Phase diagrams in Material Science Engineering

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Lecture - 29
Hypo-eutectoid steels

So, in this lecture I am going to discuss about both, hypo and hyper eutectoid steel. And as you see here, I have drawn two lines, one red, one yellow, on the diagram.

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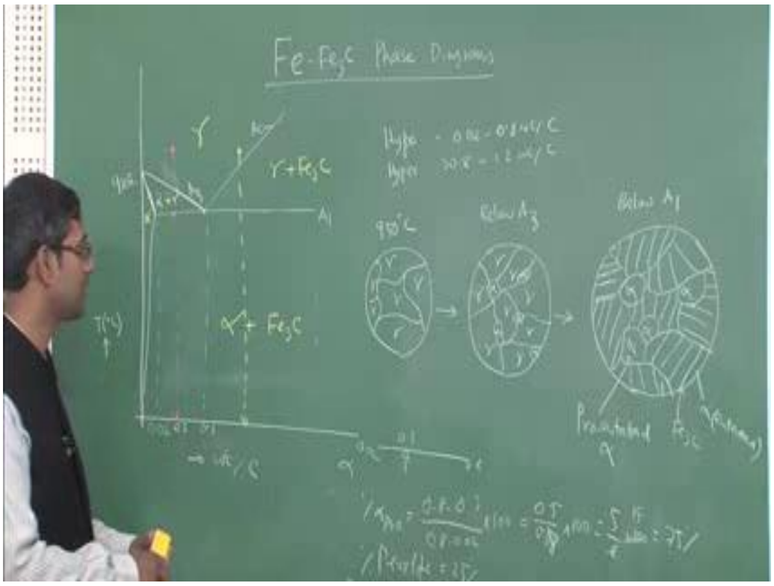

The red one corresponding to hypo eutectoid steels, whereas, the yellow one correspond to hyper eutectoid steel. Let us first discuss the hypo eutectoid steel. You know, hypo eutectoid steel falls, any steel composition between 0.8 to 0.02, that is, the hypo eutectoid steel compositions below 0.8 and more than 0.02, 0.02. On the other hand, hyper eutectoid field, basically, theoretically more than 0.8 up till 2, but practically from 0.8 to 1.2 percentage carbon steel.

So, hypo, I write hypo, means, hypo eutectoid range is 0.02 to 0.8 weight percent carbon steel and hyper, basically, 0.8, more than 0.8 to 1.2 weight percent carbon. As you see, this category of steel, which falls between 0.02 to 0.8 percent carbon, weight percent carbon. They are the ones, which are widely used in the industry because most of the steels, which are produced in this, are called mild steels. The copper composition varies from 0.15 to 0.5 percentage carbon concentration and they are widely used. All these steel transformation what I am going to discuss is very, very important for you to know because whether in foreign industry or in teaching institute or you are in a research lab, this basic fundamentals are very, very important for you to understand.

So, if I start a steel with suppose, point, about 0.3 weight percent carbon, this on the red arrow, I am going to heat it up to about 900, 950 degree Celsius temperature. I know that 910 is basically the stability of alpha phase with pure iron, alpha iron. So, 950 degree temperature, as you see from this diagram, it is completely, it is like gamma austenitic stage. Gamma in the microstructure I have shown you, all the gamma grains will be that. Now, if I cool it down, what will happen? If I cool it down, nothing will happen till I hit this line or this curve called A 3 curve. This is A 3, A 3 curve. So, this A 3 curve will, will be the first curve it will hit as you cool it down and below this you have a region called alpha plus gamma. So, therefore, at 950 degree Celsius temperature you will have all gamma grains, let me draw.

And below A 3, below A 3 what will happen? You will have gamma plus alpha, that means what? Some alpha grains will form from the gamma, sometime gamma grains will transform into alpha and you know any phase transformations. The regions at the boundaries or the junction points are ones in which nucleation is very easy. So, therefore alpha will nucleate a form like that, this is alpha, this is gamma or it can also form along the boundaries or it can also form here, at the entry points. These are the alpha grains, which will form.

And as you know, alpha, as the alpha forms, alpha will have the concentration of this given by this one. This is the alpha curve, correspond to this alpha composition will be given by this. So, alpha concentration will be much, much lower than this 0.3 weight percent of carbon for the alloy composition, which I have taken because alpha has almost, alpha contains virtually no carbon, almost have very little carbon. As alpha will have no carbon, so as the alpha grows, the carbon will be going out from alpha and they will be enriching the gamma grains. Is it clear?

The carbon from alpha will be enriching the gamma grains because alpha does not require the carbon, so it will say, carbon go away. So, carbon will go away from alpha grains and they will join all the gamma grains. So, gamma will be enriched, enriching carbon concentration and because of the carbon concentration is, gamma grain will follow this curve, as I have drawn a thick curve, you see here. And as these transformation from gamma to alpha will keep on happening from this temperature, this temperature at which it hits this A 3 line till above A 1 line. This is the range in which gamma will transform to alpha.

So, now because you have given, you have a temperature range in which alpha can grow, so there will be some gamma left over because the whole, all the gamma will not transform into alpha, some gamma will be left over because the temperature of transformation is very small before it hits A 1 temperature. And as you know, in steel metallurgy A 1 is very important temperature, below A 1 eutectoid transformation happens.

So, as you know, as you decrease temperature from these two, A 1, just above A 1, the concentration of gamma grains will reach 0.8 because gamma will be enriched in carbon. As alpha, more alpha will form, the concentration of gamma will, gamma will change from 0.3 to 0.8 and when it happens, so below A 1 when it happens, all these, all these gamma grains will transform into pearlite and alpha will also become little bigger. So, all these gamma grains will become pearlite, that is what I am drawing, this is the way, this is alpha. So, you can clearly see. So, all the gamma grains has transformed into pearlite. These all are pearlite, pearlite, this is, this is, this wide line is cementite and this region, green region is alpha. Is it clear?

This is exactly what will happen if you cool it down from 950 degree Celsius to below A 1 temperature. And below A 1 to this temperature, nothing much will happen except the microstructure will become coarser or it will, things will become bigger and bigger because you are cooling down from 727 to room temperature. It is quite a lot, that is, what is going to happen, so I am not going to draw it. So, phase mixture will change from pure gamma to gamma and alpha to alpha and pearlite.

As you know, there are two types of pearlite here; one is this alpha, which I have drawn the big blobs of alpha and another one is here, in the eutectoid alpha. So, this alpha, which I have drawn here, is known as proeutectoid alpha, proeutectoid alpha and this alpha, this within the lamellae, within the eutectoid is called eutectoid alpha. So, you can write down that also, eutectoid alpha. So, these two are formed different ways. The first one has formed directly from the gamma grain, within the grain boundaries of gamma;

second one is because of the eutectoid transformation. So, the mechanisms of the formation of these two are different.

But you know, this microstructure even is more wonderful, why? Because these alpha grains are bigger and they are very soft, so they will provide all the ductility or the toughness of the material. On the other hand, the in situ composite pearlite which is there as A, as A lines in situ composites, those in situ composites will be giving the strength of the material and that is why, bulk application or the large application of these steels are in the structural applications because structural applications requires strong and ductile tough material and these provides that.

So, as you see, as I told you in the very beginning of the course, the microstructure actually connects the mechanical properties of the material and here we can process the material in such way, I can generate the beautiful microstructure in which I have alpha grains, which will give me the ductility or toughness. And the pearlite, because of the presence of cementite in the pearlite, it will give you the strength. So, I get both, what else I need? I do not need anything else. So, this is the way the transformation will happen for this.

Now, you know, alpha actually can form many different ways and because alpha phase, protectoid alpha phase controls the mechanical properties. So, importantly, so there it is important for us to know what are the ways alpha can form. There are many ways alpha can form and I have drawn only one or rather two ways, one is at the grain boundaries, other one is at the (Refer Time: 09:58) points, there are many way alpha can form. So, first of all, before I go into that alpha formation and how alpha forms, I just wanted to tell you, that this way of transformations form 950 to room temperature, below the eutectoid transformation temperature, you must encrypt in your brain, you should not forget because this is what is normally very important for anybody who is doing this course to grasp and understand nicely.

So, all the alloys between, you know, 0.02 to 0.8 will have this transformation, what is going to change as we increase the gamma concentration from point two, 0.02 to 0.8, that means, you go from this part to this part what is going to change things, which is going to change is, that the volume fraction of this proeutectoid alpha is going to change. So, for the alloys with very low carbon concentration, like 0.1, 0.05, 0.2, 0.3, the volume fraction alpha will be quite substantially large. But for the alloys, which have higher carbon concentration, higher means 0.7, 0.6, 0.65, 0.75 weight percentage; the pearlite will be more.

So, you can see, by choosing the particular alloy carbon concentration or particular carbon concentration, I can change the relative volume fraction of this primary alpha or proeutectoid alpha phase and the pearlite and by changing, that I change the mechanical properties. How do I calculate that? Very simple, by using again by lever rule; suppose, for this alloy I am doing it, this is 0.02 alpha side and this is 0.3, this is my (Refer Time: 11:35) is present, this is 0.8. So, what will be the percentage of the proeutectoid alpha?

Very simple, this is this, 1.8 minus 0.3 divided by 0.8 minus 0.02 into 100, how much this is? 0.05 divided by 0.8, approximately this is 0.8, does not change much, 0.78 you can write, into 100. So, that means, it is 1 by 60, how much? So, let us consider this is 0.8, easy. So, 5 by 8 into 100, 500 by 8, 50 by 8, 50 by 8 is how much? 50 by 8 is, sorry, yes, 50 by 8, that is about 16 percentage, 16 percentage, how much? 50 divided by 8 that is about 16 or 17 percentage. No, not 16 or 17 percentage, I am doing something wrong. So, that is why. So, this is 5 by 8 into 100. So, this is how much? 8, 16, 15; yeah, 15, about 75 percentage.

So, bulk of this alloy, for 0.3 bulk of this, the way I have drawn is wrong, you can understand bulk of the grains of these things will be consisting of proeutectoid alpha, alright, 25 percent will be pearlite, pearlite will be only 25 percent. And opposite happen if you consider 0.6 percent of the carbon, pearlite will be for 65 percent or 75 percent and the rest will be the alpha. So, by changing that we can actually change the volume fraction of the phases and this is the way you have to calculate. This is the applications of the lever rule, simply application of lever rule.

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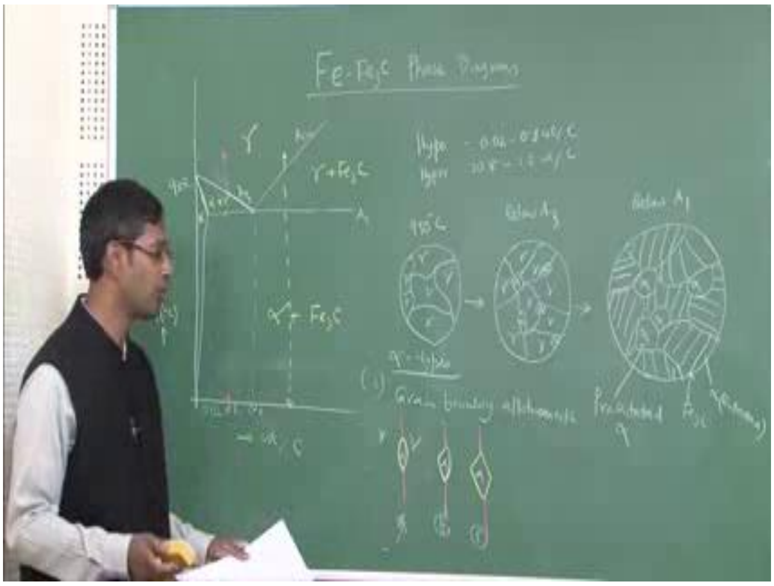

So, now let us go into how many different ways of alpha can form? It seems there are, actually I also forget, so I have written down in the page, there are actually five different, four different phases of alpha. I will write down one by one and let me do that here. So, first one is known as grain boundary alpha, the one I have drawn.

This is basically different types of alpha, first one is known as grain boundary alpha, I will write one by one and then, I will draw that picture. Grain boundary, allotriomorph it is called. Why it is called allotriomorph? Because it is allotropic transformation; gamma to alpha is allotropic transformations normally. So, and it looks like this, you know. It will be, these are the two gamma grains and this is alpha and this is a boundary or let me just put a colour thing, then you can understand. This is a boundary between two gamma grains and this is your alpha. This is the grain boundary allotiomorph.

There are many variations of these. Obviously, one variation will be very simple, faceted on the other, one side, what is that? That is, because if one side of alpha has a nice orientation relationship with the gamma, then it will have faceted morphology, very simple. Why, because it has, have orientation relationship. It will try to keep that interface fixed, it will not change, disturb that. So, that is why it will look like faceted. Same thing will happen on both side also, same thing will happen on the both side also, (Refer Time: 15:42); same thing will happen on the both side. Now, this is alpha, alpha.

So, I am doing the three variations, variation number one or variation number a, b, c, all are same in a particular microstructure, all are same. So, this is the grain boundary allotriomorph. It is the most widely seen things in the microstructure. I will show you (Refer Time: 16:12) some pictures.

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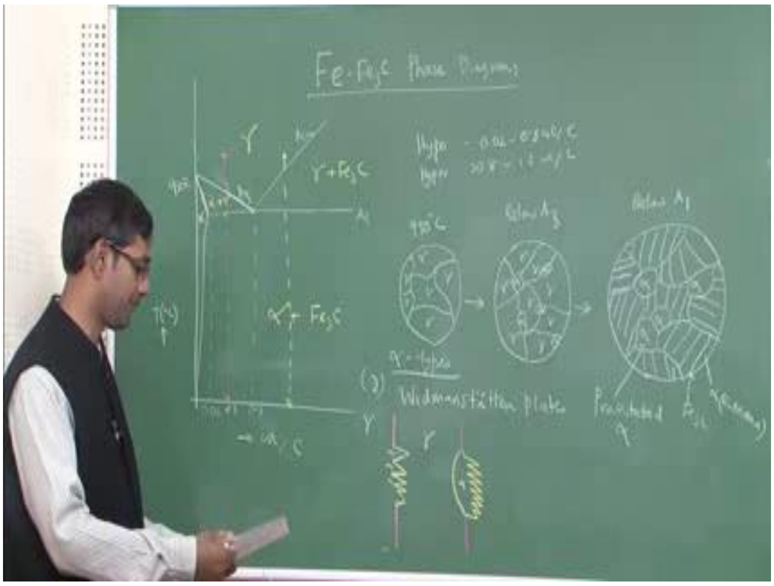

The second one, I am going to rub it up and write down second one, is known as Widmanstatten, Widmanstatten. There is a scientist from France Aloys Widmanstatten and he, first time, Wid, Widmanstatten and above a there will be two dots, it is called umlaut. He is a French person, that is why, Widmanstatten plates, (Refer Time: 16:44) plates actually, but it was discovered first time by Widmanstatten, that is why the name Widmanstatten, is a general site plates or plates.

How it will look like? It will be like this, so this is a gamma grain, this is another gamma grain and in between you have, this is alpha, this is a boundary, this is the boundary, let me draw the boundary by red colour, and these are the alpha plates. They are looking like a plate, needle basically, needle actually, you can say needle, better way to take, needle plates will have, will be like finite thickness. So, these are the alpha. So, this is one such.

Another one will be a mixture of the earlier one and this one, what it will be? Let me just draw it nicely, mixture of this one and this one, this is the boundary. So, as you see this is alpha, as you see this is the boundary, the red colour and this one, this side, it is met by a curved interface; other side, this is a plate. So, this is the mixture of the grain boundary allotriomorph and the Widmanstatten plates. So, that is how the second, this is second category, sorry, this second one, this is the second type of alpha which is seen.

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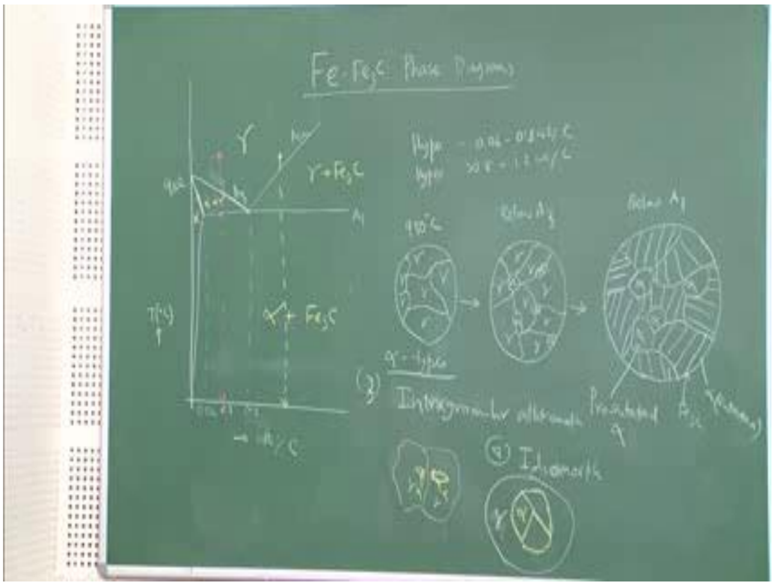

Third type of alpha is intragrannular alpha. Intragrannular alpha is, how, what, how does it look like? Intragrannular alpha will be within the grains, is intragrannular, sorry, intragrannular alpha, intragrannular allotriomorphs. So, this will be within the grains like this. These are the two gamma grains and these are actually two alpha within the gamma. They are plate like needle, like these two are alpha, this is also alpha, this is called intragrannular form and the last category is known as idiomorph. So, this is 3rd, 4th one is known as idiomorphs.

What is idiomorph? Well, idiomorph is a crystal basically, crystal, big crystal within the gamma grain. So, if this is the alpha or let me draw it again, yellow colour, and this forms within the gamma grain and this is the alpha.

So, difference between intragrannular, intragrannular allotriomorph, idiomorph is, that intragrannular allotriomorph will be (Refer Time: 20:02) or they are like a plate. On the other hand, these are crystals; these are actually crystals present inside that. So, this is, these are the four different types of alpha which can form, each one has different probability of formation. Obviously, this one is the least probability formation because this requires to be nucleated and grow inside the grain. The first one, grain boundary allotriomorph, widmanstatten, both are actually more probability form and these two are the least probability form. Each type of alpha has different mechanical properties, why? Because of the orientation relationship, because of the shape, because of the size, they have different kinds of strength with different kinds of mechanical properties. So, mostly almost all the alpha will be like this the way I have drawn.

Now in the next few minutes I am going to show you the pictures of the alpha. I do not think I will be able to discuss with you hypereutectoid steel, which I will do in the next class. As you know, steel requires lot of interesting discussions, so we will move slowly. So, you know, in the slides I am going to show you some of these things very nicely.

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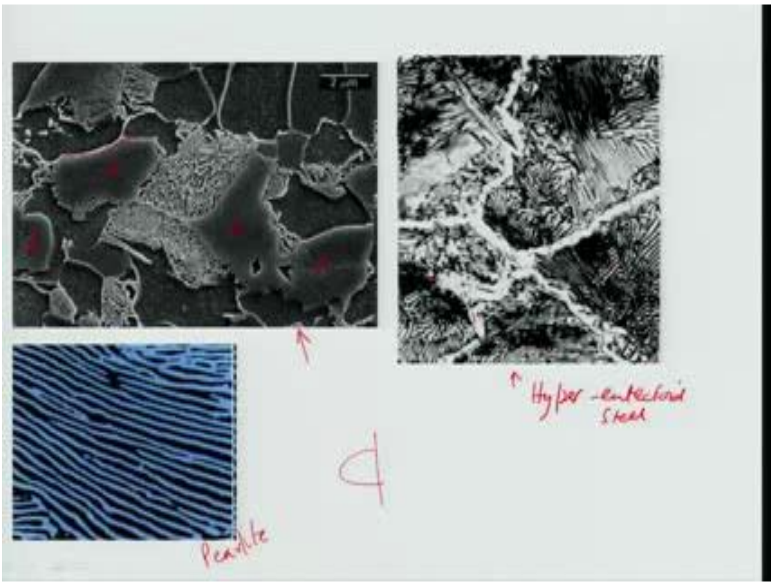

Let me just get it back. So, this first picture, this is basically hypoeutectoid steel. As you see, these are the alpha, this is alpha, all the alpha has formed prior cementite, prior austenite grain boundaries. And this is the, some of the austenite has transformed to pearlite. So, and, and now we are discussing about this morphologies of the alpha. Here, they are formed; this is the boundary, prior austenite grain boundaries. See, they are formed like the way I have drawn like this.

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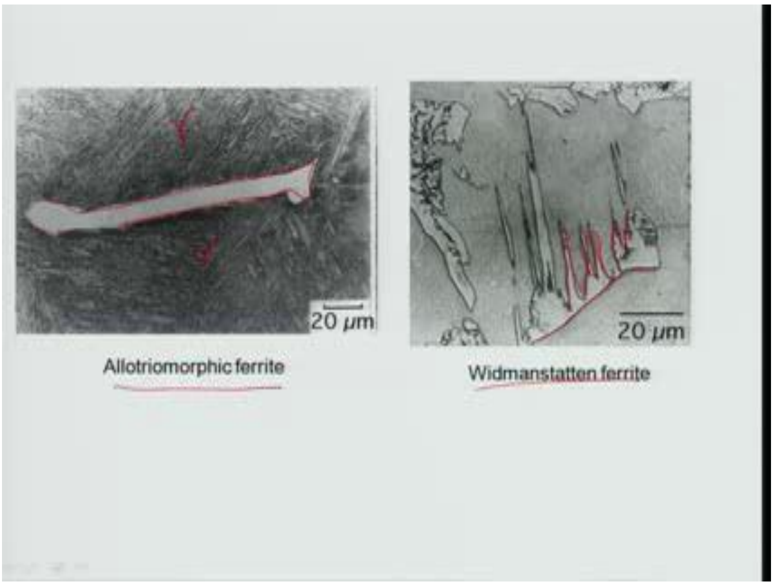

Now, I will just want to show you this allotriomorph. So, grain boundary allotriomorph, allotriomorphic ferrite is like this needle crystal. You can see here, it has formed between the two of gamma grains, of previously gamma it is transformed into pearlite already and this is known as allotriomorph ferrite. And this is the widmanstatten ferrite. You see, one side interface is flat, other side it has formed these plates and I have already drawn in a, on a board exactly similar morphology to impress you upon. So, this is the widmanstatten ferrite, this is the allotriomorphic ferrite.

So, now, actually, so I have discussed with you this microstructure. I have discussed you to completely pearlite, pearlite. What I need to discuss is this hypereutectoid steel, but to show you eutectoid steel, to show you that this consisting of cementite, this wide things are cementite crystals and the pearlite. So, the cementite crystal has decorated the prior austenite grain boundaries and these are the pearlites; that is all.

So, we are going to discuss in detail about that in the next class and finish the pearlite transformation in the next class, then I have to go on to the other transformations.