Heat Treatment and Surface Hardening - II
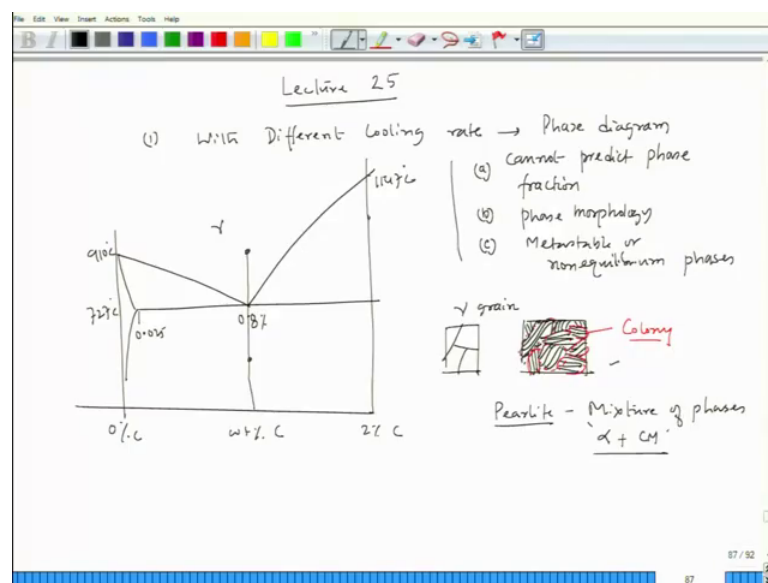## Prof. Kallol Mondal
Prof. Sandeep Sangal
Department of Material Science & Engineering
Indian Institute of Technology, Kanpur

Lecture – 25
Effect of heat treatment on microstructure evolution in steel – 11

Let us start the lecture 25.

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In last lecture we started looking at the informations what phase diagram cannot give. The first thing is we I took a reference of steel. We started looking at microstructure of hypoeutectoid steel, if we start cooling it from gamma region. And we started looking at 3 situations one is furnace annealing; that means, we keep the sample inside the furnace and then hold it there and put the furnace off. Second is take the sample out from the furnace after doing austenitization. And then keep it in here so that the cooling rate becomes faster we call it normalizing. And then that time we see that microstructure becomes finer, but both in case of annealing as well as normalizing we get to see polycrystalline pro eutectoid ferrite plus lamellar politic colony colonies.

But in case of normalizing we see that the microstructure becomes finer as well as the inter lamellar (Refer Time: 01:48) in the pearlite also decreases; that means, it also becomes finer. So, if that structure becomes finer as well as inter lamellar spacing

decreases, then the hardness goes up. Because whenever we have finer microstructure we have a higher grain boundary regions as well as if we reduce the inter lamellar spacing of pearlite then the cementites are coming closer. So, hardness is nothing but the resistance to penetration. So, if I put a penetrator on the sample. This penetrator is also accessing more m number of grain boundaries as well as cementite lamellaes. So, the hardness would automatically go up.

But the structure becomes entirely different when I do quenching and that time we get martensite. And the martensite is kind of needle like structure and it becomes very hard if we take hardness of that. But this martensite is not mentioned anywhere in the phase diagram. Because the phase diagram talks about the equilibrium phases, it does not talk about non equilibrium phases like martensite.

So, phase diagram cannot tell us what could be the morphology, what could be the non equilibrium phases that could appear. And if we like to see non equilibrium phase information in the phase diagram, then would also like to have like to know like to like to have a would also need to have a complete information of those non equilibrium phases, then we can have a kind of mention in the phase diagram. But that time that phase the new non equilibrium phase that would appear which we also call it metastable phases would have a separate metastable equilibrium line in the phase diagram.

So, that would appear that we would discuss that part when you will talk about phase diagram of aluminium copper system. Because in aluminium copper system we have 3 non equilibrium 3 metastable phases before we get to have stable a i to c u precipitate. And those sequence of transformation is basically the supersaturated alpha, which convert to up slightly supersaturated alpha plus g p zone, and then again it would convert to a little lower super saturation alpha plus theta double prime which is another phase which is metastable phase.

And then the next transformation would be again alpha with a little lower super saturation compared to the previous case previous transformation product of alpha, plus theta prime is another precipitate. And then finally, we get equilibrium alpha with no super saturation rather we have a saturated carbon the saturated copper in aluminium matrix as decided by the equilibrium phase diagram and a l to c u phase which is the stable precipitate.

So, for all the phases metastable phases we have we can draw equilibrium (Refer Time: 05:13) situation as per the free energy composition diagram. And we can also plot those situations in a phase diagram. But that would appear when you will talk about aluminium copper system. But in case of aluminium iron system iron carbon system we do not see are the information of martensite in phase diagram. So, we marten phase diagram cannot indicate those things.

So, in order to know that we need to take help of TTT, or CCT diagram because the TTT and CCT diagram would also include that at a different temperature and different cooling situations, what are the phases and what are the fractions that would appear and depending on that there are many heat treatment practices that have been developed. So, let us discuss those things. So, first thing is what phase diagram cannot tell one is with different cooling rate phase diagram cannot predict. Phase fraction, phase morphology, metastable or non equilibrium phases information. So, these are the information it cannot give. So, these are the negative or not negative the deficiency of phase diagram.

Now, since we have talked about steel and we have talked about the microstructure of hyper hypereutectoid steel. Let us get into the microstructure of politic composition as well as hypereutectoid compositions the pearlite politic compositions. Because if I draw the steel phase diagram this is 2 percent carbon and this is 0 percent carbon. This is 1147 degree celsius, 910 degree celsius, 727 degree celsius. This is composition is 0.25, 0.8 percent carbon. So, these are weight percent carbon.

Now, if I take a composition this, at this point it will be entirely austenite. So, if I try to see grain structure it would be like this. This is entirely austenite grain and of course, poly crystals. Now if I reach there I would have politic transformation a 0.8 percent austenite. So, I would get a structure like this. And interestingly you notice that pearlite whenever there is a particular sequence of lamellar, you can say that this is one sequence if I try to pin point that sequence.

This is one sequence this is another sequence, this is another sequence, this is another way of distribution. So now, you see that there are blocks which have almost kind of parallel distribution of cementite and ferrite lamellas, but there is no as such grain boundary. We call this is regions are as colony. Colony of pearlite, and interestingly

pearlite is a mixture of pearlite is a mixture of phases, and those phases are nothing but alpha and cementite.

So, it does not have grain boundary. We cannot say that this this particular distribution of pearlite colonies we (Refer Time: 10:29) distribution of ferrite and cementite these zones we cannot call it as grain rather we call it as colony pearlite colony and the pearlite is not a phase rather it is a phase mixture of alpha and cementite. So, this would be the microstructure we would get. And depending on the cooling rate if we have a higher cooling rate then the pearlite colony should be finer because there will be more nucleation, and then gradually we have a closure distribution of ferrite and cementite lamely.

So, overalls are the microstructure becomes finer. So, the hardness would be much higher than sample of 0.8 percent carbon steel cooled at a very slow rate; that means, the furnace cool. So, normalized structure would be much finer. So, this normalized structure can also you can somebody can increase the fineness. For example, if somebody does normalizing in open here, and if somebody does normalizing in front of let us say when a somebody is doing normalizing; that means, the open air cooling. If I put a huge fan in front of it so that means, I am trying to take the heat out little more quicker than normal holding the sample in here. So, that time it will also increase the finest. So, gradually the hardness would increase. So, you have a control over it means I can increase the cooling rate depending on the requirement of it mean a requirement what particular cog microstructure as well as associated properties we need.

Now, when you take about talk about a composition let us say 0.9 percent carbon steel. Interestingly, here at this point it will be entirely at this particular point it will be entirely poly crystal in gamma grains, but when I come to this section these particular region I would have pro eutectoid cementite plus remaining gamma with a different composition for example, if I do this. So, this would be the composition of gamma what would be there at this particular temperature. And the cementite would have composition somewhere on the right side because, if I try to draw a line here if I indicate that this is 6.63, 6 na 6 7 percent carbon which is the carbon concentration in cementite. So, this would be the composition of the cementite. And the amount of pro eutectoid cementite would be this much. And amount of gamma would be this much of this competition.

and finally, will get to this point because as you are cooling down finally, the remaining austenite is reaching 0.8 percent carbon. So, once we go below eutectoid temperature this remaining gamma with 0.8 percent cardboard we will convert into alpha and cementite as for the pearlite transformation. So, we have pearlite plus pro eutectoid cementite. And the microstructure final microstructure would be. So, if so, this would be so, this region So, I just put it black field region this would be cementite and these are these are pearlite colonial. So, this would be the microstructure if I try to see 0.9 percent carbon steel.

So now interestingly I could see that the microstructure is changing as we are going from hypo eutectoid to hyper eutectoid steel. So, these information can also is not available in the phase diagram. So, in order to know that we have to take help from TTT as well as cct diagram.

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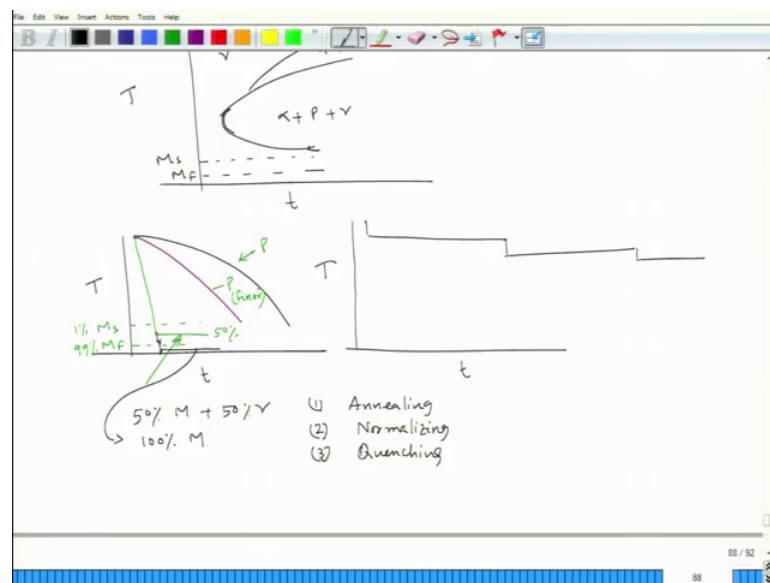
Let us say I draw Time temperature diagram for hypo eutectoid steel. So, hypo eutectoid steel I have this is my alpha plus gamma and these region is nothing but alpha plus pearlite. So, this is a typical TTT diagram for hypo eutectoid steel, and where this is my m s temperature and this is my mf temperature. Means martensite start and martensite finish.

Now, in this case I can also put gamma, means if I do not hold it for longer duration I could have little bit of gamma left. And that gamma if you cool it quench it the that gamma can transform into martensite. So, depending on that we can design different heat

treatment practices. So, the different heat treatment practices let us look at the different heat treatment practices what we can have common practice. So, we can what we can have in case of steel. So, if I try to see annealing. So, annealing temperature time, so the annealing operation would have a very, very slow cooling rate. This way is one. Another route could be I can have I take it to below temperature and hold it there for a long long time.

So, like that we gradually I can hold it like this, gradually I can hold it like this. So, like this I can have those transformations and that time we call it is an annealing. Now if we do normalizing that time the cooling rate would be little faster if we indicate the normalizing as this color different color this will be my normalizing. So, cooling rate is faster. Now we can have quenching, the quenching means the cooling rate is the fastest. So, quenching would be like this and then hold it. So, this is if I put it in green color, we should be quenching. And that time martensite start temperature that quenching point can cross martensite start temperature and if is remains in between martensite finished temperature. So, I would have martensite plus the remaining phase would be austenite. So, I would have a mixture of martensite plus austenite.

And in this case, So in this case I will have pearlite in this case also I have pearlite with finer microstructure, but here I would have martensite for example, this martensite start is let us say one percent. This is 99 percent whether the martensite finish. So, if it is between around, let us say 50 percent. So, then I would get at this this particular condition I would get 50 percent. 50 percent martensite, plus 50 percent austenite and in this case I will get. So now, if I drop it further if I drop it further, and then cross this point then I would get if I try to see this particular situation I would get 100 percent martensite.

So, one operation is annealing, second operation is normalizing. Third operation is quenching. Now quenching can be done either in water, or oil depending on what kind of operations we are doing for example, in case of heat treatment of nuts and bolts or screws because those structures are 10 per martensite structure. So, they are typically it is quenched in oil, because oil has got less quench intensity means the thermal stresses developed on the surface would be little less as well as it avoids the oxidation because it is the oily medium. So, quenching can be done oil quenching or water quenching.

Now, since I have given example of nuts and bolts. So, nut and nuts and bolts what we do, the process actual process because nuts and bolts as a microstructure of tempered martensite. Now this is a particular term called tempering, this is also an important heat treatment practice. Whenever we form martensite the martensite mix the surface sample very, very hard, but it also associated with it is associated with the brittleness because it inputs brittleness into material. So, any brittle material is not good for the actual purpose actual operation. So, you have a import toughness into it. At the same time you have to also make sure that the hardness does not decrease to a great extent.

So, if I would like to have a combination of hard sample with the sufficient amount of toughness, then we can follow heat treatment which is called tempering or call martempering.

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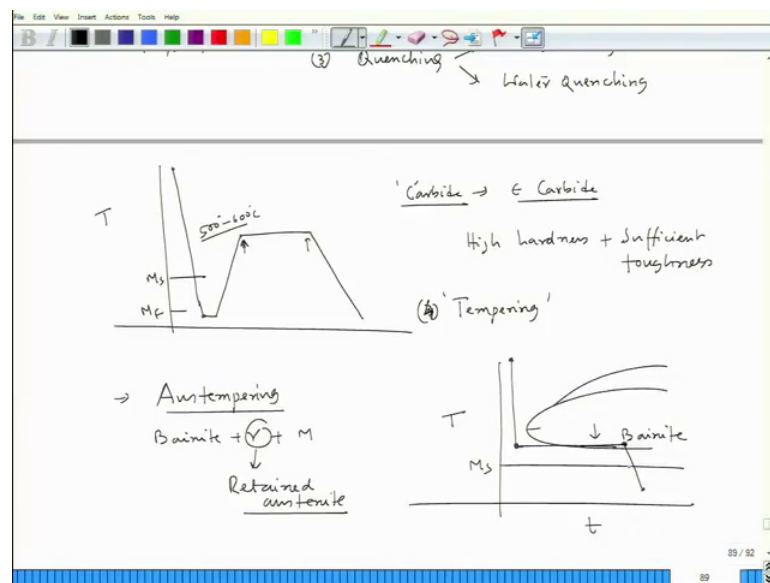
For example, that case I can have a situation like this. This is martensite start, this is martensite finish. I take it to austenitizing aust it aust it I do austenitiztion; that means, I if take everything into austenite and then quench it, and the quenching should be done if I take this particular reference of this particular let us say TTT diagram.

Quenching should be done such that it should not touch any of those c curves. So, it should be quench like this. So that means, gamma does not convert into any other phase before reaching to martensite. So, if we do that, so I cool it first I take it to this level, and then I take to this level let us a completely martensite formation. Then what we do? We

take it to around 500 to 600 degree celsius, where this martensite this is hilled for some time. And then again it is cold it is cold, at this cooling could be air cooling.

Now, when we do this that time this martensite changes it is structure. This martensite converts into forms some sort of carbide, which are called epsilon carbide. And the martensite also forms a modified a kind of morphologically different ferrite, and epsilon carbide would be embedded on it. And that process would input ductility into it, but the hardness drops definitely, but it does not drop to a great extent. So, I have a combination of high hardness plus sufficient toughness. So, this is called tempering.

Now, there is another operation called ma austempering. Now this is the third practice this is the forth practice I am talking about, because we have talked about handling. We have talked about normalizing we have talked about ah tempering ah quenching we have talked about tempering now I am talking about one particular variant of tempering. So, these austempering situations if we have a TTT diagram like this. So, this is temperature this is time in that case.

So, because this is the nose point and below that we have bainite. And this is another phase which is nothing but ferrite this is martensite start that time we take it to the austenitic, austenitic austenite zone form austenite, and then we quench this one in such a fashion that it the temperature up to which we take it after cooling. That one should be above in it is temperature. And then we hold it let us say I take it to this level and then we hold it, and then we quench it. So, in this way what I am what we are going to get is we are going to get day night plus austenite plus martensite. And these austenite we call it has retained austenite.

Since this retained austenite up to this point I get bainite the remaining austenite, because at this point or everything is 100 everything is austenite 100 percent austenite. So, once I took get to this level, austenite will convert into bainite. So, and then once we quench it here so that means, I am taking below remaining austenite I am taking it below ms temperature. So, there remaining austenite can convert into martensite. And there still there would be possibility because if we are taking it to mf this is mf temperature and if with if this temperature is below this particular point, then I would get austenite little bit about austenite still would be left out because if all the austenite that was left out at this point we will not be able to convert to completely martensite. So, I have would have a

mixture of day night written austenite and that is also called written austenite and martensite.

And this written austenite has got a huge importance in practical filled because there is a particular steel called trip steel. Transformation induced plasticity. That time in this particular still we have little bit of retained austenite when there is a crack formation in a structure did around that at this portion the written austenite is if it interacts with the written austenite the written austenite can convert into martensite. So, that it can arise the crack. So, that is what it is called transformation induced plasticity. And this particular still is costly, but it has got a very specific and important use. So, that particular trip steel is also coming due to austempering operation. So, this is also an important heat treatment practice in steel.

So, let us stop here we will continue our discussion on heat treatment of steel, and also gradually we will get into the heat treatment of aluminium alloys.

Thank you.