Material Science

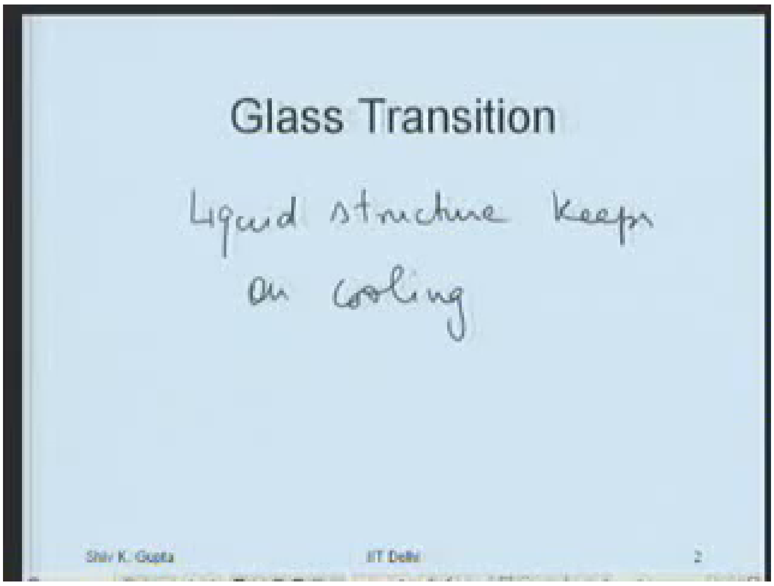
Professor S. K. Gupta
Department of Applied Mechanics
Indian Institute of Technology Delhi

Lecture No 24

Phase Transformations (Contd.)

While in the last class we were talking about the solidification process, and we continue with the solidification process, if we are able to cross the time temperature transformation diagram during cooling, the crystallization begins and crystallization goes to completion. If you do note, what happens is the liquid structure or the liquid like structure keeps on cooling.

(Refer Slide Time: 1:47)

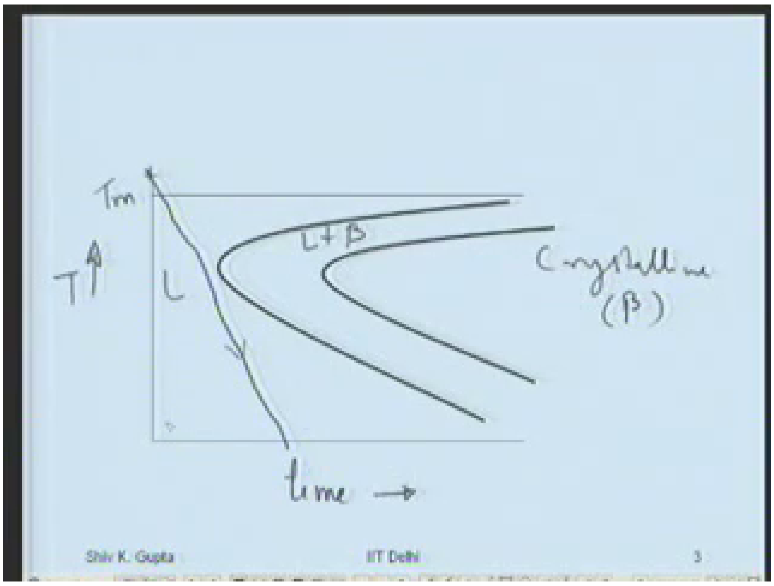


Glass Transition

Liquid structure keeps on cooling

During this cooling process below the melting point liquid like structure keeps cooling, we know thermodynamically that is not in equilibrium because below the melting point it is the crystalline form which is supposed to be the lower free energy formed but we will consider in this case also the liquid like structure which is cooling is in its internal equilibrium. Internally there is no process taking place which is maintaining its free energy higher than what it should be for the liquid like structure. That is what I mean when I say it is internal equilibrium when the liquid is cooling and that can be seen here.

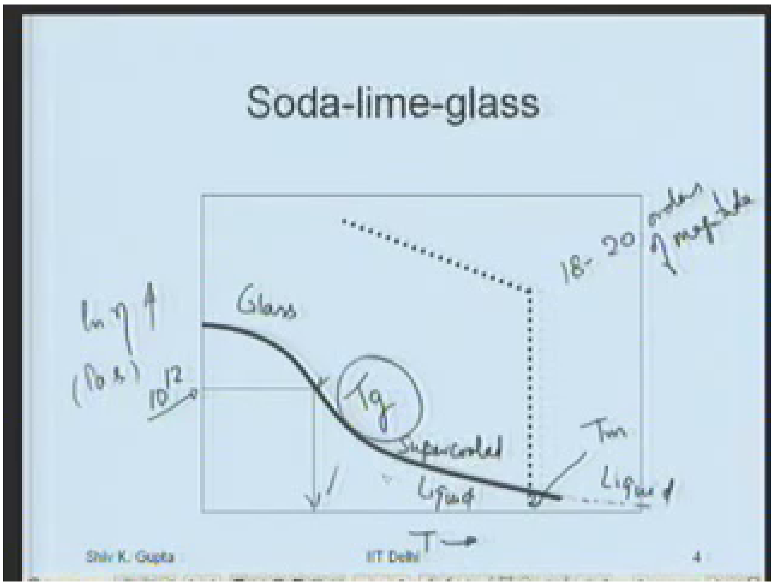
(Refer Slide Time: 2:54)



In this diagram where it is a TTT diagram, temperature on this axis, time on this axis, normally it is a logarithm of time which we plot here and that is the melting point. From above the melting point I cooled the liquid at this rate and I do not cross this curve which is crystalline solid here but it is all liquid here but it is a super cool liquid and this is liquid plus solid whatever is here.

So it is a liquid like structure which is cooling slowly, not the room temperature, even if I keep it for a long time at this temperature the nucleation would begin after a very very long time. It is a logarithmic scale it will be many-many years maybe. So no change would take place, no transformation would take place. It is the liquid like structure which shall be there, but when the liquid like structure cools a certain change that take place in the viscosity of the liquid.

(Refer Slide Time: 4:15)



Soda-lime-glass

Shiv K. Gupta IIT Delhi 4

Which is shown here on this I plot logarithm of viscosity, units of viscosity Pascal second and this is the temperature, this is my melting point here. That is the viscosity in the liquid like structure is very low and keeps on decreasing with increasing temperature but as it cools the viscosity increase and at the melting point it is sudden change of 18 – 20 orders of magnitude. In other words if it is about one Pascal second it becomes 10 to the power 18 or 10 to the power 20 Pascal second there, melt having viscosity of the order of 1 or 0.1 Pascal second, this may become 10 to the power 18 or 10 to the power 20 Pascal seconds.

So that is the sudden increase in viscosity and beyond that when we cool the crystalline solid the viscosity keeps on increasing but when it is a liquid like structure which keeps on cooling the viscosity gradually increases, not drastically but gradually, it is a liquid like structure, it keeps on increasing and then it is slowly (())(5:39) and then it accelerates goes through an inflection point then again slows down.

While this has been observed in many-many materials and arbitrarily we have found out that it is about 10 to the power 12 Pascal seconds, this value at which this inflection point occurs and that is referred to as the glass transition temperature of the material because we have define arbitrarily again, everything which has a viscosity greater than 10 to the power 12 Pascal second is a solid and anything less than 10 to the power 12 Pascal second is not a solid.

So what we call above the melting point of course it is a liquid, below the melting point we call it super cool liquid, and below this (())(6:51) temperature it is glass. This process, this phenomena is glass transition, it is not solidifying, it is not crystallizing, but the liquid like structure and its internal equilibrium is what is cooling and is going through a viscosity change where it is a rigid solid, window paints are all rigid solid, right. So that is what its viscosity has increased beyond 10 to the power 12 Pascal seconds at room temperature and it is used as glass. Alright.

Student: (())(7:33).

Professor: This one, this is the crystalline solid, this is for the crystalline solid, when this liquid crystallizes at the melting point there is a sudden increase in the viscosity and it becomes very rigid, liquid is flowing, the moment it crystallizes it is not, it is a very rigid material, that is what I said there is an increase in viscosity of 18 – 20 orders the once, liquid crystallizes to form a solid at the melting point and that is what happens and then the viscosity again gradually increased when the temperature is lowered.

However in the case of the liquid like structure getting cooled rather I should say the viscosity gradually keeps on increasing and then it goes through an acceleration, again it decelerates after passing the glass tension temperature. The inflection point that is where we are arbitrarily called it the glass tension temperature because we have arbitrarily defined 10 to the power 12 Pascal seconds the dividing line between solid and not solid which I am calling the super cooled liquid.

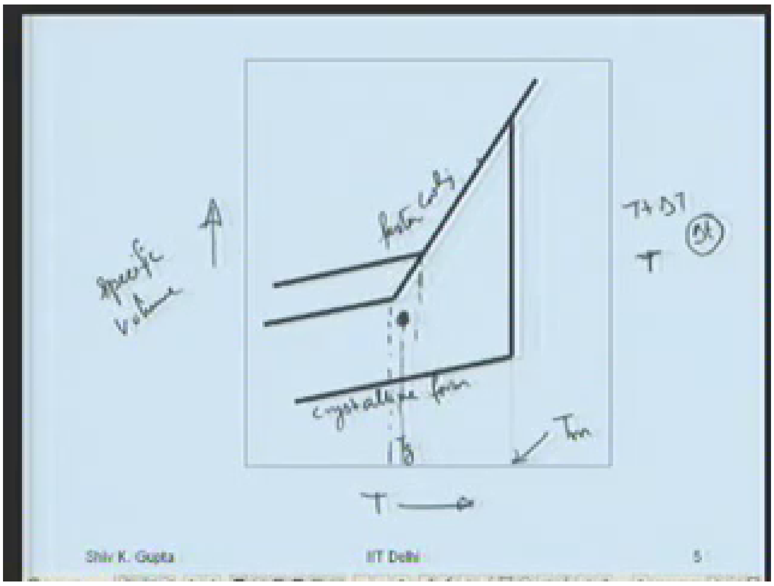
Student: (())(8:49).

Professor: Transition meaning, there is a transition, there is a change, liquid is going to a crystalline form, it is a change, transition is there.

Student: (())(9:01).

Professor: Yeah, because it is melting taking out, solidification is taking place at the melting point and there is no super cooling there, it is taking place at the melting point, right. And then the crystalline solid is cooled below the melting point, it is a common experience, in the freezer you freeze your ice, put the water and it forms ice, you can out in between the ice which is formed is rigid but the water is not rigid. There is a great change in the viscosity of that two that is a change taking place at the freezing temperature, right.

(Refer Slide Time: 9:51)



Now there is a problem in the rates of cooling because I can cool is slowly, in the liquid like structure I can cool fast, rapidly, when I cool it very slowly it is going to be, it is trying to maintain its internal equilibrium within the liquid like state, but if I don't do so it will be not in internal equilibrium and some changes do take place in the material like that. Here I show one property which is the specific volume that is volume per unit mass or per mole and this is the temperature in this axis.

Once again this is the melting point, well when this liquid crystallizes at the melting point specific volume decreases with the decreasing temperature in the liquid like state but there is a sudden change in the specific volume, while here I am assuming there on solidification there is a decrease in volume, the changes in solidification there is an increase in volume. There is a sudden change in the volume of the material, right and then it again decreases as the temperature is lowered in the crystalline form that is a crystalline form.

And there is a lowest free energy state in the material, right. But when I cool it, continue to cool it in the liquid like structure when it is not crystallizing the melting point, keep on cooling and I am assuming that I am maintaining internal equilibrium, I am doing a slow cooling. Slow cooling meaning in a temperature range T plus delta T and T, the time you spend is large, delta T. It will be faster cooling between this temperature range if you spend a time delta T very small, then it is the faster cooling.

So I am maintaining a slow rate of cooling that the adjustment between the tetrahedral networks or if it is the polymeric material adjustment between the chains which are entangled that disentanglement which has to take place corresponding to the temperature goes on and on and on because I am doing it slowly, I am allowing them enough time to go about that. I am allowing enough time for tetrahedral to readjust itself to the lower free energy state of the liquid like structure.

I am allowing to the polymer change to get disentangle to the extent free energy is the lower value for the liquid like structure and slow cooling, and then what happens is I reach a glass transition temperature and then below, the temperature below that, the specific volume does not decrease at that rapid rate, it decreases slowly but this is more than that for the crystalline form.

However if I cool it faster that means I am allowing time to be small between t plus delta t and t, that means I am not allowing the tetrahedral network to come to readjust the state of lowest free energy, I am not allowing the chain to disentangle to the extent that it becomes the lowest free energy, so entanglement remains that means rigidity in the structure would come much faster and that is what happens. We see the faster cooling, the glass transition temperature is higher, and that is for the faster cooling.

And then again we find that the specific volume is higher, if I use a plastic let us say polyethylene or I use a glass which has been cooled so rapidly, so fast that glass transition temperature is lightly higher here like this and the specific volume is also higher for this material and I use it for measuring something whether it is a thermometer, or it is a graduated cylinder where markings have been made. What would happen if such a material is used over time, after sometime this will try to come to the lower free energy state and therefore there will be decrease in the specific volume material.

And when that happens all graduations go (())(14:53) and they will not be valid anymore, so we cannot use a material like that for this kind of a work. At the same time in the industry, I do not have enough time and enough patience to go about doing things in a very very slow manner, so what we do is, after we have solidified made the glass, before the do the graduation, before we use it we keep the glass transition temperature in this region let us say, at this temperature the material is kept for quite some time, maybe a day or maybe 2 days.

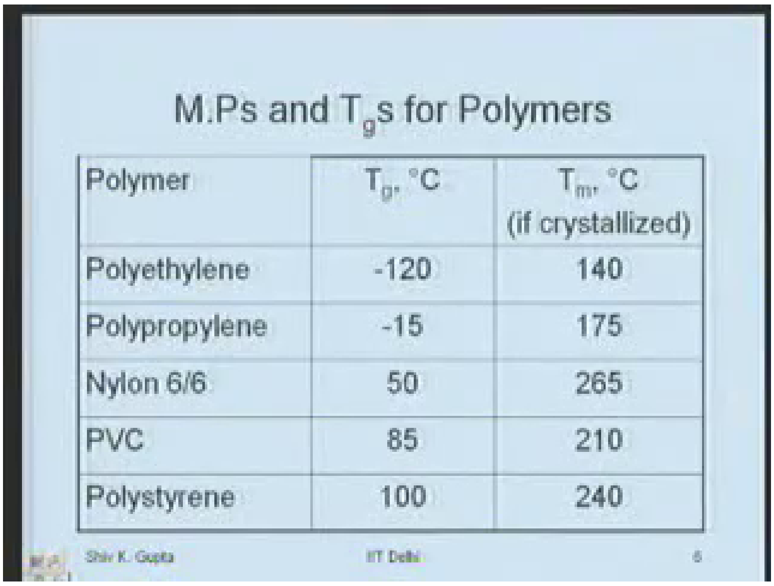
So whatever readjustment has to take place instead of doing it at room temperature it is done at elevated temperature and that would be faster, instead of taking place over 2 years or 3 years it may take place in a day or two. Once we do that allow the object to reform like that and then we can take it out, cool it anyway we like because it has come to the lowest specific volume and lowest free energy and then we can graduate it and use it.

So that is what we do with materials which are glassy in nature, we are not able to cool them very very slowly so we cool them at the way we can and then allow it to be kept at temperature closed to the glass transition temperature so that it comes to the equilibrium kind of the lowest specific volume of the material.

Student: (())(16:36).

Professor: Crystalline form in sudden chain is present, comes from the lowest energy, it comes to free energy state.

(Refer Slide Time: 16:44)



M.Ps and T_gs for Polymers

Polymer	T_g, °C	T_m, °C (if crystallized)
Polyethylene	-120	140
Polypropylene	-15	175
Nylon 6/6	50	265
PVC	85	210
Polystyrene	100	240

Shiv K. Gupta IIT Delhi 6

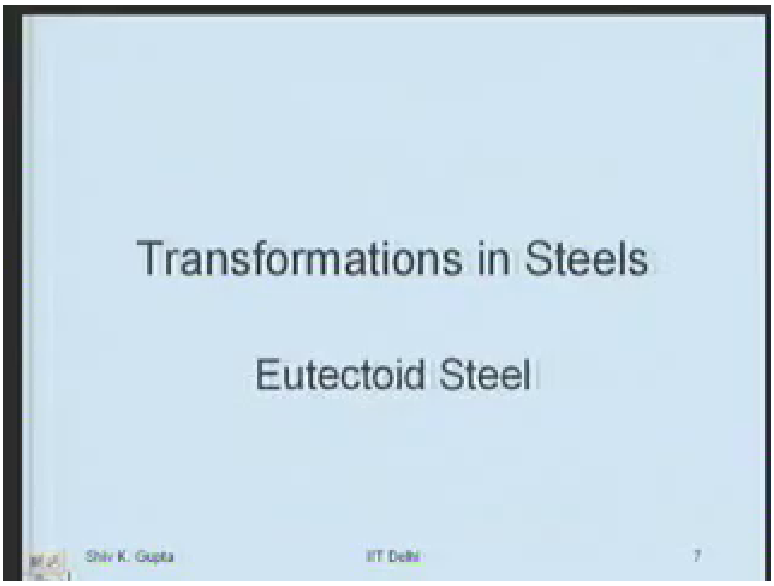
Now here I list some melting point in the glass transition temperatures of some of the material, the book would having for more. Polyethylene glass transition temperature is minus 120 centigrade while the melting point is 140 degree centigrade, the difference of 260 degree centigrade. And the room temperature when we are using the polyethylene it is in the super cooled liquid state. The polyethylene we are using looks to be quite rigid to you but this is in the super cooled liquid state, it is not in the glassy state and also it doesn’t break like a glass.

Polypropylene minus 15 degree centigrade glass transition temperature, melting point is 175 in a difference of 190 degree centigrade. Nylon 50 degree centigrade, it is above the room temperature is the glass transition temperature and melting point is 265 degree centigrade.

Polyvinylchloride 85 degree centigrade is it glass transition temperature, 210 degree centigrade is the melting point.

The PVC which we use at room temperature usually is more soft and pliable that is why because we are adding some copolymers to it. Polyvinylchloride as I talked about earlier also is a rigin material at room temperature, like Nylon is a rigid material at room temperature. Polystyrene is also very rigid at room temperature but we use it in the form of (())(18:04) at room temperature and that is we have already bubbled some gas in the liquid state and solidifies in the form of foam and that thermocol is what we use, otherwise glass transition temperature is 100 degree centigrade, at room temperature it is very transparent and rigid material.

(Refer Slide Time: 18:30)



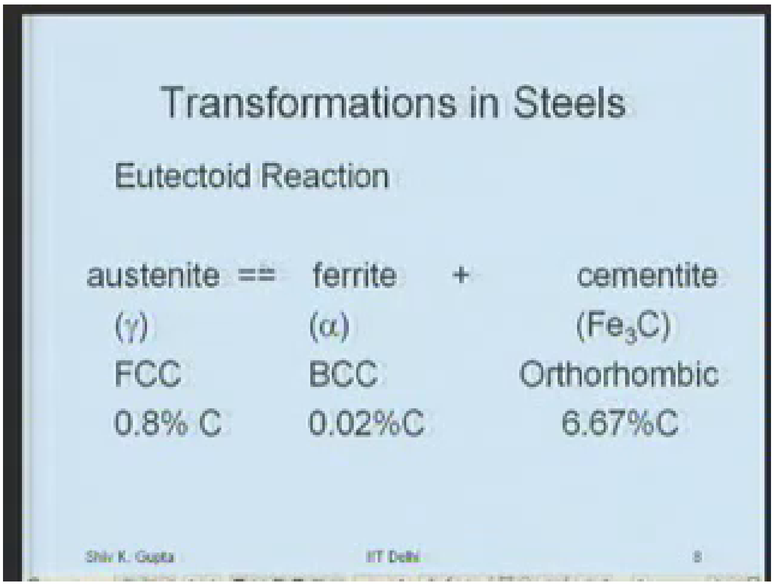
Transformations in Steels

Eutectoid Steel

Shiv K. Gupta IIT Delhi 7

Alright having talked about the glass transition in polymers and silicate or phosphate glasses, we now move on to a very important transformation for all engineers is this transformation in steel. While talking about the iron carbon diagram we have already seen the eutectoid transformation which occurs in an eutectoid steel having 0.8% carbon, my reference would be the still pure iron carbon alloy, no allowing addition, wherever I am deviating, I want to talk about alloys I will tell you that. Otherwise I am talking about a plain carbon steel containing iron and 0.8% carbon, this transformation is based on that.

(Refer Slide Time: 19:20)



Transformations in Steels

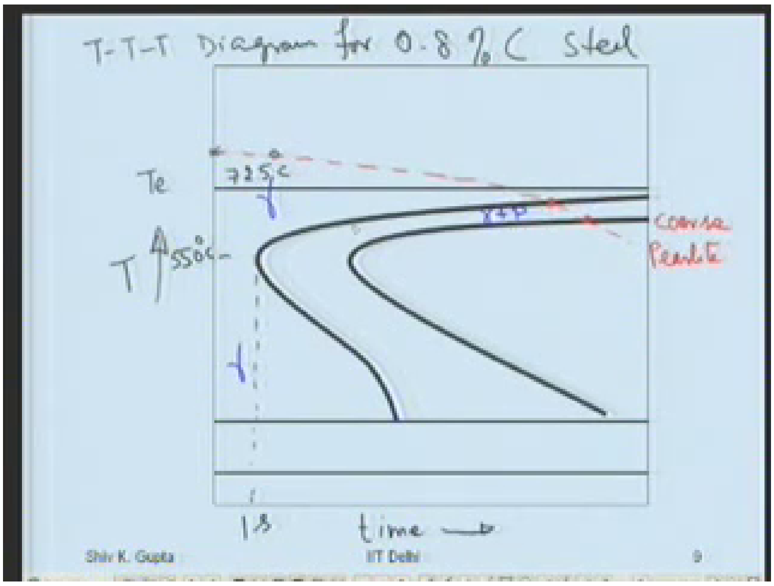
Eutectoid Reaction

austenite ==	ferrite +	cementite
(γ)	(α)	(Fe_3C)
FCC	BCC	Orthorhombic
0.8% C	0.02%C	6.67%C

Shiv K. Gupta IIT Delhi 8

This transformation we have austenite on cooling at 725 degree centigrade, go to form ferrite and cementite, while austenite is FCC the gamma phase containing 0.8% carbon, ferrite the alpha which is BCC 0.02% carbon and cementite FE3C, it is a complex orthorhombic structure 6.67% carbon. That is the eutectoid reaction that is a reaction which we are looking at. Alright!

(Refer Slide Time: 20:42)



T-T-T Diagram for 0.8 % C Steel

This is the TTT diagram for 0.8% carbon steel. Well I shall be talking about this in parts and therefore diagram will become complete at the end of the glass. This is the eutectoid temperature which is at 725 degree centigrade. This is the nose of the c curve which is at about 550 degree centigrade. We will talk about these other temperatures and the time and the nose of the C curve for this is T is about 1 second. And we take the steel at above 725 and it is all austenite.

We cool it, let us say we do the equilibrium cooling which is going to be a slow cooling, transformation begins very close to 725 degree centigrade and goes to completion also close to 725 degree centigrade. At this temperature range which is close to the equilibrium temperature, the nucleation rate is small while the growth rate is little higher. So particles of cementite and ferrite which form few of them form but they become bigger because of the high growth rate, right.

And therefore the pearlite which we have formed is coarse pearlite.

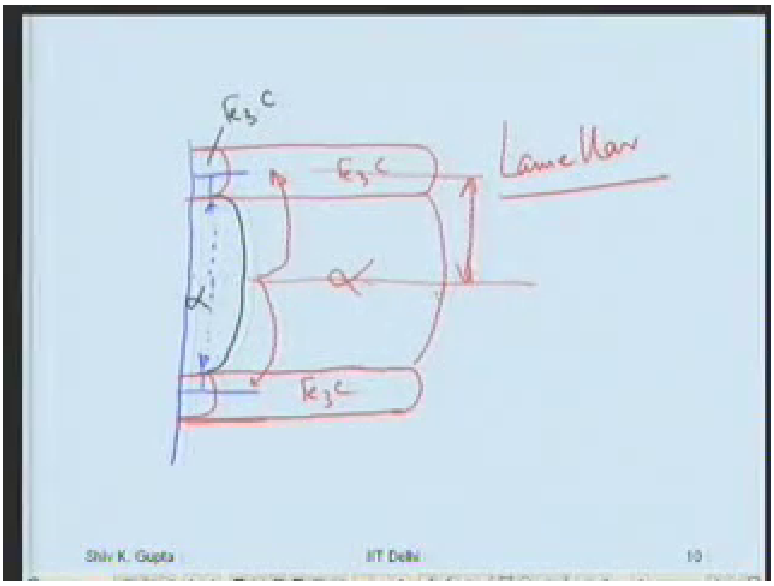
Student: What is this red line?

Professor: Rate of cooling, temperature and time, what is the line will show, how the rate at which the time and the temperature is changing with time. I am cooling it slowly and such a slow rate of cooling for steel can be obtained, steel is heated to let us say in this case 800 degree centigrade and kept in a furnace, keep the furnace closed and switch it off so all the refractory lining which is there in this furnace all around will not allow the heat to escape very rapidly and therefore the cooling would be very very slow. Such a rate of cooling or process of cooling is called annealing of steel.

Annealing usually has a connotation that you take some material, whatever is past history is irrespective of that, keep it an elevated temperature but when I talk about the annealed steel or annealing of steel means it has been taken to the austenitic temperature where it has been all austenitized for some time and then from there it is cooled in a very very slow rate inside the furnace itself, that is called annealing of steel, therefore this annealing is slightly different from the word annealing itself.

So it is called annealing of steel and we get coarse pearlite. Right so in this region I have here all austenite, these unstable austenite, this is pearlite and in between I have austenite and pearlite. Before I proceed further to show you another rate of cooling I like to talk about the way the transformation proceeds.

(Refer Slide Time: 25:11)



Let us say this is the austenite gain boundary. On this austenite gained boundary, cementite particle nucleates here and a cementite particle nucleates here, thereby carbon from here it diffuses in that direction and carbon from there diffuses in this direction, that is a distance of diffusion is from the middle of this region to the middle of this cementite region and therefore in turn what happens is this becomes a ferritic region.

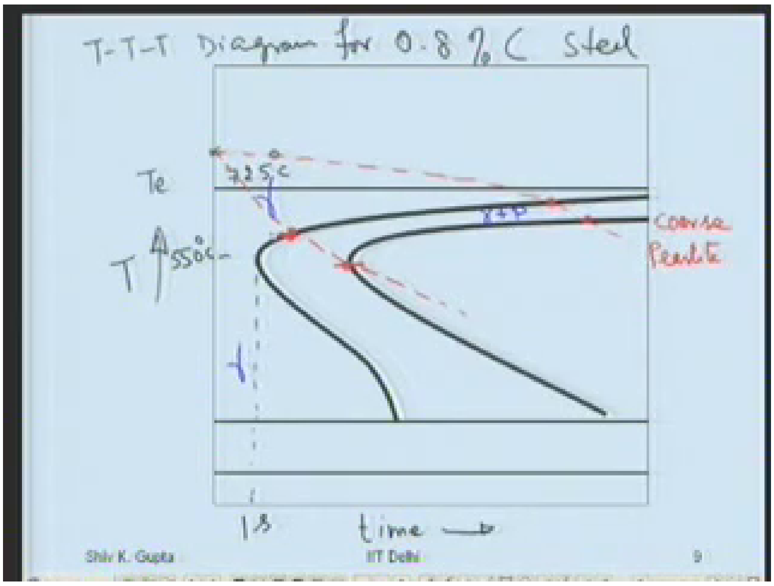
This is ferrite and this is cementite. Now carbon cannot go from here, it is already depleted, but in front is all austenite so carbon from here in front can still move in that direction and carbon from here can still move in that direction. So what happens is these cementite particles grow forward like this but they are unable to grow sideways. This is the ferritic regions and this is the cementite region.

Student: (())(27:04)

Professor: Naturally when carbon id removed carbon is depleted, once it is depleted it converts to low carbon regions and then it becomes FCC, FCC region is transformed and it is already going to go in that direction as well that is why this lamellar structure is formed, it is called lamellar structure and the carbon has to diffuse to a distance you can call the inter-lamellar spacing and when the nucleation rate is small and growth rate is high this distance is larger.

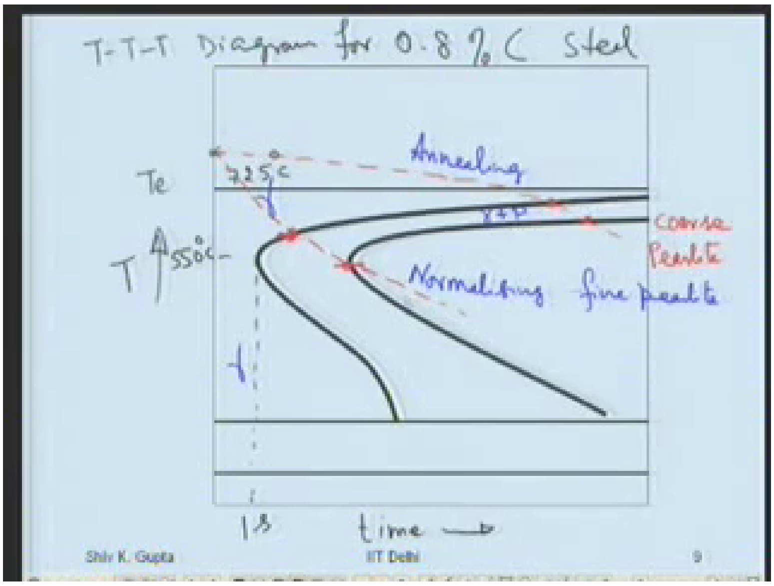
Because particles have nucleated along this length, one is cementite here and another is cementite there, and therefore the distance between them is large, but they are not growing, they are growing but they are not nucleating because nucleation rate is small. But this is happening very close to the eutectoid temperature so even carbon can diffuse to a longer distance in the given available time, right. So no problem so far.

(Refer Slide Time: 28:36)



What happens now, let us go back and see what happens when I try to cool it a little faster than that, transformation begins close to the nose and goes to completion at the nose around the nose. You have already gone down almost 150 or 170 degrees below the equilibrium temperature before the transformation can be begin and go to completion. It is here that nucleation rate is much higher than the growth rate and see what happens, we will come back to this.

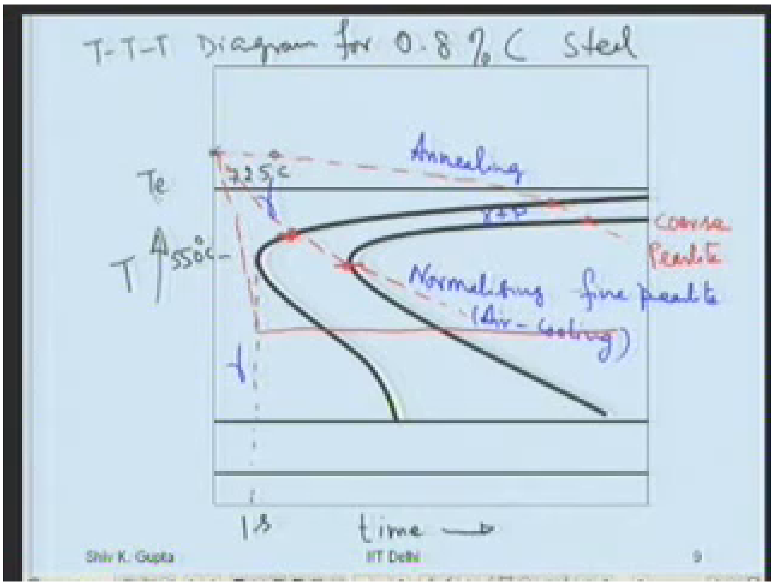
(Refer Slide Time: 29:53)



Alright I think I have to make another one. On this austenite grain boundary, I have higher nucleation rate to more cementite particle to nucleate. Nucleation is higher so more places the nucleation occurs and then these regions become ferritic regions. Same way it will grow but what I am trying to show here is the inter-lamellar spacing through which the carbon has to diffuse is smaller and temperature has become lower that means diffusion is going to be slower, distance to be travelled by the carbon is smaller now.

So one is compensating the other, there is no problem, things move alright and we still get structure and spacing between the cementite particle they are smaller and this we call a fine pearlite because this distance is smaller now. High nucleation rate means inter-particle spacing would be smaller and of course they will grow the same way and the structure would be similar but inter-lamellar spacing would be smaller. Inter-lamellar spacing is smaller is a fin structure, fine pearlite, right. Before I give you a statement today which I will prove maybe about 2 weeks later. If fine grain material has better mechanical properties. Alright. So we will go back

(Refer Slide Time: 32:41)



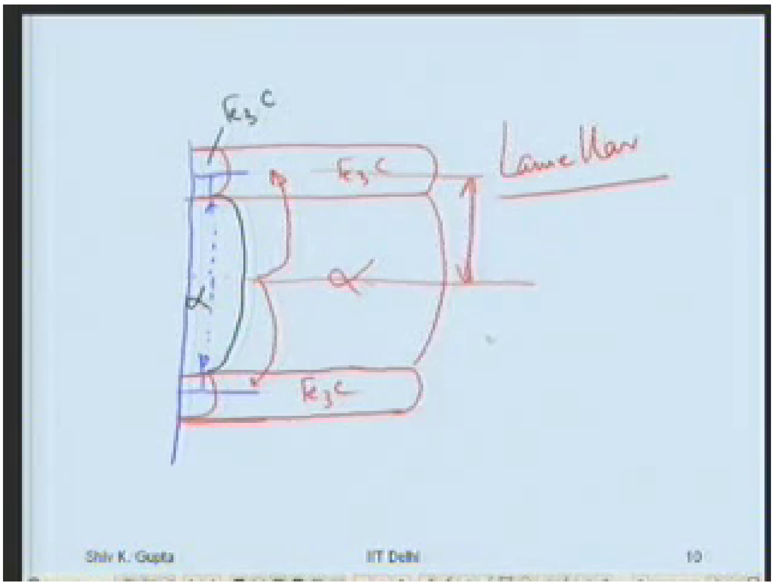
T-T-T Diagram for 0.8 % C Steel

We called this annealing a steel and this we called normalizing of steel and the product which forms is fin pearlite and we won. What I said just now, this material which his annealed steel coarse pearlite is softer while this normalize steel, the same steel is stronger, it got a higher strength than the annealed steel. Normalize steel is available in the market is usually steels are sold in normalize form, in industry nobody waits. They simply process the materials and cooled in air, this is the air cooling. This rate of cooling is obtained by cooling in air.

Now any rate of cooling which is faster than this you will be crossing the nose of the c curve. Now if you hold it isothermally, another kind of transformation occurs in the steel, now the temperature is so low, maybe 350 degrees below the equilibrium temperature you are, in the range of 350 – 400 or maybe 250 – 270, this temperature range, the diffusivity of carbon is very very small, unable to diffuse to any longer distance. So it is not possible for a cementite particle to form as the grain boundaries of the austenite.

But the driving force for FCC austenite to go to BCC ferrite is very high, delta g is very high, because under cooling is very high, therefore another kind of transformation occurs in this steel. Here the matrix transforms to form a BCC form of iron and carbontize to diffuse out to shorter distances only and that can happen.

(Refer Slide Time: 35:28)



That in the matrix either you form laths, laths are the shapes, name of the shape which is that of a ruler. You have seen a ruler, 30 centimeter long, 2.5 centimeter wide and thickness is millimeter. That is the proportion and such a shape is called lath and this can fill the space but they need not be arranged of the same length, they need not be starting at the same place and in between the spaces carbon ban come on an deposit, spaces are there in between, carbon can come and deposit, this gives a feathery to a microstructure when it is seen out of the microscope or as the second way is it forms a plate which is lenticular in shape.

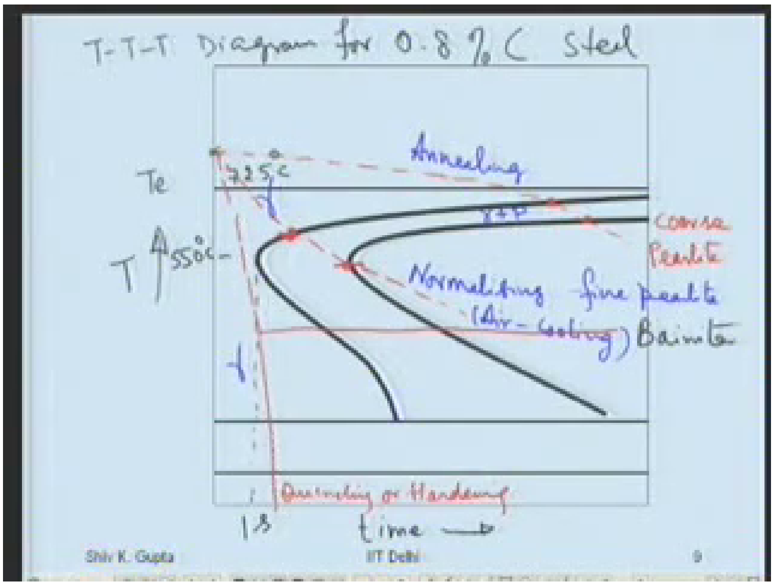
Student: (())(37:02) 38:42

Professor: Shape of the product in the microstructure. Lenticular shape is the shape of lentil dal, you have seen masoor dal, not necessarily very sharp here, it could be rounded and in between very fine needles of carbide are formed whch you cannot see under the optical microscope, to see this fine needles you may have to magnify using the electron microscope because carbon cannot diffuse to a longer distance, it can only diffuse to a shorter distance like it has happened here.

Similarly here this very very fine needles which can be resolved under the optical microscope are formed and this product as well as this product are called Bainite, they are not pearlite, though they are form of ferrite and cementite, this is another form of ferrite and cementite, it is not called pearlite, it is called Bainite. The ferrite and cementite which the form of pearlite are there they are more or less equilibrium structure and this cementite is 6.67% carbon, ferrite is 0.02% carbon.

In here these compositions could be different because carbon is enable to diffuse to a longer distance, all the carbon may not have come out of the ferrite and so on so forth so therefore this structure is called bainite and this forms…

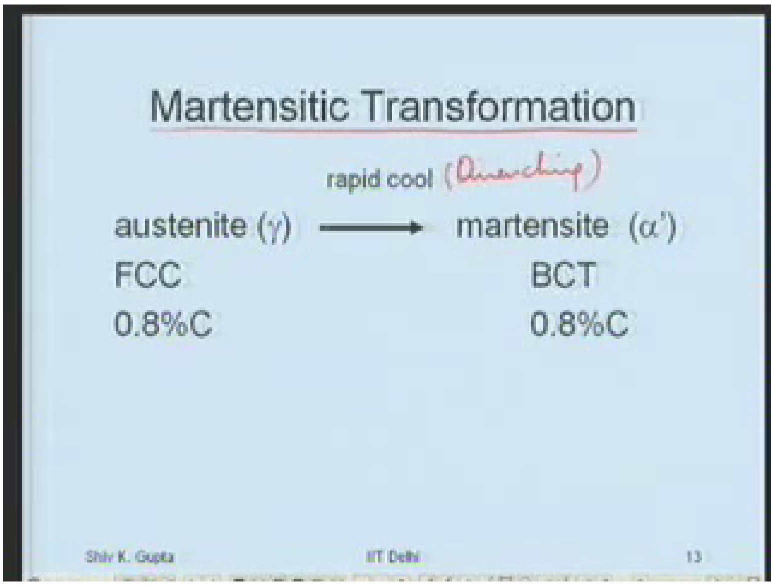
(Refer Slide Time: 38:51)



When I cool this at such a rate that it passes the nose of the c curve without crossing it and then I hold it isothermally at a constant temperature, then I form bainite because we still fine a distribution of carbide it is still stronger then the fin pearlite. Distribution of carbide is very very fine now, so that is still stronger. However if you don’t hold it isothermally just allow it to cool and bring it to the room temperature, such a rate of cooling you may be able to obtain by dropping it into water let us say at room temperature quenching. It is called quenching or hardening.

And the temperature about here with, this one thing we do so carbon is enable to get out, temperature is so low carbon is just now able to come out, carbon remains in solution and altogether a different transformation occurs because driving force for FCC to BCC is very high. Delta g has become very high, alright so what happens is that is what we shall see next.

(Refer Slide Time: 40:59)



Martensitic Transformation

rapid cool (Quenching)

austenite (γ) $\longrightarrow$ martensite (α')

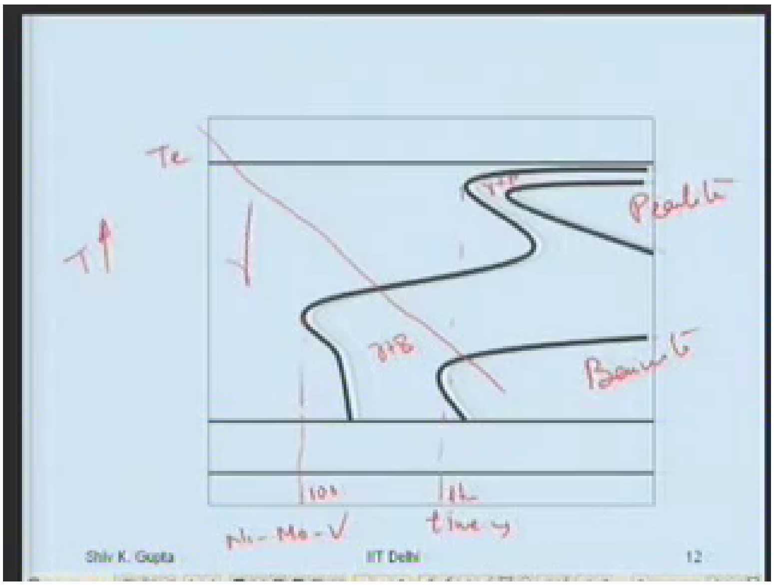
FCC BCT

0.8%C 0.8%C

Shiv K. Gupta IIT Delhi 13

The transformation occurs what we call the Martensitic transformation, this rapid cooling is something like quenching. Austenite which is FCC contains 0.8% carbon goes to become Martensite which is not BCC but Body centered tetragonal and has all carbon 0.8% carbon in it, and we call it alpha prime, symbol we give it alpha prime. Body centered tetragonal, okay. So before I look at the body centered tetragonal how do we form at certain characteristic of Martensitic transformation.

(Refer Slide Time: 42:33)



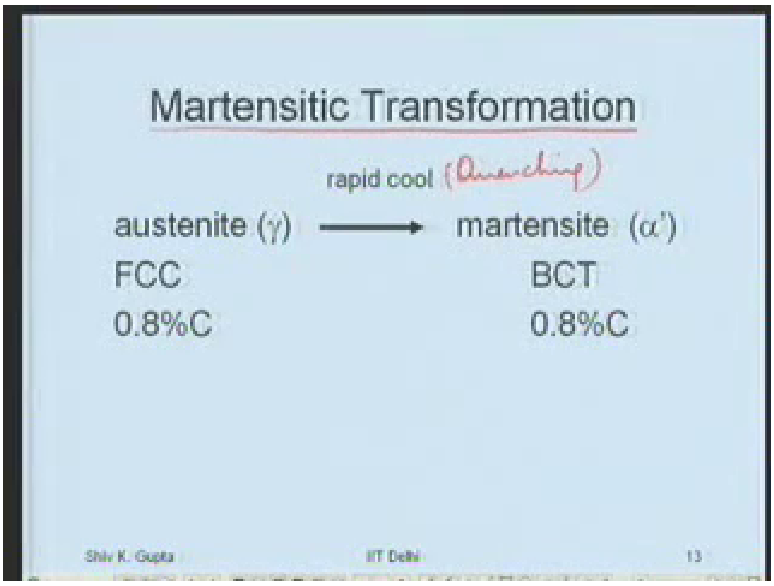
Nobody questioning me… If there is a transformation austenite going to pearlite and there is another transformation austenite to bainite I should have two different c curves but in plain carbon steel I am unable to see that because two (())(42:23) right at the nose, I see the lower branch of the bainite and I see the bainite upper branch of the pearlite, but in alloy steel which this one is an alloy steel containing nickel, molybdenum, vanadium etc, that kind of steel shows this is of course the temperature, here is the eutectoid temperature and this is the time axis.

You see the time here for the bainite knows it is about 10 seconds and that is here is about an hour, from one second it has gone to one hour and I am able to see the two c curves separately, one C curve for pearlite, another c curve for bainite. It is only in plain carbon steel that they are super imposed. Here on continuous cooling it is possible for me to form bainite but it plain carbon steel if I do the continuous cooling like this I cannot form bainite, I have to hold it isothermally below the nose of the c curve.

In alloy steel it is possible to do that, it is all austenitic region here, this is austenite plus pearlite region, austenite plus bainite region as beanite here pearlite here and these are the two lines which I have to still talk about, we are going to talk about. So what I am trying to say is this is a different mechanism because I showed the mechanism of transformation is very different and therefore the rate of transformation, kinetics is very different, so c curves are different.

We have been able to see them in the alloy steels as two distinct c curves, but in plain carbon steel this is a single c curve because they are super imposed right at the nose. So I see the lower branch of the bainite and I see upper branch of the pearlite curve in that. Alright.

(Refer Slide Time: 44:40)



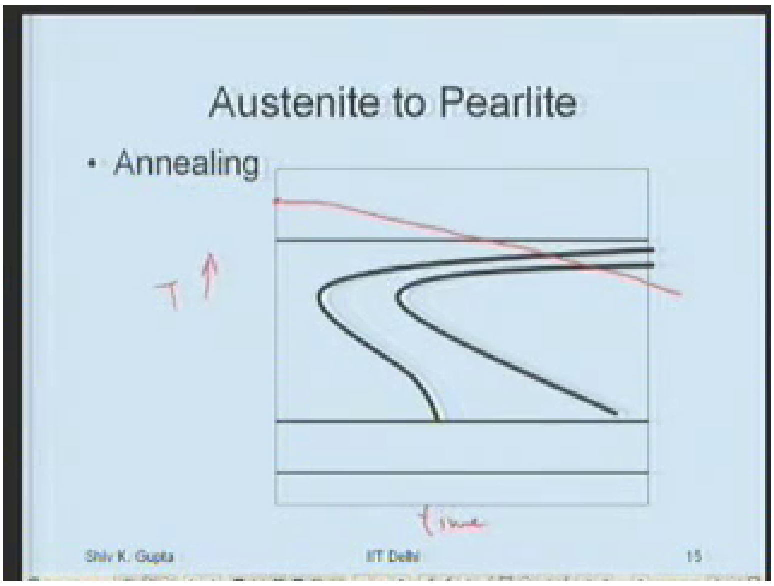
Martensitic Transformation

$$\text{austenite } (\gamma) \xrightarrow{\text{rapid cool (Quenching)}} \text{martensite } (\alpha')$$

FCC	BCT
0.8%C	0.8%C

Coming back to the Martensitic transformation, well so far as I have talked about, I have talked about austenite bainite and austenite to Martensite is what I am talking about, the three different transformation which are taking place in this steel is what I have stated here.

(Refer Slide Time: 45:12)



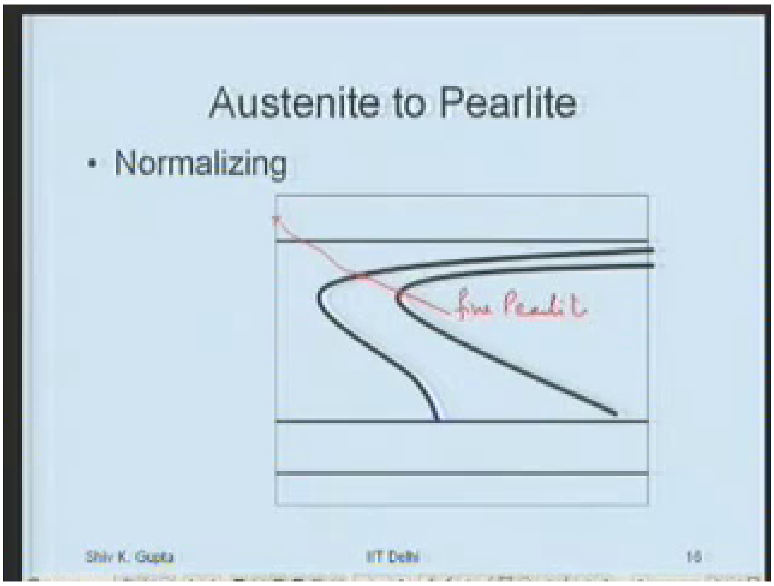
Austenite to Pearlite

- Annealing

Shiv K. Gupta IIT Delhi 15

This is good, annealing is you can put the axis, while you can put the axis I will not spend time on that, annealing is take it from the eutectoid temperature and cool it in a slow manner in a furnace, that is you get the coarse pearlite and that is annealing and I get austenite to pearlite. That is what I have already described for that.

(Refer Slide Time: 45:36)



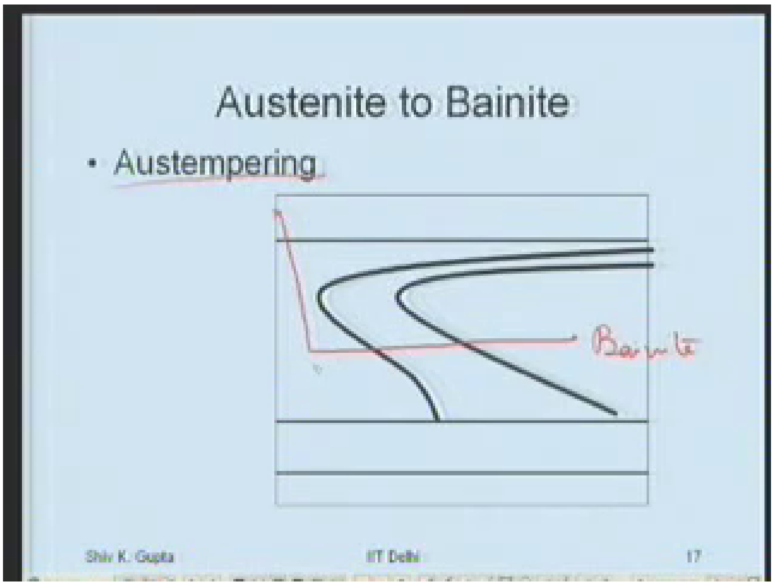
Austenite to Pearlite

- Normalizing

Shiv K. Gupta IIT Delhi 16

Normalizing is another one where we take this steel from above the eutectoid temperature and cool it in air in slow manner but it is faster than furnace cooling or annealing and I get fine pearlite, also the same diagram which you have already seen there.

(Refer Slide Time: 46:01)



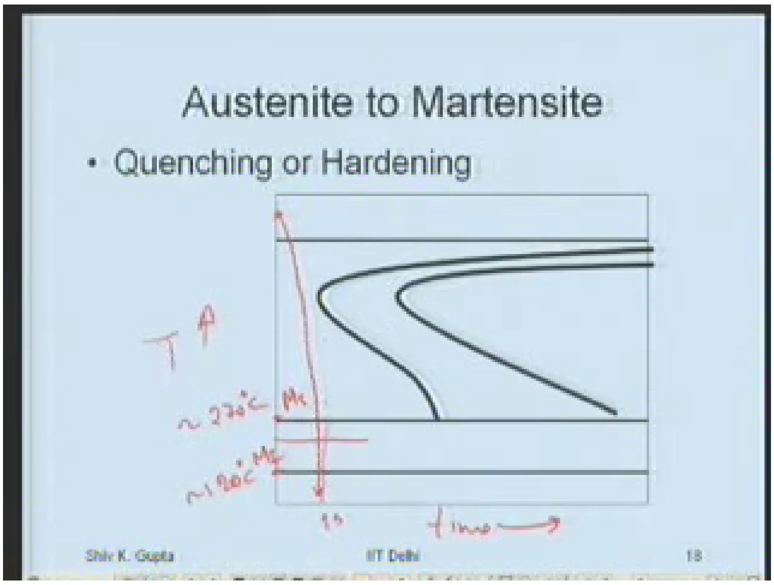
Austenite to Bainite

- Austempering

Shiv K. Gupta IIT Delhi 17

Now this is, when I cool it rapidly to bypass the nose of c curve and hold it isothermally, we refer it to the process of austempering but the product we get is bainite. That is what the next one which I am talking about is Martensite transformation.

(Refer Slide Time: 46:33)



Austenite to Martensite

- Quenching or Hardening

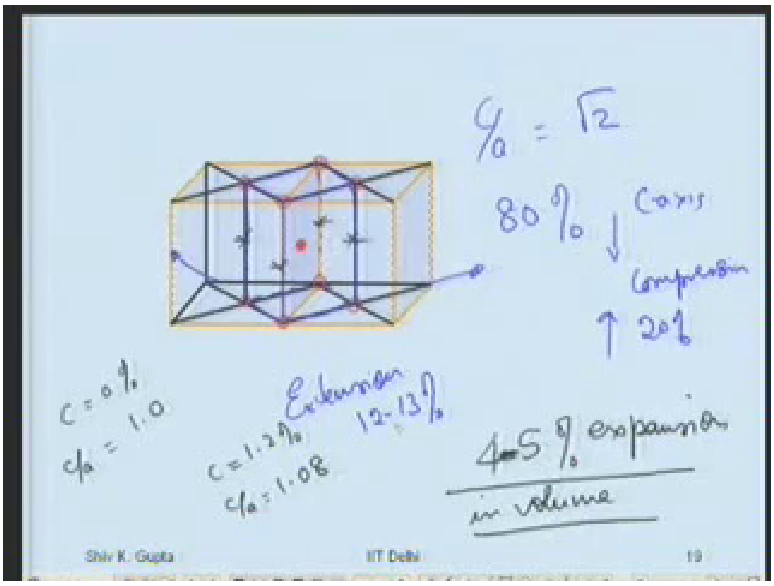
Shiv K. Gupta IIT Delhi 18

Quenching or hardening, that is from here it is simply quenched to room temperature in water. Now what happens is, this is the temperature axis and this is of course the time axis, this time is 1 second for 0.8% carbon steel as I said, I have to cool it so fast but around 270 degree centigrade in this, this martensite begins to form and at about 120 centigrade this goes to completion. We call it martensite start temperature and martensite finish temperature, that is the third transformation so I should have the c cruve.

But I am showing 2 parallel lines here, there is no c curve because carbon is unable to diffuse at all, there is no diffusion process involved, so time taken for the process is not going to be there, and that means by the time I reach a particular temperature a certain driving force has already been achieved because of the under cooling so according to that driving force whatever amount has to transformed is transformed. The moment I reach the temperature it is transformed.

So time is not there and therefore there is a, there are 2 parallel c curve lines, so time is not involved in this, curves the characteristic of the transformation is diffusionless, okay.

(Refer Slide Time: 48:22)



Now how this diffusionless transformation is brought about, how does this FCC becomes BCC, if I have not carbon I will take pure iron, quench it like that to room temperature and it will become BCC, it will become ferrite. See I have put two unit cells of FCC side by side and in that let us look at these atoms which are the 4 corners of the unit cells and these are the 4 phase centers and this is the phase center here and look at this, well let me put a different color for that, let us look at this cell which is outlined here.

It is a body centered tetragonal, yes. That is a body centered tetragonal. But the c by a ratio is under root 2. Well if there is a sharing force acting such that along the c axis it reduces by about 20% that means it becomes 80%, the c axis that means there is a compression of about 20%, and these axis which are the phase diagonals, along these there is an extension of about 12 – 13%. A sharing force which acts in such a way that in these 2 axes there is an extension here, there is a compression there, it would become BCC.

Alright. Well that is how the BCC can be formed by FCC (())(51:00) simply a deformation mechanism what is called as shear mechanism, by shear deformation I can do that and where are the octahedral holes in FCC.

Student: (())(51:13).

Professor: That is where the carbon is sitting, so carbon is sitting in these locations, Body centered (())(51:28) and FCC. So you see what happens that if carbon is present it doesn't not allow the compression of 20%, but there is no carbon and no problem because there is an extension that is possible, 12% extension is possible but its compression is not allowed. As a result if carbon is present C by A doesn't become 1. If carbon is not present with this kind of compression and extension I will get C by A equal to 1.

So when carbon is 0, I get the C by A equivalent 1.0. However when carbon is present to the tune of 1.2% I get C by A equal to 1.08. So it is a small tetrahedral (())(52:24), with 0.8% carbon it would be around 1.06107, (())(52:33) would be there, right. That is how the BCC becomes BCT without allowing any atom to move out from its location, no jumping, only compression is there and tension, shear strain is there, the matrix, the whole volume is transforming.

During the process there is also an expansion of the volume 4 to 5% so the matrix gets change a lot when this happens. There is a deformation of the matrix and there is an expansion 4 to 5% of the volume and also this transformation does not take place in the whole volume simultaneously. Again these particles of Martensite form either in the form of lenticular plates or in the form laths which I described for the bainite. Those are the shapes they take and laths can still fill this space but lenticular shape cannot fill the place.

So there is untrasnformed austenite left over in between, so that is how the martensite form and martensitic structure looks like that. However another thing which I have to say today is that carbon in this martensite is all in solution and a solute when present in the matrix also increases the strength, this also I shall prove. So all the point 8% carbon is in solution so therefore this strength is very very hard, hardness of this material is very high but because of the changes which are taking place the formation of cracks makes it brittles but then we shall see how to make it ductile and usable tough material in the next class.