Phase Equilibria in Materials (Nature and Properties of Materials-II)
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Lecture - 27
Phase diagram of Fe-C (contd.)

Welcome again to a new lecture, this is lecture number 27 of Phase Equilibria course. So we will first do a recap of last lecture.

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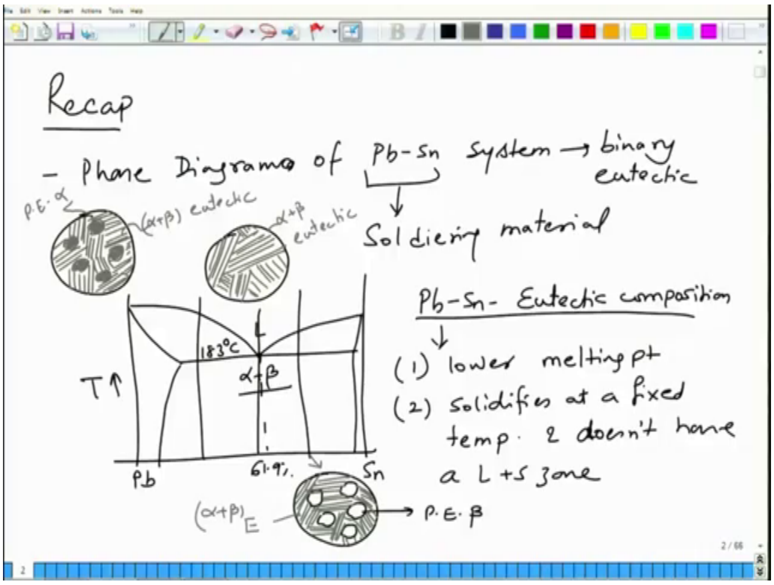

So in the last lecture, we looked at phase diagrams of phase diagram of Pb Sn system, Pb Sn is basically eutectic; binary eutectic system and Pb Sn is basically important material, because it is used as a soldiering material. And the reason, why it is used as a soldering material is because, it has a eutectic phase diagram in which so, you have led and then you have tin and then there is a eutectic at about 170 degree centigrade, which allows it to melt at lower temperature than its constituents so, it is 61.9 percent.

So this is led, this is tin, temperature and what you have here is at about 183. So, this is 183 degree centigrade at 61.9 percent led, it makes a eutectic where liquid actually transforms to alpha and beta phase, eutectic mixture. So, this has lower melting point than, either of the constituents as a result. It fulfills the requirement of a soldier to melt at lower temperature and solidify quickly does not have, you know broad solidification regime. So, Pb Sn soldier of eutectic composition so, it has following attributes number 1 lower melting point and 2 it has solidifies at a fixed temperature as a result, it does not have and does not have a liquid plus solid zone.

Now, liquid for solid zone is avoided and welding, because you do not want your weld to be mushy, you want your weld to solidify quickly so, that the parts are retained. So, the parts are integrated fast. So, as a result, we prefer lead, tin, alloy for of eutectic composition for soldiering; however, we looked at micro structural evolution in various regimes. So, we chose 3 regimes, one is the eutectic hypoeutectic regime, second is eutectic regime, third is the hypereutectic regime and when we look at, the microstructure in the hypoeutectic regime, you had these crystals of pro eutectic phase of alpha. So, this is pro eutectic alpha and this is surrounded by these beta phase, which is this is surrounded by the eutectic; which is a lamellar structure like this.

So, this is alpha plus beta eutectic and this is pro eutectic alpha. So, here the pro eutectic alpha is the led rich phase and alpha plus beta is the eutectic, which again consist of alpha and beta, but presence of alpha in 2 different forms is makes a distinction between, the 2 alphas. Then we had this eutectic composition; for eutectic composition, you get a microstructure, which is basically a lamellar microstructure. So, you have so, you had a lamellar microstructure so, this is only alpha plus beta eutectic. And then third composition, that composition that we took was this, hyper eutectic composition for which we had crystals of let us say, beta and these pro eutectic beta.

So, this is pro eutectic beta and this is surrounded by your eutectic mixture of alpha and beta. So, this is alpha plus beta eutectic. So, again you have 2 different forms of beta, one is the beta in pro eutectic forms, second is the beta in the eutectic form, both of them will have same composition, but there morphology is different. So, these are the micro structures, that we were looking at and then we looked at iron carbon phase diagram. So, that is what we will continue in this lecture with as well.

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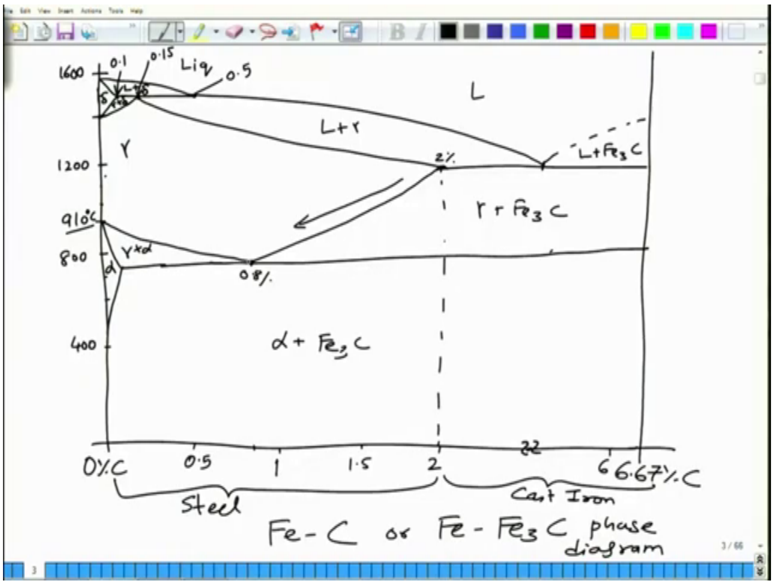

So let me draw, the iron carbon phase diagram. So, this is iron carbon or it is also called as iron cementite phase diagram. Cementite is a metastable phase so, that is why, it is normally referred as iron carbon phase diagram, because carbon is the more stable phase of the two.

So, let us say I have so, this is 0 percent carbon, this is 6.67 percent carbon. So, if I, now divide this is 1, 2 ok. So, this is the phase diagram of so, this is 1, 2, 3, 4, 5, 6, let me do one thing, let me just truncate, let me just expand on this side and contract on that side. So, let me just make it 0.5 1, 1.5, 2 and then let me put a break here and let us let 6 directly come there ok.

So, let me just, so, this is 0.5, 1, 1.5, 2 and then I put a break here and then directly I go to 6. And let us say, temperature wise we are at so, this is this would be your roughly 1600 degree centigrade. So, this where we would be at about 800 and this would be roughly 400 and this would be approximately 1200 degree centigrade.

So, if I now and go about plotting this, so first, I draw at 727 degree centigrade. So, this is 600, 700 somewhere, here so I start from like this and I go up to all the way this point, this point is 0.22 and then I connect this to because this is 1900. So roughly here, this goes down there and then I draw a line at 0.8. So, 0.8 is this so, that would be roughly 0.8 right and then I draw. So, this is 0.22 then, I have somewhere here, 1493. So, this is

1400 somewhere, here I have a peritectic region line ok. So, this is 0.1, this is 0.15 nearly and this is about 0.5.

So, let me just connect these 3 points right. So, let me just connect these regions, there may be some error, but by logic should be all right then, we have 4.2 somewhere here. So, this is 4.2 percent so, what I do is that, I connect this point with that point, from this point with this point and then I have a dotted region. So, this is liquid phase, all about this is liquid plus delta, this is delta, this is gamma, this is liquid plus gamma, this is gamma plus delta. So, this point is 0.1, this point is 0.15, this is 0.5, these are approximate numbers ok.

So, they vary between books as well, this is no I am sorry just, I made a mistake here, this line there should be a line at 1200 and 1147, it should be somewhere here. So, this is 1000, 1100, so somewhere here, I will have a line ok. So, this value started about 2 percent. So this line, when it started about 2 percent and it will go all the way up to this point so, you have.

So this is what, I will have a phase boundary all right and then 4.2 will be here. So, I can remove this, 4.2 from ok. So, I have this as that ok, now it is better. So, liquid this is liquid plus gamma and this is liquid plus Fe 3 C, some people also fight and here you have a mixture of gamma plus Fe 3 C here, you have gamma and this is gamma plus alpha, this is alpha, this is alpha plus Fe 3 C.

So, it is according to this phase diagram up to 2 percent, what we have is steel and beyond 2 percent, what we have is cast iron. Now there are few things that, we need to know we have looked at a few micro structures of this, we know that this is a eutectoid reaction, this is a eutectic reaction and this is a peritectic reaction, we also know how these reactions takes place.

Now, about this phase diagram, you can get all of information from this phase diagrams. First is alpha goes through a transition in the pure state at 910 degree centigrade.

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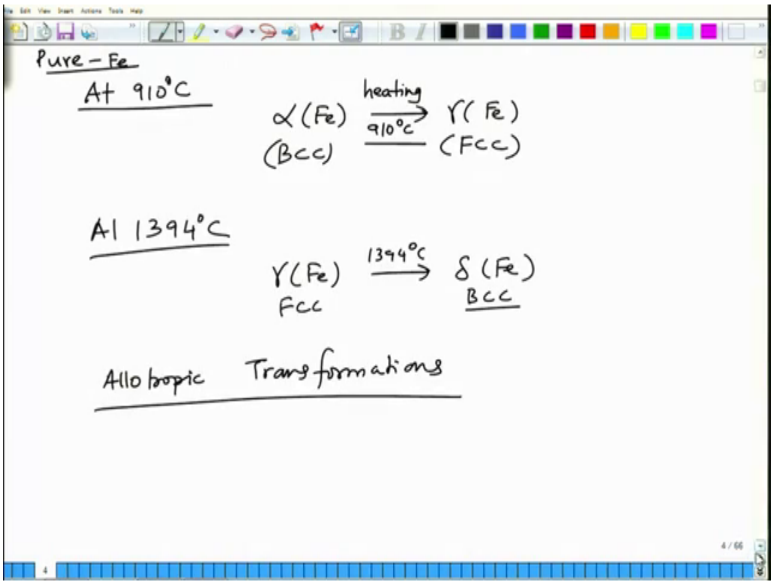

So from alpha to gamma phase and this transformation so, at 900 degree centigrade alpha Fe transforms to gamma Fe. So, this is BCC alpha transforming to FCC gamma upon heating and then at high temperature this gamma; so, this is about pure iron ok. So, at 1394 degree centigrade, your gamma Fe transforms to delta Fe at 1394 degree centigrade upon heating. So, this is the transformation allotropic transformations. So, these are called as allotropic transformations, which occur when you heat pure iron as from room temperature to high temperatures.

So, this gamma Fe is again FCC and delta Fe is again BCC. So, these are the transformations that occur in iron. Now when you look at other aspects of this phase diagram, what you see is that the most important part of this. So, there are 2 important aspects of this phase diagram, first is the steel then second is cast iron.

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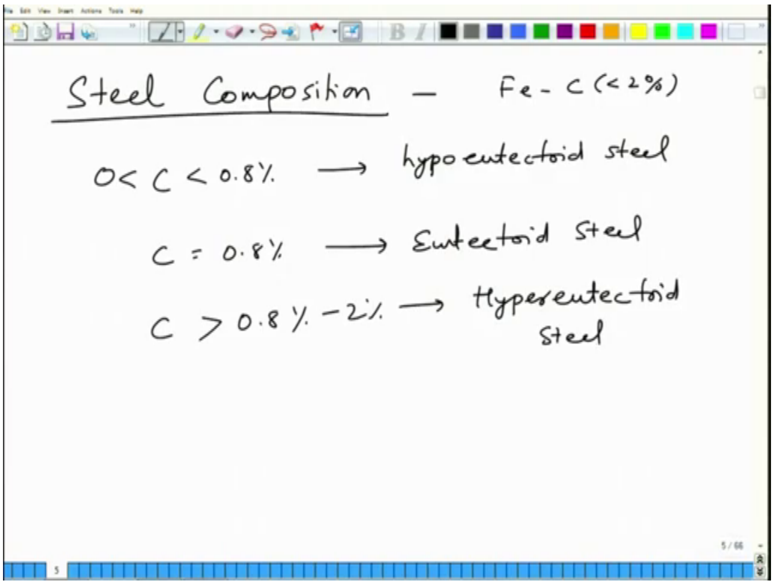

So steel, so for iron with carbon less than 2 percent is called as steel and when carbon is 0.0 to 0.8 percent, then it is called as hypoeutectoid. So, let me write it in a different way. So, carbon is less than 0.8 percent greater than 0, it is called a hypoeutectoid. Carbon being equal to 0.8 percent, it is called as eutectoid steel and carbon being greater than 0.8 percent to 2 percent is called as hypereutectoid steel.

In general steel is used in compositions, which are of hyper hypereutectoid or eutectoid steel because, when you go to hypereutectoid steel, you have very steel becomes very hard.

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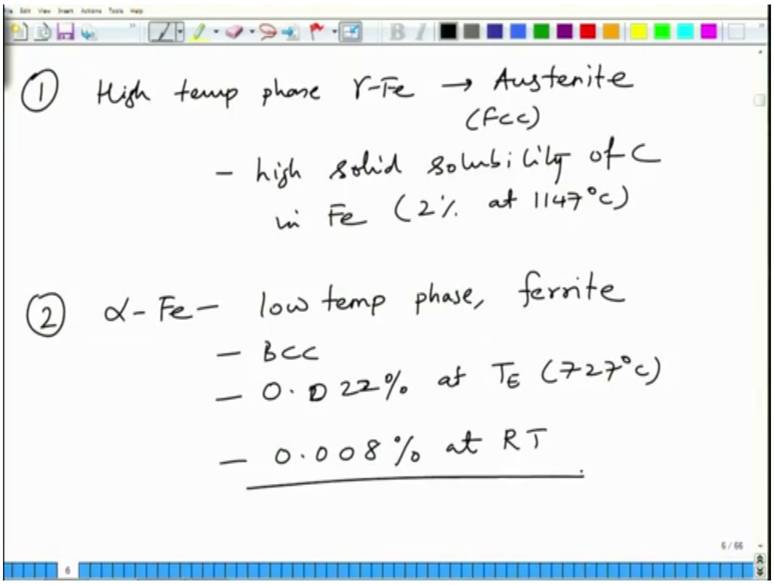

There are 3 phases that we generally consider in transformations in a steel. First is the high temperature phase gamma Fe, which is called as austenite, which is which has FCC structure and it has high solid solubility of carbon in iron and about 2 percent at 1147 degree centigrade and the solid solubility of iron in carbon in gamma F e goes down that this line. So, this is 2 percent, this is 0.8 percent.

So, this goes down as decrease the temperature from 2 percent to 0.8 percent, then we have. So, this is first second phase, that we have in this phase diagram is alpha Fe, which is low temperature phase and it is known as ferrite. Ferrite is BCC structured it is all the solid solubility of steel carbon in ferrite is about 0.022, 0.022 or 0.025 percent. So, it is about 0.02 percent and this was at eutectoid temperature, which is 727 degree centigrade and this goes down to roughly 0.008 percent at room temperature.

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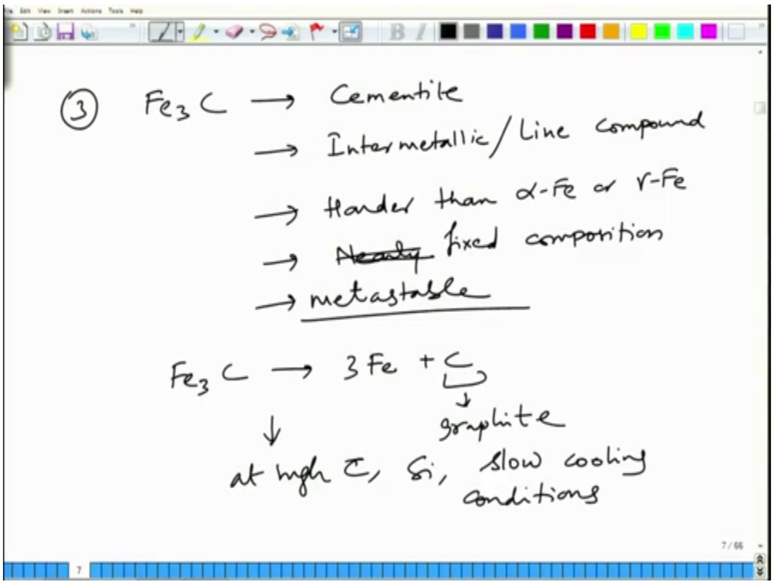

So, virtually pure iron does not consist of any carbon in it at low temperature, but whatever carbonate possesses, it is sufficient to provide it higher strength as compared to absolutely pure iron. And third phase that we have available is cementite, which is a line compound and this it is a inter metallic or line compound it is harder than alpha Fe or gamma Fe, it has nearly fixed composition.

I think it has phase fixed composition, let us not say nearly fixed composition and it has a metastable phase. So, if you provide appropriate conditions to steel, it happens not in steel as such, but it happens more in cast iron, when the carbon percentage is higher, it tends to decompose into, so Fe 3 C tends to decompose into Fe plus C and the C is nothing but, graphite and this happens at higher carbon concentration, silicon concentration or slow cooling conditions.

So, it is very much a reality in cast irons. So, the first phase so this is where now, it is the mixture of these phases the morphology of phases, which determines the properties of a steel and this is why understanding of a phase diagram of steel is extremely important. So, let us just focus on the phase diagram of steel as of now.

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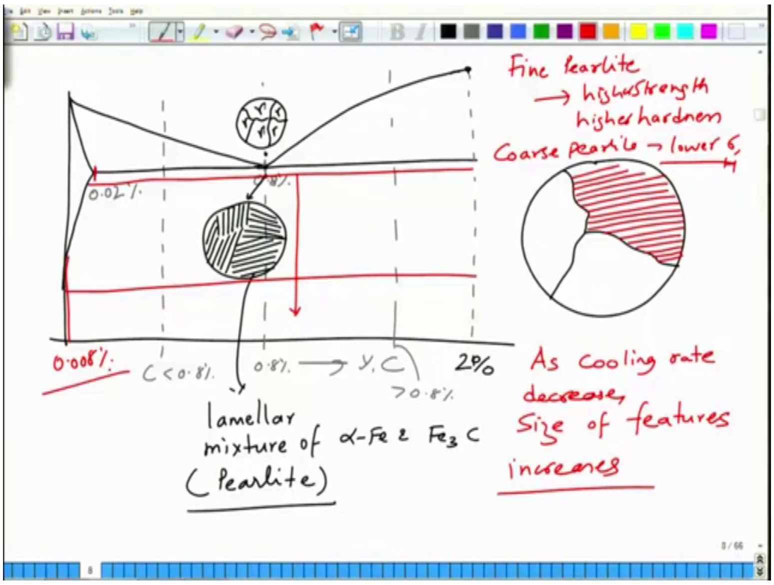

So, let us draw the particular portion consisting of let us say, we are up to about 2 percent and this is 0.8 percent, this is the 0.02 percent ok, this is percentage carbon. So, there are 3 compositions, which are of importance. The first, other compositions which are of carbon less than 0.8 percent, second is the composition which is of 0.8 percent and third is the composition, which is greater than 0.8 percent.

So, the microstructure that develops here. So, last time I showed you, what the microstructure is of hypo of eutectoid steel. So, what happens here is you have so, if you start from eutectoid steel. So, up to this point, you have a microstructure which is like this, you have grains of gamma. So, this is gamma FCC phase and the moment you cross this temperature, just below eutectoid temperature the microstructure transforms to so, this is called as lamellar mixture of alpha Fe and Fe 3 C.

So, of course, since the carbon is very small, alpha Fe proportion is that alpha thickness of alpha Fe plates is much higher as compared to cementite plates and this is called, as this mixture is called a pearlite and the microstructure in reality as I showed also last time it looks something like this.

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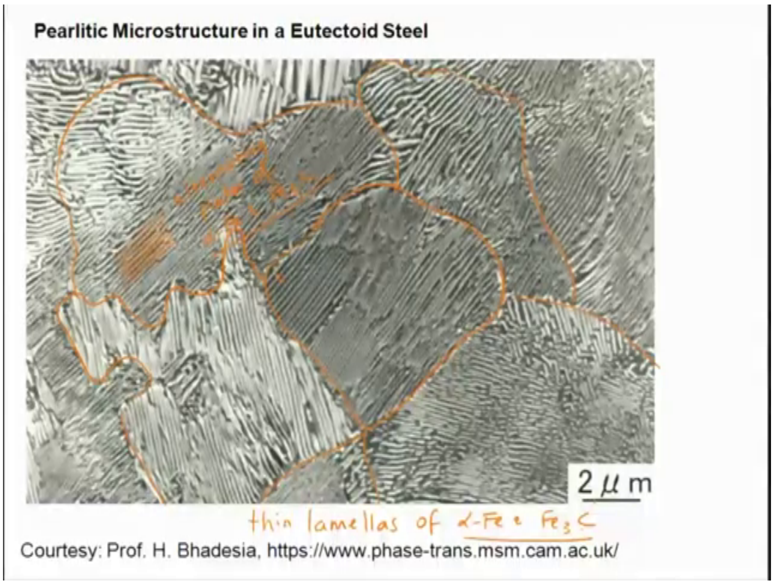

So, this is what the pearlitic microstructure looks like phase. So, we have these you can see that these are the plates that you have here. So, these are the alternating plates of alternating plates of alpha Fe and Fe 3 C and thicker plates will be that of alpha Fe and the thinner plates will be that of cementite and you can see that you have colonies. So, this is one colony, then you have another colony here, then you have another colony here, then you have another colony here you can see and then you have another colony here, you can see the boundaries between the colonies quite clearly, you know optical microscope and so on and so forth.

So, you can see that these are different pearlite colonies and how do they grow these pearlite colonies. So, what happens is basically you start from so you have a microstructure, in which you have these gamma grains ok. So, I will just draw these 3 grains; originally it was gamma and at the grain boundaries of gamma, you have the sudden growth of these 2 plates. So, these plates grow in this fashion and they grow quite fast since, they grow quite fast. The growth is there is not much growth as a result the feature size is fairly small. So, if you go to the micrograph you can see that although, the length of these is about you know. So, this is this is nearly 2 micron marker, this is roughly 10 micron by 10 micron area.

So, this is roughly 10 micron by 10 micron area, but you can see that within this 10 micron, you have nearly you know about 50 or 50 to 70 plates. So, each of them is extremely thin. So, if this is the thickness of this. So, this is the thickness of let us say 2 plates. So, this is nearly approximately equal to this, which is about 1 I do not know about one-fifth of 2 micron, which is so it is about half a micron a quarter of a micron. So, this is about quarter of a micron and you can see that each of these lamellar is less than, it is about 0.1 micron, 0.1 micron is above 100 nanometers. So, these are very thin plates. So, you can have thin lamellas of alpha Fe and Fe 3 C

So, if alpha Fe is thicker Fe 3 C is going to be even thinner. So, as a result you have this so, you can control the thickness of these by controlling the cooling rate. The rate at which steel is cooled so that, you can change the amount of time, that is needed for solute partitioning and the growth of these phases.

So, generally as you can you can probably see in phase transformations, but generally as cooling rate decreases, size of features decreases size of. So slow cooling results in a coarser microstructure and as a result the coarser plates of ferrite and cementite and this has profound influence on mechanical properties. So, the finer pearlite gives you higher strength.

So, fine pearlite. So, micro structure consisting of fine pearlite results in high strength, high hardness whereas, coarse pearlite results in higher; I can say and coarse pearlite is lower for a given composition. So, lower sigma and hardness ok. So, these are the relations of size of features, which are not predicted by phase diagram, but which are related to kinetics of phase transformation, which is out of purview of this course. Now the third, so, this is the phase diagram, this is the phase, this is the phase from phase evolution or microstructure evolution for 0.8 percent carbon steel.

And similarly, you can go about now, as you go the transformation is complete at this point. So, as you just cool from here to here, to from 727 to lower temperatures, nothing much, happens in terms of phase evolution of the phases remain the same, as you lower the temperature and the you can determine their phase fractions by applying Lever rule. So, if you calculate the phase fraction at this point and the phase fraction at very low point. It is not going to change much, because you can see the solid solubility changes from 0.02 percent to nearly 0.008 percent.

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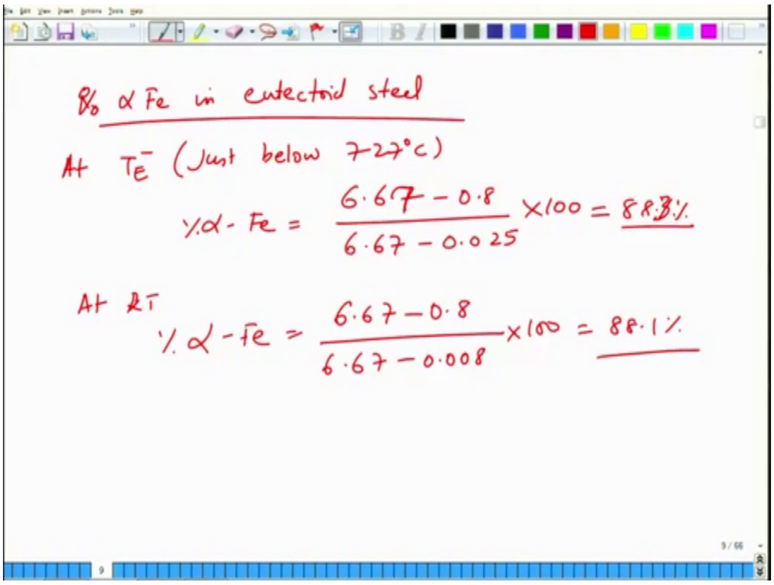

So, 0.02 percent itself is quite low. So, that the reduction so, you can calculate actually. So, we can calculate percentage of alpha Fe in eutectoid steel. So, at T e minus that is just below 727 degree centigrade so, this alpha percentage alpha Fe would be equal to 6.67 minus 0.8 divided by 6.67 minus 0.025 and at room temperature percentage alpha Fe would be. So, this is into 100, 6.67 minus 0.8 divided by 6.67 minus 0.008 into 100.

So, you can see that, if I do a quick calculation, this is 6.67 minus 0.8 divided by 6.67 minus 0.025 and this is about 88 percent and if I make a change in the values there, 0 0 8, this also leads to about roughly 88.1 percent, this was about 88.3 percent. So, it does not change much. So, the when you come from temperature just below eutectoid to room temperature, the percentage for it remains nearly the same because, there is a very little changes solid solubility of alpha ferrite.

So, what we will do in the next lecture is we will look at the micro structure evolution for hypo and hyper eutectoid steel, considering the phase diagram and then we will move on to the cast irons and brass and bronze micro structures, which are the common engineering materials before, we get into ternary phase diagram.

Thank you very much.