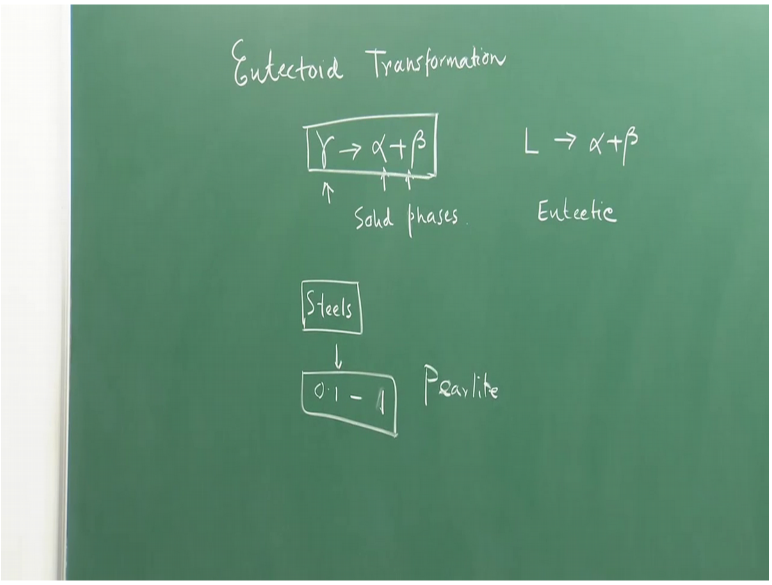
Phase Transformation in Materials
Prof. Krishanu Biswas
Department of Material Science & Engineering
Indian Institute of Technology, Kanpur

Lecture - 39
Eutectoid Transformation

We are going to start another new phase transformations in the solid state; that is known as eutectoid transformation. As you know eutectoid transformation is a major class of phase transformation we observe in different materials and the transformation can be written as like this. Normally we write that a phase which is a high temperature known as the gamma phase undergoes a transformation and forms 2 phases simultaneously.

(Refer Slide Time: 00:37)



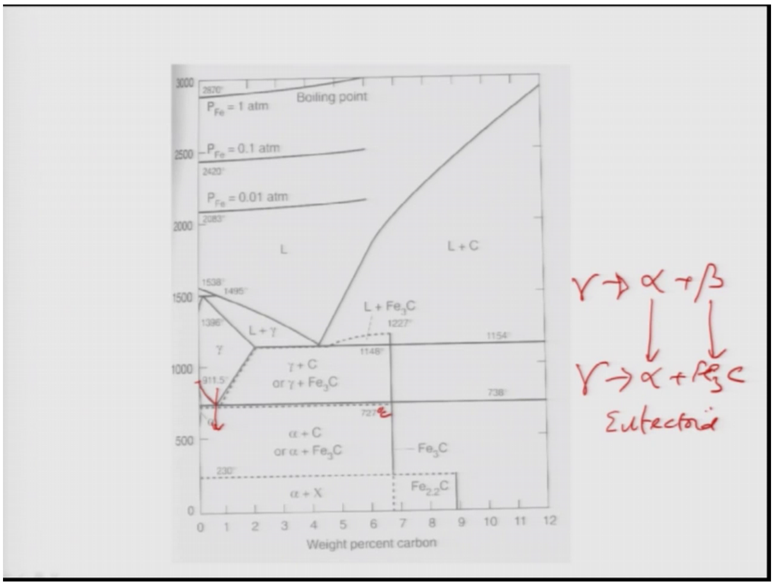
Here all these phases are actually solid remember that is why it is called eutectoid transformation. Now this as a similarity with the eutectic reactions which I have discussed in solidification; we know the eutectoid reaction is given by liquid going to 2 solid phases alpha plus beta.

So, that was simply replacing liquid with solid phase gamma we could see that the phase transformation eutectoid can be achieved. So, this is the eutectic and whenever we have a T quad in the transformation which is it in must involve a liquid phase, but whenever eutectoid attached to a word is a less involved solid state fast transformation. So, this is the classic reaction which you must remember which is basically giving the idea of a eutectoid transformations remember the eutectoid transformation is very important in steels.

So, most of our discussions in this will be taking example we will be taking example from the steels and explain you how the transformation happens the steels which is which actually has a composition from about point you know one to basically point one to let us say one percentage. So, is the products known as Pearlite and which is well known to all the metallurgical community or material science.

This Pearlite actually is nothing, but a combination of the 2 phases forms because of the transformation of the high temperature phase gamma. So, that is the important aspect which is remember now as I told you that one of these important caller id of the eutectoid reaction is the microstructure the steels.

(Refer Slide Time: 02:32)

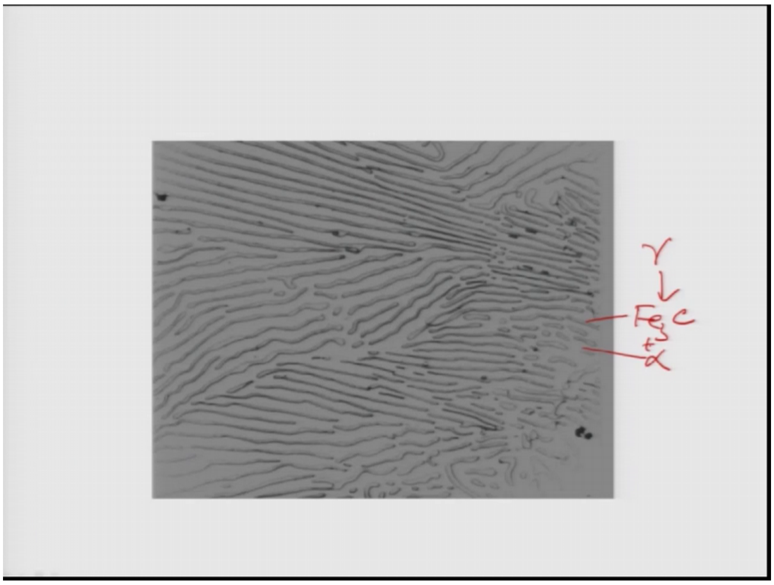


So, we will start with the iron carbon phase diagram; you know steels basically iron carbon alloys and predominantly; it contains iron little bit of a carbon, it can be as low as point one or less than even that or as about 1 percent carbon. So, this is the iron carbon phase diagram shown on this you see here that this y axis is basically temperature in degree Celsius. So, and x axis is 1 percent of carbon this diagram is well known to you or it should be well known to you if not please go back to my own lecture on phase diagrams in material science engineering you will find the detail discussion on these phase diagrams.

So, as we are going to discuss about the paralytic transformations; especially the eutectoid transformation in the steel; we are not going to discuss the whole phase diagram only; I will be concentrating on the salient person which are required for our discussions what you see here basically equilibrium between 2 phases alpha iron which is nothing, but a solid solutions of the carbon in BCCRN and another phase which is known as Fe3C, it properly known as cementite and this is basically carbide and if you see here the gamma which is basically another solid solutions of carbon in FCCRN undergoes a transformation here at this temperature undergoes transformations oh the transformation actually is can be easily shown this transformation what I am discussing at about727 degree Celsius temperature.

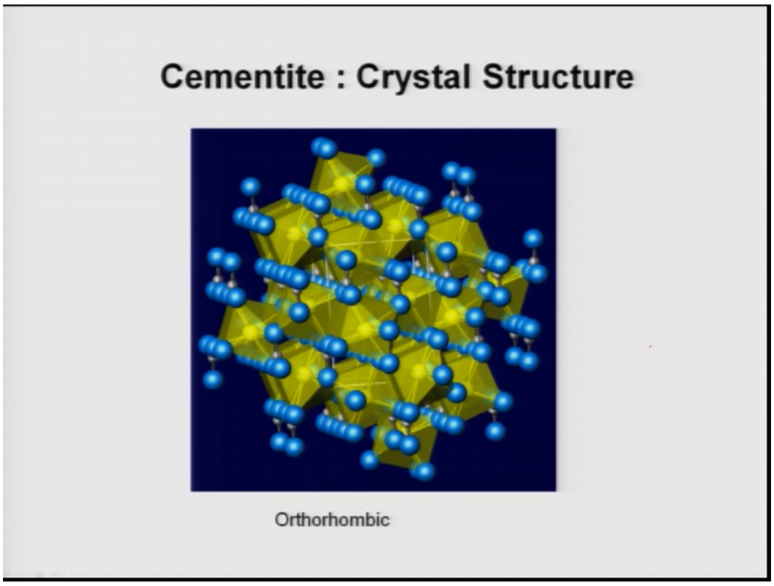
In which the gamma is undergoing a transformations to alpha plus Fe3C this is also similar to the reaction which are would gamma going to alpha plus beta. So, alpha is alpha here and alpha is basically alpha iron and Fe3C is beta. So, therefore, this transformation which is happening here is important in all the steels because as you see steel as a composition between 0 and 1 atom percentage that is why in all the metallurgical steels basically preserve metallurgical steel basically revolves around understanding these reactions that is what we will see as you know as one phase gamma which is present at high temperature undergoes a transformation leading to formation 2 phases.

(Refer Slide Time: 05:19)



So, therefore, the micro study is very simple here, it will be Like a lamellar one which you have seen for the eutectic let me just explain to you first of microstructure and comeback this is a typical optical micro gap of a Pearlite which you normally see in the plain carbon steel as you see here, it consisting of 2 phases one which is wide continuous other one is say like a plate. So, and these actually plates having different orientations in the microstructure. So, normally these plates are actually known as Fe3C they are the carbides and whether this continuous phase is known as alpha. So, therefore, the microstructure is basically consisting of transform gamma into 2 phases Fe3C plus alpha if we want to the know little bit amount let us go back by the way cementite has a very complex structure it has orthorhombic crystal structure and tou see these are the carbon atoms and shown here.

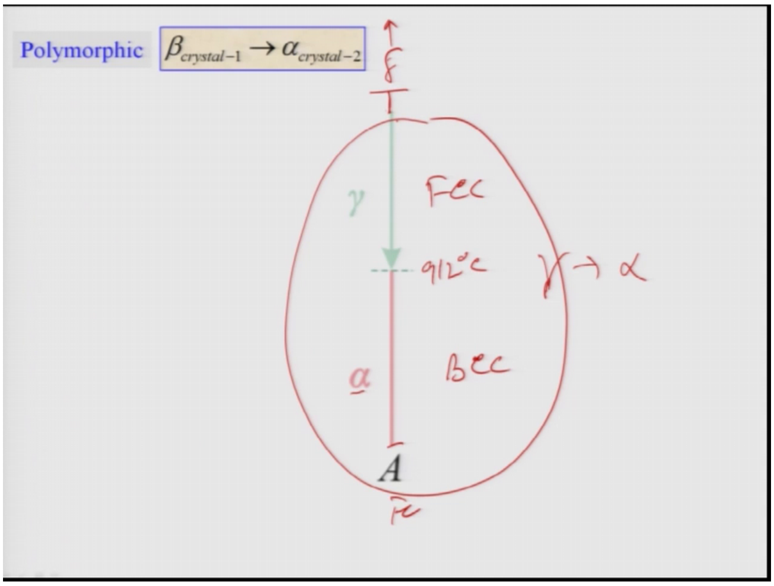
(Refer Slide Time: 06:05)



So, these are the carbon atom inside and these are the blue colour atom sized (Refer Time: 06:20) atoms present on the lattice; they actually forms like a tetrahedral coordination between these atom; sorry octahedron condition between these atoms this octahedron inside each of these; these are the octahedron atom; octahedron cornets in on which the iron atoms are sitting and inside that there is octahedron centre on which the carbon atom is sitting and this octahedron actually are in a attached each other along the cornets as what you see here this cornets actually attached in the octahedron that is why this orthorhombic complex structure forms. So, basically carbon atom goes to the (Refer

Time: 06:57) in the BCC iron lattice. So, that is why actually it forms distort the lattice and leads to formation of orthorhombic structure.

(Refer Slide Time: 07:04)

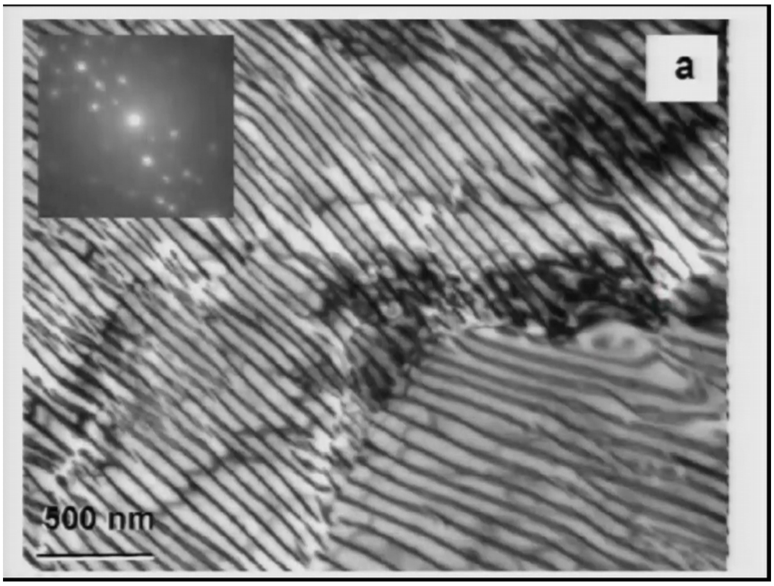


Now, as you know iron is a classic metal which undergoes polymorphic transformations as I discussed in few you know lectures back; that iron actually is a BCC structure at room temperature which is known as alpha, alpha iron at about 912 Celsius temperature in order goes to gamma iron and becomes FCC structure; again at the high temperature at about 1492 is again it is become delta and then finally, at 1539 degree Celsius temperature these melts down to liquid. So, therefore, the important transformation power discussion is between basically between gamma and alpha and this is for the pure iron, then when there is no carbon the moment we had carbon into it, things gets changed that is what is shown in this phase diagram.

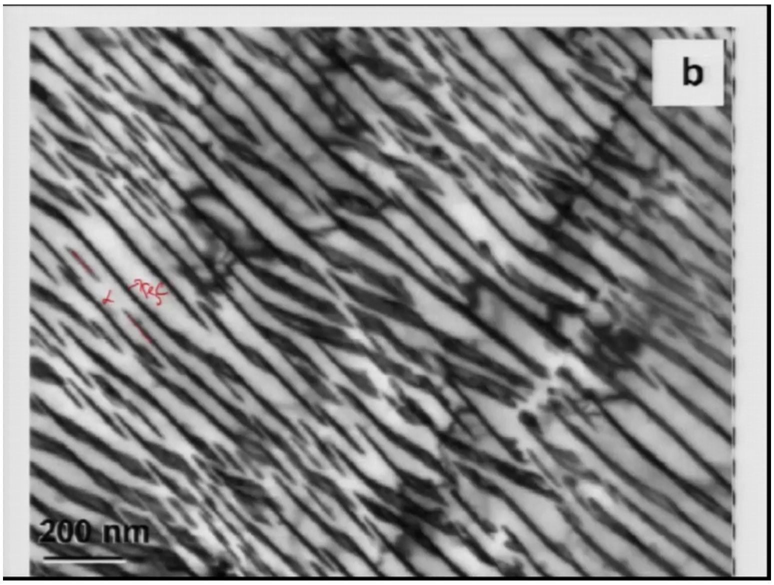
As we had common into it as you see here the transformation which was happening for the alpha to gamma at 912 degree Celsius temperature, it decreases that is what is shown by this line; this line which is this curve which is swing is telling you that transformation temperature of gamma to alpha basically or alpha to gamma is a strong function of the carbon concentration alloy. So, this decreases very rapidly to our 0.778 percent of the carbon and where there is it deep or there is basically here you know bluest minimum position and at this temperature there is a horizontal line this is here this horizontal line correspond to a reaction and that reaction is basically eutectoid reaction which you have discussed few minutes back and at a higher concentration of carbon again this transformation temperature increases.

It goes higher when the alpha to gamma transformation has to happen; so, therefore, and at a high temperatures again several other failures forms which are not our concern. So, important thing to remember is that this transformation temperatures which is 912 for the pure alpha pure iron and at 727 (Refer Time: 09:10) temperature for the eutectoid reactions. So, let us; now we will discuss how this transformation actually happens; obviously, any transformation will happen by nucleation and growth correct. So, this is the typical microstructure if you look at in a electro micro scope, this will look like plates as you see here the black thing is basically F 3 see and the white coloured thing is basically white contrasting is basically alpha phase and this has a nice play like microstructure alternative of these phases present in the micro structure.

(Refer Slide Time: 09:24)

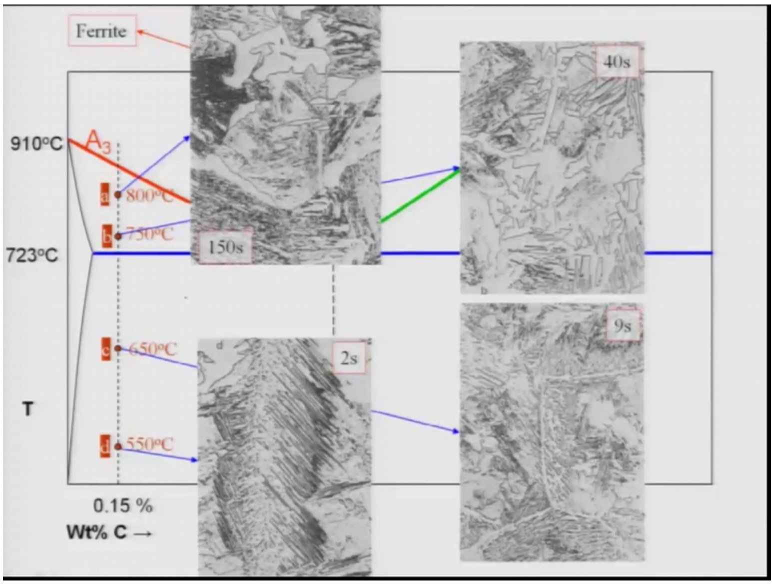


(Refer Slide Time: 09:44)

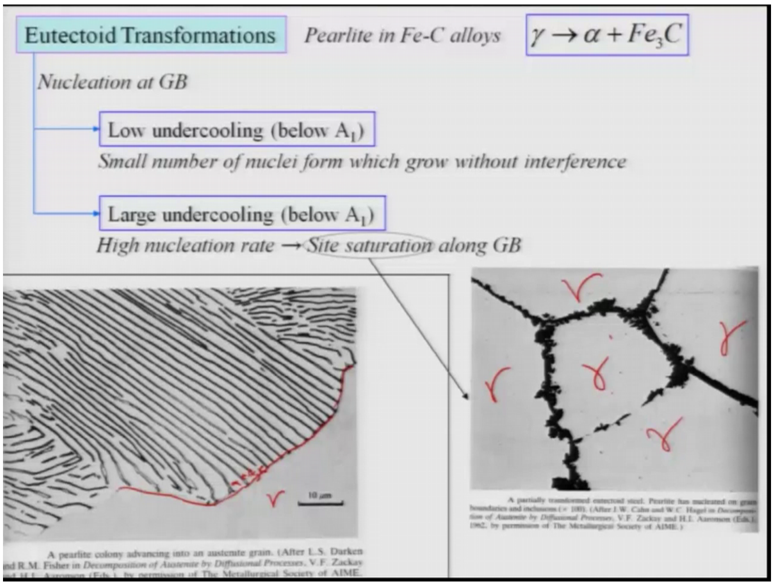


Similarly, here also you can see even the plates are there; some of their cases are this as the broken plates, but this is alpha this is cementite present as you clearly see if you do the phase diagram calculations properly there normally the fraction or the polymerization of the phase is at about eutectoid temperature for the 0.778 person carbon alloy will be 85 percent of alpha and so remaining about 14 to 15 percent is Fe3C. Now if we know the densities of these alloys, both of the phases alpha and the Fe3C; we can you can clearly see the ratio of the thickness of the cementite and alpha will be seven is to one that is possible to calculate. In fact, this will be one of the problem in your assignments to calculate the this to this thickness of these phases in the microstructure.

(Refer Slide Time: 10:34)



(Refer Slide Time: 10:43)

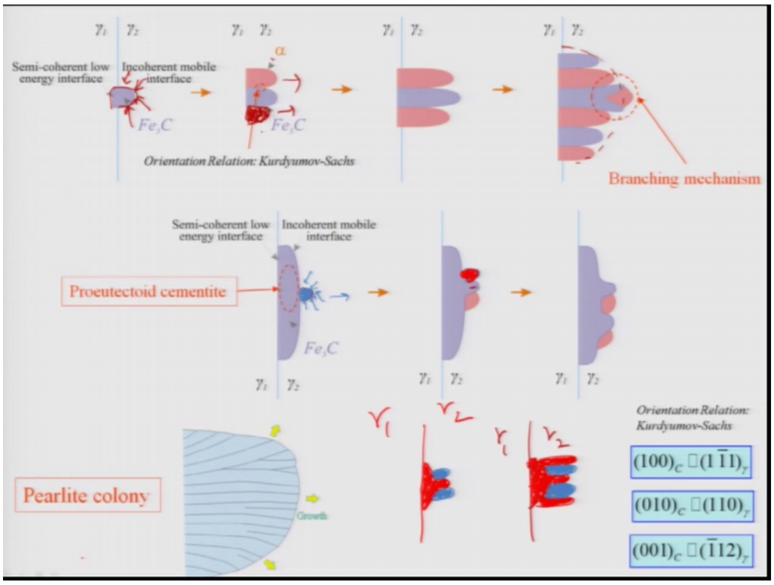


So, let me just explain you how the things forms how the xt transformation happens let me just go and obviously this is the classic microstructure which is normally shown in the books this is taken from you know from the book by darken and fissure and decomposition of austenite by dipressional processes this is the interface this is the gamma and that interfaces between gamma and the reaction product the between reaction product is; obviously, alpha and Fe3C this is Fe3C as you see here. So, what you see here as the interface moves both the phases are going together so; that means, this is a cooperative growth, but before that let me as tell in most of the cases nucleation of these phases happens and the grain boundaries of the gamma phase these are the gamma.

So, nucleation is normally happens on the gamma that is obvious because the grain bound is the regions of grain boundary grain corners grain edges or even triple points other regions of you know where the nucleation probability is high we have seen that in our discussion on nucleation the same thing will happen here also. So, all the nucleation starts happening from the grain corners or they are grain boundaries or maybe edges that is what is you seen here, then these colonies grows inside the grains it can also happen within the grains something like that if there is a compositions in homogeneity or is some defect structure present like a dislocations or a wear of vacancies present like that its possible, but preferentially nucleation happens along the grain boundaries or grain edges and grain corners that see one important aspects.

Now, once the nucleation happens the nucleation can happen for the any of these 2 phases either alpha or Fe3C both can nucleate you know side by sides or they can nucleate separately. So, mostly it has been seen that for the hyper eutectoid alloys the alloys contain less than about point eight percent carbon nucleation is normally happens for the alpha phase on the other hand for these hyper eutectoid allies its speed mostly starts with Fe3C; why do not be the situation the transformation does not change transformation process does not change much.

(Refer Slide Time: 12:48)



Let me just tell you; how it happens; let us assume there are 2 grains of gamma; gamma 1 and gamma 2; here and let us assume that the Fe3C is the phase we start nucleating on the grain boundaries; let us assume, it can be you can also assume that alpha nucleus that grain boundaries and as C as you know Fe3C as a composition of a Fe3C as a large amount of the carbon concentration.

It has a carbon concentration of 6.67 percent ca weight percent carbon under than alpha as a very low carbon concentration it is about 0.02 percentage at 900; a 727; these are the temperature a room temperature is almost 0 that is what is seen in the phase diagram. So, what will happen as the Fe3C is a carbon is compound; it requires more carbon for its growth. So, when it grows into the one of the grains which it has in corner interface that is obvious because the grain with future each of the corner interface will remain stagnant because it would like to keep these corner interfaces or semi corner interfaces present it will not try to disturb.

That allows us to have a low energy and the moment the grain with to choose has in corner interface that will be the one which will be mobile. So, as this Fe3C grows into the gamma to grain; it grows requires carbon. So, all the carbon from the nearby region will diffuse into it that is why it can achieve a sufficient amount of carbon for is good to happen and because of carbon diffusion from these nearby regions in the gamma to grain; the resist agents should be lean in a carbon concentration because carbon is going; carbon is moving actually diffusing in through these gamma and reaching these Fe3C gray Fe3C nuclei; nucleus to get grow and this will lead to a huge reaction with carbon concentration nearby regions and therefore.

This allows nucleation of the alpha because alpha is almost no carbon in required; that means, it has no carbon into is there any (Refer Time: 14:54) in the phase because alpha as I told you at 727; this is the temperature it is carbon concentration alpha is about 0.02 weight percentage (Refer Time: 15:02); it has no carbon concentration require. So, because of that it can grow very easily nucleate actually on the both sides of the gamma sorry both sides of Fe3C and nuclear can grow in the same direction as you see here in this direction correct and as growth of alpha requires rejection of carbon it does not require any carbon. So, therefore, near regions will become reaching carbon and this will lead to further nucleation of the Fe3C.

This is exactly how these nuclei; the nucleation growth of these phases happens and this leads to colony formation; this is a colony and that is we have seen in the microstructure the colonies forms; let me just this is one such colony see here shown in this picture that is the this is a one colony and this is a gamma grain this colony is growing in to the gamma grain and this is normally observe. So, therefore, I can easily explain the formation of or the growth of these paralytic colonies in the during the transformations. Now you can also have something like you know alloys which are not 0.77 percent carbon; it can be provide the hyper eutectoid or the hyper eutectoid if it is hyper eutectoid you will have a pro eutectoid cementite.

We will discuss; how it can happen because the alloys which has more than 0.77 weight percent carbon will always have a pro eutectoid cementite present and these pro eutectoid cementite, if it is present on the; it will present on the grain boundaries mostly because grain boundaries once which will allow nucleation of these poetry cementites and if it is present on these; it will lead to easy nucleation of these cementite for the Pearlite that is what you seen here this cementite which is there can easily nucleate overheat very easily and because of that because it can nucleate over it very easily and because of that; it can actually have such an kind of structure like that and again once it once it goes into the gamma grain this look has more carbon.

So, all the carbon will diffuse in the region and the near regions will be lean in carbon concentration and this will allow you to basically nucleate alpha phase very easily on the both sides of these gamma both sides of the cementite and this will again lead to formation of colonies.

So, therefore, nucleation of these phases is can happen in many ways similarly for a hyper eutectoid alloys will have a alpha on the grain boundaries like you have 2 grains gamma one gamma 2 and then you have a alpha peasants which is provide to at alpha and this alpha will again allow the nucleation of the alpha phase of the Pearlite very easily because it is said as a nucleation and it is a nucleation on the same phase; so, therefore, energetically this is very favourable and because the growth of alpha requires little less amount of carbon or actually no carbon. So, the what will happen the near regions will become very rich in carbon and on the carbon concentration of these critical concentration required for the nucleation of these Fe3C; Fe3C a nuclear on the both sides.

Finally it will lead to a formation of a colony and this colony is we will have these space which is pro eutectoid sorry pro eutectoid pro eutectoid alpha as nucleating straight not the gamma a grain boundary, but pro eutectoid alpha and this will be followed by formation of these colonies and these colonies will be again looking like a same like a Pearlite.

So, as you see a nucleation is could not a very critical step for the formation of pearltes that is a very clear nucleation can happen many ways it can happen on the p existing grain boundaries of gamma or it can happen in the p existing pro eutectoid phases either cementite pro eutectoid or pro eutectoid alpha and this can lead to formation of these colonies. So, therefore, either way what are be the situation it will lead to formation of these colonies which you have seen in the microstructure like that.

So, that is how actually the most of the phase transform most of these they or the important transformation of paralytic phases happens paralytic phases means the phases of gamma plus alpha plus cementite actually had takes place in these steels please remember that this looks like a very simple, but when analyzed kinetically it is not. So, there are many important aspects which you which you need to deal with the first one is how actually the nucleation rate and growth rate will depend on what are the different aspects; obviously, the important thing to considered as the diffusion carbon whether it is a growth alpha our growth of cementite.

In both cases, you require either carbon to be diffusing out or carbon to be diffusing in case of alpha requires carbon to be defusing out from the alpha to the gamma and in case of growth of cementite, it requires carbon to be diffusing in from the gamma to the cementite. So, it is basically diffusion of carbon which is more important that is very clear second important aspect; obviously, the interface energies between these between the gamma alpha and cementite.

So, these other than that there are other things like amount of diving force available which is kindly to the under cooling and; obviously, the nature of interface is created this will all be playing in part on role in eutectoid nucleation the growth rates. So, in the next lecture; we will discuss in these aspects in a little manner.