

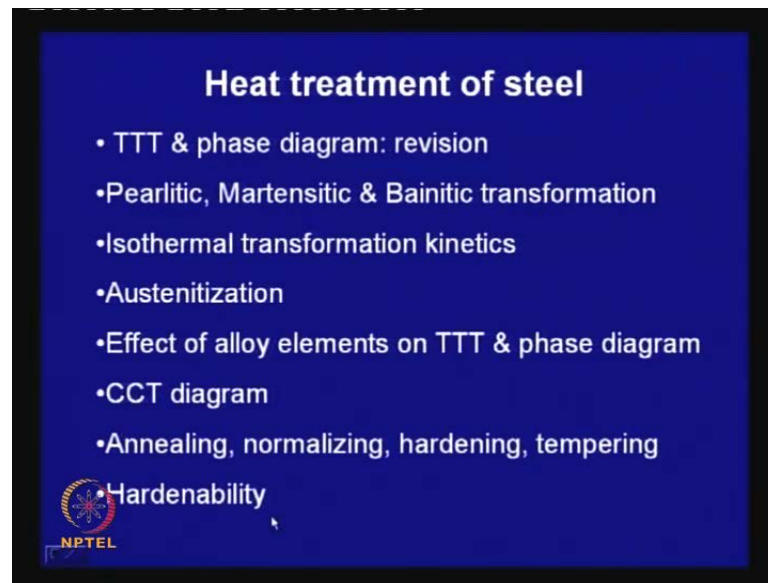
Principles of Physical Metallurgy
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Lecture No. # 31
Heat Treatment of Steel

Good morning. Last couple of classes, we looked at one heat treatment process, that is called precipitation hardening, and in this particular case what we saw that if you have terminal solid solution, and in that case heat the alloy to a temperature, where it is a structure it is a homogeneous, it is a single face and then you quench it. And when you cool it to a room temperature, what you do? You suppress the precipitation process and subsequently you find room temperature or let it age room temperature or may be you let it age or enhance the aging you keep it to a little higher temperature. Then what happens? Very fine precipitates form and these precipitates are so fine that they cannot be seen under optical microscope, but as a result of this process as a result of this transformation that takes place in the super saturated solution, it is strength increases and we look at this in some details.

And today, we begin a new chapter that is called heat treatment of steel, and steel that physical concept - basic concept was already introduced. We looked at phase diagram and we also know that also by changing the composition, you can get varieties of properties, and we will see and by giving heat treatment; how the structure can be modified.

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So, what we are going to look at under this next may be 6 to 8 classes is we will revise, look back something which has already been covered, so that you are able to follow this lecture, we talked about face diagram; we talked about time temperature transformation diagram. We will see that in this time temperature diagrams; there are three distinct regions, you can see when basically a you can see that you can get three distinct properties, microstructural features, say one is pearlite, another is martensite and in between you can get bainite type of structure. We will look at how the isothermal kinetics of the process, and any heat treatment that you do say, if you have a steel at a room temperature and you have to give it a heat treatment, you will find light in a solid precipitation hardening, you heat it to a temperature. So, that means you take it to a temperature where steel transforms to a high temperature crystallography form, that is austenite and this process is called austenitization.

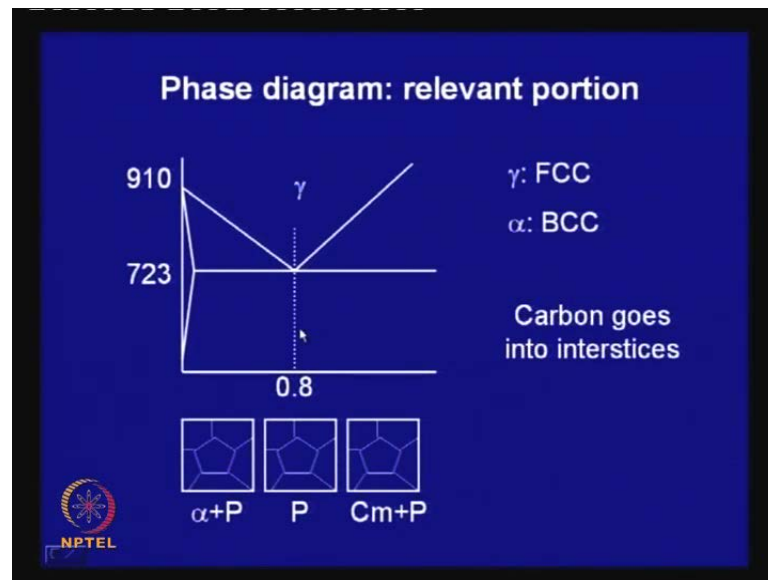
We will look at (()) austenitization, and what are the factors that determines the process of austenitization, and how long should you heat sample at a particular temperature, so that it becomes fully uniform or homogeneous austenite. We will also look at effect of alloy elements on time temperature transformation diagram, and face diagram. And many often and very often we do time temperature transformation, and these are drawn at the isothermal condition, these blocks or these diagrams are generated experiments conducted in the isothermal condition. But normally when you cool a steel when you quench at a temperature at a particular point in the steel changes continuously. Now, we

will see that what is continuous cooling transformation diagram, is there a relation between CCT and TTT diagram, then we will look at few commercial heat treatment very common heat treatment processes annealing, normalizing, hardening and tempering and we will also look at hardening.

Now, coming back you know it may be worthwhile to look at one basic difference between precipitation hardening and the hardening treatment that we are going to talk about steel, now in precipitation hardening, when you heat a metal to a high temperature then quench it rapidly what happens, you trying to keep excess amount of solute in the lattice. So, your solid solution strengthening may they are to a some extent, but your lattice is not distorted very much or your actual strength does not increase, so the quench to material may, so the lower hardness then the structure you had, initially you may have a two phase structure, you take it single face region, quench it very fast you are retaining more amount of solute elements. So, normally one would expect that since you have more solute it should be harder, but it is not so you find that hardness decreases, but when you age, you form a very fine precipitate all through the matrix and which gives it high strengthening or now the situation is little different in case of a steel, when you quench what happens? You hit it to a stage where that ferrite normally at a room temperature steel is made up of.

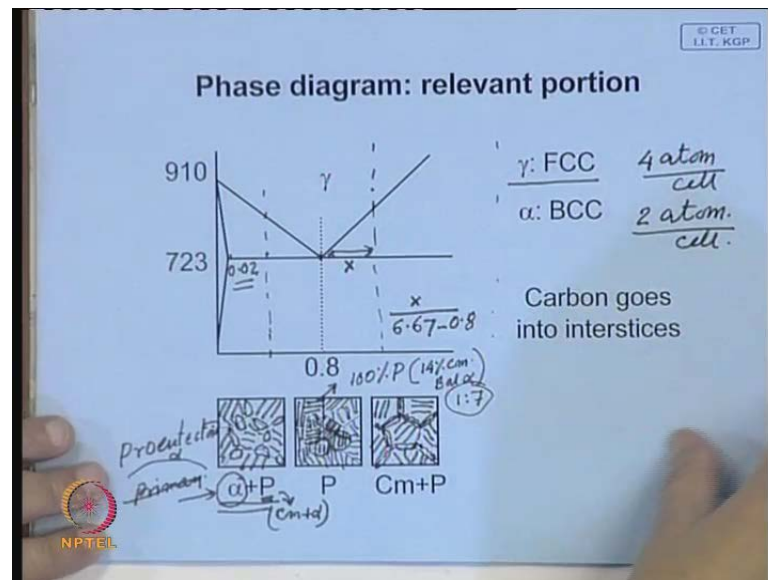
Let us say ferrite and cementite hit it to austenite temperature that cementite or carbide dissolves in a matrix you have a single face structure, and when you quench it you retain high amount of carbide no doubt, but we will see in this case unlike precipitation hardening instead of going down strength goes up substantially and we will try and see.

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Why this happens and in fact the reason lies within the transformation processes that takes place in the steel during the treatment process and we recall the part of here, what we have drawn is a part of the phase diagram that is iron meta stable phase diagram. Now, why we have drawn a part because most of the time, say we have a steel, say suppose we have a point 8 percent carbon steel, let us first consider the process of heat treatment with reference to this particular steel and when you heat this is called eutectoid steel and when you heat it to the austenitic region, what happens you get homogeneous austenite. If you leave it above this temperature called as a eutectoid temperature around 723 degree centigrade and if you heat it above thirty to forty degree centigrade above in that case, it will become homogeneous austenite within a reasonable span of time. And now, we will try to see what happens to the structure what type of structure will it develop if you cool it on the different conditions and if you recollect this idea this particular steel is known as eutectoid steel.

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This particular steel is known as eutectoid steel and if you remember that structure that is when you cool this steel, so what you have pearlite forming and pearlite is made up of alternate layers of cementite. So, this is the way this pearlite forms, so this is a module of pearlite, in that way you will find number of modules they develop, so when the cementite develops here can also develop austenite grain on the other side. So basically, so what happens on this growth you know both will grow parallel? So, within one grain you may find there will be several modules of pearlite, which are made up of alternate layers of alternate layers of cementite usually in the microstructure, what we see that normal microstructure steel that you... In that case, the cementite touches the boundary cementite plate is so fine that it appears as a dark line, so it will be hundred percent this will be hundred percent pearlite, so hundred percent pearlite which is made up of roughly around fourteen percent cementite and rest balance ferrite.

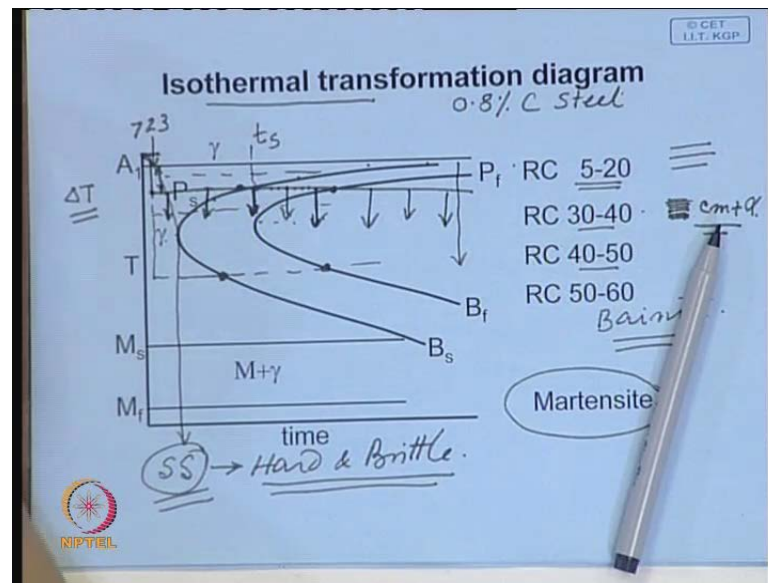
So, you will see rest balance thickness of cementite they will be 1 is to 7 around. Whereas, if you have a steel on this side which is known as hypo eutectoid steel and here, the structure will be there will be some primary or we will say that this is called pro eutectoid ferrite. So, ferrite which precipitates or forms initially it may form on the grain boundary and they grow these are the ferrite grains and balance will get converted once it reaches, will convert it into pearlitic structure. So, the structure here will be made up of eutectoid ferrite and pearlite and this pearlite essentially again will be made up of cementite plus ferrite. So, in fact the amount of eutectoid ferrite, this will be maximum at

this end and as you pro eutectoid an amount of pro eutectoid ferrite goes on decreasing, so same thing happens similar thing happens here what you have, when you cool this is called hyper eutectoid steel and when you cool from this prostenitic region, initially the pro eutectoid cementite will form. And then this cementite when it forms you will find along the grain boundary first, and they often find a thin film around the grain boundary because these are the likely places, and in fact and when it grows you know, you can clearly see, because normal it ages only the boundary between the cementite and austenite cementite and ferrite.

So, you may find that there are quite this type of network quite network around this and balance will be this portion will be pearlite, but interesting thing which you will find in hyper eutectoid steel, because of this composition nature here, you know the amount of ferrite increases this they from let us say, zero percent here at point two to around hundred percent to close to 0.2 carbon, but in this case, the amount of pro eutectoid cementite this will be proportional to this portion only this over that entire and that means is portion is x eutectoid cementite.

And this will depend on this is 6 point 6 7 amount of carbon in cementite somewhere in this side 6 point minus point 8 is larger, so amount of proeutectoid which you have in steel is very less and that is why you know, you will have only can expect only a thin network of cementite and cementite is very brittle and this type of structure therefore, a brittle network at grain boundary is unwanted and all heat treatment process we have to see that, we do not let this happen and we know that you must recollect that this crystal structure austenite. This is face centered cubic it has 4 atoms per unit cells. Whereas, in BCC it has 2 atom per unit cell, and then carbon where does it go, amount of carbon it goes into the interstitial sites and which we will see in subsequent.

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And we also have seen, define, you know what is isothermal transformation diagram, we explain you know what is heat to, let us consider this eutectoid steel that is 8 percent carbon steel and when you heat it above this you know 723, the temperature is around 723 centigrade, you have heated it here and then what you do after heating, you know once, you know that it is homogeneous cool it to a particular temperature. Let us say, you have a bath, so a metal bath molten bath you have dipped it a sample, and you are able to follow say, suppose you are and you are able to follow say suppose keep it for certain different lengths of time and then you quench, say one after this time, another after this time, another after this time and you can look at this microstructure of each of these room temperature, what you will find, that structural feature until this particular point is exactly same.

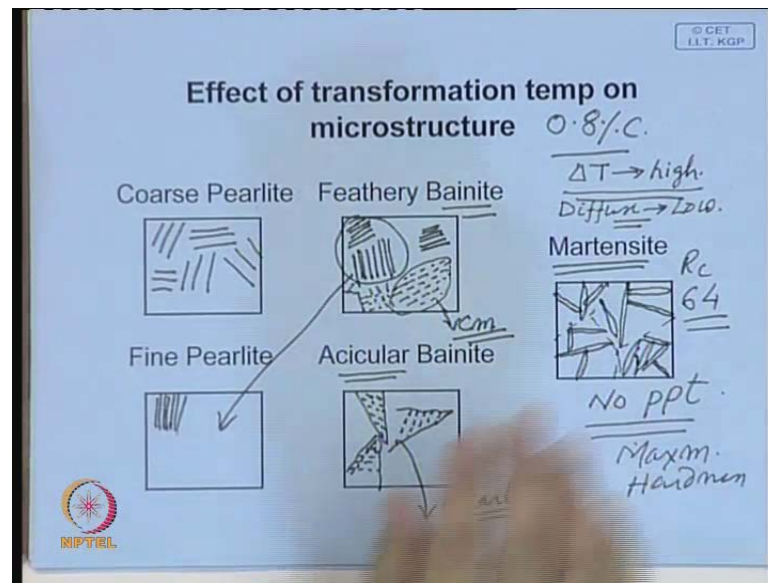
Say, similar identical feature but once it crosses a particular point, you find the pearlite starts you do not from pearlite, if you quench from here, quench from here and then you start seeing pearlite from this point pearlite goes increasing with time and somewhere here it reaches 100 percent pearlite and after that if you go on quenching, no change in structure and from this type of experiment, what you can find is when you cool it at a particular temperature there is certain amount of under cooling. Let us say, this under cooling is ΔT we see that for different ΔT , the transformation starts at a specific time and it is completed after a specific time. So, this is start of transformation this line represents end of transformation or completion of transformation this line represents end

of transformation completion of transformation and if you repeat the experiment at different temperature and join these points you find you get like this. And similarly, you will also find, you quench it for low, you get a different line here you start getting a different type of structure. Nevertheless, here also it starts after a particular time.

So, this type of C type of curve similarly, what you kept during precipitation, hardening, quenching also we talked about this type of C shape curve and you know, you must cool it faster than a critical cooling rate to get specified structure. So, there also to get a super saturated structure. Here also you will see, you will cool faster than a critical cooling rate, then here also super saturated structure and we will know about it little detail a little later. Now, difference here is unlike precipitation hardening the super structure is extremely hard and brittle. So, this is the basic difference between precipitation hardening and the hardening that takes place by rapid cooling in steel and we have also defined, we have also shared that the structure you get becomes finer, as you go down the transformation temperature goes down structure becomes finer.

Here, it is a little coarse pearlite, coarse pearlite means lamellar are wide apart, whereas if you cooling somewhere here, these lamellar they are much fine sometime it may be. So, fine that it may appear as the dark patch in the microstructure, but at a high magnification the resolve and we can see that the also made up of alternate layers of cementite and ferrite and as the structure becomes finer its hardness increases, this is the hardness features, and when you come here the structural features changes. And this type of structure is called bainite and when you quench rapidly it has a different types of structure here, you are not allowing movement carbon atom taking to take place, so you get a super saturated structure and this structure and this structure is called martensite.

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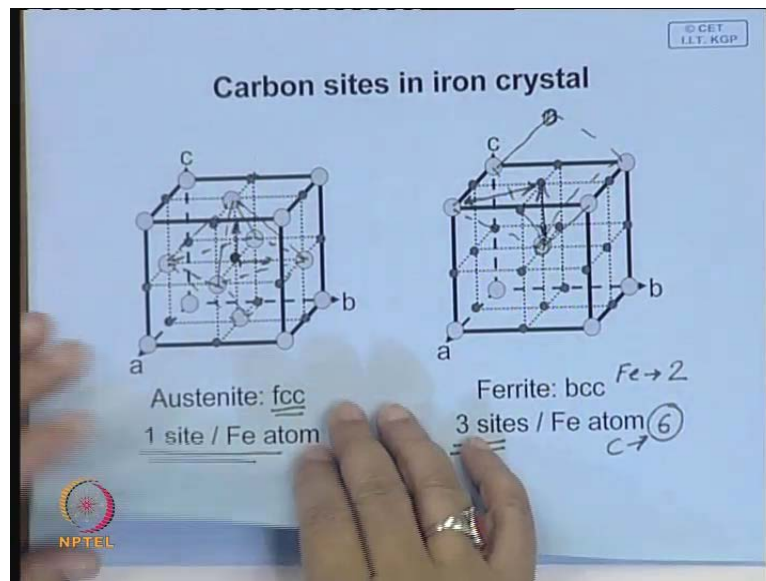
And now, let us quickly, there are little differences in this we are just in coarse pearlite because this pearlite, these are pearlitic structure, coarse pearlite in fine pearlite they will be much this plate distance cementite to cementite plate distance will be much smaller something like this they will be much smaller and entire portion will be filled up. If it is point 8 percent carbon steel, it will be hundred percent, sorry this is the fine pearlite, we will come to this bainite little later. So, this structure actually is, so this is where you have very fine pearlite.

So, bainite we have distinct type of bainite. Here, what is happening here under cooling is much more so that means this is quite high so rate of nucleation will be very high. But since, the temperature is low the rate at which carbon atom can diffuse this is low so the distance through which carbon atom can diffuse is will be much smaller here and these pearlite, where you have this long cementite, instead of that what you have so may have this kind of structure these platelets, they may not be and they will all originate they start from nucleation boundary, and they will always you know plates will be very fine and this will be impossible to see under optical microscope. So, rest of the portion so you will have such fine broken platelets of cementite in ferrite matrix, so this will be the structure, and since it is much finer much fine than pearlite it is stronger and again kind of bainite. Here, what happens you have some platelets of some ferrite nucleating and then you some types of carbide these are meta stable carbide these are even fine and this type of a structure called acicular bainite.

So, you see so you will have some plates of ferrite nucleating and within this, since this carbon atom they form a particular angle to the direction of this; if this is the acicular means little light, if this is the shape of a ferrite drain what happens you have this carbide like this these are precipitated, and I think you mentioned this carbide here, and this cementite and this carbide is called epsilon carbide, and we have seen that metastable structure is different competition different crystal structures, and now when you see this, when you have this, when you have a martensite, you do not allow the carbon to precipitate out what you have you have this austenite drain within this austenite grain. You have this type of a needle type of a structure forming an entire thing they cannot cross the grain boundary, but this entire thing these are single face structure so will be their fineness will depend on how large is this austenite grain some of these if grains are closer you can see this needle like structure in optical microscope and this type of structure is called martensite.

It is, there is no precipitate what you have is no precipitate and here this is the type of structure and quenching that is maximum hardness say R C scale it may be R C 64. So, it this is an extremely hard structure you get on the steel; now the question becomes why is it so hard, I mean what happens carbon atom go when you cool it very fast that answer lies into that crystal structure, and the atomic size of the iron atom and carbon atom.

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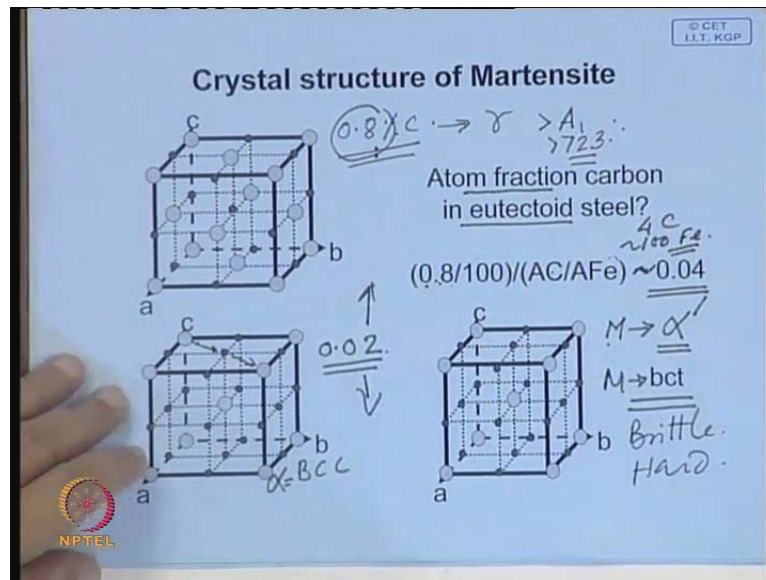
And if you look back your these figures, see this is the austenite structure you have face centered these are the potential sides and if you go back to your earlier notes, how to find out the number of interstitial sites and it was shown you have one interstitial site per atom. So, you have very large number of sites available, but it may be worth looking at how many carbon atom you have so all sites accommodated, if you have every site that is carbon atom then atomic, I mean in that case percent solute will be you can go upto 50 atomic percentage which never happens it cannot accommodate so many, because if you look at the dimension of this interstitial sites these dimension of these interstitial sites are large enough to large enough to accommodate carbon atom lattice distortion. So, if you accommodate carbon atom here, there will be lattice distortion we have seen that lattice distortion here in this case is little less, I mean it is symmetric in all direction you look at this atom, surrounding is exactly same surrounding of all interstitial sites is exactly same look at these atoms these site, it is exactly similar face centered cubic.

Now, if you join these, what you get is an octahedron 8 faces you can join similarly, top and bottom and it is possible to show it was shown also that it is the dimension in all direction the gap, in this direction the gap they are identical. So, this is, if this carbon atom goes here it will only have an hydrostatic stress field. Whereas, look at these atomic sites, so here so carbon goes into this octahedral sites, but which is octahedral the all these surroundings we are seen if you try and find out that number of atoms these interstitial sites in BCC structure. You will find, there are three sites per iron atom so that means a number of atoms you have two iron atom whereas, you can accommodate up to 6 carbon atoms the sites are available, but the point is if you look at this octahedron here, so best way to imagine that octahedron here also you have similar it will be exactly same say look at this octahedron, how does it say you join these they are all identical so this is half octahedron and similarly, if you join this atom this iron atom layer just above this you will find there is an iron atom centre iron atom in the next unit cell and if you join this you get.

Now, look you get this octahedron if you look at this octahedron is much larger than this dimension and this is very small, it is so small that there will be lattice distorted unevenly, it will be distorted in this direction much more possibly in this direction, it is so large there would not be any rather it will be this, will try to come or even it will come closer. Whereas, this side is less than much less than the atomic diameter of carbon, so

this side these atoms will be pushed apart significantly. And this leads to an acetetic lattice distortion and which has much stronger field than this it is not only hydrostatic will also have shear stress field; therefore, these type of stress field can block the dislocation motion much more effectively.

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Now, a point about that how many items or carbon atoms you have in steel say suppose, you look at this. How do you calculate say atom fraction of carbon in eutectoid steel, so eutectoid steel you have 0.8 percent carbon. So, to calculate to convert it into atomic fraction what you have to do this 0.08 you multiply by atomic rate of carbon multiply by atomic rate of carbon so this and if you do that, you will find that even in eutectoid steel you have 4 atoms of carbon 4 carbon atom within say, let us say hundred say roughly hundred iron atoms so ratio between is 4 and hundred, so even within the unit cells so basically what is the if you have a face centered cubic structure, you have very large number of sides so the position of the sides does not arise, you have plenty of sides to accommodate carbon atom.

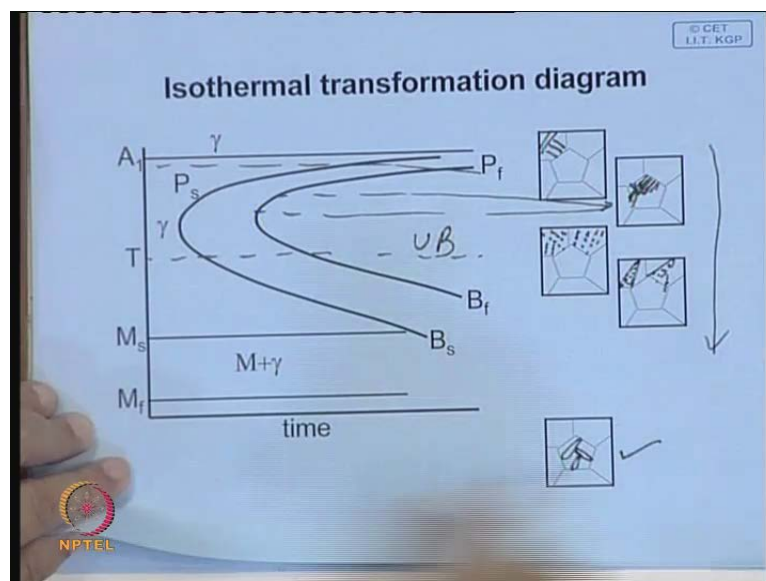
So, carbon atom and these and if at all a carbon atom is located here the lattice will be distorted no doubts you keep 5 4, I mean some amount of carbon atom, but this distortion and will be uniform in all direction so carbon concentration goes in so the austenite lattice parameter is, but it will be it will not the lattice parameter, but what happens if you do the same thing here what I mention is, if you have a side here gap is very less, so

this will try to expand whereas, this side is larger than this gap. So therefore, what happens is lattice you keep, want to keep more amount of carbon that is lattice will get distorted.

So, carbon see 8 point 8 percent carbon is fully soluble in austenite that is, if the temperature is greater than A_1 or if or greater than this 723 centigrade, now imagine you have heated this to this, you have point 8 percent carbon so here also you have plenty of sites much more than what you have here but this sites are smaller and if you want to keep this so many carbon atom by force and mind you, if you have carbon solubility in BCC is very less point 0.2.

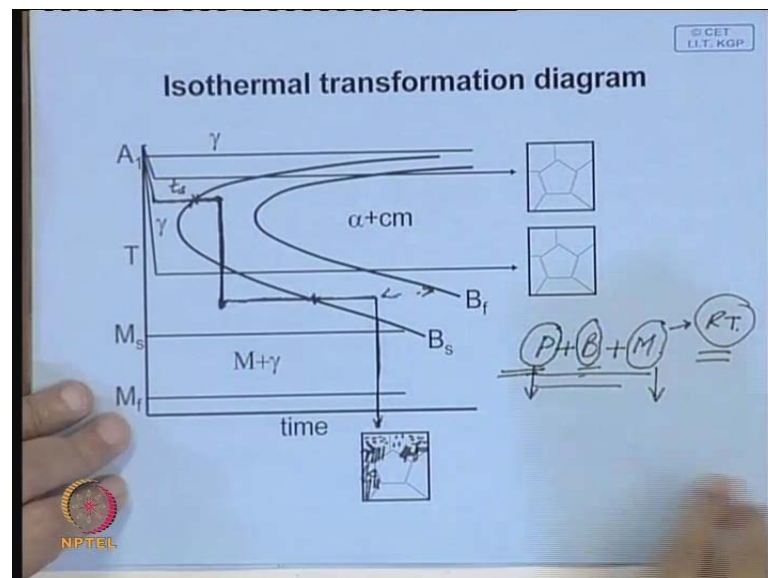
So, if you are trying to keep this much of carbon imagine the amount of to the extent to which this lattice will get distorted and this distortion is so large that this crystal structure also changes it is no longer this is BCC ferrite is BCC. But martensite is body centered tetragonal is shown or people is shown saturated solid solution of carbon, people often consider as a super saturated solid solution carbon in alpha iron we can often, we write it as alpha prime and since it kept so many carbon atom by force that lattice will be highly distorted, highly strain and you have so many carbon atom in the lattice and this carbon atom will inhibit the amount of dislocation and that is why this microstructure is extremely hard and with it is it becomes brittle as well this hard and brittle.

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Now, we in fact have talked about it, this transformation diagram depending on the isothermal transformation, you get if you are transforming somewhere here you get coarse pearlite structure somewhere here having a transformation, somewhere here somewhere near the nodes, you have very fine pearlite; similarly, in this bainitic region upper bainite called upper bainite which is favourable you have broken cementite platelates broken cementite platelates and here you have acicular needle structure and within this needle you have needle like this. And you have very fine epsilon carbide and in case, if inside you have full needle like structure martensite, and you have increasing as the structure becomes finer and you get maximum hardness over here.

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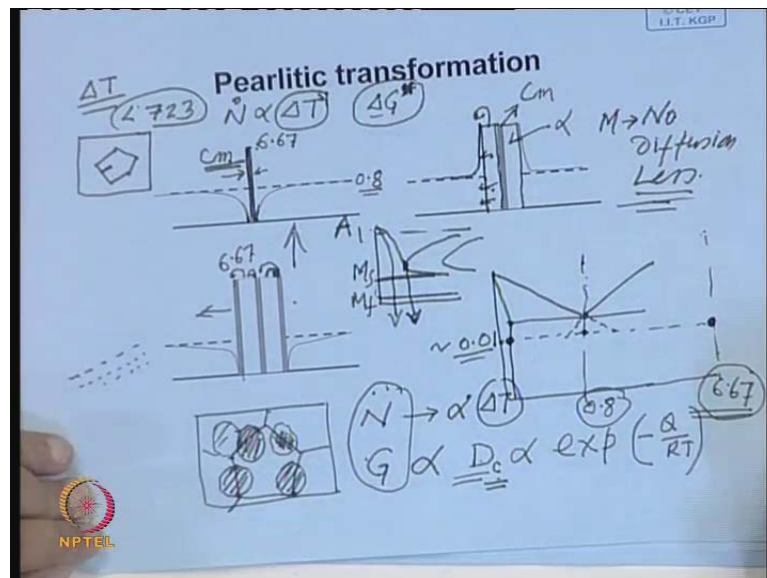


Now, the question comes so that means you can get a wide range of microstructure in the steel depending on how you allow the steel to cool. So, one can design and think of various types of isothermal heat treatment process. Suppose, we say that various design the process of heat treatment where you will get mixture, let us say in a eutectoid steel you can get some amount of pearlite, some amount of bainite, and balance martensite is possible. So, if you look at the diagram here, so then you have what you have to do you have maintaining a bath a number of bath different temperature say, one where pearlite can form and another temperature where bainite can form and another path, where you can quench may be path this room temperature some water bath you just quench in water this you have one bath mentioned at this temperature.

So, this path if you follow this path, let it remain over here and holding time should be greater than the time at which pearlite transformation starts, it must cross this and then keep it until then you quench to another path and when you quench mind you even though it is passing this area does not mean benite will form because for benite to form carbon will diffuse and when you are quenching you are not allowed knowing the time, so even though it is processing the time looks it is passing through this, but mind you this is isothermal transformation diagram. It represents this c curve is unless you have a whole time here transformation cannot take place.

So, what you do you come over here then you hold until benite transformation starts, here the benite starts keep it for sometime then you quench this transformation till part is this portion is untransformed. So, then you get a mixture you get a mixture of pearlite you can get benite, pearlite, benite and also martensite little and this property will be you can see composite type of relationship can use, that it will depend on hardness will depend on how much pearlite, how much benite how much martensite you will have this will have maximum contribution upto this stand, this will make minimum this will have intermediate contribution.

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Now a critical look at, how a pearlitic transformation actually takes place let us look at the mechanism by which pearlite forms in an austenite matrix. So, here you have austenite grain how does this pearlite form now pearlite the pearlite to form you

have to give a certain amount of under cooling and this under cooling that is ΔT , so you have to keep this steel at a temperature that 723 degree centigrade and now here, the rate of nucleation depends on nucleation rate depend is proportional to ΔT . So, nucleation is the you can see is the stochastic probabilistic and this is controlled by ΔT . So, that means that is three factor that is nucleation process that it has to overcome area and it talk about critical energy area that how it will that free energy barrier for variation to take place that is the critical, and the energy hump that is to be crossed and this is proportional to ΔT .

If you have, let us say first cementite plate nucleus when cementite plate nucleus, if you look back at this phase diagram say, if you are looking at eutectoid steel see you have come over here now, look at what will be the composition of cementite now, which can remain in equilibrium with ferrite so here, you draw you will draw a line like this so cementite is somewhere here 6.67. So, now the cementite concentration is 6.67 ferrite is let us say, around or virtually 0, let us say ignore this let us say, virtually 0 it will be very small it will be let us say, 0 it will at this temperature say it is 0.01. So what happens when cementite nucleus, it will withdraw say around it for cementite to form you will need so much of carbon content, so if a cementite plate forms imagine it will capture all the carbon atom from the nearing region, all carbon atom even nearing region goes here to form cementite this carbon atom from this, so what happens the neighbouring region carbon drops down drastically from so let us say, this carbon content is this carbon content is neighbouring point 8 percent carbon here the carbon content is 6 point 6 7 percent.

So, it comes here when the carbon takes place here, so this the plate of cementite where cementite has been created. And now once this goes to a certain point this carbon content decreases so much that a plate of ferrite nucleates and when a plate of ferrite this is cementite this is ferrite, ferrite nucleates it will reject ferrite has hardly any carbon content but austenite steel here you have 0.8 percent carbon. So, from point 8 it has to reject the carbon the surrounding area is 0.8. So, if it rejects the carbon again at the boundary therefore, the carbon content starts bending up and this process continues this is rejecting carbon, carbon it is rejecting is all carbon from ferrite comes to this region when it comes as this carbon concentration increases to 6.67 again a plate of cementite it creates, so that is what is happening in the process two things are happening to diffusion

say carbon moving from here to here and carbon moving from ferrite to this place ferrite here, here and with this process these can go in this direction can through nucleation and subsequent grow in this direction.

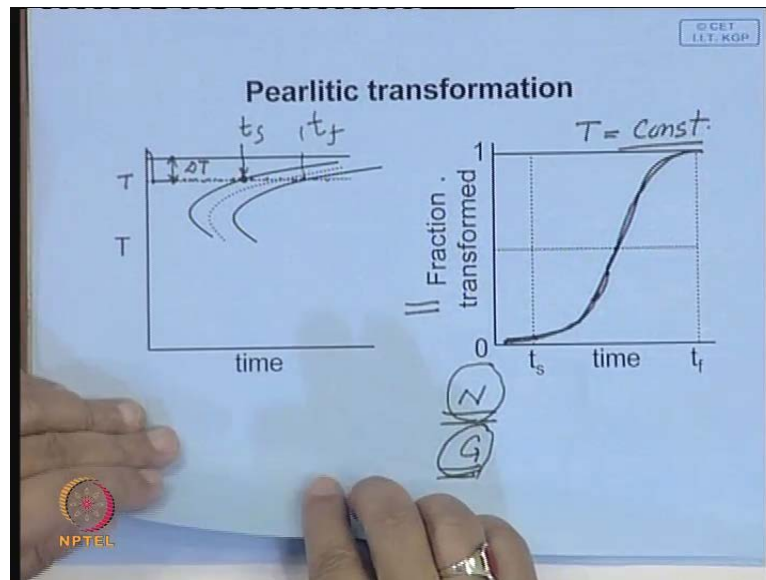
So, it will grow in this direction as well as in this direction equally and ultimately what will happen in the microstructure what you find say, if you have a grain of austenite you have this pearlitic regions growing, it is growing in all directions, so it will be apparently they may look like this kind of a circular thing and here different types of that arrangement sometimes from a site also this plate can be created. So, this is the way and it will ultimately you will find form into a module and this will grow and until after some time they will start impinging and then the growth stops and finally, entire structure will be converted into entire hundred percent, pearlitic structure so what we say for pearlitic transformation to take place, we have two simultaneous things taking place one is a nucleation, second is growth nucleation that is proportional to level of under cooling and growth is proportional or growth is a function of proportional to the diffusivity of carbon atom and diffusivity, we know is a strong function of temperature say activation energy say it is $-\frac{Q}{RT}$.

So, this will depend on the diffusivity of carbon atom, which diffuse much faster interstitial atoms can grow much faster, so this growth will be primarily determined by the diffusivity of carbon atom and this diffusivity is you know that the temperature goes down growth becomes slower, so that is why what happens there is an optimal combination nucleation and growth where the reaction is fastest and that happens near the nose of the TTT diagram.

So, this is the equilibrium A₁ temperature and we have seen this diagram like this so this nose this is the optimum combination, where the nucleation and growth have optimum combination which gives fastest reaction or fastest decomposition of austenite into pearlite diffusion control transformation reaction. But if it exceeds martensite it is something that the diffusion, we do not allow the diffusion to take place, so that is why we do not fast there is no c curve, we do not see anything it is just parallel lines martensite start temperature martensite finish temperature and as you will go, I mean look at the kinetics of martensitic transformation and martensitic transformation is called where there is no diffusion it is a diffusion less transformation this is the diffusion less transformation whereas, in case of a ferrite structure, you know it is there is diffusion but

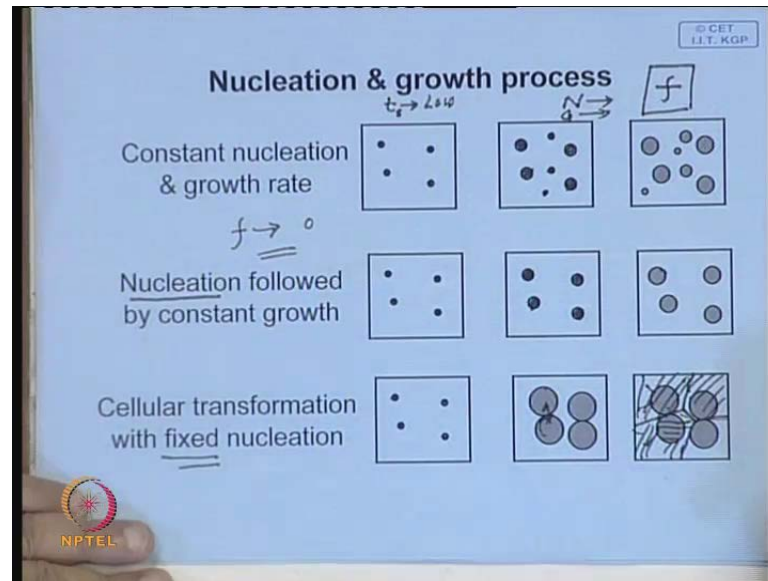
you can see the pearlite the carbon atom by large distance and in benite when this carbon atom does not have to move large, and so that is why at a lower temperature when benite forms you have such finite structure such small platelates of cementite or excellent carbides.

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Now, let us look at a little detail the kinetic or pearlitic transformation, so we have seen that it is possible to follow the samples from here and rate at a particular temperature, some temperature that means there is some amount of under cooling that is ΔT , that you maintain this bath try to follow this transformation, and we can see that transformation starts after that particular point and it is completed starts at t_s and it is completed over t_f , and how does this volume fraction increases with time, if you generate a plot to get something like this fraction transform. And if you plot this fraction transform often you find that this is at fixed temperature isothermal is constant, t is constant and here this is how the type of plot that you see that means initially the transformation is slow it picks up in between goes like this, and what we will see you know how does this take place there is a process of nucleation and growth. Now, it is often natural that we know that what type of transformation, we control the degree of under cooling, and the transformation temperature.

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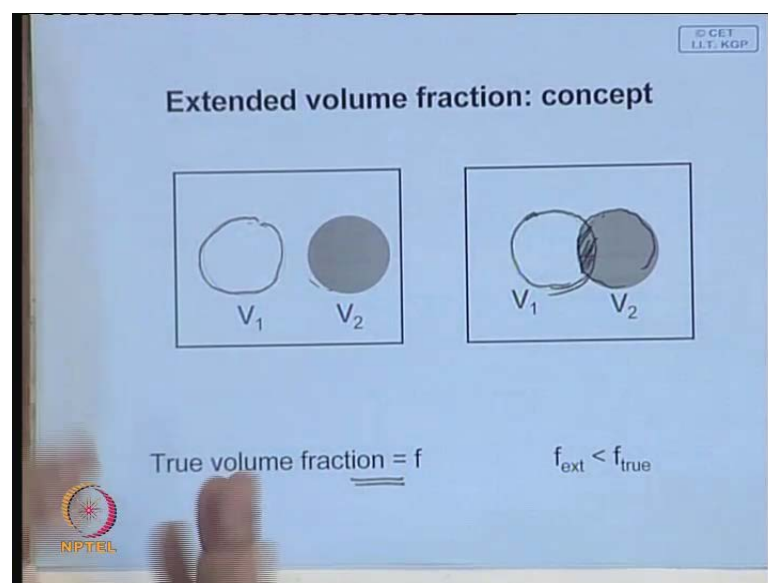


And what and know you have to visualize and you have to imagine take place. Now, there will be 2 or 3 distinct cases which is shown in this diagrammatically here and say suppose we make one assumption, there is constant nucleation and growth rate which is diagrammatically shown here time at time you will be having certain amount of nuclei forming, so right at the low t when you have a small amount, so it is close to t_s so many nuclei formed some intermediate what happens the nuclei the stable nuclei which has overcome the activation energy become true. So, they have grown to this size they have grown like this, I had the same time which nuclei can also form so fresh nuclei form so you have 2 parallel processes taking place that and this very simple assumption constant that means constant nucleation, constant growth rate which is possible to find out what is the amount of transformation that is taking place that is fraction transform.

Similarly, there can be another stage where we can say that process takes place first nucleation that all the number of nucleation there are certain specific sites, where nuclei can form and once these sites gets saturated all these nuclei can form then only growth can start, so this can be one way of looking at it so whenever to understand any transformation process we do make certain assumption, how this is taking place and if we make this assumption then derive an expression which can be connected to some of the parameters which can be measured, and then we can know and if we are matching if they match according with these and the derivation that you make with this.

And you get one expression the derivation, and if you make this assumption you will make another relationship fraction transform with the temperature and time, and then you have to match which is represents the actual situation. Now think happen as the process continues when f is very low, when f is nearly equal to 0 this question does not arise, this question of impingement does not arise now here you can see that here the nucleation here the question of impingement but when it is growing when grow to this level growth in this direction will be limited and ultimately, what happen then this can grow, so then this will grow in other directions this will grow. And ultimately we have this kind of a structure the entire area is pearlite let us say, so this is pearlite module and this is grown into this area so this is impingement area and how do you calculate the impement effect this is what we will go into.

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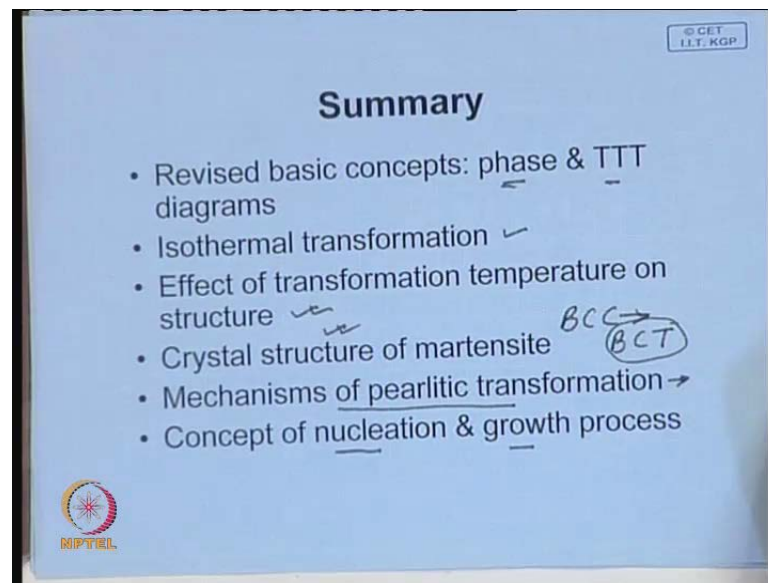


This is something like this which is shown, so if it is you do not have an impingement calculation of volume fraction is quite easy some of this is nucleus this is another nucleus add this true volume you get the net volume, but if it impinges then the problem comes up if you add the volume so your volume fraction added into 2 you get a wrong amount of volume fraction, because this area or this volume you are counting twice and we look at it that with this concept that, how it is possible to derive a expression or fraction transform like pearlitic transformation or any diffusion control transformation this in fact will be even applicable to precipitation kind of transformation and like even this type of

transformation only thing is difference is precipitation process in a super saturation precipitate is the volume fraction of precipitate is very low very small.

So, the question of this impingement is come there, so that is volume fraction is so low that it will be necessary, so with this we stop over here and what we did today is we just revise some basic.

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Concept phase diagram and TTT diagram, we look back at isothermal transformation, we looked at the effect of transformation temperature on the structure and we also tried to decide nature of martensite or what should be the crystal structure of martensite, the distorted BCC and in fact it is called body centered tetragonal structure. We also talked conceptually concept of pearlite transformation diffusion place a very important role and we also introduced the concept of nucleation and growth process. Thank you very much.