Phase Equilibria in Material and Metallurgical (Nature and Properties of Materials - II)

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Lecture – 25
Phase diagrams of Cu-Ni and Al-Si

So welcome again to a new lecture and this is lecture number 25 of Phase Equilibria course. So, we will first do a recap of quick recap of previous lecture.

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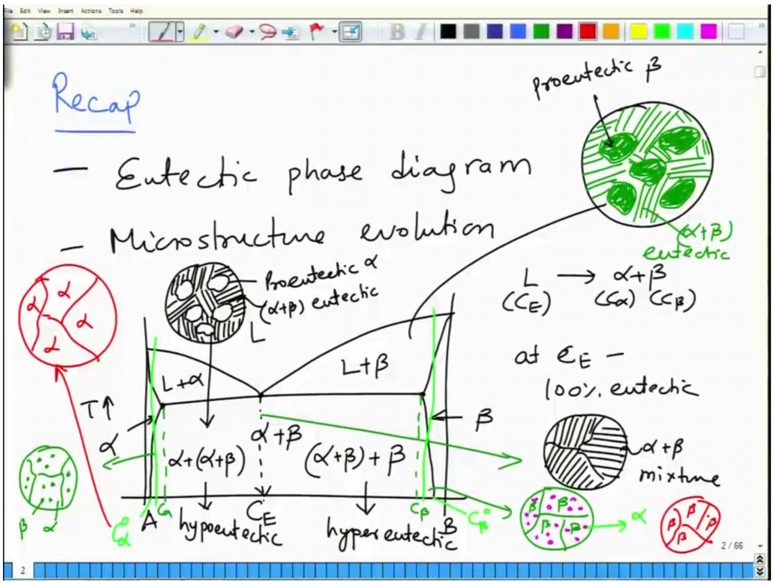

So, in the previous lecture what we did was we looked at the Eutectic phase diagram and Microstructure evolution. So, what we did was basically we took this eutectic phase diagram, so it is just a schematic eutectic phase diagram in which you have. So, you have let us say A and B between A and B and temperature you have this phase fields. So, liquid liquid plus alpha liquid plus beta alpha plus beta and you have alpha terminal solid solution and beta terminal solution.

So, this kind of phase diagram is valid for systems where A and B have partial solid solubility, that is they form terminal solid solutions with limited solid solubility on the ends, that is pure A and pure A with little bit of B forms alpha solid solution and pure B. If you go towards if you start putting A into pure B, then it forms a beta solid solution with limited solid solubility. In between they form a mixture of 2 phases alpha and beta, and if you go to high temperature this liquid this mixture of alpha and beta is of composition it is a basically eutectic. So, this is C E eutectic composition.

So, on this side you can write it as; so what you have basically is a mixture of for a you for the eutectic composition for which liquid directly transforms into this eutectic mixture it goes through invariant reaction. So, liquid goes to alpha and beta solid phases.

So, this is of composition C E, and then you have C alpha and C beta compositions of alpha and beta phase which are given by these points ok. And as you come as you come down temperature then the C alpha and C beta go along the solvers lines. The left of eutectic composition alloys are called as hyper eutectic alloys, on the right we have hyper eutectic alloys, and what we have in these alloys is basically a mixture of alpha and beta.

So, what happens is that when you move away from eutectic so at eutectic composition at C E you have a 100 percent eutectic and this has a morphology which is you know you will have colonies of let us say alpha and beta phases. So, this is alpha and beta sort of so this is alpha and beta eutectic alpha plus beta mixture. So, one phase is alpha let us say bright phase is alpha and dark is beta; however, when you away from eutectic compositions to left or right you have formation of. So, some alpha has already formed some beta has already formed during the course of solidification.

And in these regions what we have is pro eutectic alpha and pro eutectic beta. So, what you have in compositions away from eutectic composition is microstructure like this. So, some alpha which is formed earlier is like this ok. So, this is Proeutectic alpha. And in between you have this mixture of alpha and beta, so the remaining liquid whatever represent at eutectic temperature that converts into eutectic mixture so this will be alpha plus beta eutectic.

So, you have 2 kinds of alpha present in this mixture you have pro eutectic alpha and you have alpha of the eutectic. Both the alphas will have same composition except that morphology of 2 alphas is different. Proeutectic alpha is generally present as sort of globules or sort of equiaxed features, round features whereas, alpha and beta mixture eutectic mixture is present in the form of these lamellas or colonies.

What you have present in the hyper eutectic region is you will have phases which are so I will colour it differently. So, this is your you know so this is your you can say pro eutectic beta and in between you will have this alpha and beta mixture. So, this is alpha plus beta eutectic. So, this is the 3 micro structures that you will get one for eutectic composition, another for hypo and hyper eutectic alloys the moment you are beyond these solid solubility points on X and Y X on the eutectic line.

If you are below C alpha and C beta, then the microstructures are different. In these regions microstructure would be so you have this you will have predominantly alpha with some beta precipitated here. So, we will have alpha and beta ok. So, the left of C alpha is basically so the alloys will have alpha as a matrix and beta formed as a precipitate, in these regions you will have similar, but so you will have these grains of beta these are beta grains. And within these beta grains you will have alpha phase as these tiny precipitates. And alpha phases present as precipitates because there is no liquid here that undergoes eutectic reaction.

So, the if you go solidification in this regime for instance the liquid first forms first you have some primary alpha forming; that primary alpha so and once you cross this point everything is alpha, and once you cross this line alpha solid solubility decreases and some beta starts forming, but that beta forms on it is own it does not form from liquid as a result beta is present in the form of precipitate.

Similarly, on this side the alpha is present in the form of precipitates on this side. So, what you will have is alpha precipitates here; and you have so because there is no eutectic reaction that is taking place for these compositions. As a result, this alpha is not, this alpha beta is not present in the eutectic morphology it is present in different morphology. So, these are the 5 different kind of micro structures that you may encounter any eutectic alloys.

So, of course, if your composition is lower than this composition which is let us say C alpha naught, and this is C beta naught at room temperature in this case if you take the composition so lower than C alpha naught in that case you will only have grains of alpha. So, you will have alpha alpha alpha alpha and if you are lower than C beta naught then you will have only grains of beta; there will be no alpha present. So, this is the overall landscape of the microstructure that you will examine in that you will encounter in a eutectic phase diagram upon cooling. Now, what we also did in the last lecture was we also worked out in the phase fractions.

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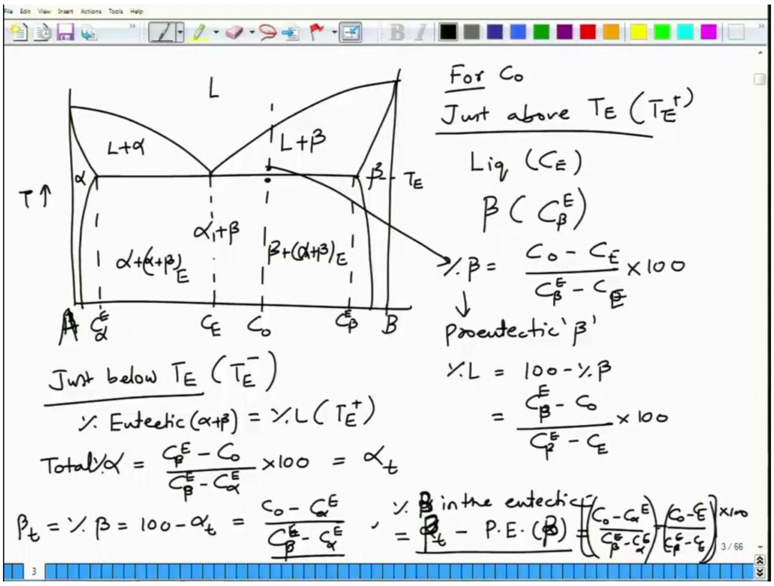

So, just to give you one example so we have this as a eutectic line. So, you have liquid liquid plus alpha, this is liquid plus beta, beta phase and then alpha plus beta for this, and then you have here alpha plus alpha plus beta, beta plus beta plus alpha plus beta. So, this is eutectic and this is proeutectic for these compositions ok. Now let me just choose a composition here let us choose a composition C naught. For C naught just above T E that is the eutectic temperature this is T E. So, just above T E, that is T E plus, what are the phases present? Phases are liquid of composition C E.

So, this is C E this is C beta and this is C alpha let us say C alpha E and C beta E ok. So, liquid of composition C E and beta of composition C beta E ok; these are 2 phases present. So, if I want to find the fraction then percentage beta will be equal to C naught minus CE divided by C beta E minus C, C E into 100 and then percentage liquid will be this beta that is formed is the proeutectic beta so this is proeutectic beta.

And liquid whatever is remaining converts into eutectic so what you have at this point. So, what we have is proeutectic beta plus liquid. So, percentage liquid will be equal to 100 minus percentage beta, which is equal to C naught sorry, C beta E minus C naught divided by C beta E minus C E into 100. When you go to temperature which is just below T E that is T E minus then whatever liquid is left has converted into eutectic phase. So, percentage eutectic that is alpha plus beta mixture will be same as percentage liquid at T E plus.

However, if you want to find out what is the total alpha is given now not with respect to eutectic composition, but with respect to the alpha and beta solid solubility. So, total percentage alpha is C beta E minus C naught divided by C naught minus C alpha E this is total alpha in to 100.

So, this let us say is alpha t and total percentage beta is nothing but 100 minus alpha t which is equal to C naught minus C alpha E divided by C beta E minus C sorry, here I made a mistake this is C beta E minus C naught divided by C beta E minus C alpha E yeah; so this is C beta E minus C alpha E ok. So, what is now we want to calculate what is the percentage alpha in the eutectic.

So, percentage alpha in the eutectic is alpha t minus proeutectic alpha, we are taking in this case we are looking at beta ok. So, proeutectic beta in the eutectic is. So, this is percentage beta so this is beta t total beta total alpha. So, percentage beta in the eutectic is so beta total minus proeutectic beta. So, beta total is this which is C naught minus C alpha E divided by C beta E minus C alpha E this minus proeutectic beta which is C naught minus C E divided by C beta E minus CE.

So, this will be your total multiplied by 100 of course, this will be the percentage beta in the eutectic. So, total beta is the beta in the eutectic plus proeutectic beta whereas, alpha is present for this composition only in the eutectic phase. And conversely you can do the same for the hyper eutectic alloy. So, this is how you do the calculation of phase fractions in a eutectic phase diagram.

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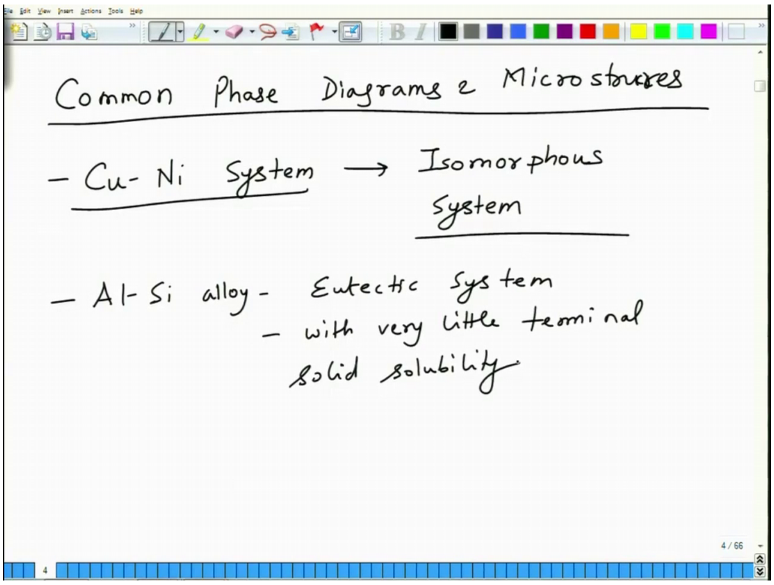

Now, what we will do is that we will look at some of the common phase diagrams, and micro structures that we get in reality. So, first we will look at copper nickel system; which is a isomorphous system all right. So, if we now go through PowerPoint presentation.

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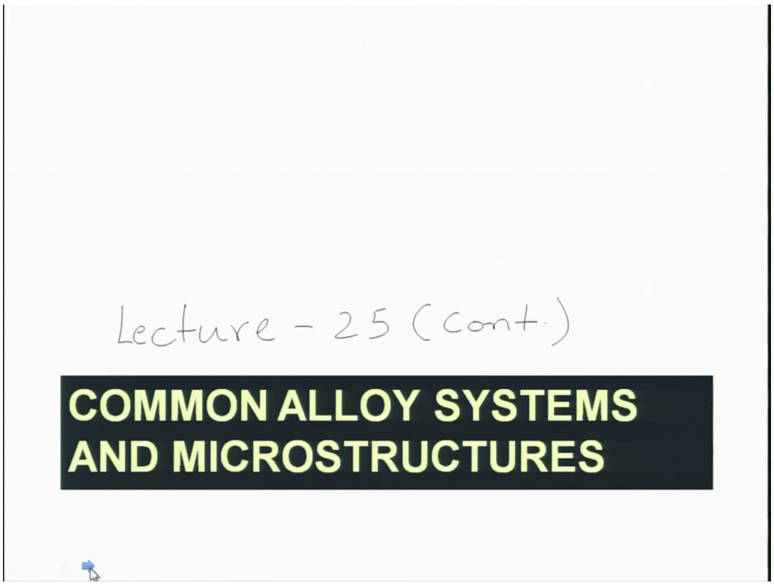

So, here we will look at so let me say this is lecture number 25 continuation all right.

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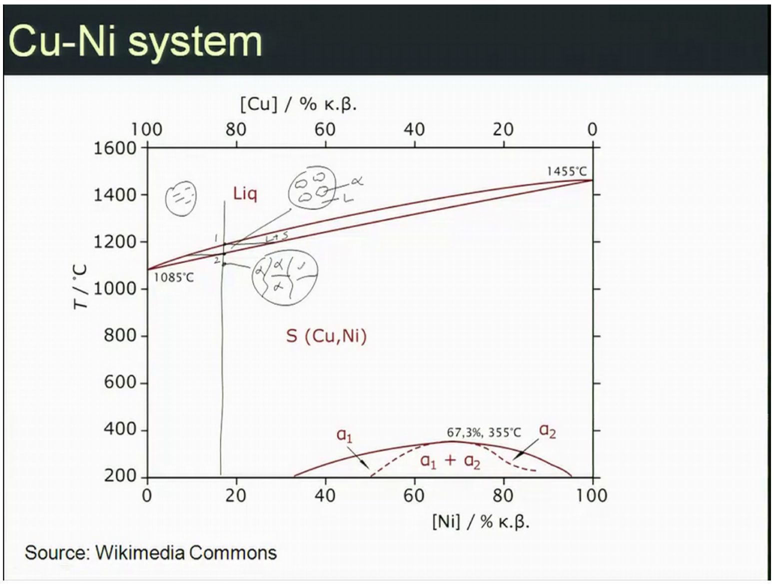

So now, so this is a copper nickel system so, this is taken from basically Wikimedia or Wikipedia. So, what we have here is on the y axis we have a 100 percent copper. So, coppers melting point is 1085 degree centigrade on the x axis we have, on the right axis we have nickel which is 100 percent nickel whose melting point is 1455 degree centigrade. And the percentage of nickel varies on the x axis at the bottom and percentage copper is shown in the reverse direction on the top axis.

So, what we have here is at very high temperatures, we have only liquid phase and then depending upon the composition the liquid starts to transform into a solid, at certain temperature before it converts into so if you start from for example, this point you start solidification at this point and finish at this particular point 1 and 2, and in between 1 and 2 you will have a liquid plus solid region.

So, this will be liquid plus solid region and solid is nothing but solid solution of copper and nickel which at lower temperatures converts into a 2 phase mixture of alpha 1 and alpha 2; which are again similar phases. So, they have similar free energy curve with certain differences in the structure. And this happens at 67.3 percentage nickel at 355 degree centigrade let us not worry about this though. So what we have here is; we have liquid converting into a solid and the solid slowly getting increased in that constant proportion you can move the tie line.

So, at this point you have very little solid and at this at this point when the solidification is about to complete you have very little liquid left and at this point somewhere here you have 100 percent solid. So, when you look at the microstructure of such an alloy in the microscope what you see is basically. So, you can see schematically you had 100 percent liquid and at this point, in between you had some alpha and then liquid. And at this point you have 100 percent alpha or solid. Let us see how does it look in reality in a microscope.

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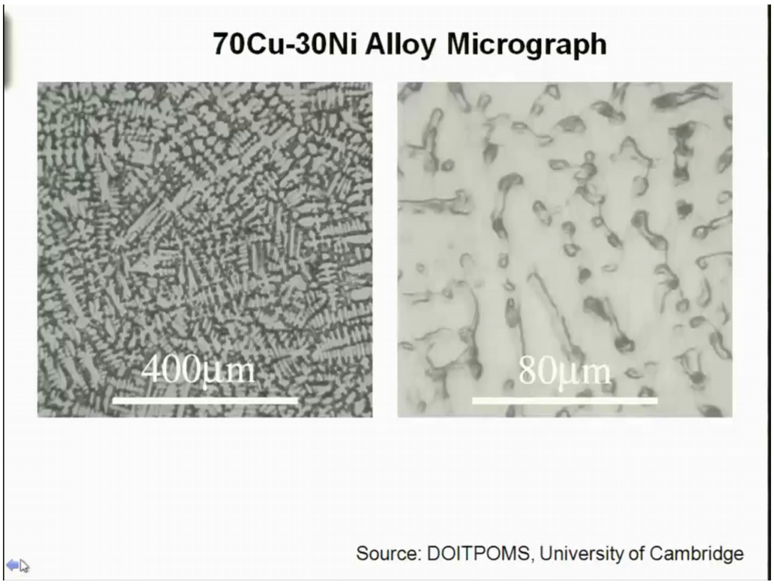

So, this is how you see a reality in a microscope this is 70 percent copper 30 percent nickel alloy micrograph. This has been sourced from university of Cambridge website where they have depository of microscopes DOITPOMS. So, this is the microscope optical micrograph of a 70, 30, 70 copper 30 nickel alloy at resolution which is fairly low at magnification which is fairly low. You can see this scale bar is about 400 microns.

So, this whole image is nearly 600 by 600 or 700 by 700 microns something like that. So, which is nearly 0.6 by 0.6 mm so basically a very macroscopic image. So, what you see here is you have regions of dark and white contrast. Now this dark and white contrast is not expected in the single phase alloy after all we are looking at we should only see the grain boundaries.

Now, this happens because of non-equilibrium cooling as I as I explained in previous lectures, that alloys are tell them cooled in such a fashion so that composition fluctuations will not be there in the alloy. Because of non-equilibrium cooling you have compositional variations as we can if you look at the previous slide, the first alloy which is thus first solid formed which is here, but the first solid is already formed. So, when the next solid forms the next solid has composition which is like this; so as a result the solidus line shifts.

So, your composition keep shifting and because of compositional differences because of non-equilibrium cooling you have. So, overall alloy composition is different as compared to and so you will have first alpha forming of one composition.

The next alpha that will form is of composition which is let us say this composition. After this you will form another alpha which will have composition which is different which is let us say of this composition. And this will keep going on until your cooling is over. And so, you will have these multiple layers of compositions.

And these layers of compositions will give you the contrast and the optical microscopes; as a result, so if you magnify this image for instance you see this dark and white regions, and dark and white regions are nothing but manifestation of composition fluctuations in the alloy formed as a result of, but this is basically a single phase alloy alpha with the compositional fluctuations. So, this is what you are likely to see in a single phase alloy under a optical microscope in reality.

So, the next one that we want to look at is the let me see which one is it; it has led at an aluminium silicon alloy. So, the next one that we want to see is aluminium silicon alloy, which is a eutectic system with very little terminal solid solubility. And this is an aluminium silicon have very high difference in the melting point despite that they form a eutectic system.

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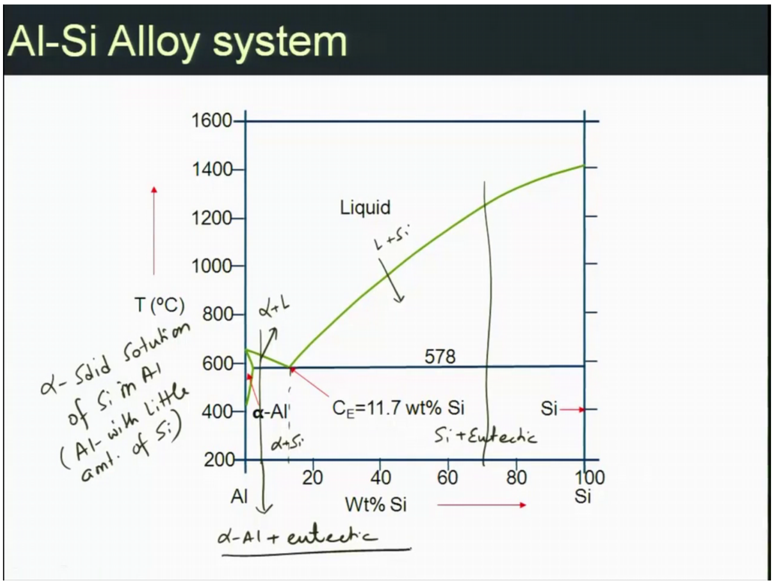

So, aluminium has a melting point of 670-degree centigrade nickel has silicon has a melting point of nearly 1420 degree centigrade. They form a eutectic at about 578 degree centigrade. And eutectic composition of the law is 11.7 percent silicon. The solid solubility of silicon and aluminium and is virtually 0 at room temperature, but at high temperature it has at eutectic temperature it has solid solubility of the order of few weight percent.

Whereas solid solubility of silicon and aluminium and silicon is virtually 0. So, basically what you have present is within this phase field you will have alpha aluminium plus liquid sorry, let me change the skin this colour. So, within this we will have alpha plus liquid here we will have liquid plus silicon ok, this alpha is basically solid solution of silicon in aluminium. So, basically it is aluminium with little amount of silicon ok. So, and here you will have at eutectic you will have alpha plus silicon.

So, again you can see that within a single phase region for very pure aluminium very aluminium with very little amount of silicon you will see basically alpha aluminium forming at high temperatures, which converts into alpha plus some amount of silicon at low temperature.

So, all the silicon precipitates out at low temperatures for these compositions you will only see silicon with little amount of aluminium, no solid solution forms on this side at all. At eutectic composition you will see some alpha and silicon forming and the microstructure if you look at for instance in microscope.

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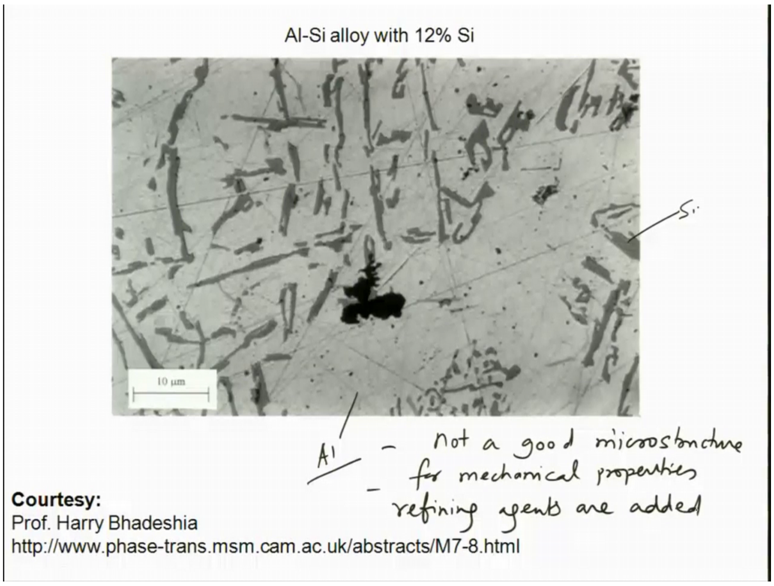

This is for example, this courtesy professor harry Bhadeshia from Cambridge University. So, this is the aluminium silicon alloy with 12 percent silicon, 12 percent silicon is very close to eutectic composition. So, what we must observe is basically a eutectic mixture of alpha aluminium and silicon. So, what you see here is basically you see alpha aluminium and silicon you see a 2 phase mixture.

So, this 2 phase mixture you can see that you have, this is the silicon and this is aluminium. White phases which has lot of scratches is basically the soft phase aluminium phase which is nearly pure aluminium and what you have is the dark phase, which is where you have this long needle sort of or plate sort of features which is silicon.

And this microstructure is not a very good microstructure from the perspective of these mechanical properties, because you can see that these silicon precipitate silicon crystals are elongated. They have sharp ends and they give rise to high stress concentration. So, it has poor mechanical properties, as a result some sort of refiner is added to these micro structures to improve the microstructure such as such that the formation of silicon in the eutectic does not happen in this form rather silicon forms in the form of round roundish shape. So, you can say that this is not a good microstructure for mechanical properties.

So, as a result refining agents are added, refining agents such as little bit of sodium is added to the microstructure to improve the microstructure, and make silicon phase into round phase which reduces the stress concentration and improves the mechanical property. So, this is the microstructure of aluminium silicon alloy with 12 percent silicon.

So, if you go back to this phase diagram now, if you want to if you take alloy composition on this side which is basically hyper eutectic or hyper eutectic alloys, you will essentially see today's alpha you will see. So at this point it will be silicon plus eutectic, and at this point you will have alpha aluminium plus eutectic, and again they will appear in the same fashion as I explained before for various alloys. So, what we have done in this lecture is we have just looked at how the proportions of proeutectic phases phase is related to the total phase content in the hypo or hyper eutectic alloy.

We also looked at the micro graphs of 2 common systems that is isomorphous aluminium nickel copper aluminium nickel copper system and copper nickel system as well as aluminium silicon alloy system, aluminium silicon is a eutectic system with very little solid solubility basically you have 2 pure phases that is all.

So, it is just a mixture of pure Aluminium and pure silicon with very little solid solubility within each other that is because of differences that melting points are very different the variances are very different, the bonding is very different silicon is covalently bonded aluminium is metallically bonded. Crystal structures are somewhat different aluminium is FCC silicon is also diamond cubic FCC, but lattice parameter silicon is far bigger than aluminium because of 4 tetrahedral hands. As a result, these the system that is formed is basically a mixture of al pure aluminium and pure silicon.

Pure Aluminium may be called as alpha aluminium with very little amount of silicon, but essentially it is a mixture of pure Aluminium and pure silicon. And microstructure gives you information about what kind of morphology of phases is present and then you can take action to improve this microstructure by adding certain elements to improve the morphology of phases in the alloy. So, that is what that in aluminium silicon system the morphology is such that it has poor mechanical properties, but if you are refiners turn the sharp edges of silicon into round silicon morphology, which improve the mechanical properties.

So, what we will do in the next lecture, we will again look at some more phase diagrams and micrographs of different alloys before we move on into the further contents of this course.

Thank you.