Principles of Physical Metallurgy

Prof. R. N. Ghosh

Department of Metallurgical & Materials Engineering

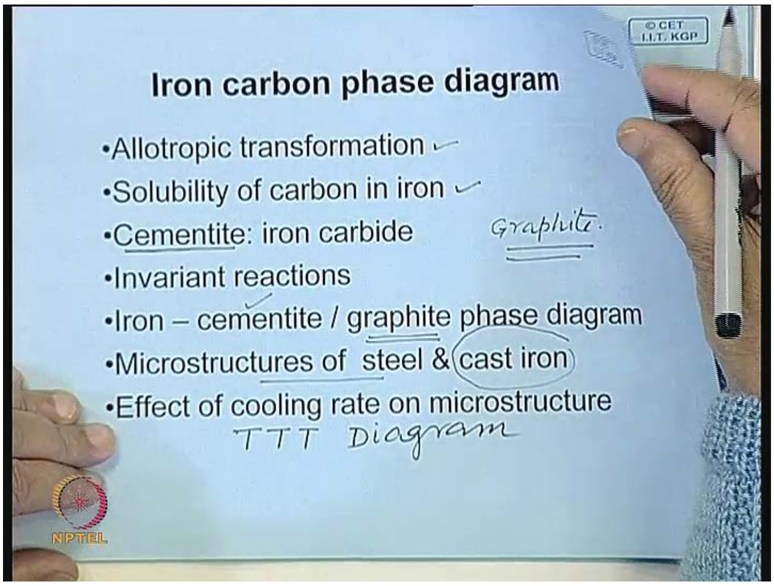
Indian Institute of Technology, Kharagpur

Lecture No. #24

Iron-Carbon Phase Diagram (Contd.)

Good morning. Last class, we started a new topic, a new chapter that is an iron carbon phase diagram.

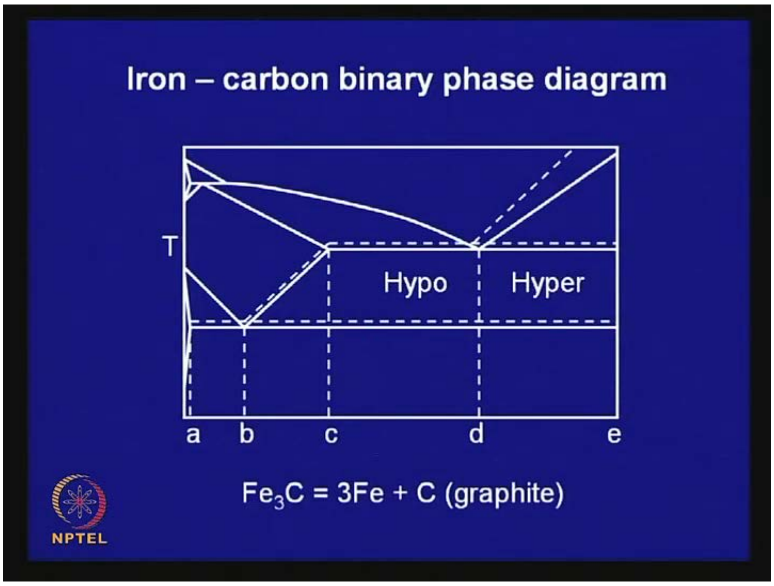
(Refer Slide Time: 00:33)



And we have so far looked at this allotropic transformation, looked at the solubility of carbon in iron. We talked about a meta stable phase iron carbide that we get in the system, and we also said that this is not the stable phase. Stable phase is graphite, stable form of carbon is graphite. So, today we will look at a bit deviate we look at iron graphite diagram also, but the process of the composition of cementite to graphite is very slow, and in most materials of commercial importance in iron carbon alloy, we do get carbide. I mean, carbide is the form in which mostly carbon is present in steel. We looked at invariant reactions, and we have looked at iron-cementite phase diagram.

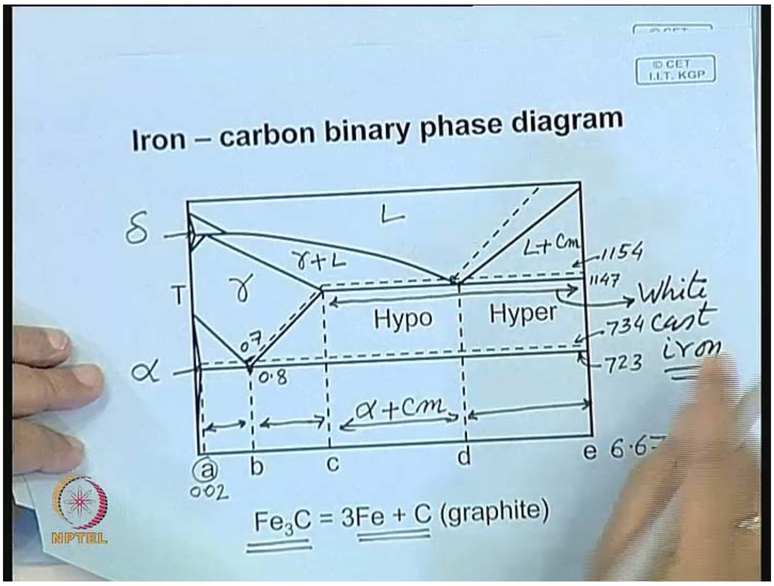
Today, we will see what happens if cementite breaks down. How does the carbide I mean diagram changes, and then we also looked at microstructure of steel, and a part of cast iron, where carbon is present as cementite. Today, we will see what happens if this cementite breaks down into graphite and we get another type of cast iron (( )) cast iron. We look at that and then we will try and interpret what is the effect of transformation temperature or cooling rate on microstructure that you get in steel. And introduce a new concept a new diagram called time temperature transformation diagram.

(Refer Slide Time: 02:49)



Now, let us look at this phase diagram. This firm line is what we looked at we discussed in the last class and here each of these points, which are marked you know they have definite composition.

(Refer Slide Time: 03:05)

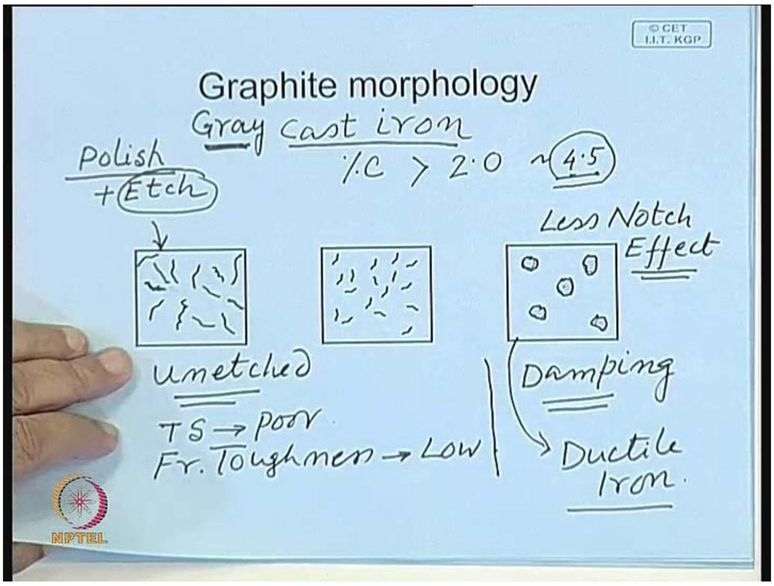


Like here, we say that this is the 0.02; this part is cementite; here carbon is 6.67; this portion, it is liquid. This is where you have austenite and this is where you have delta ferrite and this is the region terminal solid solution. This is the part you have alpha; here you have gamma plus liquid; here you have liquid plus cementite and here you will have two phases primarily, ferrite and cementite. But the way they are distributed, the structures are quite different. As you move from this this region to this region to this, each of these regions you have different structures, structural features. And looking at the structural features of iron carbon alloy, it is possible to guess what the amount of carbon present in the iron carbon alloy is.

Now, as I said as has been mentioned, this is the meta stable phase and if you keep it at the system remains at high temperature for sufficiently long time, this type of decomposition takes place. And infact, in many of these materials say particularly steel, which are used in power plants and also in the petrochemical industries, where the steel is exposed to higher temperature during service. And people have looked at micro structures of such such material after 20, 25 years of service and there they find that cementite has broken down into ferrite and graphite. So, that means that shows that prolong holding at high temperature, the graph it is possible that cementite will break down.

And you will have graphite and tendency for this graphitization is high as you move towards the higher carbon content and in this diagram, we have certain lines. So, these are the dotted line shows that these are the equilibrium line. Say, if that eutectic it is slightly different more or less the eutectic temperature is may be slightly higher; may be 10 degree higher than this. Say, if it is 1147; this is 1154; this is 723; this is around 734; so something like that; this point is 0.8. So, in a graphite eutectic, this is slightly this side 0.7. So, more or less we can say that same diagram it is possible to interpret the micro structure, if graphitization does take place and it is most prominent in the higher as the carbon content goes high.

(Refer Slide Time: 06:44)



And in there are certain high carbon alloy, which are known as a cast iron cast iron. They have carbon content percentage carbon is much greater than 2 and particularly, if it is around 4 or more 4, 4.5 or beyond. So, there are many cast iron, where you have carbon of this much order and there, the graphite suppressant the cementite breaks down and graphite suppressant like flakes like this; say, flakes flaky graphite. And and this you can see only by polishing, you need not etch. Normally, to examine a micro structure you polish the surface you polish the surface; make it scratch free, shining and then you etch.

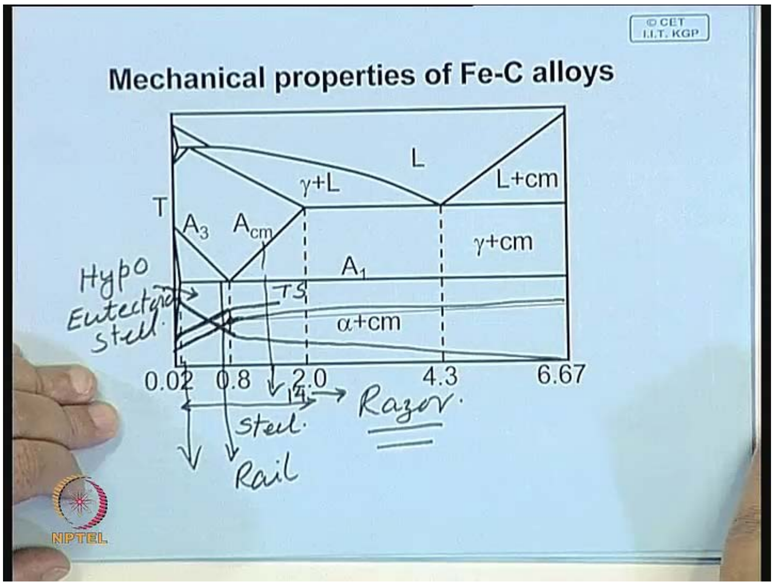
And while etching, it attacks certain phases and particularly the boundaries and then the structure becomes visible. But in case of cast iron, where carbon is present in the form of graphite and its lusture is so drastically different; that even without etching, these graphite flakes or graphite morphology will be visible. So, these are whatever see is unetched structure and this depending on the size. And this morphology of this graphite flake can vary; it can be long; it can be short or something like this. It can also by controlling the process of solidification and some inoculation treatment in certain forms of graphite, cast iron. It is possible to get graphite in nearly this kind of nodular shapes, the round.

So, difference is if a material has this kind of a flaky structure, they are like fine micro cracks. So, these properties that you expect, they will have poor tensile strength. The tensile strength will be poor; fracture they will fracture easily; that fracture toughness fracture toughness will be very low fracture toughness will be low. But presence of this kind of a graphite phase, it gives cast iron; a very good property called damping property damping property. So, therefore it is a very commonly used material for construction, where you know you do not subject the material; that material is not subjected to tensile stress but compressive strength.

It has good compressive strength; no doubt and you need damping resistance. Say, suppose the turbine basis, where the turbine is supported or machine basis they are made up of this type of gray cast iron. And nodular cast iron, if you can control its morphology, here this notch effect is less notch effect; so less notch effect. So, therefore here the chance of crack propagation that is little less. So, this form of iron is also known as ductile iron. So, that means by controlling the morphology of graphite and this cast iron, which is a form of cast iron; where carbon is present as graphite is called gray cast iron. The term gray derives from the nature of the fracture.

If you look at a white cast iron, where the cementite is this; where this carbon is present at cementite and (( )) is quite brittle and there the fracture appears to be very shiny. So, that is called white cast iron. If you look back here (Refer Slide Time: 03:05) this firm line says that it is the iron cementite diagram. So, these are region if it is present in the form of cementite carbon is present in the form of cementite, so these are white cast iron. We did look at its structure in the last class. As against that, the graphite morphology is more stable and this type of cast iron has good damping capacity and good compressive strength; but poor tensile strength and low fracture toughness.

(Refer Slide Time: 12:12)

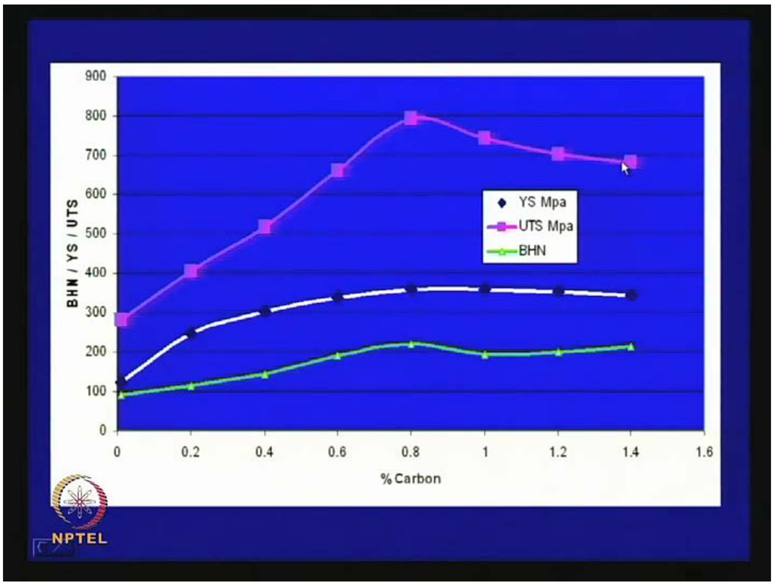


Now, let us look at… So, that means that properties of iron carbon alloy is significantly that carbon is a major alloying element, which defines the nature of this or the properties of iron carbon alloy. For example, in the steel (( )) this portion is steel and here if you look at under normal the structure that you get. We will later come about special types of heat treatment, where properties can be changed substantially. But normally air cool or furnace cool steel that means where the structure is more closer to equilibrium, which is described by this phase diagram. There you will find if you increase the carbon content in this portion, there will be a slight… because of the solubility, it increases slightly.

And then this part, it is a linear and then here around this almost you get that optimum property and thereafter, this property increases very slightly. So, this is you can say tensile strength. If you measure hardness is very commonly, this hardness also increases linearly in this part, where this is called hypo eutectoid steel eutectoid steel. So, here this portion, it more or less increases linearly and cementite is quite hard. But thereafter, this hardness increases is not much; I mean slight increase is there. But the ductility look at the ductility. So, here as the strength increases, ductility goes down. So, carbon is the alloy element, which controls the properties of steel to a great extent.

And bulk of the steel are for most application like (( )), they are very low carbon steel. They will be almost close to this end, which will be mostly ferrite little pearlite and you have rail and these are medium carbon steel say may be 0.6, 0.7. These are the steel is a rail steel and say cutlery and then hacksaw these razor blades etcetera. They will have carbon content around 1.4. This is a razor blade or hacksaw razor blade or two steel will be somewhere in this region; whereas the… So, that means by controlling the carbon content, you can get different types of property with high very high hardness. And later on we will see by controlling cooling rate, it is possible to change these properties to a much higher extent. I think next diagram.

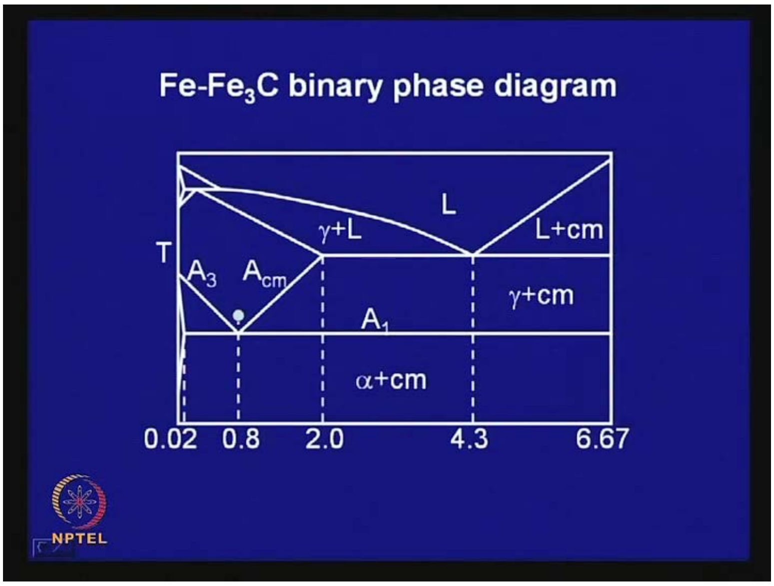
(Refer Slide Time: 15:50)



Here, this typically shows I mean whatever I talked about do you look at this with the carbon content. I took this data from hand books for steel, which are cooled at a very slow rate; annealed steel and these these are this axis gives either (( )) hardness (( )) hardness is shown by this. So, look at this part, the hypo eutectoid steel. It is very strongly dependent; but thereafter, the change is not much. This is yield strength more or less at 0.8 percent, it becomes maximum and this is the UTS; here also around 0.8 percent, it becomes maximum.

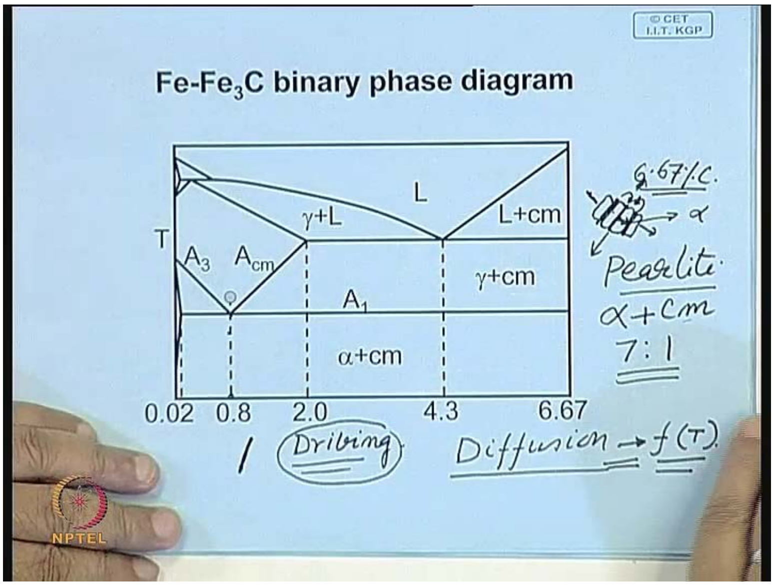
So, infact eutectoid is a structure; eutectoid steel, the structure is the good mixture of a is a very fine mixture of ferrite and cementite. Cementite is harder and this type of fine mixture gives or you can see that optimum properties; that is maximum possible yield strength or a tensile strength. But beyond that if at all the strength and hardness increases, that increases marginal. But definitely, the ductility will be much lower. As the ductility as you go this side, which is not shown. The ductility plot possibly will fall like this.

(Refer Slide Time: 17:24)



Now, let us look at the structure of this eutectoid steel critically. Last class, we looked at that if you cool a steel from this austenitic region, which has a carbon content which corresponds around 0.8. So, this is the eutectoid point. What happens as you cool at this eutectoid temperature around 723? As you go below the 723 degree centigrade, you have precipitate; I mean this austenite breaks down simultaneously into a fine mixture of ferrite and cementite and this is called pearlite.

(Refer Slide Time: 18:14)

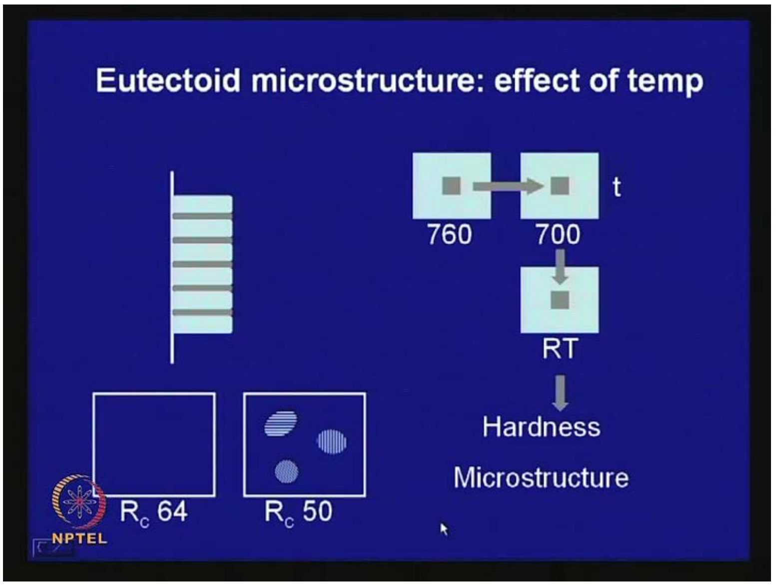


And this pearlite this pearlite we have seen that here that pearlite you know as has been mentioned, you have a cementite particle nucleating; a plate of cementite nucleates, it takes of 6.67 percent carbon. And where does the carbon come from? It will come from the surrounding region. If it comes from the surrounding region, the nearby region gets depleted of carbon and it forms ferrite and when this ferrite grows, it rejects carbon. This carbon goes to the interface, you have another plate of cementite nucleating, and this is how the process continues. And it grows in this direction and it will also grow in this direction as well, until it encounters another particle or another similar colony of pearlite in the structure. So, this is how the pearlite forms. This is the pearlitic structure; this is called pearlite.

Pearlite, mind you it is not a phase; it is made up of alternate layers of ferrite and cementite. And we saw that around this, the width of this cementite ferrite plate is around if it is 7, then cementite width of the cementite is around 1. So, they will be in this ratio, 7:1 and which comes directly; you can derive it directly from the composition points which are given in the phase diagram. (Refer Slide Time: 17:24) Now, let us see we what we do? We take a piece of steel; keep it in a furnace and then what happens? We cool it to a particular temperature and try and follow how does the micro structure change take place; because here you have to allow time. We looked at the process here. Once this cementite nucleates, it has to nucleate by when when the cementite precipitates out, it takes carbon from the side.

So, carbon has to move. So, that means you have to allow time for movement of carbon atom and diffusion. And we have also seen the diffusion is a strong function of temperature and but we also need to provide another activation; that means when a cementite plate forms, it creates a new surface. So, for that we need a driving force and this driving force is provided by the degree of super cooling. If you cool more, then the driving force is higher. So, that means nucleation of this cementite particle will be faster; chance of nucleation (( )) of cementite particle will be higher. So, that means there are two computing factors. One you need a driving force to drive the reaction second you have to allow time or you have to control the temperature which will allow the carbon to diffuse to form cementite and this is what, we see in this.

(Refer Slide Time: 21:59)

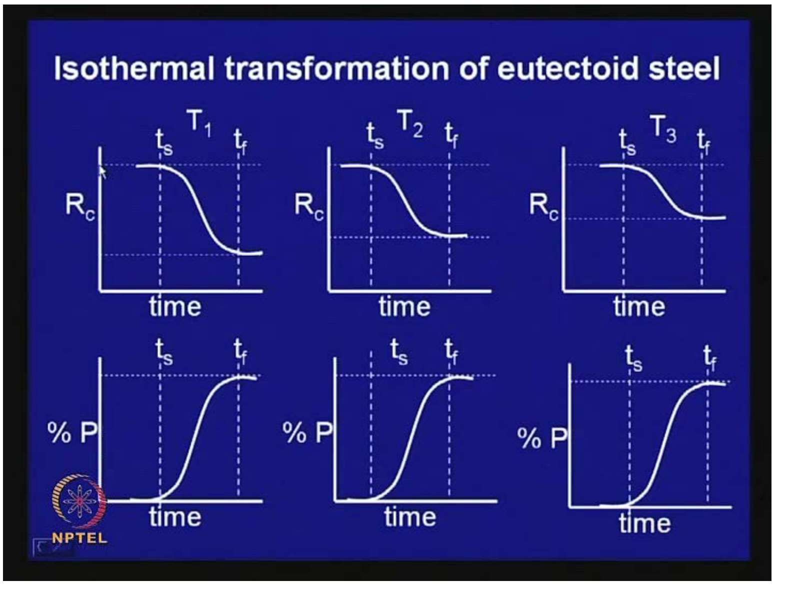


So, this is the pictorial representation of that how eutectoid structure that pearlitic structure forms; this is ferrite; this is cementite. Now, suppose you take a piece of steel; you put it in a furnace a bath, which is maintained at 760 degree centigrade, which is little higher than the eutectoid temperature and we keep it for sufficient length of time. So, that this piece attains uniform temperature from surface to the centre and we assume that the size of this sample is very small. And then what we do after keeping it for sufficient time? You transfer this to a bath maintained at 700 degree centigrade, which is little lower than the eutectoid temperature and then after keeping it, then we monitor the time. After keeping it for a time t, we transfer it to another bath at room temperature may be we quench it quench it to room temperature; maybe we quench in water.

And then we measure hardness and we polish the sample and etch and look at the micro structure. And we can repeat this experiment by maintaining the bath at 700 degree centigrade and say suppose another sample, we take transfer; we keep it for a time greater than the earlier previous time. And then we can have a series of sample, which has been kept here and then transferred. Then quench during temperature and then there let us measure their hardness and micro structure and then we will see that if you measure the hardness. In one case if you draw the micro structure, you will find that will be very difficult to etch. We will look at it structure little later and its hardness but is very high, which is 64. Now, Rockwell c scale hardness; if an steel Rockwell c scale is a very popular hardness scale, which we learnt in our earlier classes.

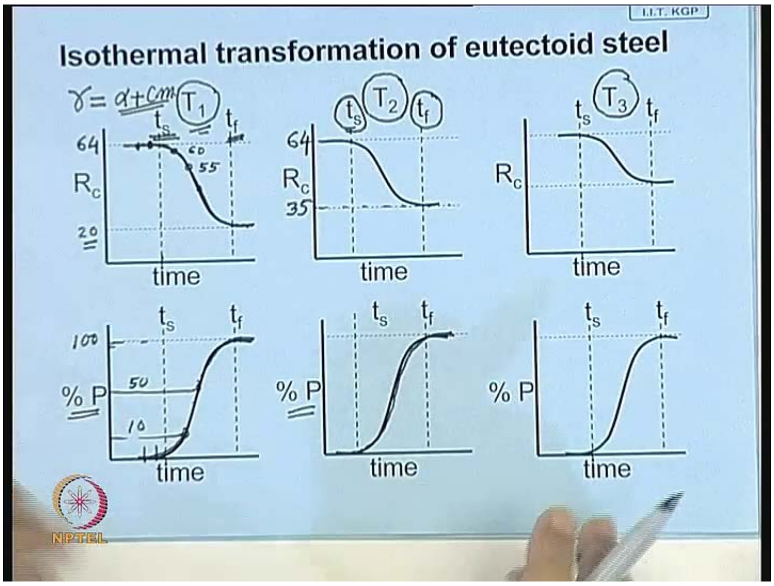
A method of measuring hardness and next look at another, which has been kept for a little longer time and here you see some nodules of this lamellar structure is forming alternate layers of ferrite and cementite. And when these modules are growing, so this the etch very easily. So, this you can see and this will etch very lightly and we will see that its micro structure little later. And this type of process and as the amount of this pearlite increases, you will find that the hardness decreases; here it is R c 50. You keep it for little longer time, you will have more number of such nodules and you will find its hardness is still less. And these type of experiments if one does and then then if one looks at the data.

(Refer Slide Time: 25:23)



Say, you prepare a table or you make a plot let us say. If you make a plot say first how does at a particular temperature? Say, suppose this is the intermediate bath has temperature T 1 and in that case what we have seen? The first sample when you quench after certain time, you get the maximum hardness and this is around 64. Say, this is what we have seen.

(Refer Slide Time: 25:54)

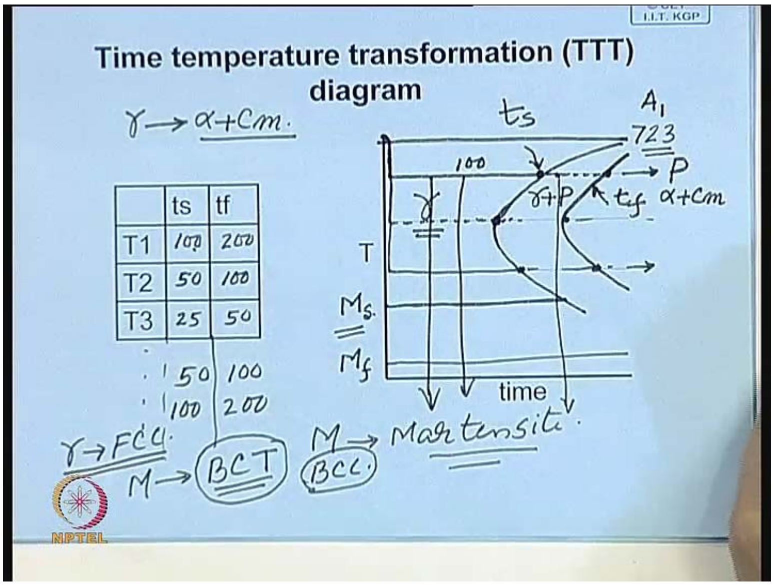


Here, this is around 64 and may be the second sample also… the first sample is 64; second sample also 64. After sometime, we may find that this is say little less; say this is say 60; then you get say say somewhere 55. So, this is how it will go on and may be somewhere here, it goes to may be R c 20 and then you if you join these points, you will get a plot like this; say sigma it have kind of plot. Similarly, if you look at that micro structure and try to find out the percentage of that pearlite nodule. And then you will find, here also you will get a similar structure initially. If you remember that previous slide, (Refer Slide Time: 21:59) here there is no pearlite. So, for certain cases there is no pearlite here; no pearlite.

And then that percentage pearlite goes on increasing; may be here it is 10 percent; here it is 50 percent and here it is 100 percent and here also if you join this point, you get this type of a sigmaidal curve and then what you do from here? You try and find out from where it starts deviating from this peak value. Then we say that this is where that decomposition of austenite, say the mean transformation is austenite is decomposing into pearlite. So, this type of structure; this is called pearlite. So, formation of pearlite starts from here. So, this we can say the t s that transformation pearlite transformation that is begins at this temperature. And similarly, where it reaches 100 percent that lowest hardness value we say that here the transformation is complete.

And we do the similar experiment that you have done by keeping that intermediate bath at T 1. We repeat the same experiment at another temperature T 2 and there also you exactly do the same thing and here you find that although this temperature, this part is still say 64. You will find here that hardness increases; say may be from 20, it become say 35. We will see why it becomes harder and then here also you try and find out the time at which the transformation begins or starts and time, when the transformation is over; that is finishing time. And similarly, that percentage pearlite from micro structure also; looking at the micro structure also, you can do the same thing and do another temperature and I am repeat this for a number of temperature T 1, T 2, T 3, T 4 and all. And then what you do? You compile a table.

(Refer Slide Time: 29:36)



If you compile a table at different temperature that is how does austenite decomposes into a mixture of ferrite and cementite. So, for this temperature T 1, say start temperature you get some number; say may be say say you you may find say this may be say this may be 100; this is 200; let us say 100 second, 200 second. I am putting arbitrary number and if you go down further, you may find that it has come down; this is 50; this is 100. If you come down further, maybe it is 25; this is 50. If you go down again, you may find again it starts increasing; somewhere you find that again, it becomes 50 and 100 and then again say suppose, it becomes 100 and 200. I am putting these numbers arbitrarily.

This will depend on… these are not the exact figure. I am just putting some arbitrary value. Now, let us say from this let us try and construct a diagram. Now, here let us say this temperature is the eutectoid temperature; that is let us say 723 and in phase diagram this is also represented as a temperature called A 1 temperature; critical temperature A 1.

Now, let us say this is the temperature here. Now, at let us say 700; this temperature these let us draw; this is start; this is the finish point. Similarly, here this is the start; this is the finish point. Similarly, another temperature we have seen once is start decreasing; then again it starts increasing. So, this is the way it goes and then if you join all these t s.

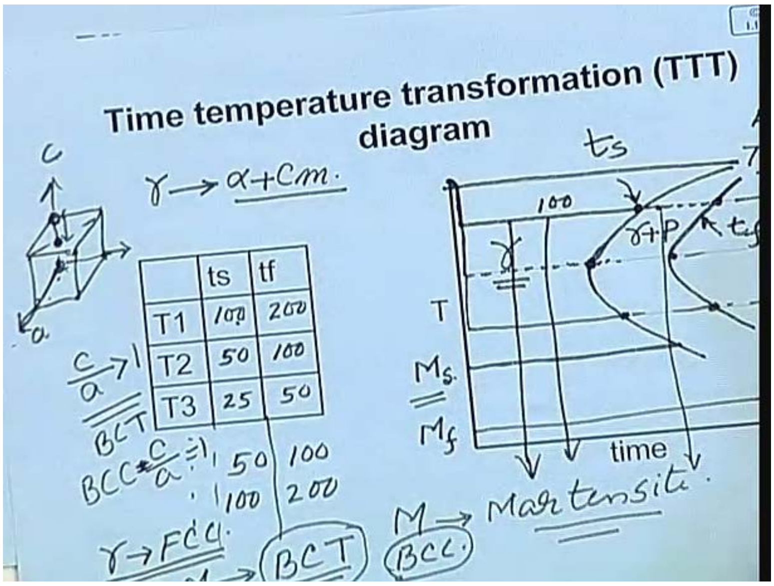
So, these are t s points; then you get a line like this and you you also get another line by joining these are this represents time of completion of pearlite completion or formation of pearlite or pearlitic transformation. So, this portion of the diagram here you have gamma. So, what you really have? You are cooling it. Say, suppose we visually look at what we are doing in this case. We are cooling it like this; then holding it for some time. So, this is let us say this is 100; the transformation starts and then it is completed here and you get pearlite. Similarly, in the second case you are cooling it here and you are holding your several samples.

Some of the samples you have cooled from here. We will see what happens in those cases. And then after it comes here, then the pearlite transformation starts and here it is completed and pearlite you know it is made up of ferrite and cementite and this is in between what you have? You will have a mixture of austenite plus pearlite. We also look at what happens. If some of the things we quench from here what will be the structure. Same thing here as well we will see here if you hold, this is the start; this is the finish. Here also, we get a similar ferrite carbide structure. But what happens when we cool? There is a temperature say some where here.

If it exceeds this temperature, we call this temperature M s. We get a totally different type of micro structure and there is a similar term M f. So, these are temperature; this calls the martensite start temperature; M stands for martensite. Now, we know that austenite is a solid solution of carbon in iron. All carbon which are there; they are present in the interstitial sites and if you quench and you do not allow this carbon to precipitate out, carbon is retained by force in the micro structure. Then you get a different lattice structure altogether and this structure see austenite is face centred cubic and martensite is called body centred tetragonal structure. And infact this deviation from body centred cubic structure is very little.

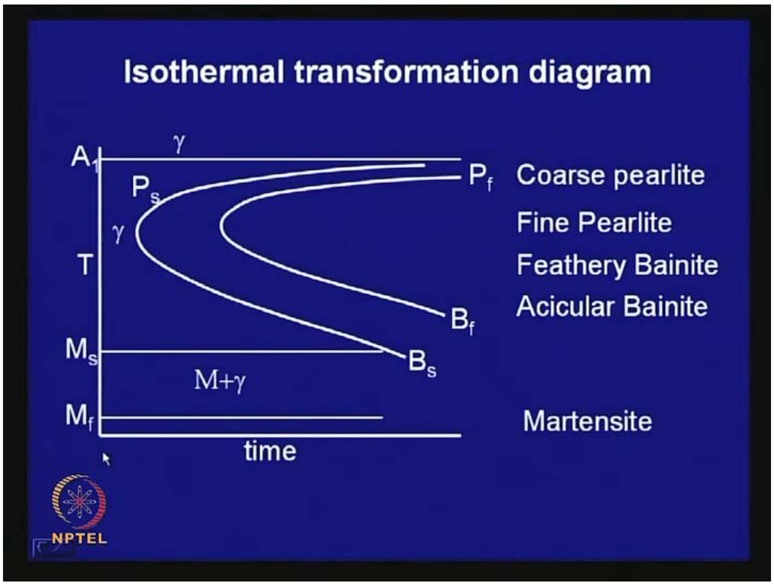
So, one can also assume as if it is a distorted a little distorted body centred cubic structure. We will talk about it later in other lectures as well. We will come back when we go to different subsequent chapters also. So, it is a distorted lattice. So, if you retain carbon say if you have a lattice structure and we know that diameter of carbon atom is little more than the interstitial site present. And we also have seen in the last class that interstitial site particularly in BCC that octahedral site, it is not symmetric; two direction you have the gaps are different. So, if you want to keep this carbon atom in the lattice site and still retain the structure as BCC, what happens in one direction? The lattice increases. So, that is the c axis.

(Refer Slide Time: 29:36)



So, we have say in a BCC structure; in a BCC lattice, a and c they are equal. In a BCC, distance atomic distance along the c direction and atomic distance along the a directions; they are same. Now, here if your carbon atom is over here; if it pushes this apart rather than the other directions, it has enough space to accommodate. But in this directions see in this direction, it has enough space to accommodate. But this direction is shorter; this gap is shorter. So, therefore in the so in this direction, it is shorter. So, therefore what will happen? This parameter will increase and what you have? c by a will be little greater than 1, in case of a BCT structure; whereas in BCC, this is 1; c by a ratio is 1. So, in one way, one can assume that this martensite martensite is a super saturated solid solution of carbon in alpha iron.

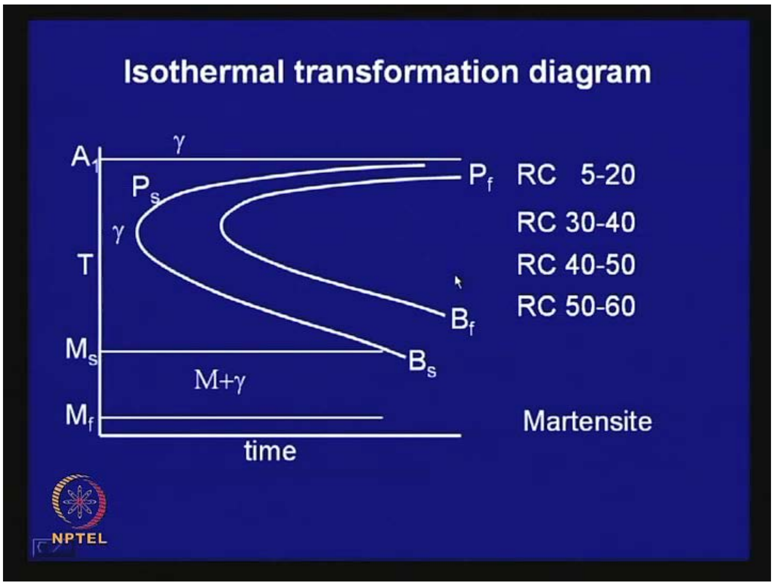
(Refer Slide Time: 37:50)



Now, let us look at now if you compile this diagram, what do you get? So, this is the type of diagram what you will get here. This is the A 1, the critical temperature; above it is totally austenite; this is the pearlite decomposition begins; this line represents the time. Say, if you cool it at isothermal temperature different isothermal temperature, this is the time you have to allow for this transformation to start and this is the time, when the transformation is complete. And if you get if you keep the steel at this temperature and allow the transformation to be complete, you will get a coarse pearlite structure; exactly it is lamellar structure; but spacing is wider. And if you go down, then diffusion distance decreases; lower temperature diffusion distance will be smaller.

So, you get a fine structure; fine pearlite structure and if you quench, you get a martensite and in case of a martensite, there is no diffusion. Carbon atom does not move. So, this type transformation is very fast. So, while the pearlitic transformation is diffusion control, formation of martensite is diffusion less transformation. There is no diffusion of carbon atom here and marten site. So, that is why if you are retaining carbon atom by force in the solid solutions, its hardness is very high and that hardness, it may comes almost the maximum hardness that is possible around 64 R c; that is what you get, if it is 100 percent martensite and so from here, where you have martensitic structure and a coarse pearlite, which is the softest structure.

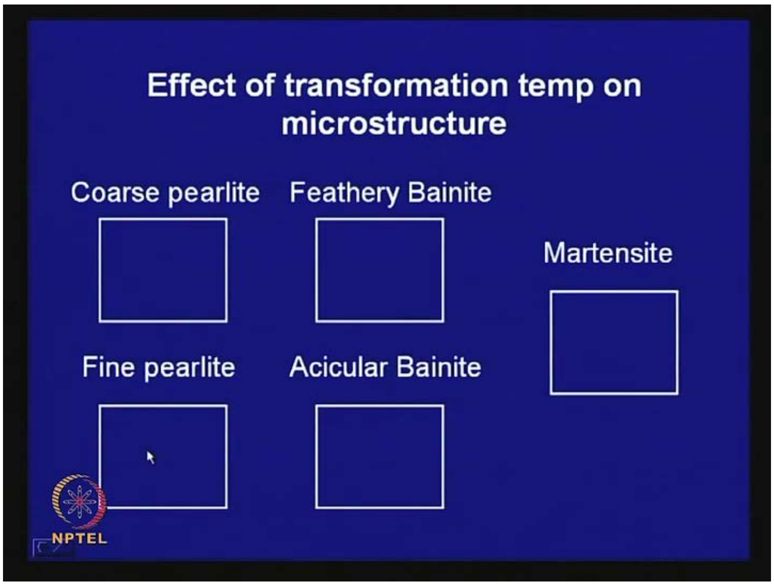
(Refer Slide Time: 39:40)



The next diagram, I think we have put down the values of the hardness. If you have a coarse pearlite, hardness is in this range. Fine pearlite, hardness is in this range. You have a little different structure; this is also ferrite plus carbide. But the way the carbides are present, they are not long plates of cementite; these are broken cementite plates. But very much similar closer to lamellar; whereas in this particular case, these carbides are still finer and the shape of this ferrite (( )) this carbide precipitates is little needle like type of structure. That is what happens in this particular case and this type of structure this one is called bainite and bainite, you have two classifications. (Refer Slide Time: 37:50) In the previous one, we name it which is closer to pearlitic structure.

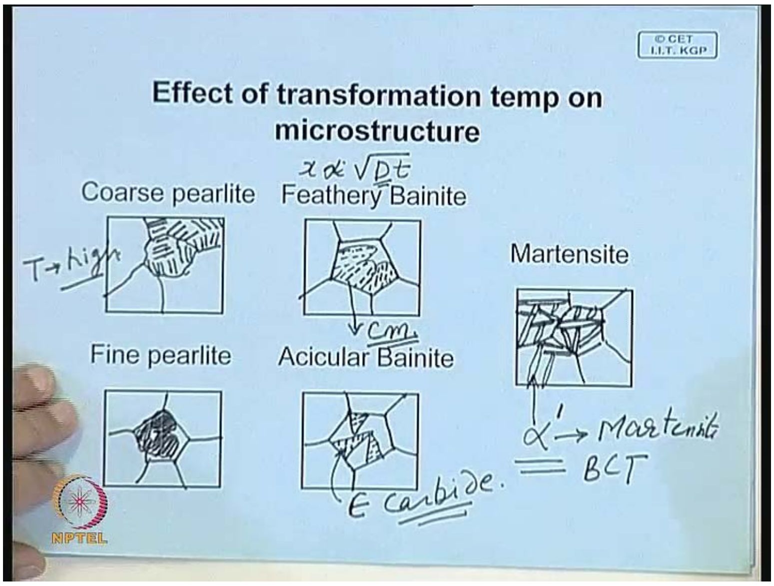
We call this feathery bainite. It only depends on if it in the optical micro structure, the structure is so fine. It will not be revealed in optical micro structure. But in ACM or TEM, if you look at that micro structure, you do see the nature of carbide and these platelets are broken and that can be seen. And similarly, the nature of this austenite ferrite grain and its morphology can be seen very clearly in electron microscope. And martensite structure, it is a single phase structure; it is a phase whereas pearlite and bainite, you cannot call them phase. They are mixture of two phases; whereas, martensite is a single phase and here you have more than much more than equilibrium amount of carbon present in solid solution and that makes this structure very hard. And it is the strongest phase that is possible … the bulk phase that is possible in conventional steel.

(Refer Slide Time: 41:55)



Let us now look at the nature of this structure. What it looks like? Pearlite we have seen.

(Refer Slide Time: 42:04)



Say what happens in the austenite? These are the austenite grains. So, you have this austenite grain and so here pearlite starts forming cementite nucleus; then these are cementite and white region is ferrite. So, this is how the pearlite structure will look like; there will be lamellar and this is how that entire area will be filled up. And only difference is here you can see that optical micro structure; you may see that this pearlite they are (( )) whereas, in this case if this is that these distance between these plates will be so small; that it will be difficult to… you may see that it is a very dark region this type. And you look and they will resolve and show that this type of lamellar structure, if you look under high magnification electron microscope.

But essentially, they are also made up of exactly similar lamellar structure; only the distance between these platelets plates are very small and they are so closely space that you cannot see these plates clearly. Now, in case of a bainite what you have is say suppose, here say we say that this is a this is an austenite grain in the structure. And when bainite starts forming, what happen? Here that mind you this is takes place at a temperature is high temperature is high temperature is high; whereas, here the temperature is low. And we know the diffusion distance is proportional to root over D t the diffusion distance is proportional to root over D t and lower temperature, the diffusion this D value is very small.

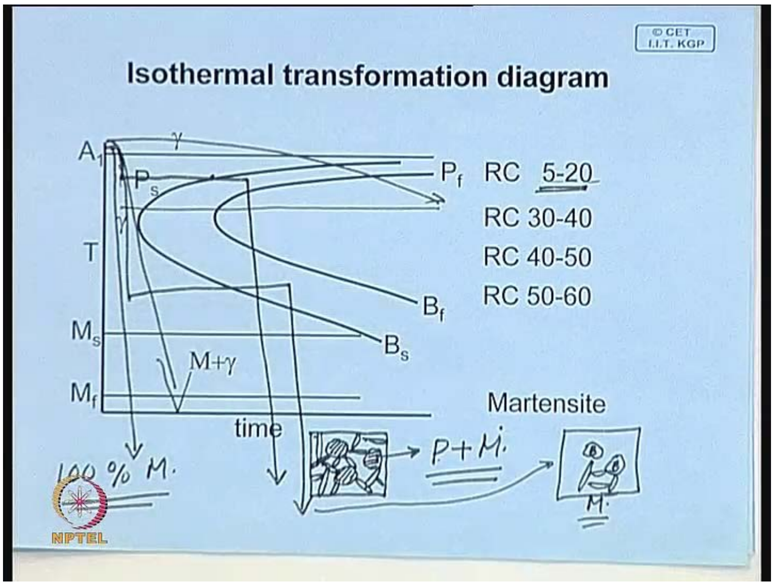
So, therefore that carbon atom will not be move able to move over large distance to form this type of a lamellar structure. So, what happens here? So, you have this cementite; these are broken like this; they are not… Say this is the ferrite grain and these are broken. So, this is another; so this type of broken carbides you will get in that ferrite grain and the structure is very fine. And what I am drawing here is a very enlarge view and optical microscope; it may look very much similar to this. It will be extremely difficult to distinguish between fine pearlite and feathery bainite; whereas in acicular, here here also this transformation always takes place starts near the boundary.

And here, whenever sometime it is say sometime this type of ferrite grain form and here you have carbides and these carbides are differently aligned. Here it is along the grain and here it makes a particular angle and they here; so it may have several this type of structure. So, ferrite has a typical needle like feature and these carbides are like this and this carbide here although it is cementite, same as in pearlite and here this is this is called different carbide. Its carbon content is little different, which is called epsilon carbide. This is you can say this is meta stable carbide and in martensite structure is also a extremely fine structure and here also the structure is a needle like structure and this growth takes place very fast. So, that means once a needle forms, it extends over the entire grain boundary. It forms; it goes through this.

It cannot cross the boundary and this is that way the structure develops. So, entire structure gets converted into this type of needle type of structure say this type of and they are so fine. This normal optical microscope and it will be very difficult to etch also. When you etch this steel you know polish and etch, etching actually attacks these boundaries and here such boundaries are not existing; that carbide boundaries are non-existent. So, it is little difficult to etch and later on, we will see. When we look at heat treatment, if you give a little tempering treatment, then they etch very easily. And when that carbide precipitates out in these platelets, these are called needle like; they are all BCT structure. Each has its own characteristic that is different orientation and we name it as alpha prime and this is called martensite and it has a body centred tetragonal structure.

(No audio from 48:45 to 49:03) And if we go back now (Refer Slide Time: 37:50) look at the structure what is happening? In a martensite, where you are not allowing the carbon to come out and the structure is the finest and this is where, it has the maximum strength; whereas, the coarser structure you get in this region. So, coarser structure has lowest hardness; finer structure is the martensite; in between you have a mixture of pearlite and in between you have a mixture of coarse pearlite fine. I mean in I mean the in between this intermediate isothermal temperature, the micro structure changes from coarse to fine, feathery, acicular bainite. As you go down that isothermal temperature, the structure becomes finer and it becomes much stronger and if we look at this and what happens if you quench in an intermediate fashion.

(Refer Slide Time: 50:20)



Say, suppose let us look at this diagram what type of structure you will get here. Say, suppose we have seen that when you quench like this, you get 100 percent martensite.

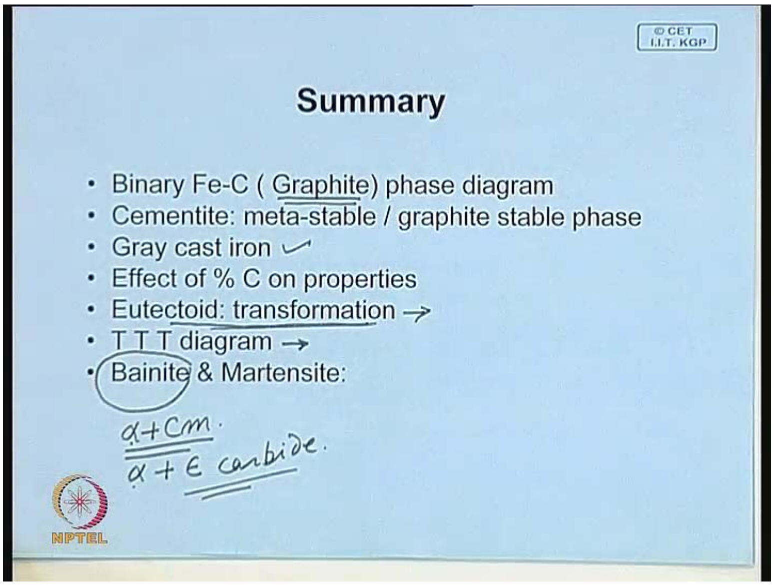
So, here the hardness is maximum; but when you come here and hold it and then you cool. In that case, what will be the micro structure? Here that micro structure you can visualize like this. You have once this point exceeds, you had these nodules of pearlite forming. These are nodules of pearlite have formed and then rest of the thing if you are quenching, here you do not allow time for the carbon to diffuse and form and continue with the process formation of pearlite.

So, here what will happen? You will have this type of needle like structure this type of needle like structure you will have. So, this is martensite this is martensite. So, what structure you have in (( )) between is a pearlite plus martensite structure and depending on the temperature, it can be coarse pearlite or fine pearlite. Similarly, if you quench something here, hold it and from here, you quench. In this case, the structure will be… In the same way, you will have colonies of bainite forming and rest portion will convert into martensite. So, the structure is a mixture of ferrite and martensite.

So, that is why here when you measure hardness, your hardness is in between martensite and pearlite. And if the transformation is the highest temperature, that lowest hardness that you can get is around this. If you if your transformation temperature goes down here, so that is why if you go back and see that lowest minimum hardness goes on increasing as the temperature decreases. And later on, we will see this can be extended; this concept can be extended to continuous cooling. So, normally this type of isothermal transformation is difficult to conduct.

And it is also possible to use this type of diagram to interpret what happens when you cool it structure slowly and when you cool it fast. Here also, I mean this concept is very useful to understand effect of cooling rate on the formation of micro structure in steel. And this we will come back later, when we talk about heat treatment of steel in a subsequent chapter. So, therefore we now finish that iron carbon system and mind you we have only looked at binary iron carbon system and if you have a third alloy element, the the phase diagram will alter. So, also the time temperature transformation diagram will also change and all these we will take up in subsequent lecture.

(Refer Slide Time: 54:20)



To sum up in these, today we looked at iron carbon phase diagram, and we have seen what happens how the diagram modified, if a stable graphite phase forms in the structure. We looked at gray cast iron. We looked at effect of carbon on properties of iron carbon alloy. We looked at eutectoid transformation; ofcourse, a qualitative explanation of eutectoid transformation, and we looked at the importance of the temperature in determining the micro structure of the transformation product. We talked about time temperature transformation diagram, and we also learnt about two different types of micro structure that you can get depending on the transformation temperature. One is bainite, which is little different from pearlite, but it is also mixture of either a carbide called ferrite cementite or it is ferrite plus epsilon carbide. And we will later on we will get opportunity will talk about it in detail, when we take up heat treatment subsequently at a later date. Thank you very much.