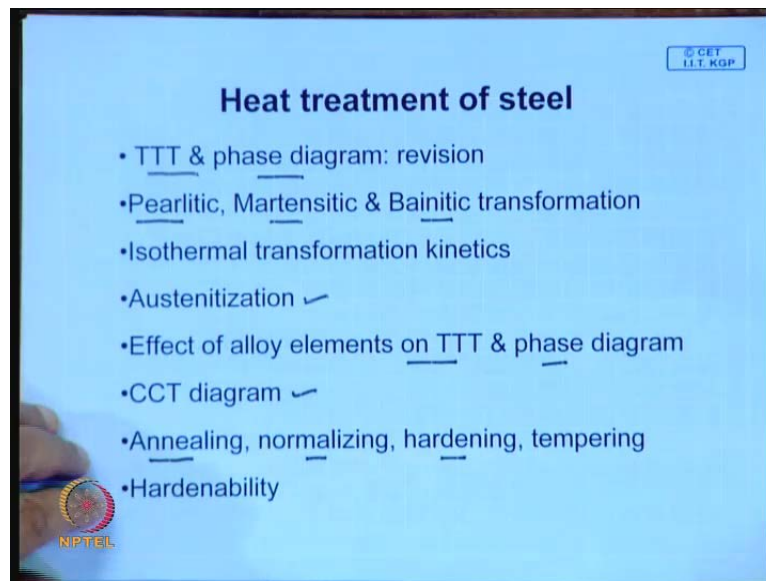# Principles of Physical Metallurgy
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## Lecture No. # 34
Heat Treatment of Steel (Contd.)

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Good morning, we continue with our lecture on heat treatment of steel. This is the forth lecture on this topic, and that if we recollect what we covered so far is the we looked at transformation diagrams, phase diagram, because they help you in understanding the basics of heat treatment. We talked about the different types of transformation that takes place pearlitic, martensitic, bainitic transformation. We looked at isothermal kinetics, we looked at today we will look at the process of austenitization; we will look at effect of alloy element on the TTT and phase diagram. And we also have looked at already the CCT diagram, and last class we introduced three common heat treatment processes annealing, normalizing, hardening.

And today, we will concentrate on this, and last class we discuss this primarily with respect to eutectoid steel. Today we are see (( )) we shall look at how this process changes (( )) with the if the composition or carbon contain density will changes.
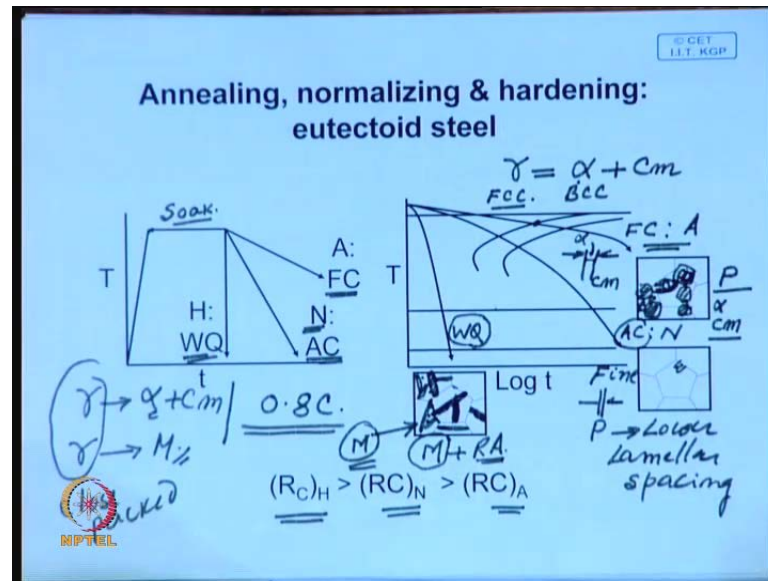
And then if we look at these three heat treatment processes for eutectoid steel, what we do is we heat take the piece of steel heat it to a temperature. So, this is the heating cycle; this is the soaking cycle you have to soak it for certain length of time, so that the temperature from the surface to the center of the job becomes uniform and this whole time will depend on the size or dimension of the job.

And then if you hardening what you do you have to quench in a liquid and one of the ideal or very good quenching medium is water. So, you quench in water and if you a normalizing, take out the sample from the furnace and let it cool in air still air, so air cooling this process is known as normalizing and I am representing it as the N. And annealing what you do you just after soaking you switch off the furnace, so in that case the cooling is called furnace cooling and you allow that means the cooling rate is extremely slow.

If you super impose these cooling rates on the time temperature diagram, then you will be able to follow the nature of the transformation that you expect. Now, this is let if you are doing annealing, which require the cooling rate is nearly equilibrium cooling rate is a slow cooling rate and this is the type of plot that you may get if you plot temperature against log time and this is furnace cooling, so this is annealing.

If you cooling air, then it is air cool this is normalizing if you water quench the quenching rate or cooling rate is very fast water quench and here you you you get it totally here different kind of structure.

Now, what type of structure will you get here? So, consider this particular case annealing and once scheduling during annealing this is the CCT diagram. On the CCT diagram this shows that time as it crosses this, then the decomposition of austenite starts it is eutectoid decomposition austenite which is face centered cubic, which has a face centered cubic structure it transforms into a mixture of ferrite and carbide, which is called cementoid this has body centered cubic structure. And when this happens you have a nucleus of cementoid nucleating or forming at these interfaces and when this forms the surrounding region.

When the cementoid form surrounding region gets depleted of carbon contain therefore, simultaneously you have a ferrite plate or the region ferrite grain will a nuclei just beside cement and this process goes on an and this is called pearlite, and this in a grows in all direction until and unless its meets another such pearlitic region. In that case there is an (( )) and ultimately each of these grains austenite grain will be converted into several numbers of pearlite modulus.

And what you have finally, this structure will consist a pearlite which is a lamellar, which has a lamellar structure which is made up of alternately of ferrite and cementoid. Now, here since the cooling rate is very slow it cuts or intercepts the CCT diagram near the top half of this. So therefore, the lamellar spacing spacing's between two consecutive cementoid plate this is cementoid and in between you have ferrite, so this distance is inter lamellar spacing and this distance is large. So, in annealing structures you have a course rather course structure and this can be easily resolved under optical microscope.

Now, the process of transformation in case of air cooling also will be exactly similar only difference will be the rate of transformation will be faster. So, when this the cementoid grows you know the rate is so faster so that means the nucleation of both cementoid as well as an cementoid as well as ferrite plates you know they they form one after the other and the process is so fast. So, in this case the lamellar spacing will be smaller. So, it will be more difficult to resolve.

So, this you here you will have fine pearlite, so this has lower or smaller lamellar spacing. Whereas, in the other case as you have you are quenching in this case you do not allow any moment of carbon atom when pearlite and cementoid nucleates here in austenite. Carbon atom has to move over a relatively long distance and in this case when you are water quenching you do not allow such moment. So, the transformation takes place through diffusion less transformation process which is a thermal we looked at characteristic.

And in case of eutectoid steel, the carbon contain is quite high 0.8 percent carbon, so here what you expect is plate type of is this cementoid. The martensite plates will form and these plates will be made up of various micro twins which will be not possible to detect or see under optical micro scope even you know and these plates when their grow they cannot cause this boundary it is if it is starts from here, it will end in the boundary if it is start from here it will end in the boundary. Later on subsequently the when this new needles form the formed likes this.

So, in this way here the structure will be made up of martensite and this martensite forces is a diffusion less process, and it it it takes place through shear mechanism there is deformation in the lattice, and which increases I mean which makes this steel very hard and also since carbon atom is get by four (( )) solution this also get substantial amount of solid solution strengthening. Now, whenever these needles develop you know this any decomposition process whether it is austenite to ferrite plus cementoid or whether it is austenite to martensite.

We look at this has a this side you have a close packed structure you have a close packed structure, and when this product forms you have this is BCC it is rather open this is BCC. So, there will be substantial volume expansion, and that is why you know surrounding regions there will be lot of stress fields develop, and some time it can prevent a part of this between these fluids you may have some amount of retained austenite left.

So, when you quench ideally at room temperature although you expect full martensite but because of this constrain when it expands and the process is very fast, what happens? This surrounding region this untransformed region that will be such a high level of stress which will not allow compressive stress which will not allow the austenite to transform

because austenite to transform it has it means space to expand, so in that space is not for wider in that case some amount of retained austenite will be left behind.

So, your micro structure will primarily martensite and may be some amount of retained austenite structure will be so fine, but it may not be resolvable and infact under optical microscope on which these martensites also these are very bright. And they often they do not etch well although this boundaries, but if you temperate slightly as we will see the etch very well and you can receive this structure even under optical microscope, but not the final details we did not one plate of martensite.

So, that they are the level of resolution decade is in the nanometer region I am in that is extremely small, so you need electron microscope to resolve the structure within the plate martensite plates. Now, here if we look at that hardness as you increase the cooling rate hardness moves on increasing and so this is the Rockwell hardness(( )). After hardening, this is in a normalize; this is in case of annealing. So, this will be the sequence.

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Now, let us see to let let us look at, what we will be a comparison between these three processes which are listed here, in annealing you get coarse pearlite, in normalizing you get fine pearlite, hardening you get martensite. But in some cases it is a it most (( )) it is expected to be single phase, but some time, because of that volume expansion some amount of retained austenite may also be there.

Now, this section size effect he has seen we are cooling at a very slow rate that that the temperature gradient between this if you have a job, will always have a dimension though therefore, if you are cooling at a very slow rate, the temperature difference between the center and the surface we will be very little.

So, here we do not expect much of a system size effect in a normalizing, you are cooling it air cool relatively fast, so there may be little more difference in cooling, so here you may see depending on the job that you job size you may have some amount of some little effect such section size effect, but in the case of a hardening where you are quenching there will be a large difference in temperature between the surface and the center.

Therefore, this we will have a good section size effect the hardnesses which are mention the rough I am in guideline. An another reason is an residual stress since here the gradient thermal gradient is very low. So therefore, you do not get any residual stress here, but in normalizing depending on the section size, so normal weight is low, but in the job is large then there is a possibility there may be some amount whereas, hardening you may have land up with very high residual stresses.

About stability annealing structure this is more stable this will be also is a stable structure, but may not be since the lamellar I am in it may not be as stable as this, and this certainly this structure is unstable, you also have un transformed retained austenite. Therefore, the structure is unstable and it can transform even at room temperature are long holding or subsequently the temperature goes up a little they will be structural change here. Ductility in this case see will be very good there will be medium good and here this will have the here very poor ductility in fact this high carbon martensite is very brittle.

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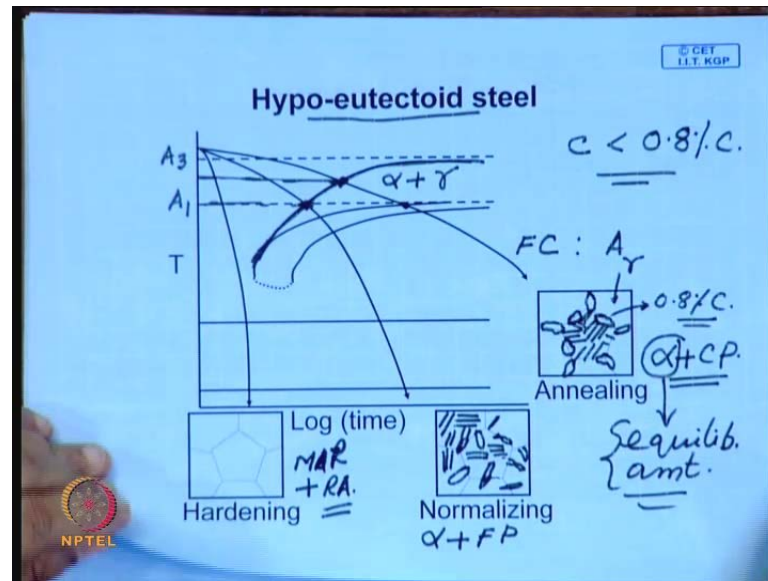
Look at this hypo-eutectoid let now having done that. Let us now look at the heat treatment of hypo-eutectoid steel. Now, hypo-eutectoid steel if you know that means the carbon content is less than the eutectoid composition which is around 0.8 percent carbon. And the typical the CCT diagram if you recollect there will be a additional line here, which will represent starter precipitation of pro-eutectoid ferrite, so this part this is the A 1 temperature lower critical temperature this is the upper critical temperature.

So, this phase diagram <mark>sorry</mark> this continuous cooling diagram CCT diagram for hypo-eutectoid steel which will help you in understanding this process you know that which is drawn over here. And here also if you cool very slowly you get this is furnace cooling, so this is the annealing; air cooling this is normalizing, and you quench in water; then it is hardening. Now, this structure is actually will be very similar to what we talked about there may be a little difference over in these two cases then in micro structure.

So, here what will happened once it crosses during annealing, you will have pro-eutectoid ferrite grains forming and this will be most likely place will be this grain boundary grain corners, so these grains will formed. And this process will continue until it reaches this point, once it reaches this point at that time <mark>(( ))</mark> you know when this process are precipitation of ferrite continues the composition of austenite will keep changing. And when it reaches this point say goes below the eutectoid temperature the <mark>temp[erature]</mark> composition of austenite around this will be close to 0.8 percent carbon.

And this is when what happens the pearlite nucleation starts and pearlite nucleation here also can take place from here, and you will have this pearlite modules forming this is how, so what we will have you will have pro-eutectoid ferrite plus course pearlite in case of annealing. And this amount of (( )) slow cooling amount of pro-eutectoid ferrite will approach to equilibrium value equilibrium amount as predicted by the phase diagram.

Whereas, in this case also this structure will consist of pro-eutectoid ferrite some of these ferrites can also form you know (( )) structure say some ferrite plates plates forming here and then balance will be converted into pearlite, and this pearlite which forms here. Look at it, here the precipitation of pro-eutectoid rate takes place at a much lower temperature here annealing at starts from here it is start from around here; therefore, you have a higher driving force.

So, you may have this kind of this (( )) ferrite also forming because the process is quite fast, and balance you will have remaining will be pearlite, and this pearlite will be fine, so you will have pro-eutectoid ferrite plus fine pearlite.

And here I think I want go in to this it will be a martensite plus depending on the carbon contained or composition, there may be some amount of the this is martensite and plus some amount of retained or austenite.

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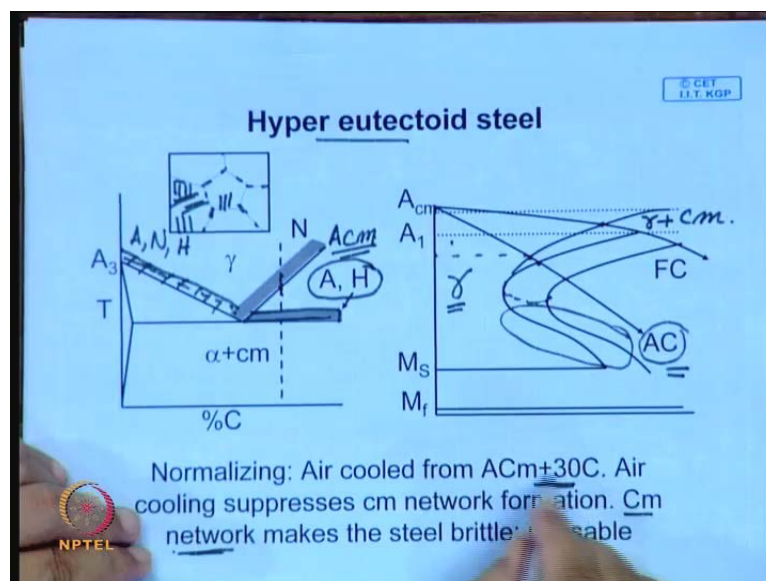
Now, the question comes I think (no audio from 20:48 to 20:59) there is now in the case of hypo-eutectoid steel just we looked at all for all annealing for hypo, we had seen this side at the composition irrespective of whether it is annealing, normalizing or hardening you heat it in this temperature range. Whereas, in case of a hyper eutectoid steel there is a little difference and what is this difference in case of a normalizing, you can heat it at that this line called ACm line where this line represents the temperature at which pro-eutectoid cementoid starts precipitating whereas, for annealing and hardening (( )) austenitization temperature is in this region now obvious question comes why.

So, in case of here also when this when you you form austenite, so you will have say in case of a normalized structure if you are heating here, you will have austenite completely austenitic structure is fully austenite. And then you are cooling by you follow air cooling and what happens as the temperature goes below this, so that means on the CCT diagram you have to look at the CCT diagram rather, so this is an isothermal diagram CCT diagram possibly this (( )) region may not be there in grain carbon steel, so you have to look at this part.

And when you are cooling, so pro-eutectoid cementoid precipitate at starts from here, so here you have austenite and here you have austenite plus cementoid and this pro-eutectoid cementoid will also form at the grain boundary. Initially there will form in the grain boundary and usually the composition amount of cementoid that will precipitate out may not be enough, because this process cooling rate is higher.

So, this may not be able to form a full network and before this full network much before, the network can develop the process of decomposition of austenite to pearlite begin and you will have pearlitic structure here, so you will have fine pearlite. Once you cool, you will have fine pearlite and broken this pro-eutectoid cementoid that the network will be broken.

Now, you do not want a main aim is to suppress cementoid network formation, because cementoid network it develops along the austenite boundary this makes this steel brittle and unusable. So therefore, for normalizing you heat it here say around thirty to forty degree centigrade about this you can heat.

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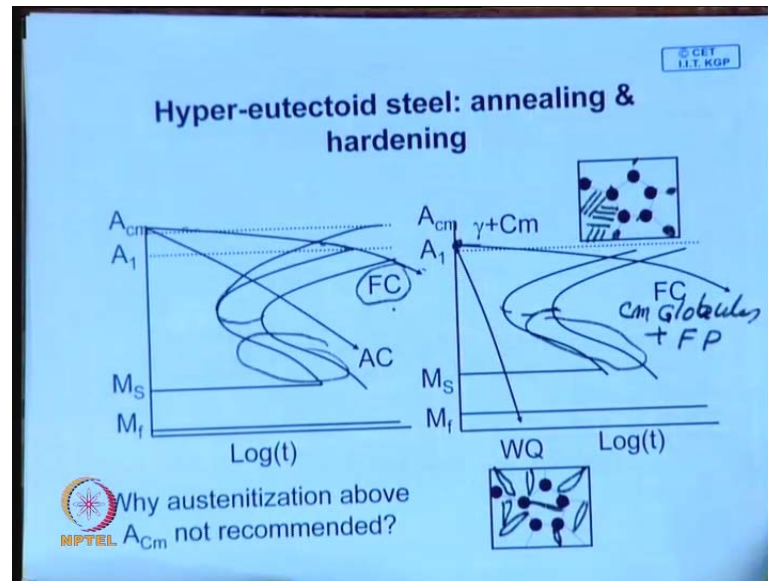
However for annealing and hardening, if you follow the same thing here, so we will concentrate on this CCT diagram, so this portion we ignore which you may not get in continuous cooling, so here what happens if you heat it over here and when you do furnace cooling your cooling like this. So, then what happens here your cooling rate here in this furnace cooling you are cooling it very slowly, so that cementoid amount of cementoid nearly equilibrium amount of cementoid will try to form. So, what happens you may get a continuous network of cementoid.

So therefore, what is done instead of heating going over there normal annealing process you heat it in 30 to 40 degree centigrade above the A 1 then furnace tool. So, here you have austenite and you will have these are the carbides, so normally if you etch with nitrates they may not appear that although, I am representing it as a dot here. So, these are and these carbides will not let that of austenite being to grow.

So, you will have fine austenite grain and when you cooling furnace, the balance will be converted into course pearlite, so this is the type of structure we will have you will have globules of globules of cementoid globules plus fine pearlite and which is a preferred structure. Certain days if you water quench also from this, there is a advantage is these cementoid carbides that cementoid globules will not allow this austenite to become course and the balance will convert in to martensite plate martensite this is form in to

plate martensite. Now, here additionally if you have cementoid particle, it will give wear resistance.
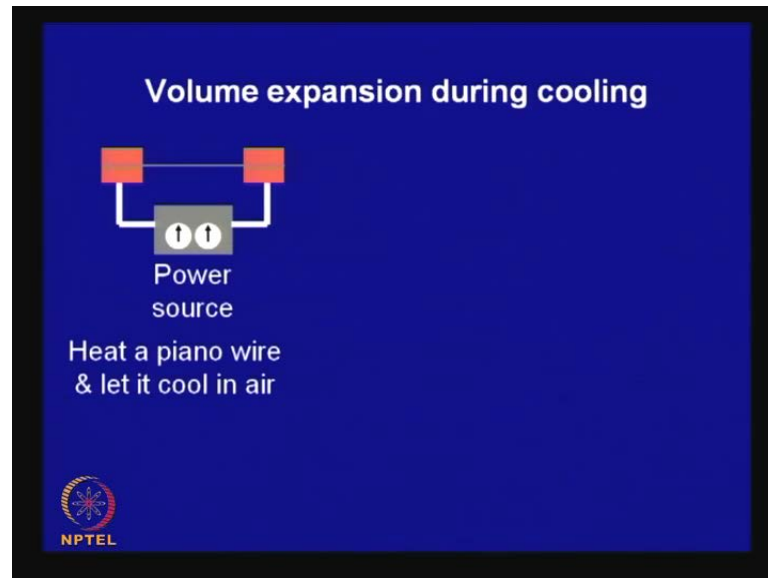
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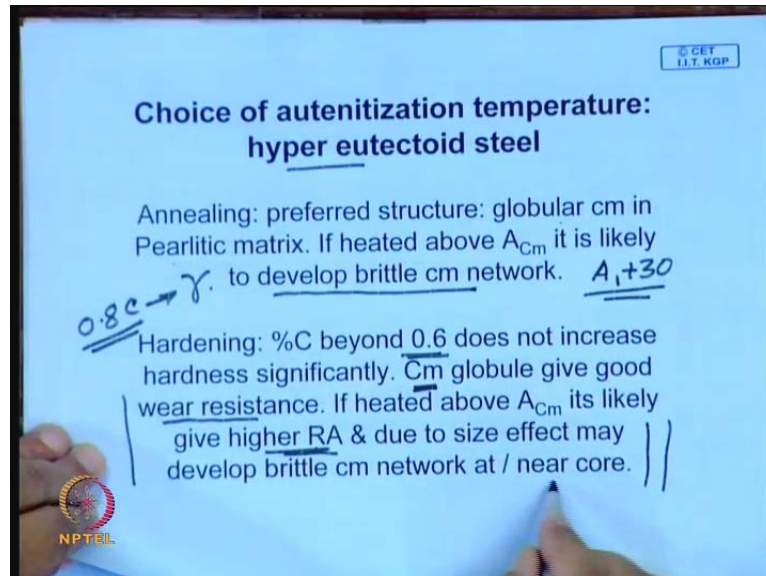
So therefore, if you choice of austenitization temperature for hyper eutectoid steel, you see that annealing the preferred structure is a globular cementoid in pearlitic matrix. And if heated above this it is lightly to develop a brittle cementoid network, which is undesirable. So therefore, you prefer that heating above A 1 plus around 30 degree centigrade. Hardening also you do not get much advantage if you keep more than 0.6 percent carbon in solution, so therefore and when you go above the one you already have 0.8 percent carbon in austenite.

So, if you quench and this austenite gets converted into martensite, you will get maximum possible hardness and these cementoid globules which remain will give additional wear resistance property. Now, if you heat this case above A_{Cm} the amount of carbon contained and austenite comes quite high and we know that martensite the temperature (( )) temperature temperature at which martensite forms. That is the function of carbon contain and it may go in it become so low that even at room temperature, that martensite transformation will not be complete you will have a very high amount of retained austenite.

And also that size effect is also important, if this dimension is large somewhere in the core, you may have likely you may develop brittle in a cementoid network at austenite boundary.

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Now, if you look at (no audio from 28:56 to 29:08) a quick look over here (no audio from 29:10 to 29:21) So, we mention that when you actually heat steel you know if there is a there is a transformation taking place.

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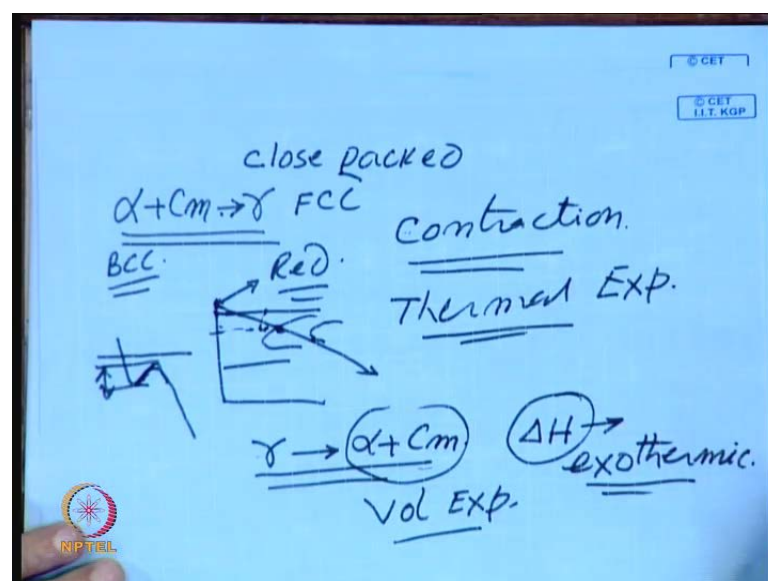
And this transformation is you know when you heat, you have ferrite plus cementoid structure it becomes austenite, so this will take place when this takes place there should be contraction that means volume decrease in, because this is a close pack structure this is a close pack structure which is FCC this is BCC so this, there is a volume there is contraction.

So, when you keep heating when this transformation takes place certainly that steel piece, the dimension will try to shortened and when you heat there is accompany thermal expansion also. So, when it is simple experiment one can set up by heating a piano wire which is shown over here, so these are some copper connectors here you can tight the piano wire here and try to heat this from a power source, may be the power source like that will use for welding let say low voltage high current source.

And if you allow the current to pass through the piano wire, this is the bulky and you may water cooler of this also that contact resistance is low. So, this is the portion if you apply a high current they will get heated very fast, so when you heat this wire one happens as soon as this critical temperature is pass, because this process is so fast that when this critical temperature is crossed you just stuff the switch off the power supply. And when it gets red hot, that is the time it gets converted into gets converted into austenite. Now, what is happening is during the process there is a thermal expansion, thermal expansion also simultaneously there is a contraction, because of this process and both they balance each other.

So, when it becomes red hot you may still see you know it has become red hot it will still be straight, so you heat it. And after that if you cool what will happen if you cool suddenly, it starts cooling when it will become from red hot it will become dull and which is shown over here that is primarily because transformation does not take place immediately. Look at that transformation diagram the piano wire is will be close to an eutectoid steel.

Let us say and you have this, so when you are cooling in air you will pass through say let us say this region, so transformation when see here it is red hot when it cools down, it becomes dull. So, here that glow is not there and once this transformation starts, this transformation austenite to alpha plus this is the phase transformation taking place here there is this is an exothermic reaction, so heat comes out this is exothermic.

So therefore, it may get heated up and you may question that will it exceed again this? That does not happen, but it may temperature while it is, so that means when the temperature is going down suddenly, it gets heated up and again through eutectoid temperature is possibly here and this rise is large enough to make it red again and that is what you will see. And when it becomes red, you will find that it is sags.

And this is the case is there is a thermal expansion and also there is expansion when this transformation takes place this also there is a volume expansion, so both add together and this sagging here is feasible and after, so this process this called recalescence. It again getting heated up this process is known as recalescence and it is experimental becomes feasible. And if you have some temperature measuring device, you can possibly may find out the transformation temperature as well.
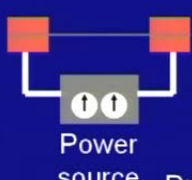
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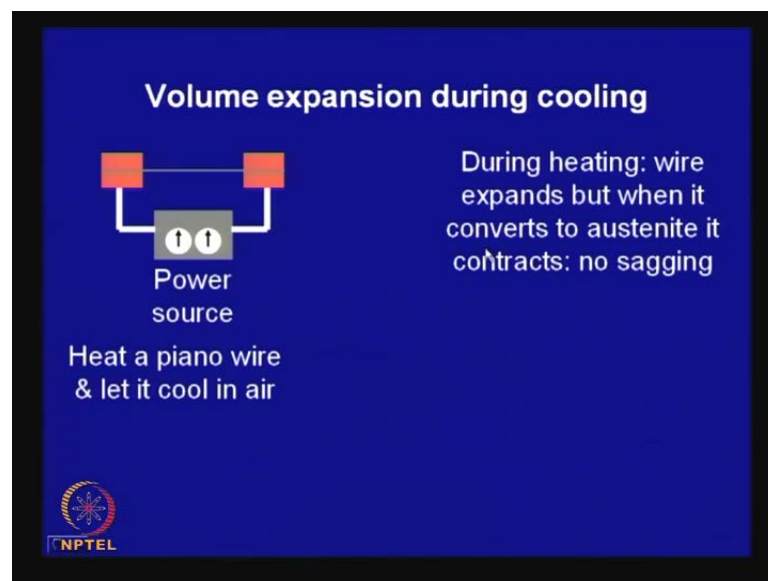
Therefore, this I have already explain that during heating, where expands that when it gets converted into austenite this contract that is no sagging; whereas, in the other case both add up and there is a sagging.
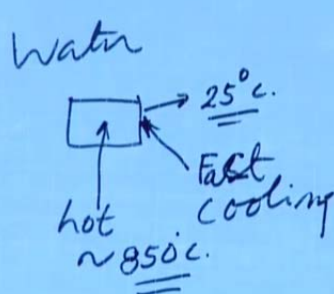
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Now, because of this process of you know because of this process of the volume change and both super impose with the temperature difference often when you give a heat treatment say particularly when you are quenching a job, you know if you are quenching a particular job.

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When you quench this portion quench in water, this cools very fast. Fast cooling <mark>fast cooling</mark> here, but inside still remains hot. This temperature possibly will come to the water temperature may be the room temperature 25 degree centigrade, but still this still

remains hot may be close to depending on the carbon contained 850 degree centigrade. So, there will be a large temperature gradient set up.

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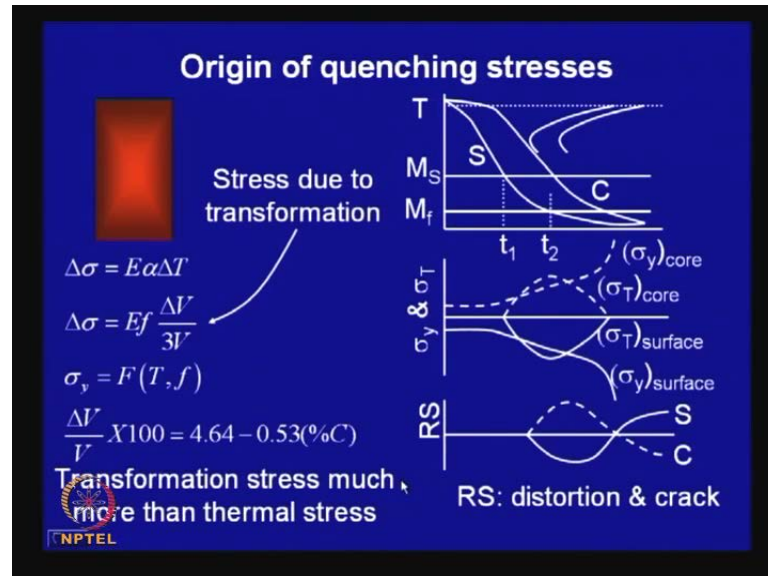
And this gradient set up can lead to thermal and thermal stresses no doubt and which is shown over here. So, this is the job when you quench the inside is still hot, but outside it has become cool. And because of this large thermal gradient which is shown over here this is a CCT diagram on this, the cooling curve for the core and the surface which is plotted here surface cools faster, core cools slower and both cases we are assuming that cooling rate is fast enough to avoid that nodes of the CCT diagram.

So therefore, you are going to have martensite at the both surface as well as center, but look at when the martensite transformation starts at surface after this time T when it crosses a mess temperature.

And the process is a thermal it continuous to take place as long as the temperature goes an decreasing and it completes over here. And possibly at that time transformation may not have started at the core, so there is a lag of that there is a time lag in transformation that takes place at the surface and the center, and this induces and this transformation will be accompanied by volume expansion. Imagine qualitatively if you say that the surface already transformation has taken place and when it forms martensite is twice to expand whereas, the center is not allow in it to expand.

So, you will have one kind of stress set up whereas, when the transformation starts taking place at the core which will try to expand, but this surface will not allow it to expand. So finally, when it cools down to room temperature you will find that such as a result of this quenching, you will have a significant amount of residual stresses develop on the job, and particularly they are on the nature of the stress we will be tensile at this surface compressive at the core. And this slide explains that origin of this stresses during quenching this is E is the young's modulus, alpha is the coefficient of thermal expansion, and delta T is the temperature difference between surface and core.

Now, this temperature difference so like this, so as it cools down there will be the thermal stresses will also go on changing, but the material strength also say at high temperature materials strength is low. As you cool down the material become cooler, its strength also increases it yield strength also increases which is shown over here the strength of the material as it cools down with the time.

Initially when it is very hot the yield strength is low, whether intension or compression this is low and as it cools down its strength increases. And whenever the stress develops whenever it goes exceeds this yield stress, then there is a local deformation and this is the permanent deformation, and this local deformation can lead to distortion.

Now, what we have shown in this particular case is the effect of transformation stresses. You can similarly, find out they they are the stresses originating, because of thermal stress, but whatever we have shown is this diagram. How the stress is developed at various stages of cooling? And once it is finally you come to the room temperature over here you may find, so which is this time very long time. And here what you will have you will ultimately find that, the surface there is a the tensile stress this side is positive this is compressive this is a tensile. So, surface you have a tensile stress, center you have compressive stress and then transformation stress.

In this particular case if you look at that volume expansion, is contribution is possibly much more, so there is around four percent volume expansion and this expansion will also depend on the amount of carbon content and then four percent volume expansion is much more than that the thermal coefficient of expansion. So therefore, what we can say during quenching this stress that develops in the material will be primarily because of this transformation stress.
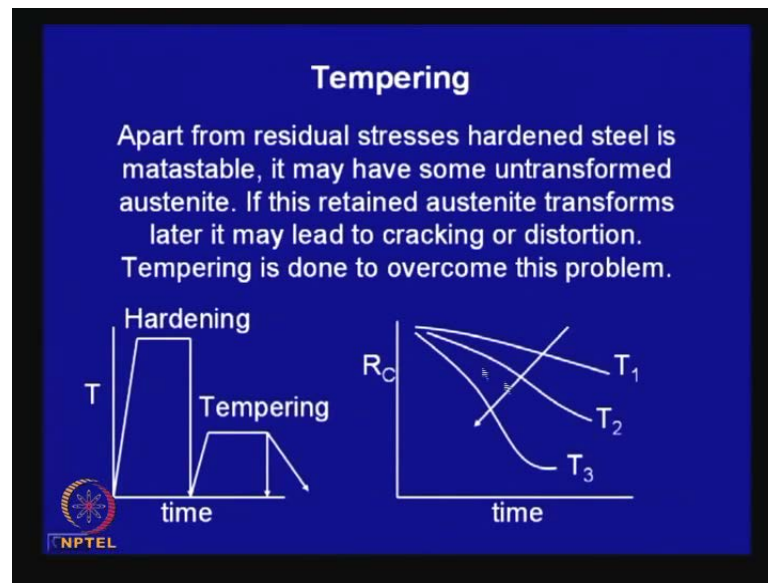
And since in a quench structure, you have high amount of stresses that develop in the material it is proven to susceptible to cracking. And also we have seen that, because of the stresses the micro stresses which are generated, when martensite plates are forming surrounding region we also have substantial amount of micro stresses. And to relieve this stresses to remove retained austenite, you need to give a subsequent at heat treatment courses called tempering.

So, since you have this red that means apart from residual stress harden steel also is metastable. Martensite structure is not the stable structure it is the super saturated solid solution of carbon in ferrite and it also have some amount of untransform austenite. And if this austenite transforms later, it may lead to cracking and also if austenite transforms there will be accompanying volume change, it can lead to distortion. So, leads to dimensional instability and tempering are done to overcome this problem.

And while tempering, you can heat this is the hardening step heating, soaking, quenching and then a heating to a temperature much lower than the critical temperature. You can heated almost up to 700 and depending on the temperature, you would get that specific properties. And after tempering does not matter you can often quench, because your productivity you want to have productivity, you can quench in oil or water or you can let it cool in air.

Now, in the process of tempering since you martensite is unstable during the process of martensite, there will be some phase transformation taking place in martensite. And as a result its hardness will keep decreasing and you can monitor the kinetics of these tempering processes by measuring hardness. And what you can do you can heat a series of sample say at temperature T 1 temper at this temperature T 1, and after tempering for certain length of time, you quench to room temperature measure the hardness and make it plot. So, this keeps the kinetics of hardness change at temperature T 1, and you will find if you increase the temperature, rate of that hardness decrease becomes faster.

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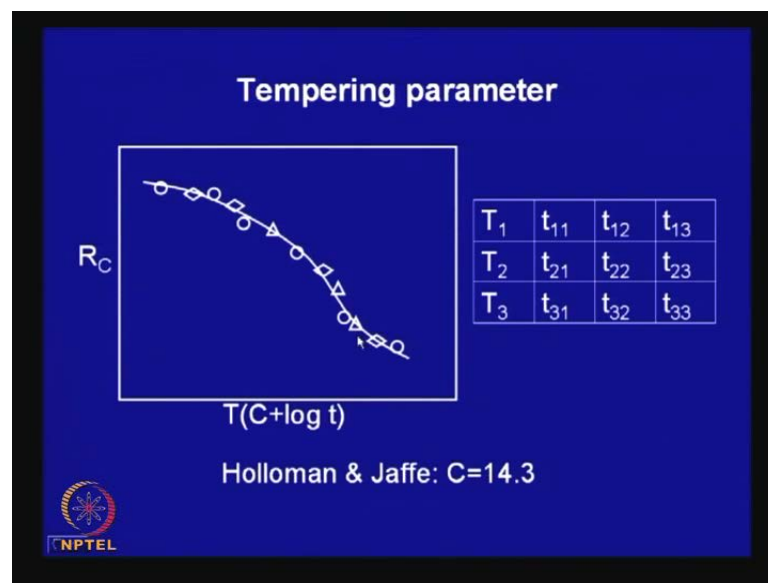
And it has also will found, that this kinetics of transformation is the function of both time as well as temperature. If we go back the previous see look at a for a particular time of tempering you see if you heat it, tempering temperature is higher transformation is faster within that time the temperature drops up to the Rockwell hardness drops up to this level whereas, if you had tempered here, it would have dropped only to this level.

So, that means this Rockwell hardness is the function of both the tempering temperature and time and it was reported first by Holloman, and Jaffe that if you represent this hardness plot, against state time temperature parameter called tempering parameter. Also sometime refer to as Holloman Jaffe parameter and this is temperature in degree, absolute c is a constant and log time and this time you can take in second.

Let us say and he used it for different certain varieties of steel, we looked at we found the c to be around 14 and what you do, so main advantage is say if you do the experiment at temperature T 1 for different length of time, and for each you have a reported hardness. Similarly, at T 2 temperature also you heat it for different length of time and for each of these combinations you will have at hardness.

So, you plot this hardness on this y axis and on x axis you find out the tempering parameter with the combination of this and this, then you see plot it here. Next you find out combination this and this, you plot it here and you will find that irrespective of the temperature and time they may fall on a one single master plot. So, this is called a master tempering graph and which helps you in determining actual tempering temperature selection of tempering temperature combination of temperature and time for a particular application.

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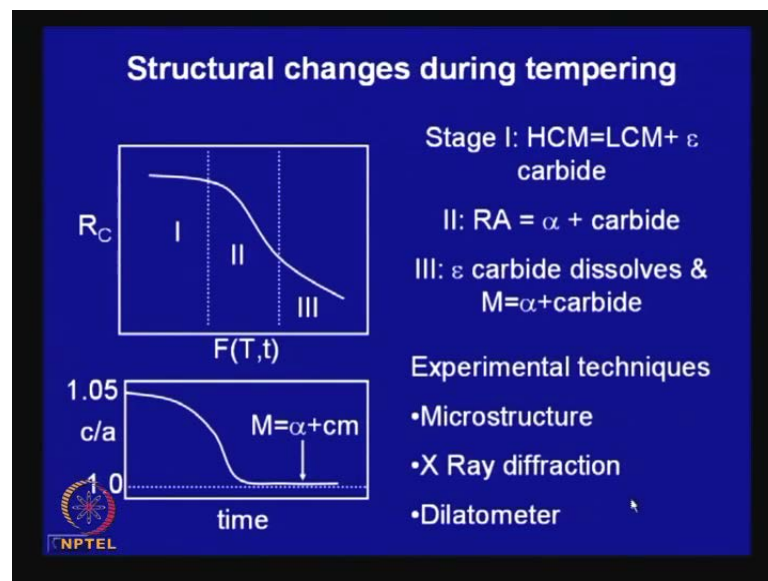
Now the question comes, what are the structural changes that take place during tempering which is listed here? If you follow this hardness against that the time temperature parameter hardness plot, you can possibly divide into three regions initial region whether is a little change in hardness, second region where is a substantial change in hardness, in a third region where also there is a substantial change in hardness. Now, stage 1 what happens is a high carbon martensite will break down into low carbon martensite and a special form of carbide it is a metastable carbide call epsilon carbide.

This has little higher amount of carbon contained than cementoid and this low carbon high carbon martensite has a plate type of structure.

So, that is unstable and low carbon martensite usually have a (( )) type of structure if we talked about it and so this is the main change that takes place during stage 1. Stage 2 the main changes if there is a retained austenite, it breaks down into ferrite and carbide possibly depending on the temperature. If the temperature is high, tempering temperature will be ferrite plus cementoid if the temperature is in the lower that they (( )) temperature range in that case it could also be a ferrite plus epsilon carbide and in the third stage a new the cementoid appears. Now, cementoid appears this can happen into is this can dissolve epsilon carbide and new carbide will precipitate or the carbon concentration gets adjusted and it changes over to cementoid.

So finally, over here you have cementoid ferrite plus carbide structure and this carbide is cementoid and if you continue to a temp, further the cementoid will grow and it can become very large at a higher temperature which can be very easily seen in the optical micro scope. And the main change that takes place whenever this transformation takes place is one is the type of martensite and martensites that crystal structure is also a function of carbon contained and high carbon martensite, then it has a body centered tetragonal structure where if you measure by X Ray diffraction or (( )) pattern. You can find out the crystal structure find out the c axis and a axis and the ratio of c to a is an indicator of the amount of carbon the martensite has in solution.

And if you plot this against so let us a tempering time at a particular temperature you will find that is c by a ratio changes like this. Therefore, this X ray diffraction is a powerful technique to follow the kinetics of transformation that takes place during tempering in steel.

And apart from this, we obviously use micro structure also as a tool, micro structural examination tool follow the tempering kinetics and X ray diffraction you know in this particular case in the if you are in the third stage if you have look at that X ray diffraction pattern, you will see apart from the diffraction line coming from ferrite you may get the diffraction line coming from a cementoid, which are characteristic of cementoid whereas, here this stage if you are taking this diffraction pattern here if there is sufficient amount of retained austenite, you will also see the peak corresponding to austenite. And you can

measure the intensity of austenite peak, and compare it with a austenite this ferrite peak and this ratio will give you the related proportion of retained austenite and ferrite.

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Structural changes during tempering

Temp range	Microstructure	Properties
100 – 200 C	LCM + ε carbide	Slight increase in hardness
200 – 260 C	RA: decomposition	Hardness starts decreasing
260 – 360 C	ε carbides pick up C to form Cm: not resolved in OM	Marked decrease in hardness
360 - 723 C	Coarsening of Cm	Fully softened

Tempered martensite having Rc 25-45 has excellent combination of strength & toughness. Problem?

So, X ray diffraction no doubt is a very powerful tool to follow transformation kinetics in tempering. To sum up this structural change is that take place during tempering, which is listed as a temperature range in the lower temperature range, you have low carbon high carbon martensite gets converted into low carbon martensite plus epsilon carbide. Property while that is a slight may be sometime slight increasing hardness sometime people reported particularly in elastic some amount of brittleness as well.

Next is this is the temperature range where this also temperature range also coincides with the b nitrons temperature range and here, you will have retained austenite converted decomposes and the hardness also it keeps changing, and parallely this martensite also will keep changing and that will be significant change in or drop in hardness.

And in this temperature range epsilon carbide can pick up carbon to form cementoid, but these are not resolved in optical micro scope this structure they, but there will be mark decrease in hardness whereas, about this temperature the cementoid coarse and this is the time this clearly the structure will be (( )) resolvable under optical microscope. So, this is the fully soften structure and extend of softening will depend on the maximum as you approach the eutectoid temperature and tempered martensite having this hardness around this has excellent combination of strength and toughness.
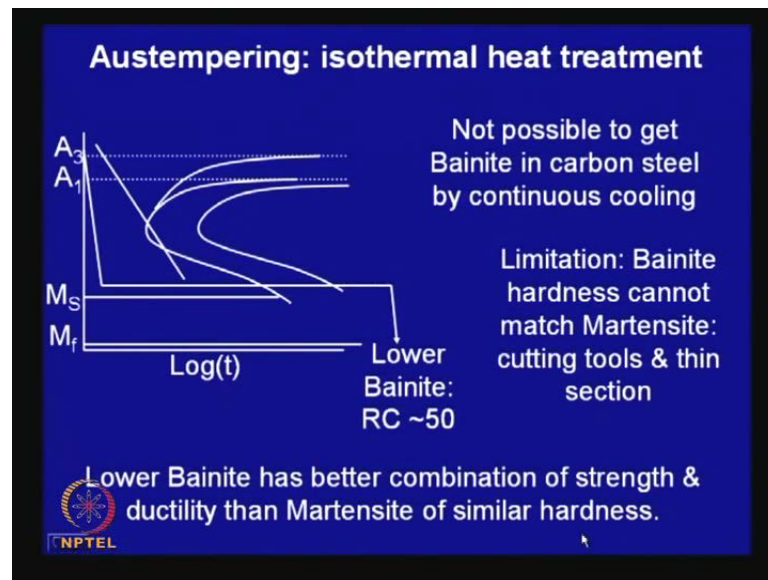
But then while what is the problem of this I think this I will stuff here to do to overcome so what we have consider is to do to overcome, so what we have considered is today we looked at quickly we looked at primarily these annealing, normalizing and hardening process. We looked at origin of stresses that develop and how do you remove this stresses, and how do you give in the more structural stability to unstable structure that you get in hardening that is the process of tempering in little detail.
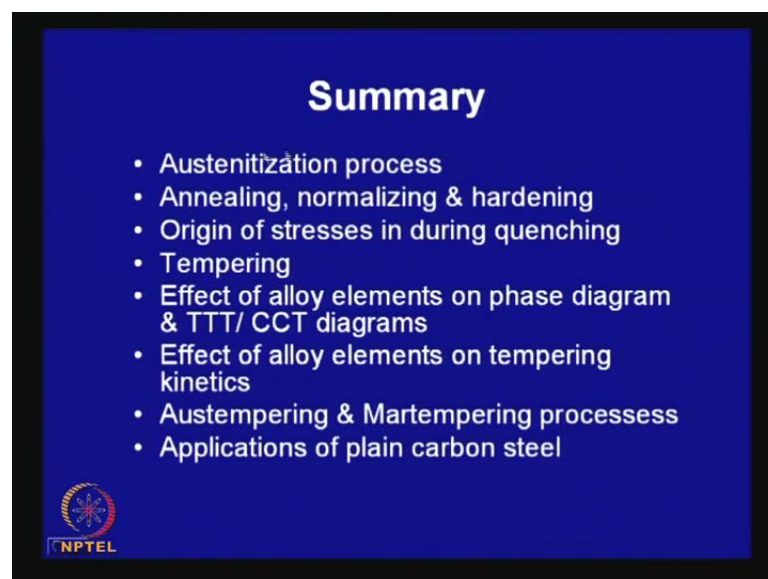
And and we also looked at the type of structures that develop during annealing, normalizing and hardening in three different rates of steel. That is eutectoid, hyper eutectoid, hypo eutectoid and hyper eutectoid steel and we try to also be the justification on the selection of austenitization temperature, and each of these cases I thought of talking about the austenitization process, but maybe I will this I have mess today.

So, I will go back do this in the next class and also we will see that, there will be there are certain types of transformation processes, where there is a possibility you can cut down the tempering process becomes redundant, because we have seen you can get a widely different micro structure and steel both by continuous cooling as well as by isothermal transformations.

So, there are certain special heat treatments which one can think about and also there is also a considerable importance on section size, that means says in case of a plane carbon steel what is the dimension up to which you can get a quench a martensitic structure is it dependent on then you do it in a say point if you have a 0.5 percent carbon in a steel, can you develop fully martensitic structure write up to the center. If you quench in water if the job is a little big say may be one inch diameter or half inch diameter, and where you have more chance of getting completely martensitic structure from surface to the centre, so today I think I will stop here, and rest I will take up in the next class, thank you.