Materials Science
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Lecture 19
Phase Diagrams

Well, we were talking about the phase diagrams and yesterday after having a look at some simple diagrams we started to look at little more complex possibilities where more than one 3-phase equilibrium could be present. Steels, the iron-carbon diagram pertains to and this iron-carbon diagram has three such 3-phase equilibrium, that is what we were looking at in the last class. We shall continue with that.

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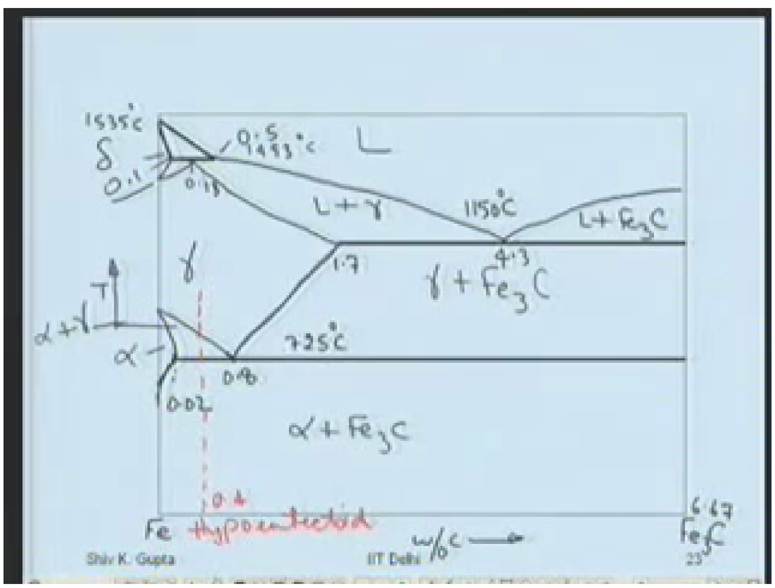

This diagram, okay, this is the pure iron and this is the end for Fe3C which we call cementite. And the phases which are present in steels, iron-carbon diagram, they are all rhyming, ferrite, austenite, cementite. And the mixture of phases also we will see that, they are all rhyming. So that is not difficult for you to remember that. And here I have weight percent carbon. Normally all these carbon percentages in steel are given in weight percent, not in atomic percent. And this here is the temperature. There is a melting point of iron, 1,535 degree centigrade.

And this of course, composition is 6.67 percent carbon. And we have a peritectic reaction here. As I told yesterday my diagram may not be to the scale because values I shall give you. All that is liquid phase field, here I have the alpha phase field, gamma phase field. Alpha phase field we call ferrite, gamma we call austenite. This delta phase field we call it delta-ferrite. And in between the two single phases here it will be liquid plus delta, here it will be gamma plus delta, here it will be liquid plus gamma and that is Fe3. So it will be liquid plus Fe3C here.

These places I have the small space, I am not writing that, you should see what is on the left and what is on the right. Those are the two phases present. And here I have alpha plus gamma region and this is alpha plus Fe3C. All right. I shall write this one, is little important, alpha plus gamma region. And the composition, this is a very small carbon composition, 0.02. That is why I said it is not to the scale. This is 0.8, this is 1.7, this is 4.3 and this composition is 0.5, sorry, this one liquid is 0.5. That is 0.18. This one, this is 0.5 and this is 0.1.

Where is it? All right. So these are the compositions and the temperature here is 1,493 degree centigrade for this equilibrium. Temperature here is 1,150 degree centigrade for eutectic and eutectoid here the temperature is 725 degree centigrade. This is the iron-carbon diagram which gives me one peritectic reaction here, one eutectic reaction here, one eutectoid reaction here and this is Fe3C what we call cementite iron, iron carbide diagram you can say. Fe3C is also called iron carbide. So iron-carbide diagram, it is not iron-carbon diagram. Okay.

Another thing which before I proceed further like you to notice, the difference between a peritectic reaction and eutectic reaction. In 3-phase equilibrium there are three phases and they have three compositions. Composition like in this is one, is on the left, delta phase. One in the middle is the gamma phase, one on the right is the liquid phase. Similarly in the eutectic I have one on the left, the gamma phase. One in the middle is the liquid phase and one on the right is cementite, Fe3C phase.

Between this reaction and this reaction, looked at the phase which exist in the middle composition. Here it is gamma and here that is liquid. This middle composition phase does not exist above the equilibrium temperature anywhere in the diagram. Similarly here this middle composition phase does not exist below this temperature. That is how you will be able to identify whether it is eutectic or peritectic. But there one of the phases should be liquid.

If all three phases are solid, this becomes eutectoid and peritectoid. See again eutectoid, the middle composition phase does not exist below the equilibrium temperature and the middle composition phase is gamma, the austenite. It exists above 725 in the diagram, does not exist below 725 degrees. Is this clear? So that is how you can identify the reaction is eutectic reaction or peritectic reaction. The prefix to the word, whatever you are using.

All right. Now what we do is we shall take one alloy which is a steel and let us say we take one somewhere here. Let us say this composition is 0.4 percent carbon. Machine components can be made with this kind of a steel. What happens above this temperature line which is a dividing line between gamma phase field and 2-phase field, alpha and gamma? It is all austenite. At this temperature which is around 1,200 degree centigrade, it is all austenite. 1,150, it is all austenite. 1,000, 910 up to this temperature, it is all austenite.

Before that it might have gone through this reaction here, the peritectic reaction, 0.4 percent. That is all washed out. When we have single phase here, that is all washed out, the effect of that is not seen. So I do not talk about that. To what I see at the room temperature or even when I hot-roll the steel or hot-work the steel which will be the range of 900, 1,000 degree centigrade, I do not have to worry about what has happened there. And that is why I said in the last class this eutectoid reaction is very important for engineers when we want to understand the functioning or the properties of the steels.

Before we come to that, we have to see the microstructure of steel, what it looks like. So with this alloy of 0.4 percent carbon, which is to the left of 0.8 percent, so we call it hypoeutectoid steel, it is not hyper, it is hypo. This hypoeutectoid steel I shall show you now. I have structured at different temperatures what happens.

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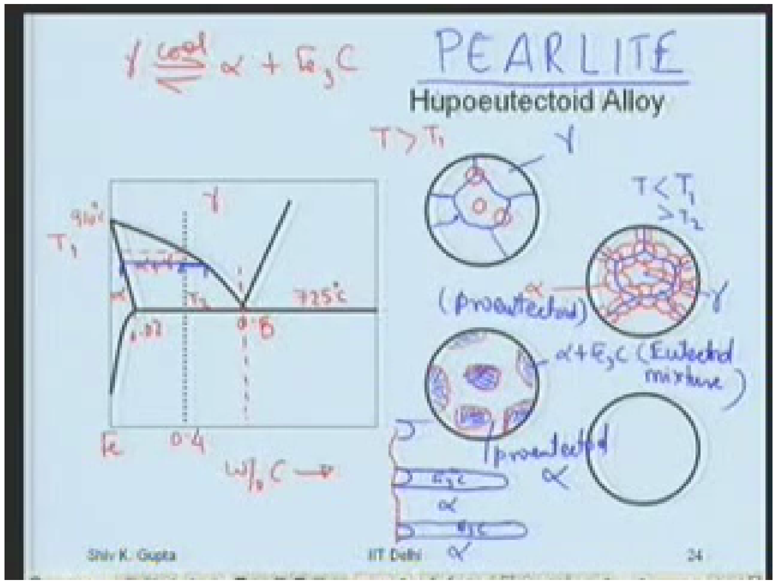

This is the diagram. That is 0.4 percent, let us not worry about that. This is weight percent carbon here. This is 0.8 here and that is 0.02. This is the gamma phase field, alpha phase field, alpha plus gamma phase field. Well, in the language of metallurgist you give this temperature line some name. Let us not worry about that. This is usually they call it A1 temperature. Let us not at the moment worry about it. We call, keep calling this line as a boundary between gamma phase field and alpha plus gamma region.

Till the temperature which are above that, let us call this temperature some name because I will be talking about this. So let us call the temperature T1. This temperature let us call, T2 which is 725 degree centigrade, eutectoid temperature. So at temperature which is greater than T1 which could be between 880 or so, 880, 890 something like that because this is 910 degree centigrade for 0.4 percent carbon steel, it could be even 840 sometimes depending upon how the line is going.

So this temperature which is greater than T1, it is all single phase and that single phase let me show, looks something like this. All right, these are the grain boundaries we have and these are the grains of gamma. Each one is gamma, okay. That is what happens. The moment I cross T1, let us say I come slightly below T1 because at exactly T1 you know the amount of the second phase is 0. You can apply the lever rule fulcrum here. This is the gamma phase weight and this is the alpha phase weight and you can find out the alpha is going to be proportional to this and gamma is going to be proportional to that.

A small quantity of alpha is going to form. But this alpha, so at temperature less than T1 but the temperature is greater than T2. This formation of the alpha phase, transformation we shall look at little later but forms usually at the regions in this. This is solid where it is energetically favorable for it to do so. When second phase particle forms in the middle somewhere, let us say it forms like this, it is going to form an interface between this alpha phase which is forming and the gamma phase which already exists there.

But the same particle, it instead here forms here. It forms the same interface, some area but removes that much grain boundary area. And the maximum grain boundary area it removes when it is on the junction. And the same thing if it forms here, it removes less grain boundary area only. So it starts with that region and grain boundary area is or any interfacial area means more energy. We want to reduce the energy.

Energetically favorable system would be when it forms at the junctions, the new phase. That is more energetically favorable and then it spreads over to the grain boundary regions. When that is filled, then it spread into the rest of the region. So what happens? Now when the alpha phase forms, alpha phase forms at the junctions like this. Once it has done, it spreads over into the grain boundary region.

So this is the alpha phase which has formed and remaining gamma phase which is not transformed yet, is still in the middle. Okay. This is still gamma here in the middle. And this situation shall go on till I reach just about T2. And also you notice that the at temperature T1, the composition of the alloy is 0.4 steel and that of the gamma phase is also 0.4. But as temperature reduces, gamma phase field or the gamma phase follows its composition along this line.

It follows it along this line. And similarly the alpha phase field and just below this it begins to form of this composition and follows the composition along this line which is solidus. It follows along this line, actually this should be all called solvus because they are all different solubility limits in the solid state itself. This is one solvus line, this is another kind of solvus line. So this is following along this line and that is following, the gamma is following composition along this line. And alpha is following the composition along this line.

When I came, come just above T2, the composition of the alpha phase is 0.02 percent and the composition of gamma phase is 0.8 percent. And that is the situation I am in. Alpha phase and well, these the other grain boundaries also get covered by the (gamma), alpha phase which forms like this. And remaining phase area is all gamma. Now it is this gamma at temperature T2 when you cool, means you are extracting heat from the system at same temperature 725, gamma with 0.8 percent carbon composition, how will it going to solidify rather.

Look at this gamma phase of 0.8 percent carbon. Like the eutectic alloy, this is the eutectoid alloy. And because of this reaction, the reaction which is gamma on cooling go to form alpha and Fe3C, so a mixture of alpha and Fe3C forms. We will show you how this happens in the phase transformations but this will form in these regions of gamma which are 0.8 percent carbon. And let us say those entrapped regions are somewhere here. These are not going to be smooth, round figures. Rest of it has all become alpha phase.

So this is going to become now the mixture of alpha and Fe3C, it is forming the solid state. When a cementite particle forms, Fe3C particle forms, it takes carbon from the neighborhood. The neighborhood becomes depleted in carbon. Therefore well, let us say this is the boundary, a bigger region. A particle of Fe3C forms like this, so it has taken carbon from here and here. This is depleted, that becomes ferrite and it cannot give more carbon. So that remains ferrite but somewhere here where the carbon has not still come from, it can become another cementite like this along the boundary.

But then from forward direction it can still pick up more carbon and can grow inwards like this. So this is the Fe3C region and this is the alpha region. Alternately, I get alpha and Fe3C but generally what we find if I cool it in the normal conditions like in air, these boundaries are too near. Under the microscope I cannot see them separately. As a result, the whole region looks quite dark to me but we normally depict this as like this because the orientations when it forms could be more than one possibly. These are all mixtures of alpha and Fe3C. This is called eutectoid mixture.

“Professor-student conversation starts.”

Student: Sir, previous one could be called as proeutectic, proeutectoid.

Professor: Yes, this alpha phase which is formed along the boundaries is the proeutectoid. Alpha, and this whole matrix here is proeutectoid. So whole matrix is proeutectoid alpha in which I have the islands, those are the mixtures. And these are the mixtures of ferrite and cementite. So that is what, how the at room temperature now below, when I come below this, solubility limit is still changing. But some changes in the composition taking place but those are not seen here. This diagram or the microstructure looks something similar only all the time.

At room temperature there will be not be much changes in this. So steel would, a hypoeutectoid composition would look like this. Whether I start with 0.4, I start with 0.2 or I start with 0.6, only the relative amounts of this phase, proeutectoid phase which is forming will change. Whether the fulcrum is here, or the fulcrum is here or the fulcrum is here, that shall decide how much is the proeutectoid phase.

So that is what is going to change. We shall work out this for the 0.4 percent carbon steel. We will understand that. Otherwise it shall remain like this. There are matrixes of proeutectoid alpha and there are islands of pearlite. Eutectoid mixture in these steels is called pearlite. And pearlite is not a phase, it is a mixture of two phases, ferrite and cementite. And in that mixture both of them are forming at the eutectoid temperature which is 725 degree centigrade.

Now in this alloy, now you have seen the, understood the microstructure, I shall try to find out how much is the proeutectoid phase, how much is the ferrite in the mixture, how much is the cementite in the mixture. Let us see we can work it out. What all we can work out with the help of the lever rule? Yes, please.

Student: 75.

Professor: Pearlite, this region which has become the mixture of ferrite and cementite like at this I showed you, this mixture is called pearlite because under the microscope what looks as one entity is called the microconstituent. This mixture is all looking like dark region, is called pearlite and is a microconstituent. But pearlite is not a phase, it is a mixture of two phases, ferrite and cementite.

And the relative amounts of ferrite and cementite, if it is an equilibrium pearlite, is also going to be fixed. That you can work out by applying the lever rule with the fulcrum at 0.8 percent carbon, cementite with 6.67 percent carbon and ferrite with 0.2 percent carbon. This will give the amount of the ferrite and this shall give you the amount of the cementite. It should be possible for us to understand that. Now in the 0.4 percent carbon-steel, let us first of all look at this structure which is just above temperature 725 degree centigrade, just above T2, that is the microstructure, we shall look at that.

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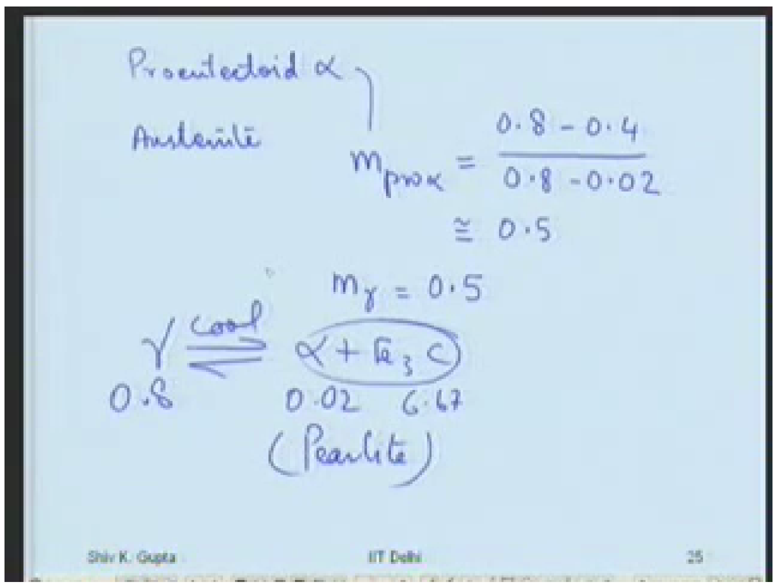

In this I have seen I have proeutectoid alpha and at that temperature I also have austenite. If you apply the lever rule, try to find out the proeutectoid alpha, just tell me, composition of the alloy is 0.4 percent and the composition of the austenite is going to be 0.8 percent and composition of the alpha is going to be 0.2 percent. So which arm of the lever shall give me the mass of the proeutectoid alpha? Let us find that out, m pro alpha, this is equal to, yes, on the other side, it will be 0.8 minus 0.4 divided by the total arm of the lever, 0.8 minus 0.02.

If I consider 0.02 approximately 0, I can get an approximate answer very quickly. It is 0.4 by 0.8, is about 0.5. 50 percent is proeutectoid alpha and remaining 50 percent is the austenite. So mass fraction of the austenite is going to be again 0.5. At room temperature or when I cool below 725 degree centigrade, it is this 50 percent austenite which becomes pearlite because that is going through the eutectoid reaction. Gamma on cooling goes to the mixture alpha plus Fe3C.

If I have this 0.8 percent, this is 0.02 percent and that is 6.67 percent, it becomes the pearlite. This mixture is pearlite. So it is this becomes pearlite but in the pearlite how much is ferrite and how much is cementite, that can also be worked out. All right, let us see that.

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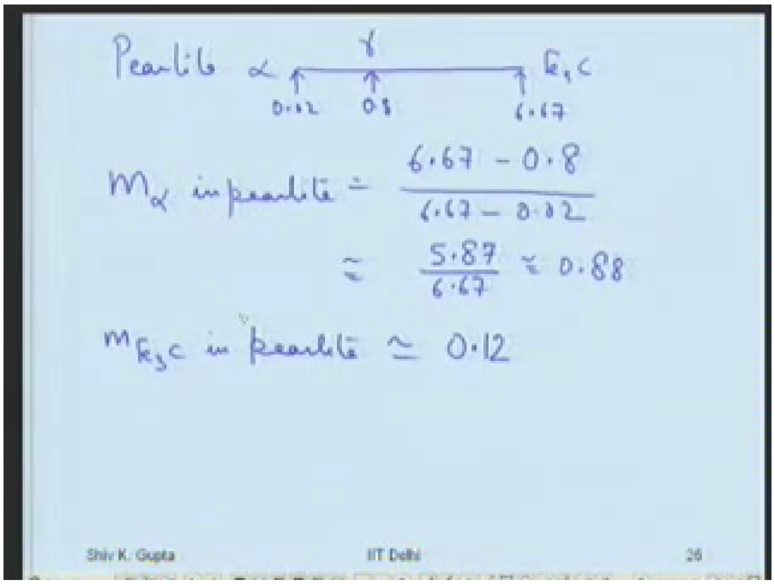

In pearlite the lever is 0.02, 6.67 and this is 0.8 percent. This is gamma, alpha, Fe3C. So when gamma 0.8 percent composition is going through this reaction it forms alpha and Fe3C. I can find out mass fraction of alpha in pearlite is how much, is given by this which is 6.67 minus 0.8 divided by 6.67 minus 0.02. All that shall be 5.87 divided by approximately 6.67. All this comes out to be something like 88 percent. 88-87 percent it will turn out to be, around that. It is just approximate calculation. Similarly we can find out what is going to be the fraction of cementite, that will be approximately 0.1213 percent.

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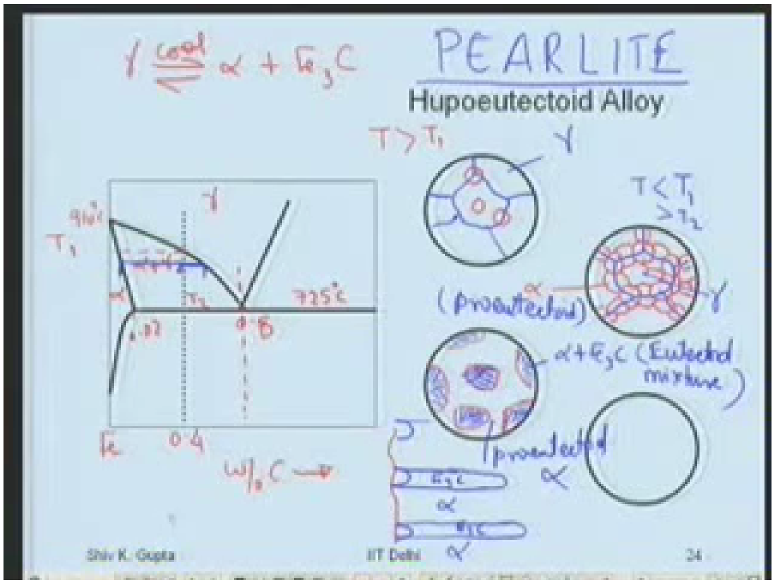

So the diagram which I just showed here, this thickness one-seventh of this thickness approximately. If I cannot see the distance between these two after magnification, there is no question I am seeing these two separately. Only at very high magnification I am able to see this as cementite region, this as ferrite region. That is why everything looks absolutely dark under normal magnification of 400-600. Unless I cut this arrangement at a very acute angle, that I shall be able to see, yeah them little quite wide and we will be to see that. That happens rarely.

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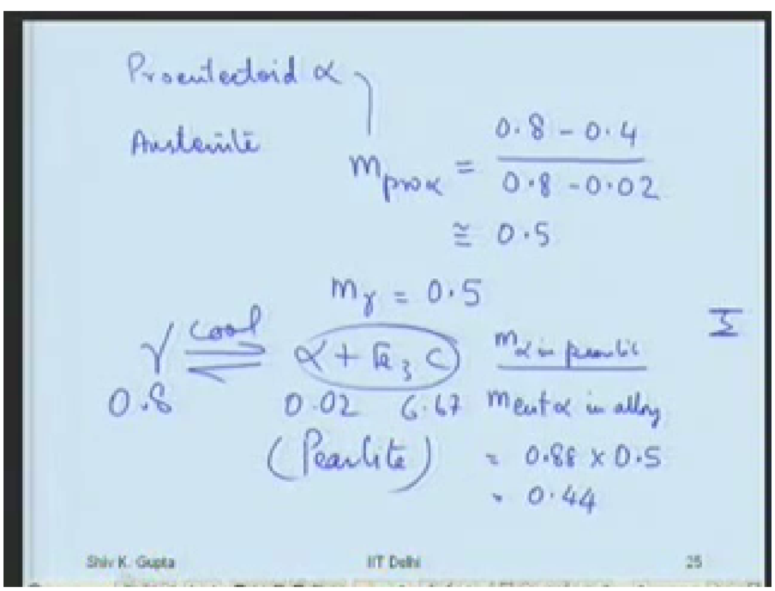

All right. So now I know this is the pearlite, this is the austenite which is going to become pearlite, 50 percent. And 50 percent is already proeutectoid alpha. So in this alloy this 50 percent shall become, approximately 88 percent of this shall become ferrite and 12 percent shall become cementite. So this alloy shall have approximately, sorry, is it working there? Yeah, mass of fraction of alpha in pearlite which I actually call now an eutectic alpha, eutectoid alpha sorry in, because the eutectoid reaction in the alloy, which is going to be the part of the pearlite.

So whatever I get in the alloy, in the pearlite is 0.88 multiplied by, because the austenite itself is 50 percent, that becomes 0.44. Similarly in the eutectoid mixture I have the eutectoid cementite which will be about 6 percent, half of 12 percent. So it is possible for me knowing how the things have gone on the microstructure, looking the phase diagram, applying the lever rule, I can find out the fractions of the different constituents in the microstructure. What is in the mixture, what is outside the mixture, everything can be worked out. So this is how one can go about applying the lever rule and getting the different amounts of different phases. This quantity which I worked out like this can also be worked out. Okay. I am sorry, where did I go?

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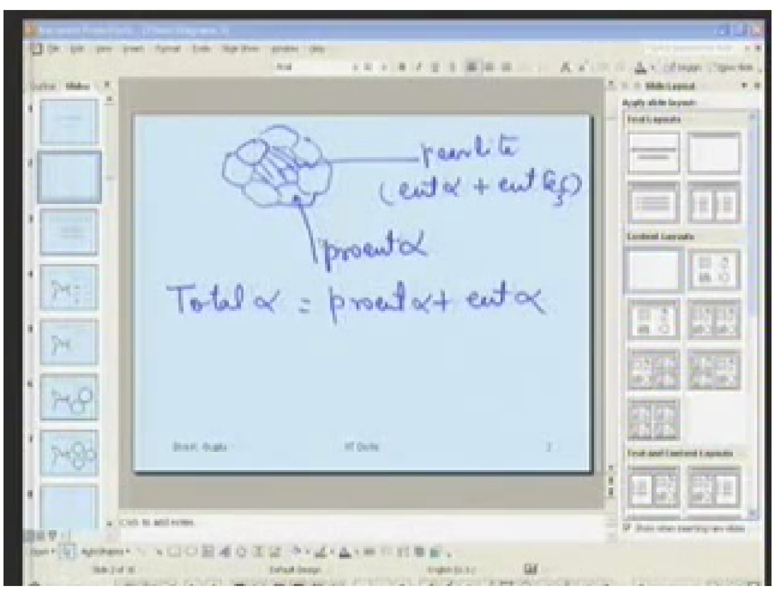

All right, so what I do is I have to, all right, see the microstructure if you recall, this is pearlite which is a mixture of ferrite and cementite containing rather eutectoid ferrite and eutectoid cementite. And this is the proeutectoid alpha. That is what we saw, that is microstructure of this alloy. So I have the alpha whether it is formed at eutectoid temperature or the temperature higher than the eutectoid temperature, crystal structure, chemical composition is the same, is not different. There is no difference between them otherwise. Only thing the temperature at which they are formed. So total alpha which I have is equal to proeutectoid alpha plus eutectoid alpha.

"Professor-student conversation starts."

Professor: And is it possible to apply the lever rule to get the total alpha directly?

Student: No.

Professor: No. Arey baba, sab padhaya likhaya sab khatam hogaya.

"Professor-student conversation ends."

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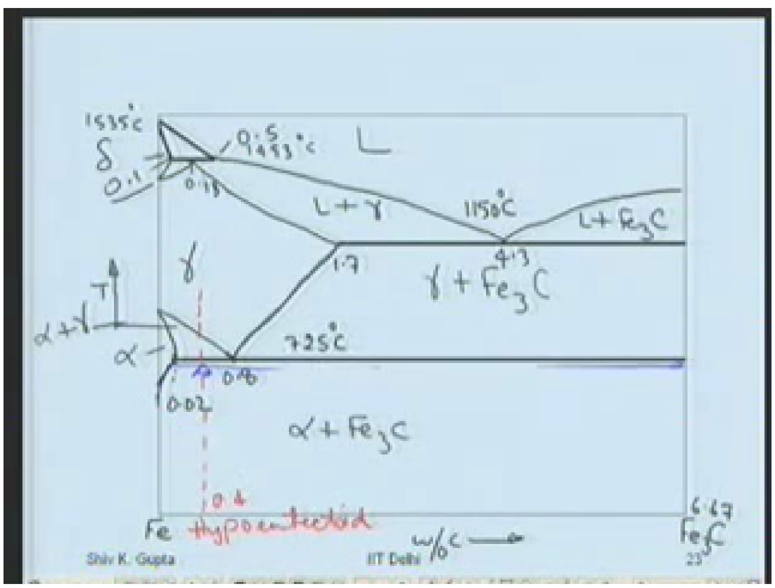

Where I have, where we will get the total alpha in the system? I have alpha and Fe3C at room temperature. So apply the lever rule here with the fulcrum there, you can get the total alpha. This is the total alpha, right? That is the alloy consists of alpha and Fe3C, two phases. After I cooled it below 725, this is what it is. So I shall be able to get the total alpha. That is how I can also work it out, yeah, so that picture has gone somewhere, no. This is, let us get out of this place.

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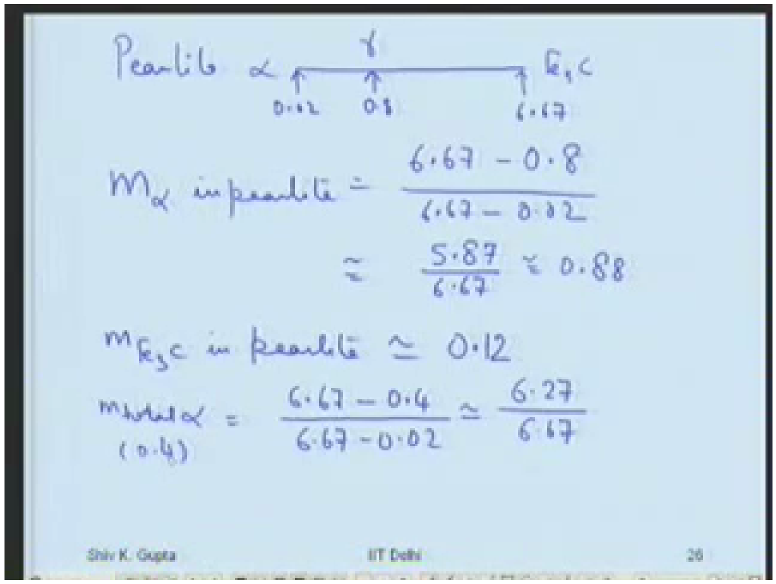

All right. I can write on this only. So I can also find out the total alpha in the 0.4 percent carbon steel, is 6.67 minus 0.4, that arm of the lever divided by the total arm which is 6.67 minus 0.02. Approximately the denominator you can use 6.27 divided by 6.67. All right, you will get something like 94 percent. Okay, and 6 percent is then? Cementite. We have worked out the other way also. And you can see that, you can apply lever rule and you can see that these two things should give me the same result. All right, that is the application of the lever rule which we have discussed today and you should be able to apply this in any diagram now.

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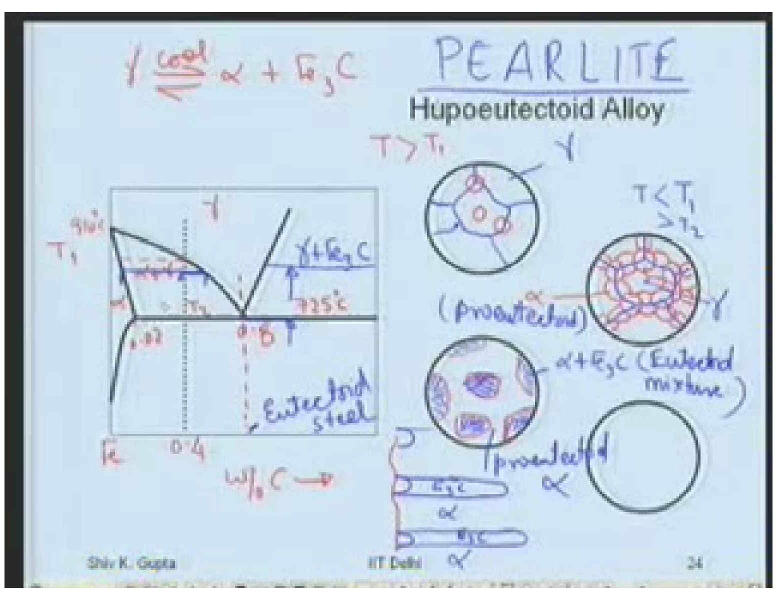

Now looking at the (micro), we have seen the microstructure in one steel but we can talk about this microstructure in other steels as well. If the composition of the steel is to the left of 0.4, I shall have more quantity of the proeutectoid ferrite and less quantity of this austenite which becomes pearlite. It will be still smaller quantity of the islands. So as I go from left to the right, amount of the pearlite is going to increase. By the time I reach at 0.8, it will be 100 percent pearlite.

There will be no proeutectoid phase because what is there above 725 is all gamma. It is the entire gamma which becomes the mixture. That is why it is called eutectoid steel. This steel is also called eutectoid steel and eutectoid steel will have only the microstructure as all pearlite. All right, this is the eutectoid steel with 0.8 percent carbon. And as I go to the right, then I go to the hypereutectoid side.

What happens now is when I cool below this temperature line which is the boundary between gamma and gamma plus Fe3C, Fe3C begins to form. This is my alloy, Fe3C begins to form. Amount of Fe3C is going to be small which forms. And proeutectoid phase is not ferrite but cementite. So that matrix remains, becomes cementite now and the islands are the still pearlite because island will be the transformation of this 0.8 percent austenite which shall become the mixture. Again the same microstructure, only thing is proeutectoid phase is different.

Proeutectoid phase is now cementite rather than ferrite. Distinction between ferrite and cementite is very important, is one which is trying to control the properties of the steels. Ferrite is a very BCC, very soft material, ductile material, typical BCC metal iron. Carbon is very small there. But Fe3C intermetallic compounds like all other intermetallic compounds too, is pretty hard and brittle. So as the amount of the cementite increases in the alloy, its hardness increases. But at the same time it is giving rise to the brittleness in the steel.

So when I start from this 0.02 percent to almost 0 percent, go to the right, amount of pearlite, the pearlite or the cementite both are increasing as I go from here left to right. 100 percent pearlite at 0.8 percent and then again now I get the matrix of cementite which is a very hard, brittle phase as I go to the right. So as I go from left to right, the hardness of the steel is increasing because the amount of cementite is increasing. And a very soft material I have is here. That is what decides what is this different variety of steels are used for.

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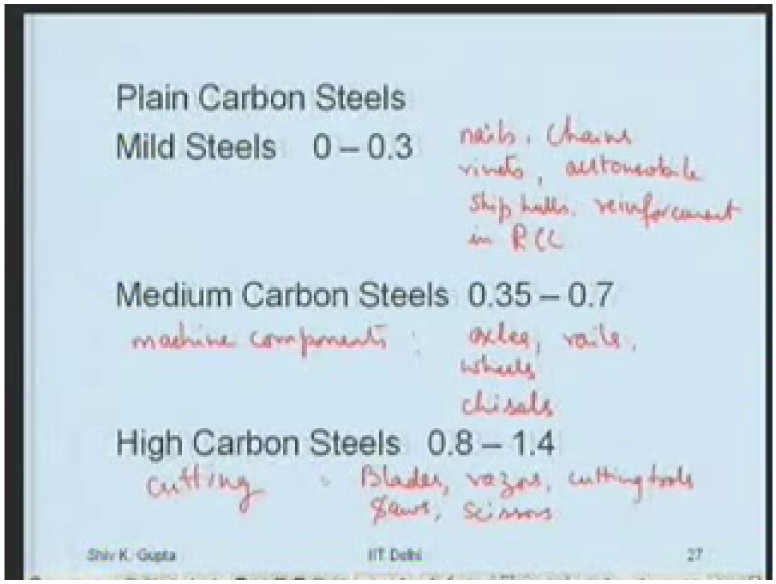

You have mild steel in the range of 0 to 0.3 percent carbon. Low carbon you can use for things like nails, chains, rivets. Then you have little more carbon like 0.2, you can use it for automobile bodies or ship hulls or reinforcement in RCC buildings you make. Now if I increase more carbon, I will get more cementite, more hardness in the steel. It will be stronger steel, it will not be so soft. I can use it for machine components.

That is called the medium carbon steels, carbon is between 0.35 to 0.7 percent and we can use machine components where the moving parts come into picture. Like you can have axles, you can have rails, you can have wheels, and so on and so forth. Well, till little higher carbon side, 0.65, 0.7, you can also have the chisels. Chisel, I need to be high hardness but at the same time I do not want it to be brittle.

But unfortunately in steels as I try to increase the hardness, it tends to become brittle because cementite is a brittle material. So therefore we control ourselves to around 0.65-0.7 percent where the steel shall have some toughness still there. Then there are high carbon steels in the range of 0.8 to 1.4 carbon. This hardness is very high but the same time very brittle. Hardness is required sometimes, many times whenever we want to do an operation what is called the cutting operation.

I want to cut an object, the object which is cutting or the tool which is cutting must be harder than the object and highest hardness you find is in the hard diamond. But steels when we get used to the tool steels are made of this high carbon steel. They are not as hard as the hard diamond but they are definitely harder than most materials which you are cutting. So you have blades, you have razors, you have cutting tools, you have saws, you have scissors.

"Professor-student conversation starts."

Student: So but they will be brittle also.

Professor: Yeah, yeah, so you are not impacting them. Brittle material can be used, not that can be used. Only thing is you should not drop or you should not hit it. It will work. All the tools which you are using the late, I think you must have been to the workshop, they are hard at the same time brittle, if you drop them, they will break. Or you hit them with a hammer, they will break. But as long as just doing the cutting operation it will keep working. Okay. Well, if there are problems of impact and jerks and other thing onto the tool, only the cutting edge I can make hard and rest of the steel I can make tough, that also I can do.

"Professor-student conversation ends."

We shall show you this how can we do it when we come to that. Right now, I am just talking about the equilibrium diagrams and the equilibrium structures, these are the properties and these are the applications which you put them to.

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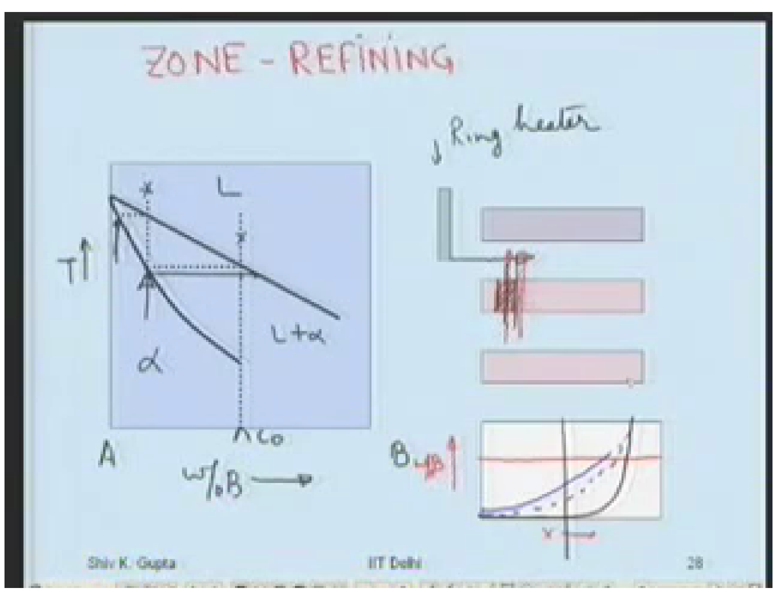

The last thing which I want to use these phase diagrams and tell you about, you recall that I discussed problem in the class that it is not possible for me to get very high purity materials and therefore engineers are contented with whatever is possible. We talked about the commercial purity, we have talked about the high purity, ultra high purity and then the semiconductor weight. How do we get the high purities? Or may even for that matter the semiconductor grade, this we shall try to see with the help of the phase diagram and I call this process, process of zone refining.

This is the part of the diagram, this is component A which is my pure component, I want to purify that. And here is the weight percent of B, B is somewhere there. This is the liquid phase, this is the alpha phase, this is the liquid plus alpha phase field. Let us say I had this alloy of this composition which I call C0. What I can do is I can put it in crucible, take it to the temperature above liquidus so that it is all liquid. Bring it, just cool it slowly after that. One can do the studying, whatever studying you want to do. Cool it slowly, bring it below the liquidus, that is slightly below the liquidus.

I have just shown it there, just slightly below the liquidus let us say and here. I shall be able to form a fraction of the solid alpha which is given by the lever rule here. But that shall be the composition of the alpha phase which I have shown here theoretically this value. But that value of alpha, I will have 0 percent of alpha. I want to have small quantity of solid formed maybe half a percent or 1 percent. I have this composition of the alpha phase which forms.

I pick out with the help of, because it is a phase it is different from liquid, I can mechanically separate it out. Remove the solid particles and drain out the rest of the liquid, throw it. Put these particles back into the crucible, another crucible, again melt it. Now you are talking of this composition, you take it to the (liquid) above liquidus, it will all become liquid and then cool it below the liquidus again somewhere here. You will get the next solid which solidifies of this composition.

Pick those with the teasers, put them in another crucible, drain out the rest of the liquid and again melt it. Do it 5-10 times, you can get a very pure solid. You can purify A but efficiency, what is your efficiency? If let us say I am picking up 1 percent every time because I want to get very pure solid. So I pick up only 1 percent. Next time I pick up another 1 percent, next time I pick up another 1 percent, you will have very tiny amount of the pure solid. Rest of it has gone into a liquid.

But we have understood the principle, that is how it is possible for us to get pure form of the solid. So what we do is we exploit this. As engineers now we do the engineering. Let us say I start with, this is the impure solid to start with my initial rod. And here I have a ring heater. Allow this ring heater to travel slowly along the length of the rod, it is circular annular ring and it can over the rod it can simply go over.

But we do it slowly. Maintain this temperature such that this rod melts and wherever it is let us say at one stage it is somewhere here, the heater. So under this whatever is the part of the solid that melts, becomes liquid. On the left, on the right, it is still a solid. Okay. And then slowly when the heater moves slightly to the right, let us say it goes, sorry I showed that, and my initial one let us say I make it slightly to the left. This is the initial one.

And that is next step when it goes through. So this liquid has solidified now. This liquid is going to be purer than the melt which is here. And that melt is also not going to be very impure because you have melted a fresh solid also. But definitely what solidified first is purer than the what is in the right. Then as it moves further, what solidifies here will be purer than what is on the right. So if I look at here, this I start with, this is the length of the rod and this is the impurity, let us say I call it the percentage, weight percent B.

To start with this is the weight percent B uniform throughout the rod. Once I make one pass, this will become very pure here, quite pure but still impure. I want still purer form of that. And purity keeps on decreasing, impurity keeps on increasing and the impurity has gone to the right hand side. If you understand what solidifies first is purer than what solidifies next. Now I have a rod like this and the heater has reached here. We witch off the heater ring and bring it back to this end.

We pass it over actually in a very slow manner. Maybe I expend almost, if this is rod of about 10 centimeters, I may take almost a day to pass it slowly. We do it very slowly to maintain the equilibrium at all places. So then when I put, the second time I do that. Okay. This was what is going to melt first. And when that solidifies, it will be still purer. All right. Let us say take black color this time. It will be still purer and purity move like this.

And after about 5 or 10 passes, your impure end has gone to the right. Impurity is all being pushed to the right because of this. The impurity has lowered the melting point, it is doing so. If the impurity was raising the melting point, then what solidifies first is going to be impure and what solidifies next is going to be pure. So after this what you can do is you can just cut off the rod, throw this part, keep this. This is the larger quantity and you get a very pure form. Semiconductor grade of silicon is produced like this, is one of the ways of producing it. This is called zone refining. All right, we shall start the next topic in the next class.