**Principles of Physical Metallurgy**
Prof. R. N. Ghosh
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Kharagpur

Lecture No. # 32
Heat Treatment of Steel (Contd.)

Good morning, we continue with our lecture on heat treatment of steel. Now, in the first class what we did is, (( )) we revised its few of the items which was covered earlier, primarily the part, relevant part of the phase diagram of steel and time temperature transformation diagram, which is called isothermal transformation diagram. We also talked about three different types of product that you can get depending on the temperature at which you allow the transformation to take place in 0.8 percent carbon steel. So, in the last class the entire topic was discussed with respect to a definite composition of the steel.

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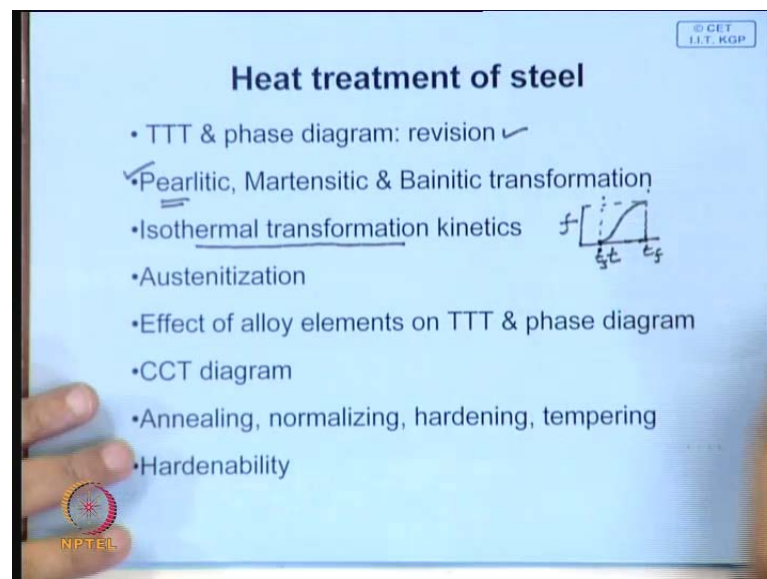
And in fact in short if you look back, what what we covered is this portion. We also talked about three different types of product as a result of three different types of transformation, and we looked little detail about how the formation of pearlitic takes place. We also talked about the nature of that isothermal transformation kinetics that means, we only looked at you know, the kind of plot that you get that is fraction transformed as a function of time and we what we found? That, there is an incubation

period this type of (( )) you get. Any isothermal transformation like the one that you get in pearlitic, it starts only after a certain length of time at a particular (( )) temperature, and it is completed only after a definite time. So, there is a start time, there is a finish time, and these are, both of these are functions of temperature. And let us build up on that a further.

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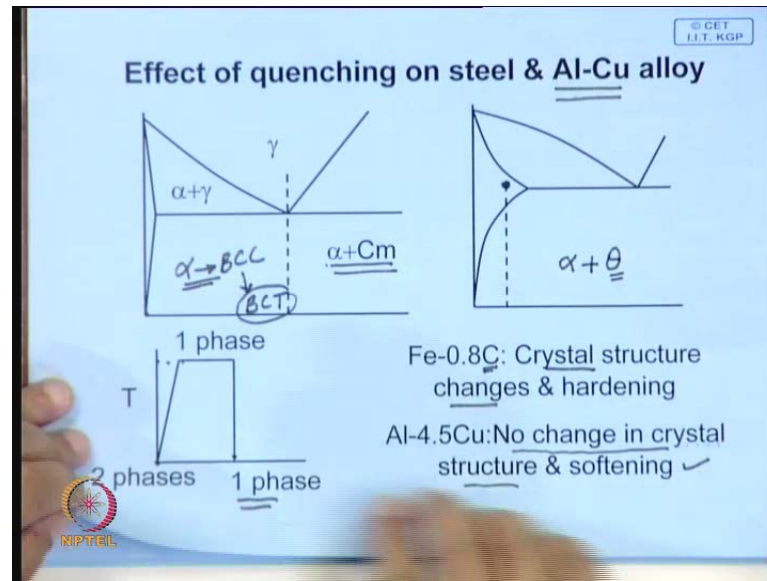
In fact if you try to recollect, there is a some similarity and the heat treatment process of what we talked about in case of aluminium copper alloy, where we heat it the alloy to the single phase region and then, if you cool it fast you get one kind of structure, if you cool it slowly you get another kind of structure. Now, if you compare the two here also, we talked about heating the steel, which is initially alpha plus ferrate plus cementite and here it is alpha plus theta, which is some (( )) compound of aluminium and copper. So, this is and here, this is an iron carbide (( )) is an iron carbide and in this particular case if you so, overall heating process if you look at a treatment process, you have initially a two phase structure, you heat it to this temperature, it single phase region allow it to remain at the temperature for some length of time then, you cooling it very fast, you get single phase structure, here also you get single phase structure, but look at the difference. Here, there is both cases, in this particular case there is no change in crystal structure and there is, and the materials becomes soft. whereas, in this case the crystal structure changes and by changing this crystal structure you are keeping by force much more amount carbon in the lattice, and the lattice gets disstorted. And instead of getting see normally the ferrate

is this is BCC, and if you keep a look at the solubility at room temperature it is virtually negligible. And if you quench what is happening? You are keeping almost nearly one atomic percent of carbon in the solid solution. And if you do so then this lattice get distorted and it changes to body centre tetragonal structure. So, we talk about this last class.

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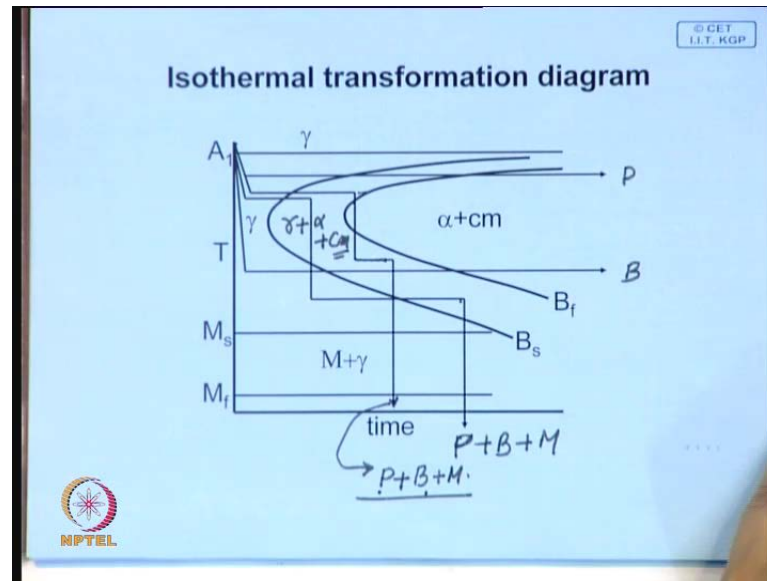
And we also see that, it is possible to design isothermal heat treatment process by which you can get different mixtures of structures. Suppose, if you quench heat a steel to this this particular steel in the (( )) region quench to a (( )) maintain at this temperature allow it. To transform completely here you get pearlitic structure, if you allow it to transform at this temperature you get bainitic structure, if you quench directly you get fully martenstic structure. Whereas, if you have with intermediate hold like this you hold it here; some amount of pearlitic forms you quench it, another and then here also and then here also you keep it for sufficiently some time length of time so that some amount of (( )) forms. And then finally, you quench; still they may be some amount of (( )). So, these the in between region actually represents, (( )) plus transformation product. Possibly, alpha plus carbide and (( )) one form of the carbide. So, in this particular case you get the pearlitic, you get bainite, you get matensite. Now, what happens in this particular case? Whenever, you draw a vertical line just thing you are cooling it, at a very fast rate. So, here there is some amount of untransformed (( )). So, that transformation you are suppressing, you are coming over here holding it was some time. So, there is a likelihood the part of this (( ))

transform and that will depend on the kinetics. Whether, the complete will transform or it will actually depend on its present structure and also how long your holding here. And finally, if there is something left, untransformed, if you quench form here, it can get transformed into martensite. So, here also all though it is crossing this line does not mean, that this pearlitic transformation is complete. This untransformed portion, will undergo transformation isothermally, here partly. And when you quench the remaining portion will get converted into martensite. So, here also you will get may be different amounts; no doubt, from this particular case, but here also you will get 3 different types of micro structure. So, total micro structure will be a composite micro structure consisting of pearlitic, bainite and martensite.

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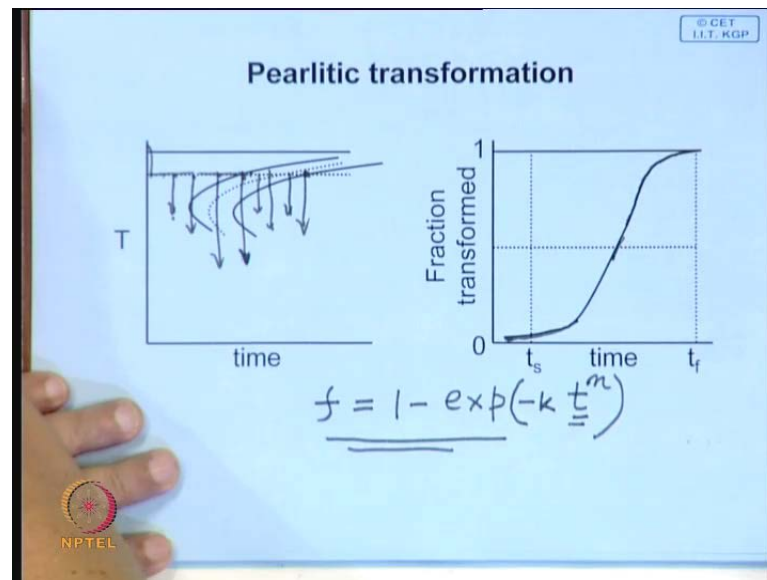
Now, let us look at that pearlitic transformation in little more detailed. Say here, say look at this and if you plot this as was mentioned earlier that, you have quenched it here, then you hold it, you cool some of these, quench from here, here, here. And may be if you look at that micro structure, you will find that in this particular case this hundred percent martensite, here hundred percent martensite, hundred percent martensite. So, all these cases it will have the maximum hardness and once pearlitic starts forming, the hardness will start dropping. And you will get a different micro structure, that is pearlitic will be able to see, amount of pearlitic will go on increasing. And it will reach nearly hundred percent over here and if you plot this fraction transform by following; either, this micro structure examination or hardness measurement, you can convert this data into fraction

transformed. And if you plot this fraction transformed you get some kind of this type of (( )) occurred. So, initially the transformation is slow, it picks up it is midway, it is the fastest and again the growth area decreases, the different modules and that try to go from different area when the transformation is nearing completion, they will impinge on each others. Therefore, that growth process will be (( )). So, again this rate of reaction decreases; so, this is the nature of this fraction transformed and if you look at that nature, you will find that it usually follows at this type of kinetics. (()) minus some constant k, take t to the power n at n, n is some exponent, t is the time. And usually this scale is often we use logarithmic scale. So, this is how it is represented, and this form in fact this shown here.

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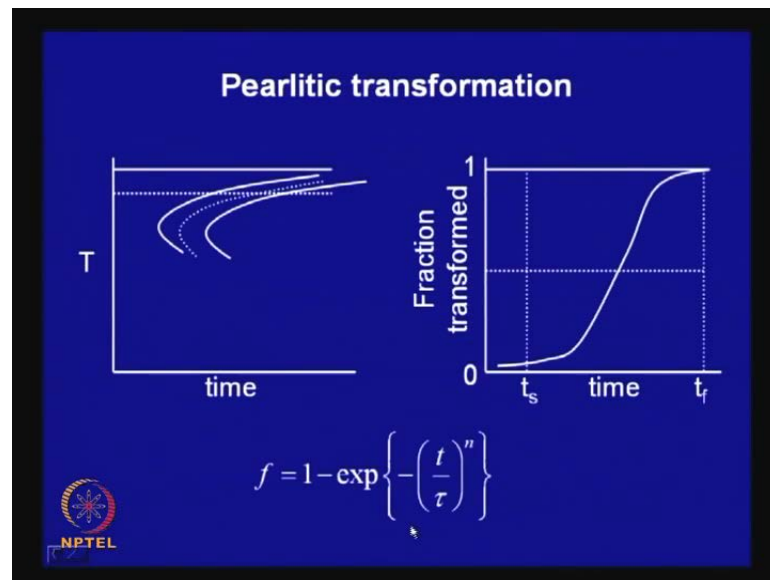
I think here look at this is the same equation which is written little differently this is the same equation written little differently. Instead of k which is outside this parenthesis, we are put tau, t over tau; tau is an characteristic kind, will come to know about it. And it is tau t over tau to raise to the power n. So, this is the famous (( )) sorry sorry, this Johnson Mahl Avrami equation and we will know about it how it is possible to derive that in this particular case. We do expect this type of representation. Now, the question comes, what are the experimental techniques one can adopt to find out this (( )) know about the transformation kinetics or kinetics of pearlitic transformation. One I mentioned is the micro structure examination, you do some interrupted quenching, from that isothermal temperature look at the micro structure. On the same sample you can follow the

transformation by measuring hardness and hardness is a function of micro structure. So, when you have martensite, you will have maximum hardness. And when you have pearlitic, you will have minimum hardness. So, in fact if you plot this hardness, say suppose you measure this hardness in (( )) scale and here is that time.

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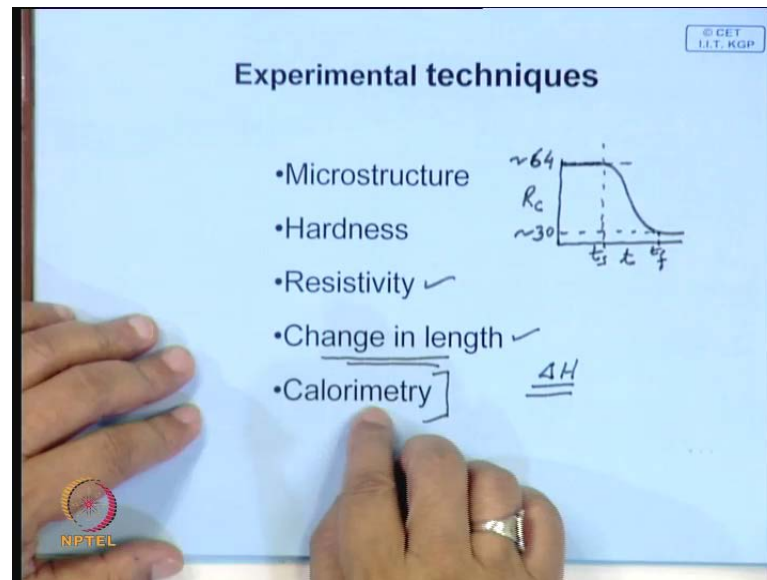
So, initially when you quench up to sometime you will find that hardness is possibly around R c 64 and it remains and there after its start decreasing with time. And finally, it levels of to a some lower temperature depending on that isothermal strength, which may be around R c 30. So, here from this plot you can say this is this start of transformation, this is the finishing point of the transformation, t f this is the starting point of the transformation.

Same thing is possible with resistivity and also it is possible to follow this type of transformation by measuring the change in length. Whenever, any phase transformation takes place the crystal structure may be changing, there is a redistribution of solid element, which results in change in length. So, this also can be used and we all know when we talk about transformation always there is some energy change. Some (( )) that heat either it is exothermic or endothermic process. So, if you can measure some calorimetry study; so, differential (( )) calorimetry or thermal analysis can also be used to follow the transformation kinetics. Now, a point about the nucleation and growth process.
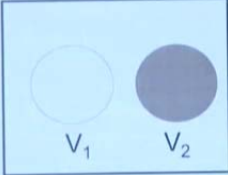
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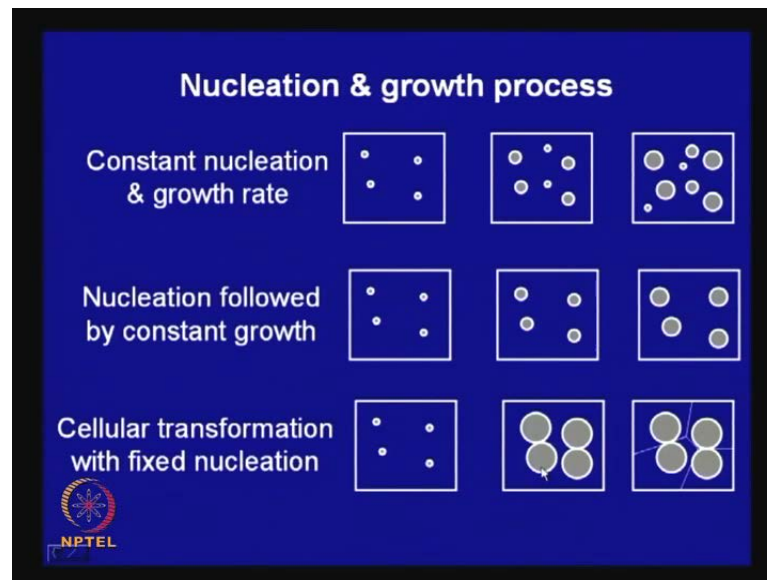
Now, here look at the nucleation and schematically it is shown over here, you have a certain number of nuclei which has formed. And which time two things can happen, one is if these nuclei they are stable, they size is greater than the critical size, they will grow which is shown over here this nuclei growing. And simultaneously, first nuclei stable nuclei may also form. So, two things take place parallely. So, you have nucleation going on, you have growth of stable nuclei. So, two processes the take place parallely. Whereas, we can also think about a process like this (( )) okay, we say that there are only certain specified site (( )) nucleation can take place. And only after all these sites are having some precipitate or some transformation product, only then the subsequent transformation will take place. So, that means this is initially nucleation starts take place and when all nucleation sites saturated then only growth process set same. So, this is that kind of a process. And finally, towards end also in both cases either here and here, you will also come up with a situation, when these keep growing and ultimately this transformation will also depend on this impingement factor something like this. Say suppose here, these are growing, then this start a stage will come, when they start touching and finally, you you know they start touching. So, here this growth in this direction (( )). So, this will growing this direction, this can grow in this direction. And ultimately you know this grows and by the time this grows comes up to here, may be this also will grow they come and you have this kind of structure developing. So, that means this is impingement is also an important factor and this thing shows up towards the end of the precipitation or transformation process.
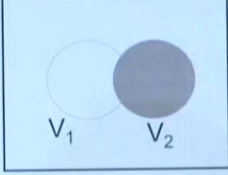
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Now, a quick look at this process which is shown over here. So, imagine so this is one nucleus which is growing, this is one grain versus growing, this is the another which is growing. And this volume is V 1, this volume is V 2 and let us say this is the volume of this total phase is V total V t. So, fraction transform you can estimate it sum of V 1 plus V 2 over total and now so, this we call if there is knowing impingement we can call that this true volume fraction. Whereas, in this particular case if you do what will you get? You see there is a area, where this two overlap these two are overlapping nevertheless we can still calculate a volume fraction base using the same expression as over here and which is done. And now, you expect and you really you can clearly feasible that and it is evident that, this volume fraction transformation this fraction transform will certainly be higher than the two fraction transform. So, we call this extended volume fraction, this (( )) extra volume fraction this is there is something extra, that true plus something extra is this. And is there a way of finding out. So, that means if you look at, say suppose we say that there is a relationship, there is a small increment in true volume fraction and then is a small increment in, (( )) extended volume fraction. Now, these two they will be nearly equal when volume fraction is very close to is very low, chance of impingement is remote, but when f approaches is say 1, in that case what should happen? Then this increasing true volume fraction will be extremely low, it should tend towards 0. So, that means d f should tend to 0. So, that means one relationship that obviously that becomes obvious, that this is likely to be given by the this is (( )) extended volume fraction 1 minus f. So, you look at it, if you put this is 0 both are equal. Whereas, if you put when it

is approaching one, then you see there is a large difference between the two. So, this is approaching 0. Therefore, where this offers a simple method of finding out the relationship between fraction transformed and which can be done very easily. Say, how will you do it?
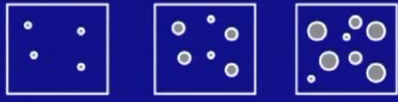
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 See in that case, what we can assume see if you make some assumption. Suppose, we make this assumption that is site saturation model, that means you have fixed nucleation site. You have only n number of nucleation site, n nucleation site and once all these n nuclei they have formed then only grows (( )). So, you can easily find out say suppose if, the radius of that nucleus is r. So, your volume will be proportional to this which is 4 pi by 3 r cube. So, this is the volume if you say that there are n nucleus of this type, so you multiply this (( )). Therefore, this we can see is equal to extended volume fraction and if you assume that there is a growth weight is constant that means r increases linearly with time, so suppose this g dot is the growth rate time. So, if you substitute this here you get an expression for extended volume fraction. Now, to get the extended what you need to do is differential at this expression this is a function of time you differentiate and this we know is equal to f over one minus f. And once you substitute this over here, then you can integrate and get that expression and which is shown over here. Look at this steps, so here these are the nucleus fixed number of nuclei and this is what has been done. You have certain fix number of nucleation site and once this all sites are saturated this is the extended volume fraction differentiate it with time, you get this. And then if you

integrate you get this expression and (( )) get look at that expression. See, this is a constant. This and you can find out this constant is equal to (( )) rather I think this should be this is 1 to the power n so this should be tau I believe. So, this you can find out what will be the tau can express, tau in terms of is not k that is can you expressed tau in terms of as a function of nucleation site and growth rate. So, in fact this type of derivation helps because it helps you to analyze the experimental data that you collect and it helps you to get a physical in site into the transformation process. And in that case if you get a good physical in site by controlling the experimental parameter, you will be able to control the micro structure and you will be able to therefore, control the property that you except. And this property in turn will affect the performance of the material.

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Now, look at I mean for that pearlitic transformation actually it has been extensible (( )) and it follows this Johnson Mehl Avrami equation. And here the assumption is both nucleation and growth rate both are constant that means nucleation there we assume that there is a fix number of nucleus in the previous model and here we say that this is constant (( )) constant and growth rate is constant. So, here also we can try and find out a small increment in this. So, at any instant there will be some amount of nucleation you know, you can find out what will be the number of nuclei at any at any time. At any time that there will be certain number of nuclei present and this you can easily find this out because this is nucleation rate is constant. So, at any time t you will have so if a time

increases say suppose we want to find out if this increases say increment in extended volume during a time period t. How will you calculate?

So, here there is a nucleation which is taking place, we can say n d t is the nucleation weight. So, what we can say that there is up to a certain time, this has been following this nucleation kinetics up to that time, n dot times t this is many nuclei already there. And these are going to grow and then, what you can do is you find out the average size of (()). So, this is 4 pi by 3 then g dot time this is the average size of of the nuclei. So, with this if you try to solve the previous equation which is shown here, I think what is missed here is another time t because there is t cube you will get n dot. So, this is nucleation rate after that here you have to insert a time t. Which is missed over here and so here therefore, you will get this will be t to the power 4 and then you integrate this, if you integrate this there is a t cube here. So, this is up to a time this d t no no its okay. This is perfect, this expression is perfect, rather I made a mistake here. You need not because up to a time this is the growth rate. So, within this time so many nuclei will be forming and what we are putting it. It is right in the beginning of the transformation process, this is the total number of nuclei which will be present at time d t, that initial right in the initial stage. So many nuclei and this is the average size of those nuclei, within that time that small time (( )), we are considering at a time t you have certain number of nuclei. And what happens at time t plus delta t, the volume fraction will increase by this amount. And then what you do? You you integrate this sense this t cube here, you will get t to the power 4 and expression comes out to be this. And here also, what you do? You try to find out tau this expression is given here.

Now look at the thing, earlier we got this exponent 3, here we get exponent 4. That means this n is an indicator of the mechanism, it helps you verify the assumption that is follows, that it follows the transformation process. So, that way we know if you try to build up this kind of equation knowing, I mean some that physical concept it is possible to get deeper inside into the process kinetics. And this is what has been done here, say in the site saturation model if the sites are are saturation model this exponent is 3. Whereas, if you have constant nucleation, constant growth rate process, then you get exponent 4. And similarly, as we it is possible to show with other subsequent mechanism, this exponent changes. And it also sometimes, it also gives you the shape of you have precipitate as well.
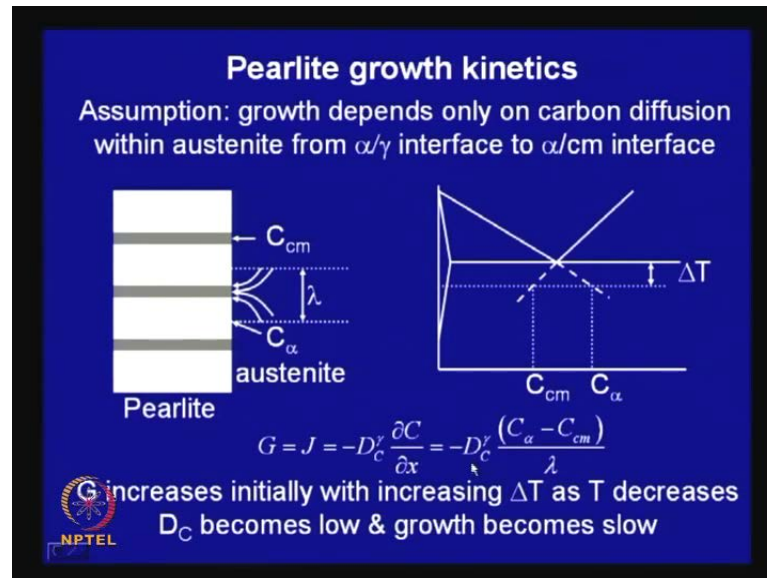
Now a quick look here, at the growth kinetics little detail the pearlite growth kinetics. And it was mention that pearlite growth it is follows through nucleation of cementite, at may be this is an austenite boundary. A plate of cementite nucleus and at this disturb the carbon concentration in this surrounding, when you have this nucleus this forming, when when cementite precipitates out. Look at the phase diagram, if this transformation is taking place at this temperature, this is the degree of super cooling you have. Here, this is the amount of carbon ferrite can have and this is the micro. Here, ferrite is the stable phase, cementite is the stable phase. And when this cementite forms from an austenite, it draws all the carbon from the austenite. Therefore, this surrounding what happens? Where with austenite, when this cementite forms so, this is the carbon concentration in austenite which is remains in equilibrium with cementite. So, that means if you have austenite (( )) over here, you have austenite this austenite will be equilibrium with cementite. And the carbon concentration in austenite near this cementite interface will be this, we given by this. Whereas, cementite carbon concentration denote 6.63. So, since that much carbon has been (( )) from this neighbouring region. Here, this carbon concentration drops, and which ferrate also it is possible to find out what is the carbon contained at this ferrate that interface. At ferrate interface you can find out by extending this, this is the carbon concentration in ferrate which remains in equilibrium, this is the carbon concentration in austenite rather, we should have may be if there is a confusion think about it, we write like this. This is carbon concentration in alpha near gamma that interface, this is carbon concentration in gamma near that cementite interface. So, there

is a difference in carbon concentration. Here you have more carbon, this carbon will diffuse inside also, here also you have 0.8 percent carbon (( )). So, from here also there is a concentration gradient it will star diffusing. Therefore, what you have using the diffusion kinetics you can find out the flux of carbon atom, which will move towards this and this will determine this growth rate. That is G dot, which will be equal to that carbon, which will proportional to the carbon (( )), proportional to the diffusivity, proportional to the concentration gradient. And this concentration gradient you can represent, this is the difference in concentration, this is the maximum difference. So, this will be the fastest movement from here to ther. And look at this distance lambda so, this is you can say, this is a average lambda is this, inter (( )) phasing that phasing between two cementite plate or phasing between the centre point of two ferrate plates. And therefore, what happens, is this growth rate it depends on diffusivity which is a function of temperature. We know that diffusivity is a function of diffusivity is a function of temperature, diffusivity is a proportional to exponential minus activation energy over r t. So, if the temperature goes down, the diffusivity becomes low. So, there are two (( )) and again is look at this driving force for the carbon movement is controlled by this distance, to higher the (( )) cooling, higher is the driving force for that diffusion. And there are two different opposing factor. Therefore, the G actually initially increases with delta T, initially it will increase, but when you go down the diffusivity this will be come out to dominate. So, it can be come slow again.

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And that is why you get the c shape curve that you get in the transformation diagram and which is so, this answers is why do we get C shaped prime temperature transformation curve. So, this is the total expression for fraction transform and usually often we talk about that 50 percent that limit actually. When you have this CCT diagram that continous transformation diagram, it is often convenient to represent transformation kinetics by a this C shape curve. Which represents actually this is temperature, this is time and this represents time for 50 percent transformation to occur. And which can easily be related to the tau, there can be some direct relationship (( )) tau and I leave this to you to show that to time to reach 50 percent transformation, can be represent expressed in terms of nucleation rate and growth rate. So, this is the type of expression you will get and to some of here, up to this is at low delta T, you have driving force for both nucleation and growth is low. And at high delta T the diffusion rate becomes extremely slow. Therefore, although nucleation may go up, but point is this growth becomes very slow. And therefore, maximum rate that you get, is an maximum rate that you will get at an intermediate temperature. So, this explains the C shape nature of the curve.

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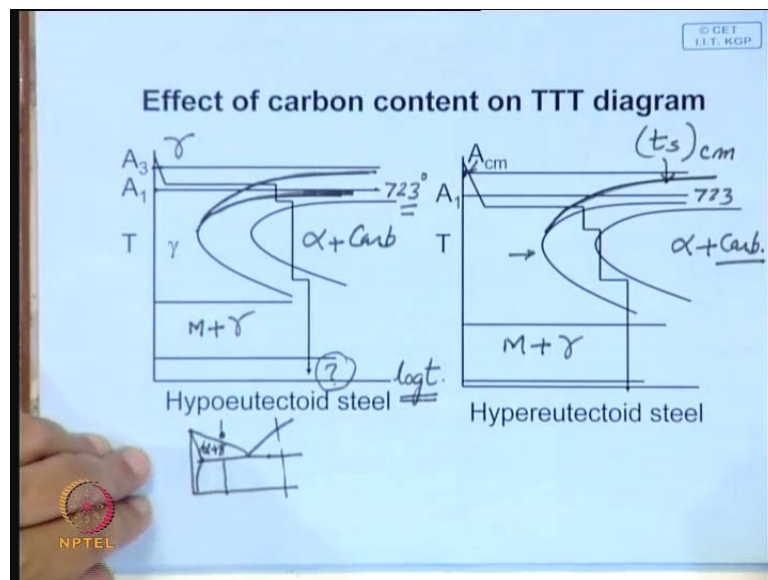
Now, a quick look just now so long we look at only (( )), what happens if the carbon content changes? In that a particular case the nature of the CCT diagram will change and what change will be there. So, here there will be some transformation, even before the eutectic temperature is reached. If you recall that the phase diagram, you have that if you recall that phase diagram you have a region like this, hypoeutectoid steel over here,

hypereutectoid (( )) this place. And both cases if you start cooling from this point, you pass through a region, where from austenite ferrate will start precipitating first. And if this happens, then how will this transformation diagram be modified? Basic nature will steel because same, but what we will happen is there will be another critical temperature. This is over this A 3 only, you have full austenite. When you heat it above A 3 you get homogenous austenite, A 1 this is the temperature eutectic temperature is roughly around 723 degree centigrade. And when you start cooling here, if you hold it isothermally after some time, (( )) will start precipitating out. So, you will get another line, which represents start of ferrate transformation. Similarly, there should be a line for ferrate completion of that ferrate transformation and which indeed is actually is start of once that ferrate is complete then automatically this transformation starts, but this cannot start unless the temperature goes below 723. So, this becomes (( )) here, this becomes (( )) over here. And here also you can think of, you know if you have this type of isothermal transformation diagram what will be the product? I will leave it to you to answer. And exactly, what you have you only have another additional line, second is of course these time value etc. That may change, (( )) what will happen possibly, this will come closer, the (( )) will come closer to the origin, closer. And usually this time is a logarithmic scale, all this TTT diagram that drawn with a logarithmic time scale. And in case of hypereutectoid steel, this critical temperature is known as A cm and here also this is 723 this line represents, initialization of cementite precipitation, to start for cementite. And here also, nature is the exactly same and this (( )) with increasing carbon contained you may find that this (( )) they shift to the higher temperature side. And rest of the part or not going into the detail, which are exactly same here also you will get (( )) site plus (( )), this also is an (( )) plus austenit and this side is ferrate plus carbide.

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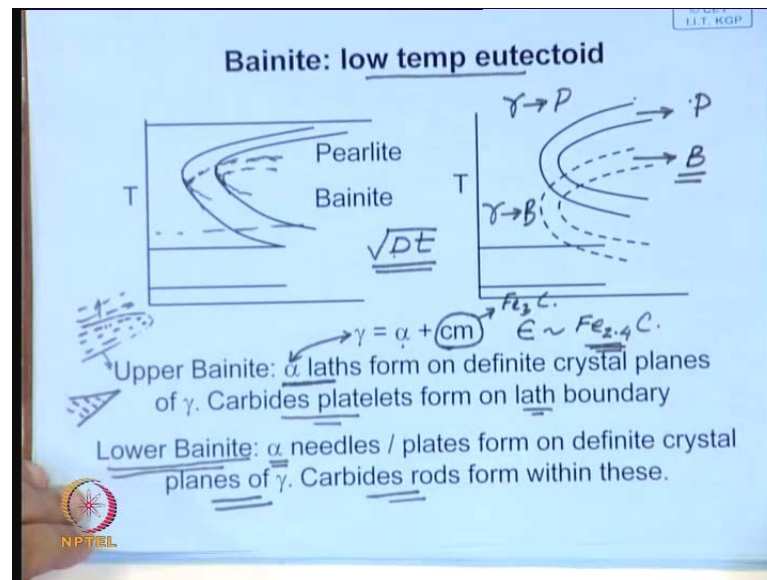
Now, let us see we talked about bainite and bainite is also and eutectoid product, what we can see this is the low temperature eutectoid product. Then you, your under cooling is very large. What happens, the diffusivity decreases significant, diffusivity of carbon and austenite is very low. And since this diffusion distance therefore, this diffusion distance which is proportionally, if you recall this the diffusion that time scale for the diffusion is proportional to root over del, d is the diffusivity take time t. So, if this becomes very small, very low, this becomes small. So, the carbon the distance the carbon can diffuses shorter. Therefore, you get much finer dispersion of carbide, another things that type of product that you get is little different and in case of and one can actually visualize that you have two such of that (( )), this is the set of (( )), which is for pearlite this is for pearlite transformation. You also have a bainite CCT, a bainite (( )). Peartlitic (( )) representing isothermal transformation into decomposing austenite into pearlite, you have similar (( )) for decomposition of austenite to bainite, which is this. And for plane carbon steel (( )) found, that they overlap. So that, mean bainite possibly this plot the see, this is the portion you can say, this is the portion of pearlite and this is the portion of bainite, they merge together. Although, so although we get apparently it looks one (( )), but it may be a super in position up to such (( )), which is shown over here. And if you look at the bainite transformation, here also you get this ferrate plus carbide sometime in some particularly low temperature instead of cementite, you may get a little different carbide (( )) epsilon carbide. Which is approximately, 2.4 C. So, this has a little cementite roughly is Fe 3 C. Here, what you can say here there is a little more carbon

possible. Now, this upper (( )), here also there is a distinction, if you look at the micro structure critically there is a I mean say if you look at pearlite the top portion you get (( )) pearlite, bottom you get (( )) pearlite, difference is only in where scale of mixing. So, one is (( )) up another is (( )). Whereas, in case of a bainite there is a little more difference and what is it? One is the way is structure develops, unlike pearlite there is some orientation relationship here. So, what happens in case of a bainite, some strips or laths of ferrate form at the grain boundary and and this this move and as it moves the carbon start precipitating as carbides. And these laths or these grains of fine very fine grains laths of ferrate they maintained a definite relationship bet[ween] crystallography relationship with austenite. There is a definite crystallography relationship between the alpha that precipitates out in gamma and we will see this let us we go on. And they form on definite crystal planes and then this carbides platelets form on that lath boundary. So, feature we had if you recollect, you you have this ferrate that plates and this is how the carbides and and this keeps growing like this. And and you have this this type of broken carbide platelets and often they are so closely spaced, that even you are likely to confuse this with fine pearlitic structure. And if your transformation temperature is lower, somewhere here, then you get a different type of bainite. Which is called lower bainite and here this shape of this alpha that that nucleates, this shape is little different. This is (( )) type and the carbide that forms may also be little different, they may be differently orientated, something like this, but here also there is a different orientation relationships that it follows with austenite. And carbides are in the form of very small rods thin rods within this within this, needless of these grains of ferrate that forms and as we will go on we will see often one (( )) get confuse between this structure of lower bainite and (( )).
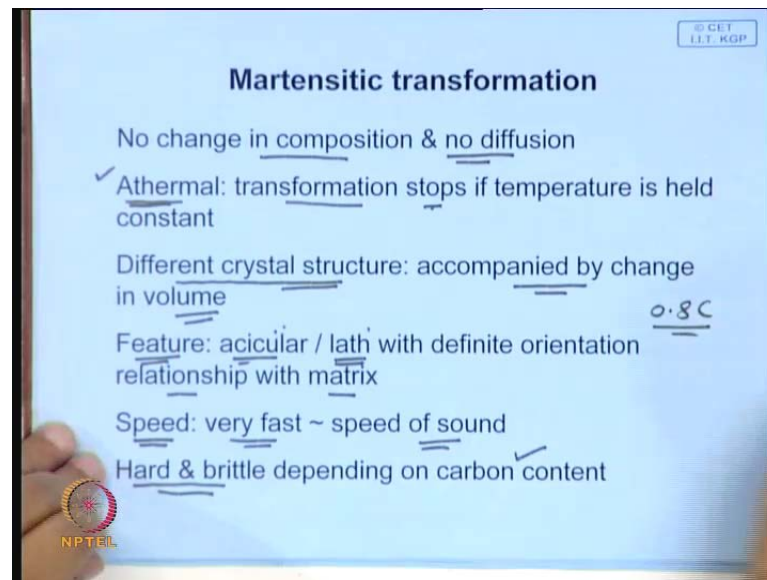
And if you cool that sample from austenite you quench it in water, you mention that you get martensit and last class we talked about this structure, but it has few other characteristics, which are listed here here. There is no change in composition. Obviously, there is no diffusion, no movement of carbon atom, it is athermal a transformation continues as long as temperature goes down, once the temperature goes below (( )), its starts when the temperature goes below critical temperature and once the temperature is crossed it goes on continued as long as you keep it cooling. If you hold in between, then the transformation stops. This is the athermal character of martensit and this is specific to (( )) carbon martensit, what we are talking about. We will later see there are certain different varieties of martensitic transformation. There is a crystal different, it has a different crystal structure and when this crystal structure forms that is accompanied by change in significant change in volume. And which (( )) a significant amount of stress in this structure and the feature appearance it depends on the composition particularly, if you are considering a 0.8 carbon steel. In that case it is acicular, if the carbon contain is lower (( )) then it is a lath character, acicular and lath; acicular its sometime you can say it is also known as (( )) or sometime we will see later. Acicular (( )) and this is lath is like a thin plates or or you can say it is a thin strip, with a definite orientation relationship with matrix. And this orientation relationship acicular and lath they have a different orientation relationship, then comes the speed it is very fast. So, that is the character ethermal character and this speed is of the order of sound, that means the (( )) moves at the speed of sound. Therefore, if when the martensit forms, if it is possible to keep an

micro phone, you can amplify and you can here the noise. That is an since you are keeping so much of carbon in solution by force it is extremely hard and it is also brittle and this extend of hardness and brittleness will depend carbon content (( )).

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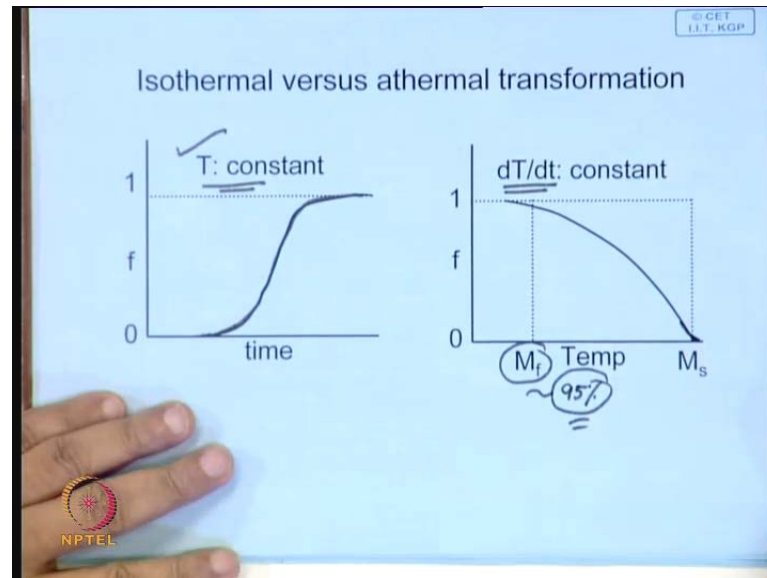
And a quick comparison between isothermal and athermal transformation. So, this feature we have very very much familiar with, this is the isothermal (( )). Whereas, athermal what we have maintaining, here temperature this is constant, here possibly you say the cooling rate is constant. And transformation starts only when M s is crossed and once this M s cross, this transformation continuously continuous like this and it is extremely difficult to find out where the transformation is complete. And we will always you see later, but some amount of untransformed matensit or austenite remains in this structure. So, usually M f corresponds to possibly 95 percent transformation.

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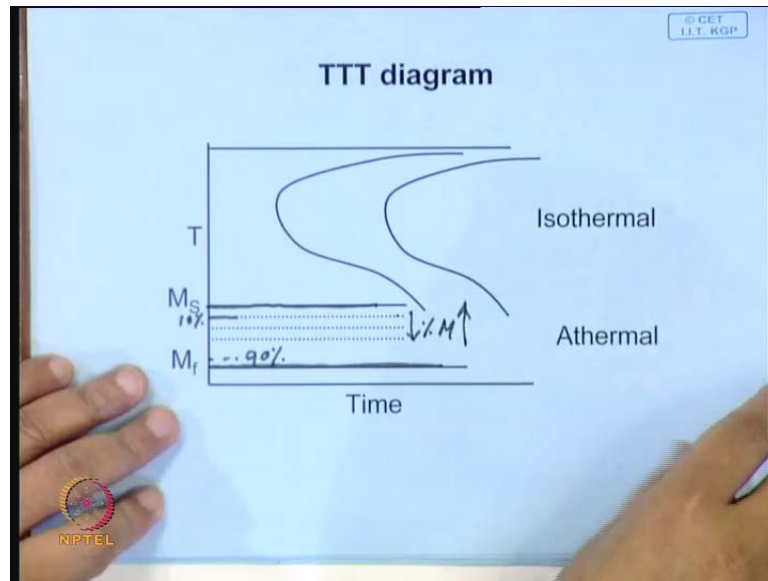
So, this is the basic difference between the two and isothermal and athermal character isothermal will have this C type of shape. Whereas, athermal martensite, you just get indicate this two temperature and as you go down, this is percentage martensite increases. This as you temperature goes down percentage martensite goes up. So, here it may be 10 percent, as you come here <mark>here</mark> may be ninty percent. So this is, this character <mark>(( ))</mark> to some a <mark>a</mark>, quick look at comparison of the three pearlite, bainite and martensite transformation, which are listed here.
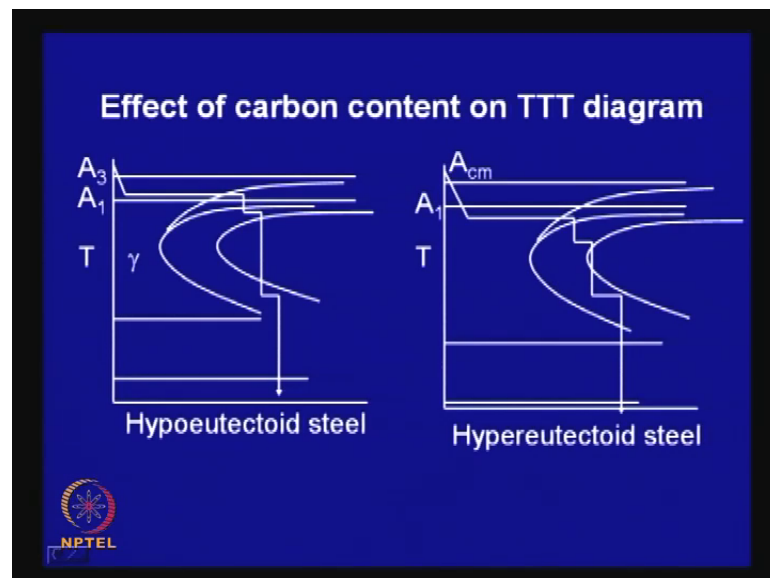
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Structure, this as a lamellar structure, bainite you have two distinct, lath plus cementite acicular plus cementite or epsilon carbide. Whereas, martensite is a acicular, in this particular case a low carbon martinsite can be lath martensite, but important feature it is a single phase. Both these are double phase, two phase mixture, that this is single phase. Here there is a long range diffusion, here also some precipitate forms. There is diffusion, but diffusion distance is low, so that means root D t that is length scale to which carbon moves, this is slow. Here there is no diffusion, transformation characteristic this is isothermal, this is isothermal, this is athermal orientation relationship, here there is none. Whereas, here there is definite orientation relationship between austenite and ferrate lath that forms. Here also there is a definite orientation relationship, you have one kind of orientation relationship in lath martensite. Another kind of orientation relationship acicular or plate martensite.

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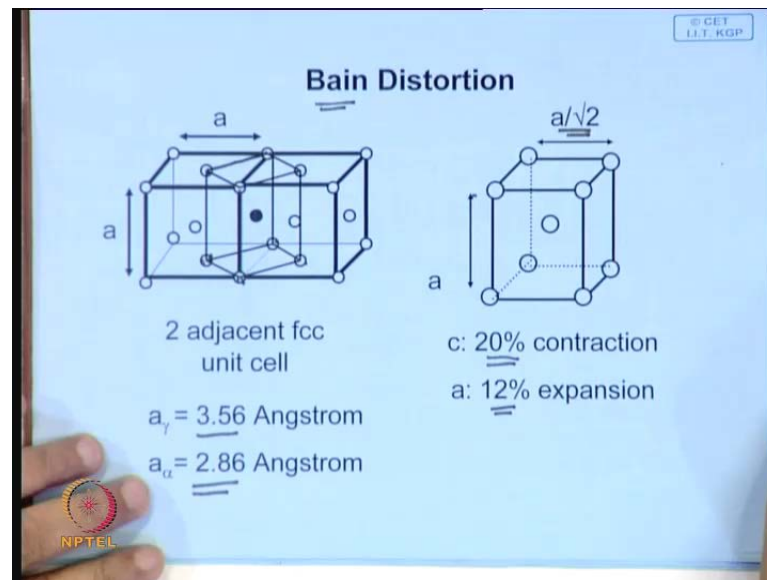
A quick look at the crystal structure. See, when martensite forms initial structure is austenite. And when it forms transforms into (( )) structure, you can visualize crystallography transformation like this. You imagine, join these then you get there is one atom at the centre here and you have these atoms at the corner, but the dimension this dimension is a, this dimension is a. Whereas, this dimension is a over root 2, this dimension is a. Now look at this dimension, lattice parameter of austenite, lattice parameter of ferrate is this. Now, when it transforms into a retain, it transform into martensite, what happens? This crystal structure changes slightly and what is the change this c axis this particular axis, undergoes twenty percent contraction. Whereas, this axis expands by around twelve percent. So, this is the (( )) transformation and this leads to a distortion, which is called as lattice distortion, which is called bain distortion.

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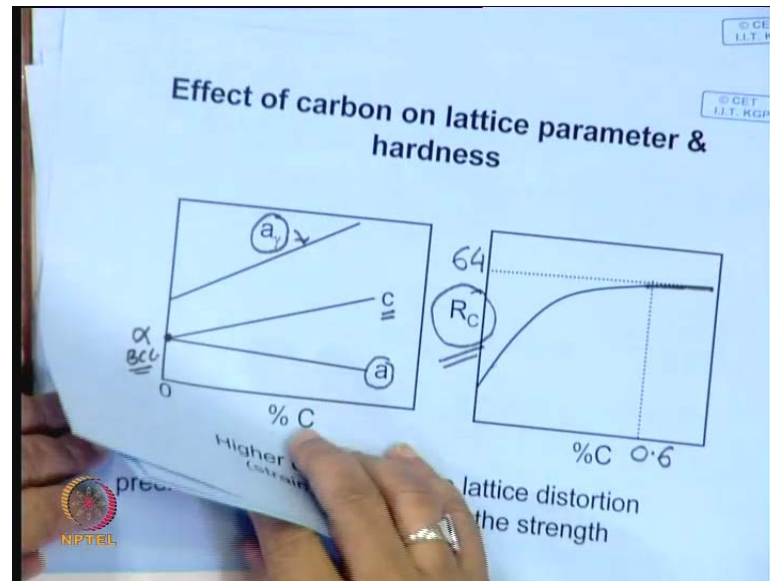
And lattice distortion means obviously, there will be change in lattice parameter and lattice parameter change which are shown over here. This is the lattice parameter of austenite, it changes percentage carbon and this is the lattice parameter of we can see martensite, when the carbon content is low this is alpha in that case this here it is nearly BCC. Whereas, as carbon content increases, this c axis increases because there is you said that there is a contraction no doubt, but still that contraction is not large enough. You know, where as this is then this expands, but still both are not no longer not necessary equal. Therefore, what is happening here this c by a ratio goes on increasing and because of this there is a heavy lattice distortion, higher the amount of carbon that is more lattice distortion and this reflects in the strength of the martensite. So, that means an martensite very often in engineering scale is (( )) hardness it is measured r c, this is around sixty four and when it goes around 0.6, this 0.64 hardness is attain. Before that, beyond this the hardness increases nominal, which is not does not show in (( )) hardness scale. So, we stop write over here, next class will talk about little more about martensite and build up on that.

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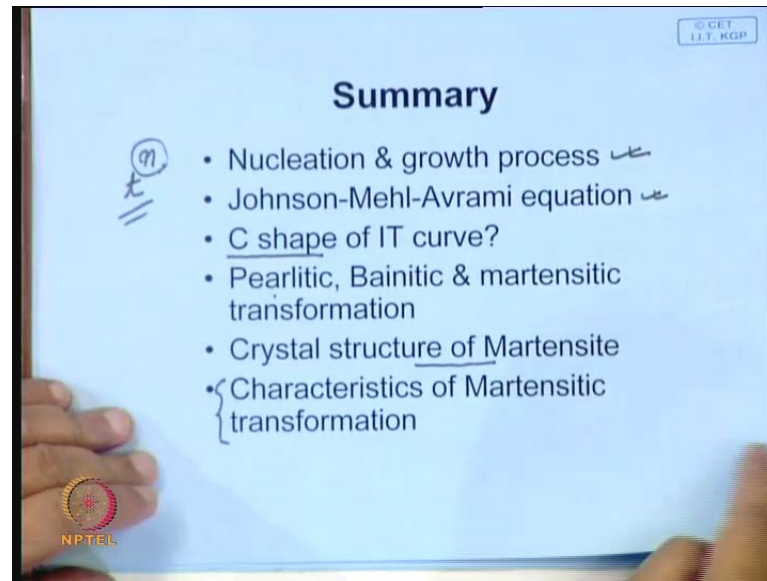
And what we have done today to some up, let us see summary, we looked at the nucleation and growth process critically. We derived the Johnson Mehl Avrami equation and we have seen this from that assumptions that time exponent a changes which and this n is indicator of the physical processes that control transformation. We learnt about why the isothermal transformation curve has a C shape. We talked about pearlitic, baintic and martensitic transformation in little detail. We talked about the crystal structure of martensite and we also talked about some of the characteristic of martensitic transformation. And may be next class will talk little bit about martensite morphology and go beyond that. Thank you very much.