**Heat Treatment and Surface Hardening - II**
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**Lecture – 24**
**Effect of heat treatment on microstructure evolution in steel – 1**

Hello everyone let us start lecture 24.

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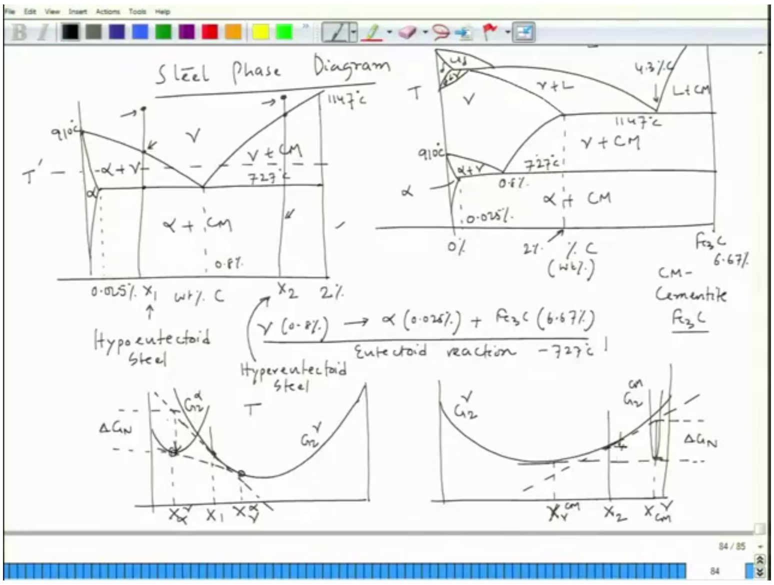


In lecture 23 we talked about the information what we get out of phase diagram. And associated free energy composition diagram. Now in this we will try to k what are the information phase diagram will not be able to give us. And what are the things we need to consider to know the other aspects like morphology of the phases. Or if we change the cooling rate for example, till now we have been talking about equilibrium, but actual operation does not happen all the time in equilibrium. And whenever we have an equilibrium process; that means, we have to give enough time at a particular temperature sufficient time to reach equilibrium.

Now, for example, if we try to see heat treatment of steel. And in case of heat treatment of steel we follow annealing we follow normalizing, we follow austempering, we fellow martempering martensite formation; that means, hardening. So, those cases we do get different morphology. Even some cases we do get some phases which are not mentioned in phase diagram, because those phases are appearing because of some martensite equilibrium condition because of some metastable equilibrium condition.

Now, since we are talking about steel. So, let us discuss the steel phase diagram. We know that, I will how iron carbon looks like. So, if we see the iron carbon diagram. This is my iron carbon diagram, where this is liquid, this is liquid plus delta this is delta. This is delta plus gamma. This is gamma, gamma plus liquid. Liquid plus CM. CM means cementite, Fe3C. This is gamma plus this is alpha plus CM, this is alpha plus gamma. This zone is alpha this is percentage of carbon, and here it is Fe3C which is nothing, but 6.67 percent carbon weight percent. So, whatever we are considering in terms of weight percent this is 0 percent carbon.

Now, we need to only look at the steel part. So, the composition and temperature of steel part we are drawing again. So, the if I see this temperature 1 1 4 7 degree Celsius and these composition is 4.3 percent carbon. This is 0.8 percent carbon. If I try to see this composition which is around 2 percent this is 0.02 percent carbon. And this temperature in 6 step 7, 27 degree Celsius, this is 910 degree celsius.

These are some important information of the steel part. So, let us draw the steel part only. So, steel part 2 percent. This is my steel part these temperature, this is gamma. This is alpha plus c l; this is alpha plus gamma this is gamma plus cm. And this particular zone is nothing, but alpha. Now here also similar to eutectic system if you just replace those liquid lines with solid gamma line, and then we also consider alpha beta instead of alpha beta if we considered alpha and cementite. We would come across we will we will get to this particular phase diagram which is called eutectoid phase diagram.

Since here one invariant reaction that is taking place were gamma with a composition, 0 8 percents 0 0.8 percent, converge to alpha of composition 0.025 percent plus Fe3C of composition 6.67 percent. So, this is my eutectoid reaction, eutectoid reaction. And this temperature of eutectoid is 727 degree celsius. Now similar to eutectic system, if I try to have a composition this or this. So, this is let us say x 1. This is x 2. And if I start from at this point and at this point so that point this point and this point it will be entirely gamma, and as we go down at some point on time, point of time. It will, if it will touched up of phase boundary line. For example, in this case it will touch here in this case it will touch here. So, if it touches here, then we would get the phase that would appear first is the cementite phase and if it touches there. So, then first phase that would appear in gamma is nothing, but alpha phase.

Now, if I try to and also as for this nomenclature if we take any composition just at eutectoid composition, we call it eutectoid steel. And if we take a composition list and eutectoid compositions; that means, this particular x 1 composition, we call it hypo eutectoid steel and the composition, which is on the right side of eutectoid composition which is 0.8 percent we call it hypereutectoid. So, this composition is called steel.

Now, if I try to see the free energy composition diagram, it will be exactly similar to liquid solid phase formation. So, if I try to see free energy diagram let us say if I see the free energy diagram for 2 situations. One case it is the alpha phase that is coming out this is alpha G 2 alpha and then gamma is here, this is gamma G 2 gamma. Now the equilibrium phases, if I temperature if I take a temperature, let us say this temperature t is considering. So, then our conditions are like this. So, this is gamma x gamma in equilibrium with alpha, this is x alpha and equilibrium with gamma. And the composition what we have taken is this one x 1.

So, then I would definitely get alpha and gamma. And the first step; that means, the nucleation in order to find the nucleation driving force, I have to draw a common tan a tangent at this point where the composition is meting gamma line. And then this should be my delta G n. And I would get alpha phase and gradually if I hold it there at this temperature gradually liquid would convert into alpha and alpha grains will form.

As we go down finally, I would reach to this point and their the remainingly gamma would convert into alpha and cementite. And that particular mixture we call it pearlite. And here is on the right side, if I consider this particular situation. This would be my gamma G 2 and cementite, if I consider this because cementite cannot change the composition much. So, that is what it the free energy curve G 2 of cementite is much steeper much constricted. So, if I try to see the equilibrium things this is gamma x gamma in equilibrium which cementite, and this is x cementite in equilibrium with gamma and x is nothing, but the composition of percentage of carbon.

So, there if I take this composition which is x 2, then as per our concept. So, will draw our tangent at this point and then try to see this particular difference from this tangent to the free energy line of cm. So, this is delta GN, that is the nucleation driving force. And of course, this becomes my overall driving force and here also this becomes my overall driving force.

Now, once it comes to equilibrium point which is equilibrium eutectoid temperature, that time situation the free energy composition situation becomes like this.

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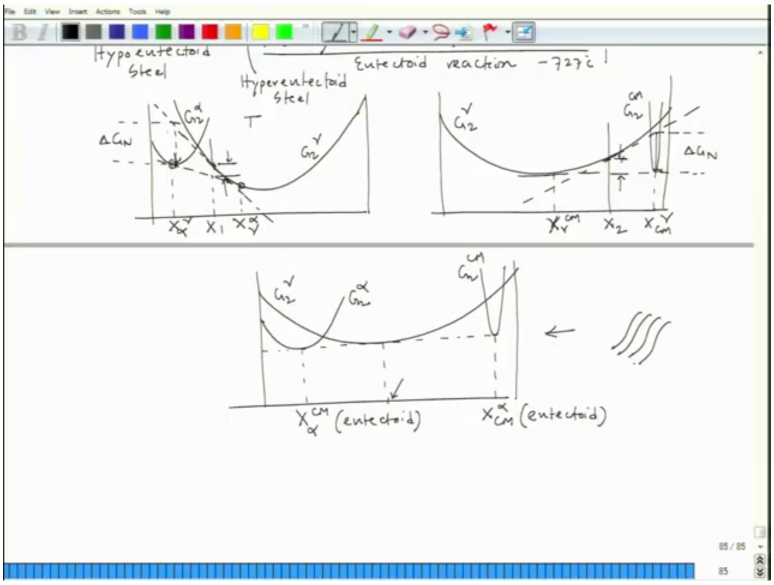


So, this is my gamma G 2 gamma and this would be my alpha. And this becomes G 2 CM this is G 2 alpha. So, we can draw a common tangent, and I form this is x alpha in equilibrium with CM. This is X CM in equilibrium with alpha, but I am just putting another thing which is eutectoid. And here it is eutectoid, and this composition is nothing, but the composition of even if there is a small amount of gamma there. So, they will try to form alpha and cementite phase. And once I drop just below the eutectoid temperature all the gamma we will convert into alpha and cementite. And that time this particular phase morphology is like this. The alternate lamellar of alpha and cementite.

So, this is cementite and this region is alpha. Because if I try to see the mass fraction from the area measurement, then I would see that alpha content is higher than the cementite content. How come? Because if I try to see this particular phase diagram let say I draw a common draw the tie line here. Then I see that if I take a composition this one, then this entire following must fraction of alpha of this composition would form and this mass fraction of cementite of this composition would form. So, that means.

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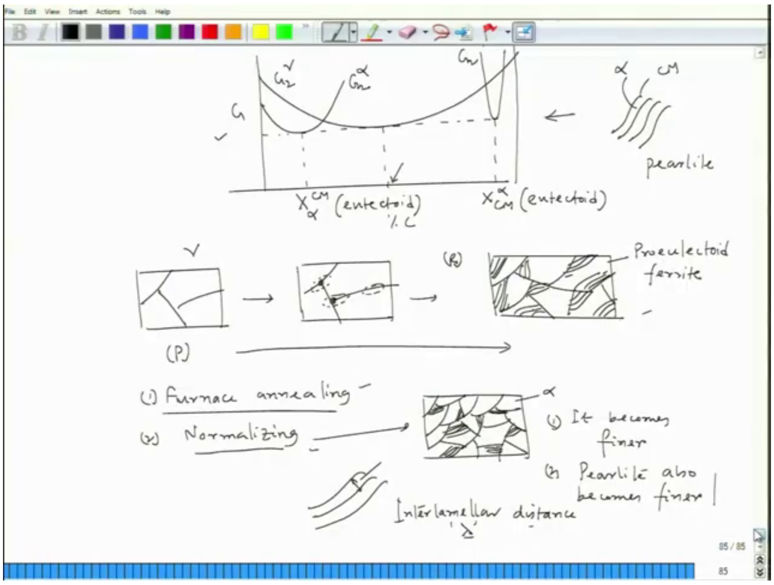


Student: Right.

So, we have taken this particular composition, if we take this particular composition of that particular gamma. Then when I drop bit and finally, at this point, at this point, I would get some pro eutectoid ferrite or alpha. The remaining gamma will convert into pearlite which is alpha and cementite. So, this remaining thing would have remaining gamma would have the compositions this. So, if I try to see the fraction of gamma and fraction of gamma for example, if I to redraw it again. So if I re draw it again, this phase diagram part this is 00.8. So, I see this particular composition, then once I reach to this composition; that means, the gamma remaining gamma and this would be my alpha phase or this composition. And this would be my remaining gamma see this gamma would have the composition this 0.8.

Now, cementite is far off on the right side. So, here is the cementite. Here is the Fe3C 6.67 percent. So, now, if I try to find out what will be the alpha in pearlite, then that would be decided by 0.8 6.67 divided by 6.67 minus 0.025. This is the wall mass fraction of alpha and cementite mass fraction would be. So, we know that this phases are appearing, but if we try to see their microstructures evolution. For example, if I go by this phase diagram, then and if this composition is let us say 0.3 percent carbon then at the point if I try to draw different points, let say this is this is one point this is another point and this is another point.

So, I would have something like that for example, initially when the point I am here it is entirely austenite or gamma. So, the this is gamma poly crystal. And if I indicate those points this is let us say PQR. This is gamma at P position. Now when it goes to has it goes down at this point first alpha phase would appear and those we will appear along the grain boundary, rather it will form first at will form around the grain corners or triple point junction. So, here the first nuclei of alpha would appear and then they will start growing and in the meantime also alpha can appear on the grain boundary grain edges.

And then finally, if we go to R position. Then I would get poly crystal of pro eutectoid ferrite since till the temperature reaches to eutectoid curve temperature, I would always get to have pro eutectoid ferrite. And then once that remaining gamma reaches eutectoid composition because as we are saying that the gamma is gradually enriching with carbon because when alpha forms alpha rejects carbon to the parent phase. And then finally, gamma phase composition reaches 0.8 and then eutectoid reaction happens the like this. So, this is G and this is percentage of carbon, and then I would get pearlite phase

So, this is poly crystal in ferrite and then at the this portion like this phase micro structured appears so; that means, from starting from gamma, I would get to this micro structure and if I try to see the what will be the pro eutectoid ferrite content I can easily find out I can find out from tie line, let us say I draw tie line here just below eutectoid temperature. Then I could understand this is my pearlite region this is my pearlite. So, I can I have to only find out what will be the pro eutectoid alpha. So, this should be my this should be my pro eutectoid alpha of this composition just below, I am just talking about just below and the remaining gamma we will convert into politic transformation this sense, the remaining gamma would appear would have this competition this 0.8 percent composition which is the eutectoid composition.

So, I will get this microstructure. Now these microstructure can appear if I do it a very slow cooling and one process is very slow cooling is you keep the sample in a furnace and put up the furnace. And gradually that and do not open the door furnace would gradually re reduce it is temperature and the sample would get annealed we call it annealing and that is also called as furnace annealing.

Now, if we do a normalizing. So, furnace annealing is one heat treatment practice in same where we do get equilibrium structures equilibrium phases, but if I do, if I do the heat treatment let us say I take it to austenitizing temperature, I convert everything into austenite then I take the sample out I will leave it in the air. So, in the air when I take the sample out in the air and then the cooling rate would be faster. So, that time we call it normalizing that in the structure modification would be there to structure would become like this the grain should be much finer grain should be much finer, which is alpha grain I am talking about the final microstructure what we will get. So, and also done pearlite also would form. So, this pearlite would form. Now interestingly here 2 changes if I do normalizing one is it becomes finer, one and second thing is pearlite also becomes finer.

What does it mean that, what does it mean what about when I say that pearlite becomes finer means, when I talk about this pearlite? We see that these are separated by this 2 subsequent cementite lamellaes are separated by a distance and this distance we call it inter lamellar distance. We also call it as give a notation of this.

Now, if I go for normalizing; that means, the higher cooling rate this inter lamellar spacing decreases; that means, it becomes finer 2. So, if everything becomes finer; that means, the amount of numb amount of grain boundary area is also increasing at the same time I am also getting a finer structure that will finer pearlite. So, what would happened to the hardness of it the hardness would definitely increase. So, here the hardness would be which will be the softest, then I will get normalizing little harder, but if I go for a water quenching. Then I would I would have entirely different picture because the phases that would appear is called as martensite and that morphology is also entirely different.

So, now from our discussion it is very clear, if we will for example, if we do if we do quenching; that means, I take it to austenite temp austenitizing temperature. I do from entirely austenite then I put it in directly I take it out from furnace and then put it in water which is kept at room temperature. So, (Refer Time: 26:34) the temperature will be drop I get a martensite structure I get a phase which is called martensite. This is metastable phase or non equilibrium phase and then microstructure is kind of sharp needle like structure the structure becomes like this. So, then these microstructure give some much higher hardness. So, rather it is the hardest phase hardest sample out of the entire sample we have we have produced from by either funniest will handling or normalizing or quenching.

Now, interestingly the phase diagram let us understand now phase diagram would it tell us what will be the microstructure, if you change the cooling rate no it cannot tell us what is the microstructure second part is what will be fraction of phases, if we cool at a different speed it will also not be able to tell us because phase diagram also all the deals with the equilibrium phase, but here actual practice we are not dealing with equilibrium cooling rather it is rather it is non equilibrium cooling. So, to the phase diagram would not tell us these particular information.

So, we would further elaborate this part in our next lecture. Let us stop here.

Thank you.