) final elimination of the voids requires volume diffusion

This concept is also used for bonding different pieces, this is called diffusion bounding which is the joining technique in which two surfaces up press together at high pressure and temperature, which causes them to born to each other.

Say we have these 2 elements which are put together and force together small application of force and temperature and, now diffusion occurs across this grain boundaries and the material joins. So, the different steps are initially you have a contact area that is small as these 2 elements are put together pressure is applied. This deform the surface and causes more area to be in contact, this increases the bounding area then there is diffusion across adjust and grains, adjust and grains start bonding. You have growth in the grain sizes the widest tent to shrink because we have diffusion and filling up of this widest with further diffusion, this widest can also get filled up.

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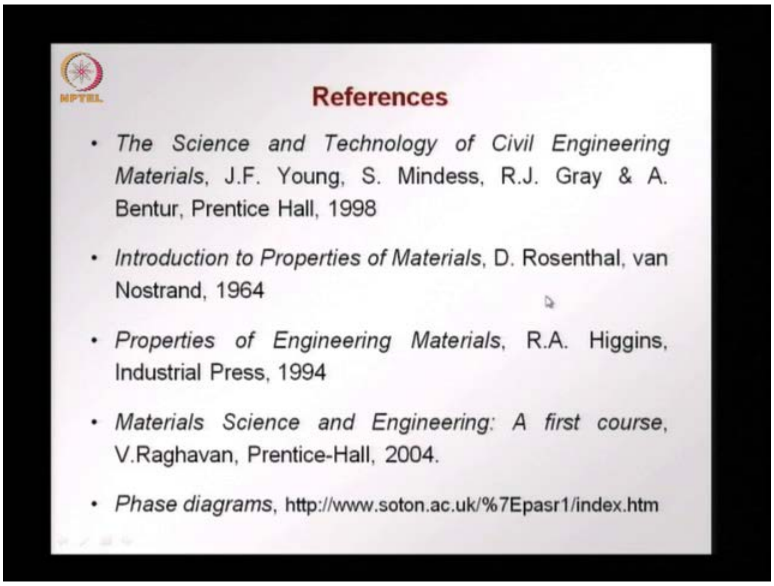

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So, we have covered different ways that microstructures forms in different materials, we looked at phase diagrams of single component systems 2 components systems or binary phase diagrams and we also saw how we can use a ternary diagram. Finally, we saw how grains structures can change due to sintering brought about by the diffusion process, thank you very much.

Student: Question and answer session

We have some questions regarding the lecture on the development of the microstructure that will take up now.

Student: Sir how diffusion is related to defects?

Well, that is the good question the movement of atoms due to diffusion is governthe lot by defects, early in this lecture or the previous lecture we looked at how diffusion is faster along some areas of defects. So, if we have a grain boundary there is region where the structure is not very compact and, therefore the diffusion is very fast through that through the grain bonds. Also, we found that in the core of a dislocation the movement of atoms through diffusion is also faster, so defects clearly effect. Generally, when we have a defect we have faster diffusion through the defects then in the bulk of the materials. Now, also what we saw in this lecture towards the end, is that when there is diffusion the defected area tense to be filled up by the atoms.

Therefore, grain boundaries also disappear you have the small grains becoming larger because the grain boundaries filled up by atoms or particles when there is a diffusion during sintering. So, there is lot of interaction between defects and the diffusion, first of all diffusion is faster in defected areas and diffusion can also led to filling up of the defects, and you have the elimination of grain boundaries, you had the question on.

Student: So, sir can you explain some applications of sintering in civil engineering structures or civil engineering materials.

Yes, lot of ceramics are the micro structures of ceramics falls by sintering, if you have bricks if you see the case of bricks there is sintering bricks and lot of the examples that I showed are ceramic structural. Ceramic which are powders that are pressed together with some amount of temperature and these grains, now point to each other and become larger? You have a sintered structures and this could also be used to create aggregates and to create the ceramics that we use in engineering.

Thank you.