Phase Equilibria in Material and Metallurgical (Nature and Properties of Materials-II)

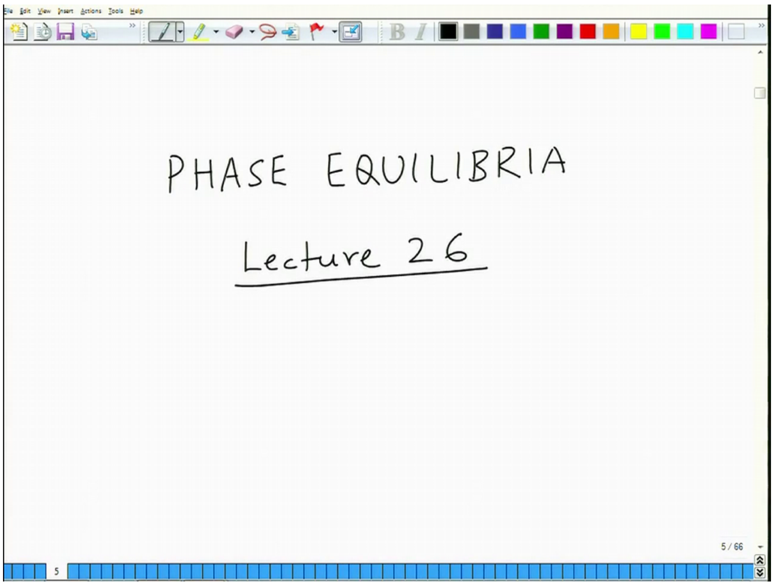
Prof. Ashish Garg
Department of Material and Metallurgical Engineering
Indian Institute of Technology, Kanpur

Lecture - 26

Phase Diagrams of Pb-Sn and Fe-C

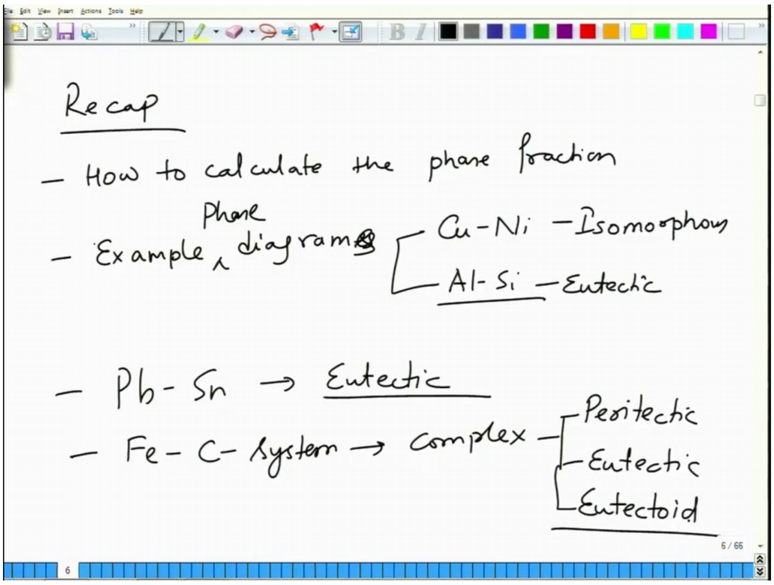
So welcome again to the new lecture this is lecture number 26 of Phase Equilibria course.

(Refer Slide Time: 00:19)



So, we will first recap the contents of the last lecture.

(Refer Slide Time: 00:31)



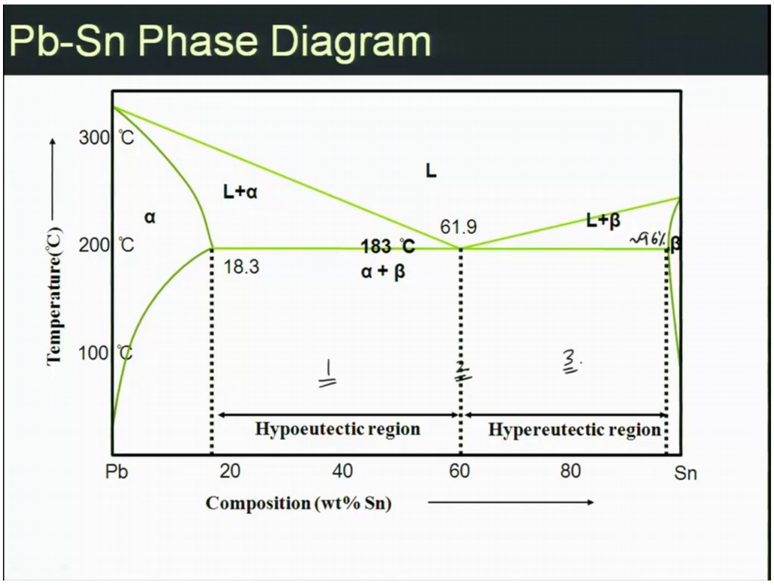
So, in the last lecture, we looked at how to calculate the phase fractions in a binary eutectic system especially concentrating at hyper eutectic composition. So, we correlated the components of different phases and then we looked at few example micro example phase diagrams. So, we looked at copper nickel which was the isomorphous system. So, we looked at how the microstructure of a copper nickel system looks it does not look like a perfectly homogeneous system it looks like a micrograph showing some contrast which is basically due to composition contrast. And then we looked at aluminum silicon system which makes a eutectic system.

So, this is isomorphous and this is eutectic which although it makes a eutectic system there very little solid solubility at lower temperatures. And as a result the mixture is basically aluminum and silicon then silicon plus being present in morphology which is deleterious to mechanical properties as a result grain refiners that refiners always a micro structural refiners are added to improve the morphology of silicon to have to. so, that alloy can have better mechanical properties.

In this lecture, we will look at some more alloy systems of commercial importance and see what kind of reactions they possess and what kind of micro structures that we obtain in those systems.

So, the examples that we will look at in this first example is latent system which is a eutectic system.

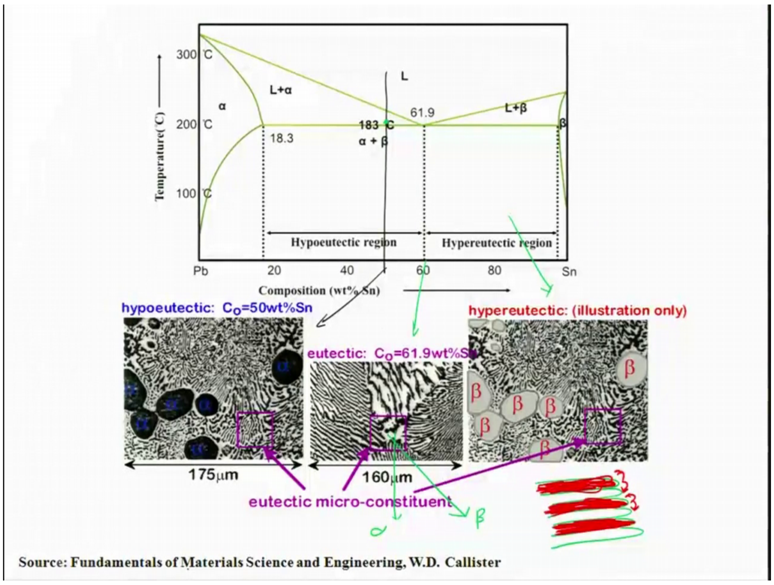
(Refer Slide Time: 02:35)



So, let us see how it looks like so this is lead pin phase diagram. It is a binary eutectic phase diagram with considerable solid solubility at eutectic temperature. So, lead is fcc tin is has a different crystal structure which has different crystal charge compared to tin they make two solid solutions alpha and beta for lead rich and tin rich ends. Later its side has considerable solid solubility at eutectic temperature about 18.3 percent whereas, the solid solubility of tin lead and tin is very little it is about 4 to 5 percent.

As a result it makes the beta phase which has very little solid solubility at lower temperatures, but reasonable solid solubility at high temperature. They have a eutectic mixture at 61.9 percent tin which eutectic mixture converts directly into unfined beta phases and they have this terminal solid solubility is of 18.3 percent at high temperature of. So, eutectic temperature is 180 degree centigrade at eutectic temperatures the solid solubility is 18.3 percent this is I think about 95 percent let me see sorry yeah.

(Refer Slide Time: 03:41)



So, the region which is between this 18.3 and 61.3 is called as hypereutectic region whereas, a region between 61.9 and let me is about I think it is about 96 percent roughly I may be wrong, but it is about it is in this range. So, between this 61.9 and this point the alloy is called a hypereutectic. So, of course, so will show you how three so microstructures look like, so we look at microstructures in the three. So, we look at microstructure which is of hypereutectic eutectic and hypereutectic.

So, these are the three compositions, so hypereutectic alloys of composition 58 percent tin eutectic composition is of 61.9 percent tin and hypereutectic basically is of high composition roughly perhaps about 80 percent 90 percent tin. So, what we have here is we have in the hypereutectic phase diagram you can in the microstructure you can see that if you draw a line somewhere here 50 percent is this line ok. So, you can see that you have pro eutectic alpha present at this point.

So, what we have is let me just change a color may be the green one. So, at this point we have pro eutectic alpha and at this point this pro eutectic alpha and liquid must have been there liquid of this composition this liquid transforms into mixture of alpha and beta. So, what you have this lamellar structure where you as you can see these parallel white and black plates at various places this is all eutectic. So, this is eutectic mixture of alpha and beta present along with hypoeutectic alpha.

So, you can find out the proportions in the manner I explained earlier. So, you can see that this alpha phases of the so this is 175 micron, so you can see that this alpha phase is nearly you know it is about 20 30 microns. So, whereas, the size of constituents in the eutectic is for smaller which is basically because eutectic converts into solid all of a sudden. As a result phases don't have too much time to grow and since phase's do not have too much time to grow the phases are finer as compared to the proeutectic phase. So, alpha and beta sizes are lower smaller as compared to protective phases in the hypo hypereutectic.

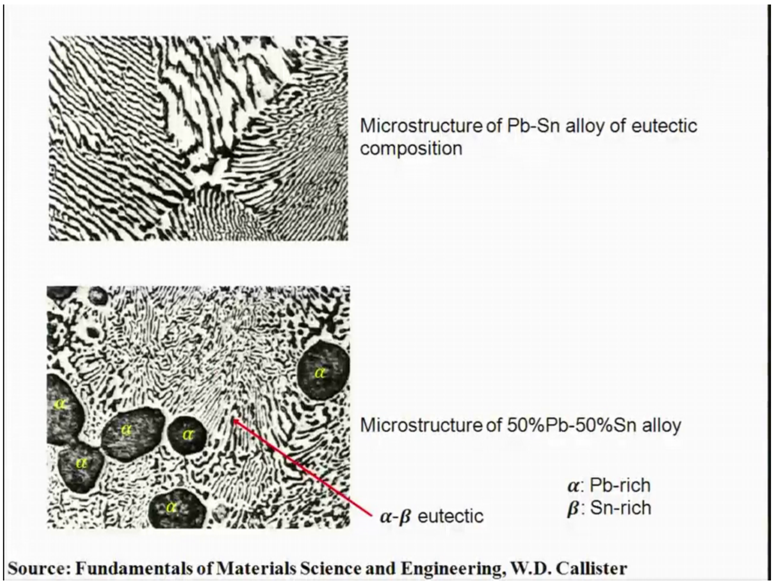
So, similarly if you look at hypereutectic region you have pro eutectic beta along with eutectic phase. So, this is the eutectic phase again you can see that the size of beta phase is smaller as compared to pro eutectic phase. So, hypo and hypereutectic microstructure are fairly similar except that the pro eutectic phases are alpha in one case and beat in another case whereas, in the eutectic phase image for this composition. So, this for hypereutectic alloy for eutectic composition you have only 6 eutectic phase.

So, you what you have is only the parallel plates of alpha and beta so what you have this is so you can say that this black one is alpha and the grey one is beta and these alpha and beta grows together and they form these colonies. So, essentially if you look at microscopically alpha and beta grow in this fashion ok. So, let us say one of them is so let us say this is alpha and the other one is beta and remember alpha is lead rich which means it has to reject in beta is tin rich it has to reject lead.

So partitioning of solute has to happen which means tin needs to travel this side and lead needs to travel this side as a result simultaneous growth and simultaneously solid solute partitioning has to happen there is not enough time for this to happen as a result the eutectic is generally finer mixture as compared to hyper pro the pro eutectic alpha beta.

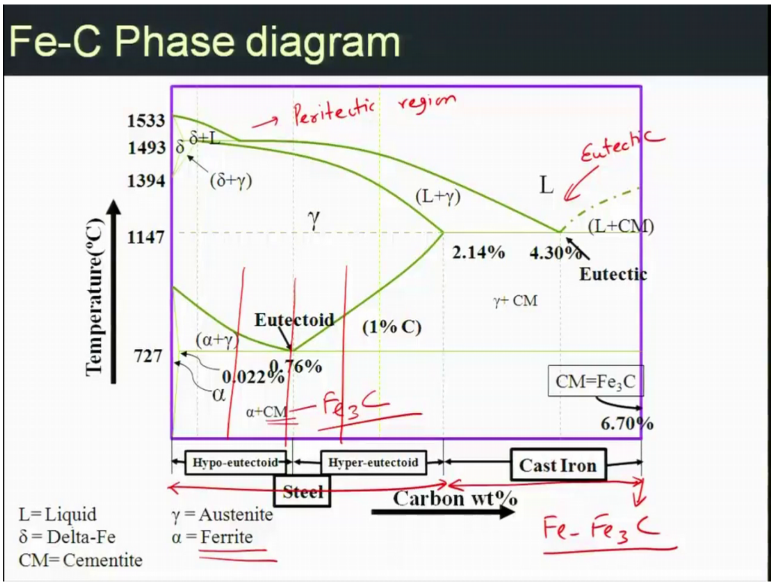
So, this is a microstructure that you are likely to observe in case of eutectic mixture of lead and tin. now let us come to next important alloy which is of commercial importance which is sorry. So, the next one is iron carbon system and this is a complex phase diagram it has peritectic, it has eutectic, and it has eutectoid reactions.

(Refer Slide Time: 09:18)



So, this is how so again this is the zoomed up image of microstructure of eutectic composition. So, the eutectic shows the parallel lamellas of alpha and beta whereas, this is the hypoeutectic alloy 50 percent tin 50 percent lead. So, you can see that alpha which is alpha phase which is the lead rich phase is pro eutectic phase and then you have a mixture of alpha and beta as eutectic.

(Refer Slide Time: 09:44)



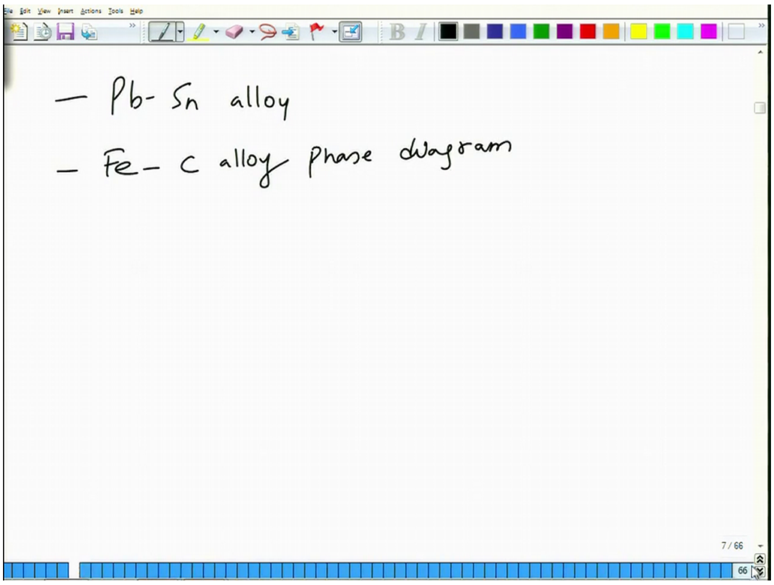
Now this is the celebrated iron carbon diagram. Now this is generally iron carbon diagram is from 0 percent carbon to 6.7 weight percent carbon basically 6.6 6 7 weight percent carbon means F e 3 c. So, essentially its F e F e 3 c phase diagram and F e 3 c consists of consists of 6.7 percent carbon in weight wise. So, it is from 0 to 6 points 6.7 percent carbon region phase diagram ok.

So, what this phase diagram has is it has multiple regions you know carbon is carbon has different structure different atomic radius as compared to iron. As a result they may they don't have complete solid solubility in various forms carbon and iron also react to form inter metallic compound called as F e 3 c at so if you have 6.7 bit percent carbon it will make F e 3 c compound.

So, everything will be 100 percent F e 3 c, so what it has is it has three regions the first region is this very peritectic region which is that carbon compositions lower than point 5 percent ok. Then we have at so this is at 1493 degree centigrade, then we have another region at 1147 degree centigrade in the vicinity of this temperature starting from 2.1 percent to 6.7 percent we have this region called as eutectic region. And then at lower temperatures at 727 degree centigrade the phase of the gamma phase of iron transforms into alpha plus cementite which is F e 3 c at a composition of 0.676, so we have this as a eutectoid region.

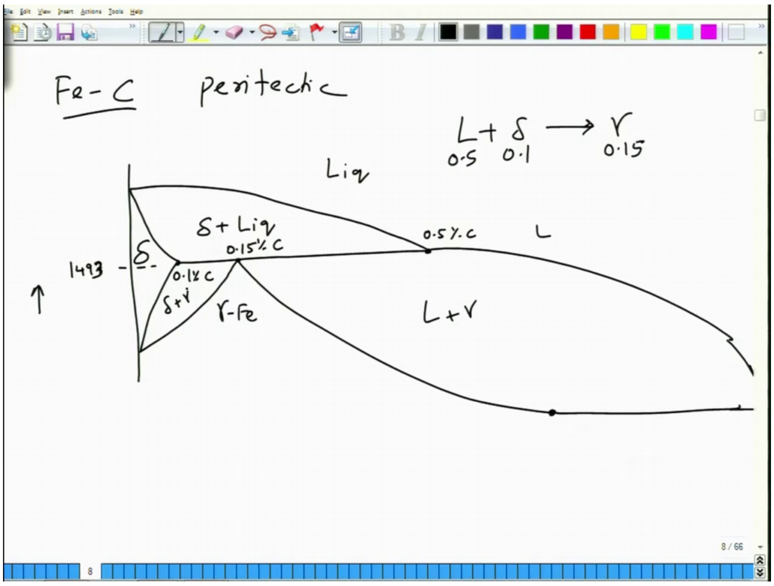
So, there are three regions of the phase diagram the peritectic region the eutectic region and the eutectoid region and these are three invariant reactions that occur in iron carbon phase diagram. So, let us look at each of these regions ok. So we first look at the region which is the peritectic region.

(Refer Slide Time: 12:08)



So, in the so what we did was we first looked at lead tin alloy and now we are looking at iron carbon alloy phase diagram.

(Refer Slide Time: 12:23)

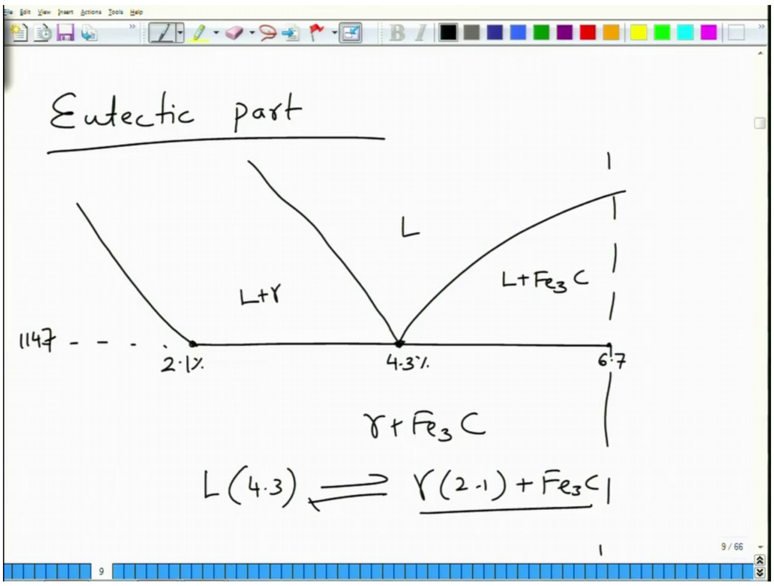


So, iron carbon the first region is the peritectic region peritectic region, so if I just draw that particular line it has. So, basically what happens is that here you have liquid present here this is that 1493 centigrade 93 or 93 let me check it is 1493 degree centigrade. So, this is temperature axis, this is 0.1 percent, this is 0.15 percent and this is 0.5 percent carbon.

So, in this at high temperatures for pure carbon you have this delta phase delta phase of carbon which has bcc structure. If you increase the temperature, if you increase the iron content further, this delta phase coexist with the liquid phase. And you can draw the composition of two phases you can determine the composition using (Refer Time: 14:03) line. This delta phase and liquid phase delta phase of composition 0.1 percent and liquid phase of composition 0.5 percent transformed into gamma phase which is fcc phase of composition 0.5 percent through a peritectic reaction.

So, liquid plus delta transforming into gamma liquid of composition 0.5 delta of composition 0.1 and gamma of composition 0.5. So, in a peritectic reaction the solid which forms has a composition intermediate to liquid and solid temperature and the liquid solid liquid composition is on one extreme this is the identification of peritectic reaction. So, this and this region is basically liquid plus gamma, so this is the peritectic region of the phase diagram and you can see the we can draw the micro structural development the way it happened in so this is delta plus gamma region and this is liquid plus delta region.

(Refer Slide Time: 15:05)



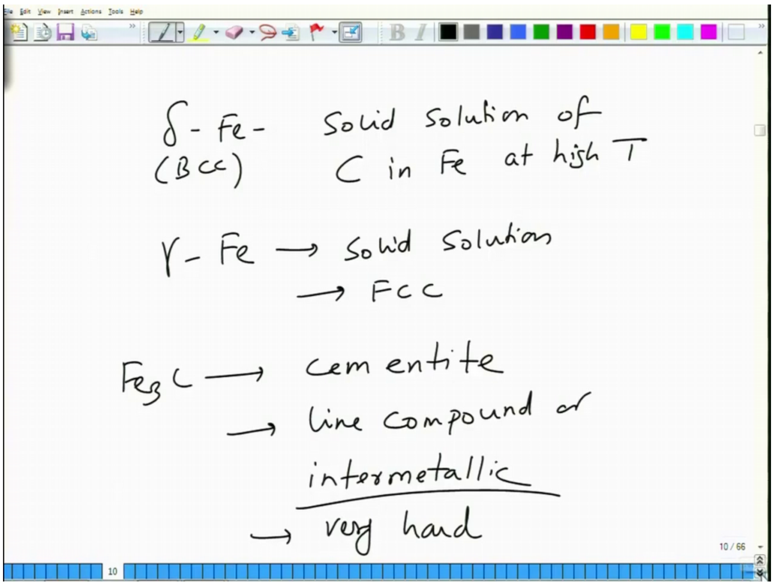
If you look at the right part of the phase diagram which is the eutectic part in the eutectic part you can see that we have liquid transforming into a mixture of gamma phase plus cementite at a composition of 4.3 percent and at a temperature of 1147 degree centigrade.

So, if I draw this eutectic region so this is the composition 4.3 percent this is 6.7 and somewhere here you have 2.1 percent.

So, you have this is 1140 7 degree centigrade and of course, you have this, these two lines coming from top from the peritectic region. So, you have liquid plus gamma liquid plus fe 3 c which is cementite and these two this converts into gamma plus fe 3 c at this temperature.

So, this is the eutectic reaction, so liquid of composition 4.3 percent transforms into gamma of composition 2.3 percent plus F e 3 c which is 6.7 percent carbon basically.

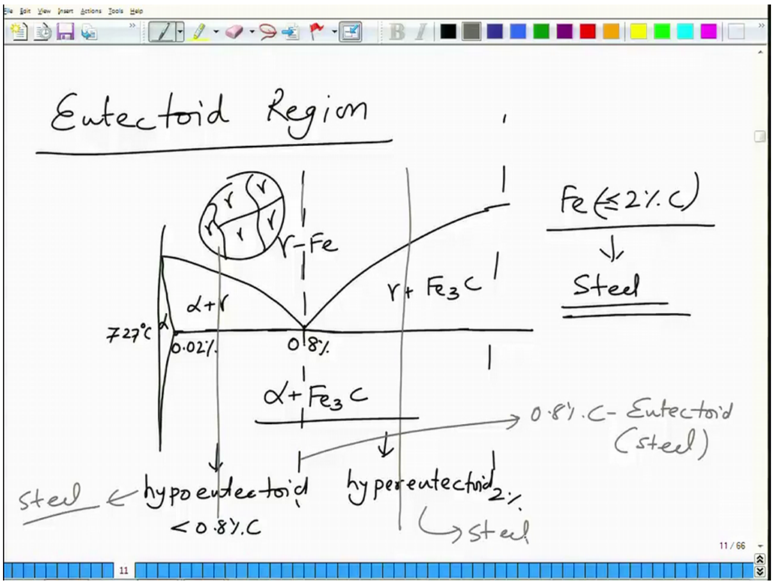
(Refer Slide Time: 16:36)



Now here the difference between alpha delta and gamma is delta is solid solution of carbon in iron at high temperature and its solid solubility varies up to the limit of solid solubility. Similarly gamma is it has a BCC structure similarly you have gamma iron which is again solid solution and it has a FCC structure. Whereas, F e 3 c is called as cementite, it is not a solid solution, it is a line compound or you can say it is intermetallic. It is much stronger than alpha and delta iron it is very hard.

So, comparatively gamma and delta delta and gamma are very soft phases F e 3 c is extremely hard very hard ok.

(Refer Slide Time: 17:45)



Now the third part of iron carbon phase diagram is the eutectoid part and this is the most important phase diagram this is most important part of the phase diagram as far as engineering applications of iron phase diagram are concerned. In this part of the phase diagram the gamma phase of composition 0.76 percent which is solid phase transforms into a mixture of alpha iron, which has very low solid solubility of carbon in iron about point 0 to 2 percent plus cementite. So, what it does is basically so it has you have a like this so this is a temperature 727 degree centigrade ok. So, this is point nearly 0.8 percent this is 0.2 percent and this goes all the way the interesting part of phase diagram is only up to 2 percent ok.

So, gamma iron which is FCC converts into alpha plus F e 3 c and this is pure alpha this is alpha plus gamma this is gamma plus F e three c. So, the region which is left of 0.8 percent is called as hypo eutectoid. So, less than 0.8 percent the region which is right of 0.8 percent is called as hypereutectoid. And iron with carbon less than 2 percent less than or equal to 2 percent is called as steel this is these compositions make up the modern material called as a steel. And this it is this part of the phase diagram of iron carbon which is extremely interesting for from the perspective of engineering this material for variety of applications.

So, what you have here is you have single phase gamma which is FCC structures when you start in this region you have these grains of gamma so this is gamma. Now depending upon whether you are cooling now depending upon whether you are cooling from this point, whether you are in this point, whether you in this region you will obtain different microstructure. So, you can see that the microstructure is going to be fairly similar to what you obtain in eutectic is it is just that it is going to happen in solid state, and since it happens in solid state the feature size is even smaller because the diffusion distances are smaller in solid phase.

So, what you have here is you have this composition 0.8 percent composition which is called as eutectoid steel then we have less than 0.8 percent which is called as hypo eutectoid steel. And then we have steel between 0.8 percent and 2 percent is called as hypereutectoid steel and it is the three phase three kinds of phase distributions which are important from the perspective of engineering applications of this alloy.

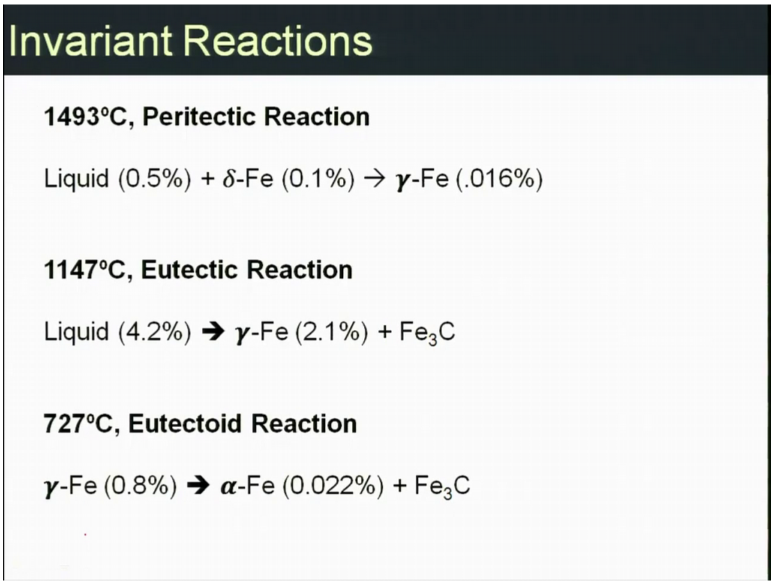
So, and anything with beyond a 4 percent beyond 2 percent carbon is called as cast iron. So, if you carbon content is between 2 percent to 6.7 percent the alloy will be called as cast iron if your composition of the alloy is below 0.8 percent 0.76 percent to be precise it is called as hypo eutectoid steel and if it is between 0.76 to 2 percent carbon it is called as hypereutectoid steel. So, this region is steel and this region is cast iron and there are various phases liquid phase is present at high temperature delta F e which is a polymorph of allotrope of iron is presented high temperature for very low percentages of carbon or for pure carbon.

Gamma phase which is the FCC structured phase called as austenite this phase is present from this has maximum solid solubility of 2 percent to 0.1 percent at a temperature of 1147 degree centigrade. And it has very large single phase region starting from peritectic temperature of 400 1493 centigrade to the eutectoid temperature of 727 degree centigrade. So, this whole region is single phase gamma region FCC structure, but this is unstable phase because the high temperature phase.

This transforms into two phases at lower temperature one is called as alpha F e which is which is called as ferrite alpha F e is called as ferrite it has very little solid solubility of carbon in iron. It has a soft phase of iron and second phase which forms at low temperature is called as cementite which is F e 3 c cementite and it is the microstructure of these three regions which is of importance.

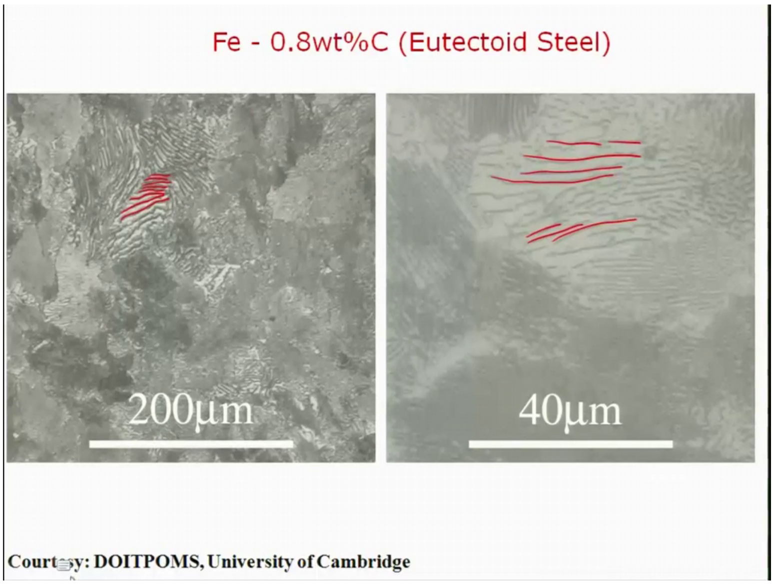
So, microstructure of this region microstructure at this point and microstructure at this point which is what is important from the perspective of engineering applications. And these micro structures can be tailored modified quite extensively by adopting different cooling rates etcetera.

(Refer Slide Time: 23:22)



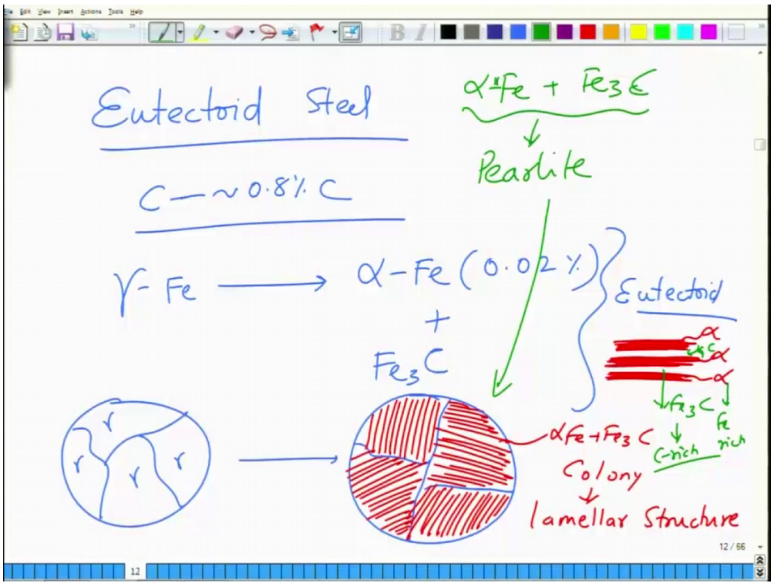
So, there are three invariant reactions that happen at one 1493 degree centigrade peritectic reaction occurs liquid of composition 0.5 percent delta of and delta iron of composition 0.1 percent transformed together to give gamma iron of composition 0.16 percent this is 0 ok. 0.16 percent 1147 degree centigrade you have eutectic reaction in which liquid of composition 4.2 percent transforms to gamma iron of 2.1 percent and F e 3 c align compound. At 727 degree centigrade eutectoid reaction occurs at which in which gamma iron of composition 0.8 percent transforms into alpha iron of 0.002 percent solid solubility and F e 3 c these are three major invariant reactions that occur in iron carbon phase diagram.

(Refer Slide Time: 24:15)



Now, let us look at what are the what are the micro structures that we obtain if you have 0.8 weight percent carbon steel which is 0.7 basically 0.76 eutectoid is to be call it eutectoid steel the composition for which the gamma phase so eutectoid steel is the one.

(Refer Slide Time: 24:44)

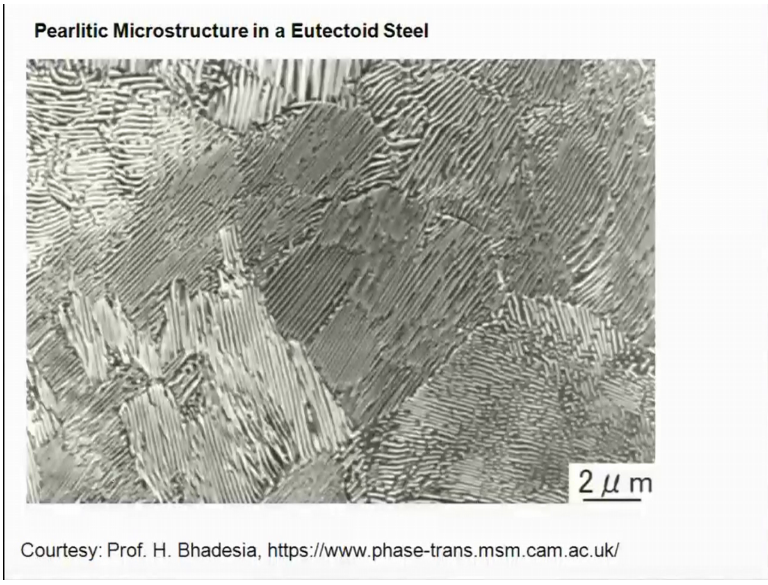


So, eutectoid steel is the one for which carbon content is in the vicinity of 0.8 percent. So, basically in this the gamma phase converts into a mixture of alpha F e which has a solid solubility of point 0 2 percent plus F e 3 c and this is a eutectoid mixture it forms all of a sudden. So, you had started with grains of gamma this is all gamma and then you suddenly convert this into a mixture. So, you had these grain boundaries of gamma on these grain boundaries of gamma you have nucleation and growth of so this is how they will form.

So, these colonies will form so this is the alpha F e plus F e 3 c colony this is called as lamellar structure lamellar structure of and if you look at it microscopically what it is going to look like it is going to look like this you have plate of let me use a different color here. So, you have a plate of alpha then you have so these are the plates of alpha. So, you have alpha in between you have F e 3 c and again just like eutectic you are going to have partitioning of solute. So, alpha will release carbon which will get into F e 3 c and iron will transform iron will move from other side to make alpha F e, so this is F e rich and this is carbon rich.

So, that is why they form a parallel lamellar structure and what you see in the micros micrograph is something like this. So, you see sort of grayish microstructure in which you can see these are the parallel plates. So, you have this as a parallel plate you can see these the parallel plates ok. So, you can see and if you zoom it up the microstructure this is the parallel plate so you have plates of cementite parallel to ferrite so this is how the microstructure looks like.

(Refer Slide Time: 28:12)



If you want to find the description of the microstructure let us look at the next so this is the final description the microstructure you have these parallel plates of alpha and F e.

So, alpha is the brighter phase you can see that there is larger proportion of alpha then cementite.

So, thicker plates will be that of ferrite and the thinner plate will be of that of cementite you can see this kind of parallel plate microstructure lamellar microstructure that you will see, and this is called as paralytic microstructure the pearlite is not a phase it is just a mixture of alpha F e and cementite. So, in steel this mixture of eutectic mixture of the alpha F e plus F e 3 c it is called as pearlite.

So, as long as you have a microstructure which has this kind of morphology which is lamellar morphology the microstructure will be called as a paralytic microstructure. And the microstructure of other two sides will be very different which we will look at in the next lecture what we what we have done in that in this lecture is we have again looked at a few common phase diagrams such as lead tin phase diagram and iron carbon phase diagram.

We have looked at the various invariant reactions in the iron phase carbon phase diagram and also how the microstructure looks for a eutectoid steel. In the next lecture we will further develop on it we look at the microstructure of hypo and hyper eutectoid steels as well as a few cast irons before we move on to the next part of the course.

Thank you very much.