Phase Diagrams in Material Science Engineering
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Lecture - 31
Martensite Transformation-I

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So, in this lecture we are going to start discussing on martensite. You know, martensite, as you know cementite, ferrite, austenite, martensite is another phase in industry. Before I start this lecture let me just tell you, martensite was discovered by German scientist known as Martens, R. Martens; his name was R Martens.

He was graduate student, in his lab, and one fine weekend, before the weekend he was doing experiment with steels to study the pearlitic transformation, to do that he has to heat the samples inside the furnace. So, he kept the samples inside the furnace and then before the end, at the end of Friday, before he was going out for weekends, he hurrily opened the furnace and mistakenly one sample came out from the furnace and fell on to a bucket full of water, which was kept near the furnace. So, he did not look into it, he just ran away and next week, on Monday he came back and he just saw the sample, which is inside the water full of, bucket full of water. And then, what happen?

He was an intelligent guy, although he was doing working on this, you know, pearlitic transformation he did not threw the sample away. Most of us will think, that what is there in the sample, let me just throw away because I am not interested what will happen if I quench a steel in water. But this fellow was intelligent, he took out the sample. First thing, he saw sample was very hard, that you can see from the, you can put, take a nylon, make a scratch on a sample, it was not. So, he went and measured the hardness of the sample and it was very hard. It was much, much harder than the normal pearlitic sample and then, he went on discovering what is martensite and the whole phase, which he discovered, he named after his name that is called martensite.

So, the moral of story is, that in your experiment if you do something, which is unusual, which you think is not important to you, please do not throw it away. You must, you know, judge it. You must, you know, you must investigate it and you may find interesting stuff like this and you may be immortal, like martensite, Martens because everybody will say the name Martensite, they are calling the name of Martens. So, that is what actually happens.

Now, you know, Martensite is separate phase in steel, is not a pearlite like mixture of two phases and martensite is a very important phase. What will happen, as I discussed about the pearlite transformations, pearlitic transformation depends on what? Depends on basically, the diffusion of carbon; the carbon in gamma iron has to partition between alpha and cementitie, then only pearlite can form because cementite contains large amount of carbon, alpha iron does not contain, and they will form like a lamellar morphology, which I have been drawing you in the last few classes and you have got an idea about it how to draw it.

So, this partitioning of carbon will be dependent on the diffusion of the carbon. So, now question is, that diffusion of carbon is the time dependent process. Although the diffusivity of carbon is very high at high temperatures because it is interstitial, but it is not infinite, it has certain value, right. So, if I do an experiment in which I draw the temperature of sample from 950 to room temperature in couple of seconds just like what martens has done, then what will happen? Diffusion of carbon will no longer possible because diffusion requires certain amount of time. You are not giving the time, you are taking the sample at 950 degree Celsius temperature and directly putting into water by, that means, by that you are bringing the temperature of the sample from 950 to room temperature within couple of seconds or within few seconds.

So, because carbon cannot diffuse what will happen, but gamma will remain gamma, do you think so? The answer is no because gamma is not stable at room temperature; gamma iron is stable only at high temperature. So, gamma has to transform something and that something is known as martensite.

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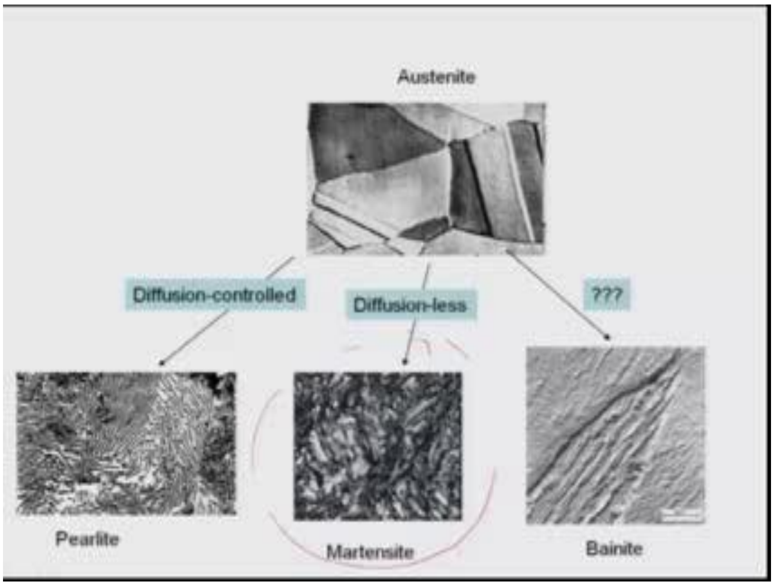

So, important thing is that what I showed in the beginning, I will go back in the slide. Important thing is, that martensite is the diffusion less transformations that is what I have shown you here.

In this picture, you see, here this is the diffusion less transformations. So, that means, diffusion of carbon is not going to take place or not going to, you know, dominate the mechanism of formation of martensite.

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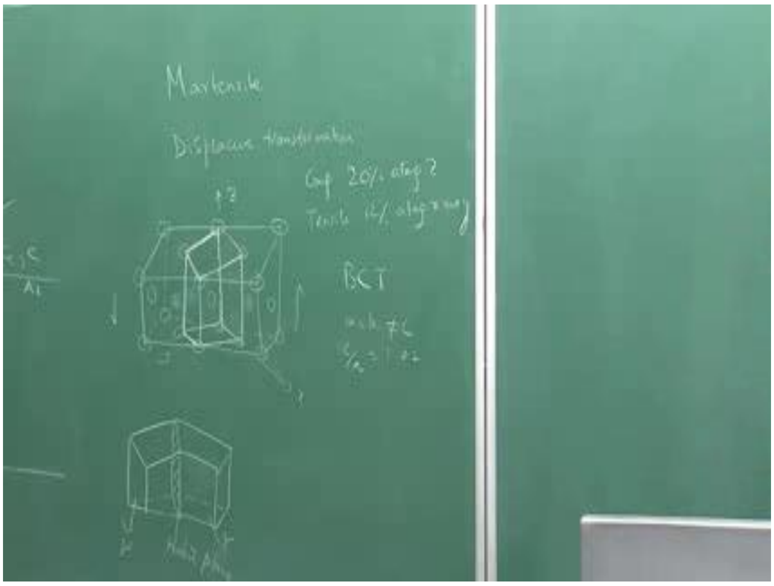

So, martensite is the diffusion less transformations or it is also known as, martensite is also known as displacive transformation. It is also known as displacive transformation. We will see, I will tell you why it is named after the discoverer Martens. It is the displacive transformations or diffusionless transformation, as I have told you. Now, question is this, why this transformation is very important?

When Marten discovered these transformations, he did not realize one thing. He thought it is uniquely iron carbon system, but that is not the case. Martensite transformation happens in non-ferrous systems, nickel based alloys. In fact, if you are intelligent enough, the same memory alloys actually depends on this martensite transformation. The same memory effect is, depends on the martensite transformation, all the thing which will change. If you, if you look at martensite transformation in non-ferrous alloys is, how the things actually happens in minute details, otherwise the mechanism of transformations or displacive type transformation will remain same.

How does it happen? This happens by cooperative movement of the atoms, cooperative movement of the carbon atoms. The best examples what one, one give or one gave, normally give in this case is very simple. Suppose you are sitting in a classroom and the chairs in the classrooms are actually lattice points, correct. Now, actually phase transformations mean what? Structural change, large rearrangement of the atoms, that is what is called, phase transformations.

So, if you want to make this change in the way the chairs arrange in a class, you can do two ways. I can, you can allow the people sitting in the chair to move from one place to another, that you can do. Then, what will happen? The transformation will take place. There will be more large change of the atoms on the lattice otherwise you can apply force, you can actually apply force. Just like the teacher can use a stick, you can apply force and allow the student to shuffle and that is what happens in martensite transformations. In martensite transformation carbon atoms actually move in a little bit in the lattice in the in the directions of z, x and y and make this transformation happens. So, that is what is actually called, that happens because of shearing application of shear forces.

Now, I will not go into exact details of these transformations, but I will tell you few important facts. Deformation happens to accumulate the change in the cell. How does it happens let us look at it. As you know, gamma is basically FCC phase. So, I will draw basically two FCC unit cell and I can show you nicely how this transformation happens side by side. So, these are my two FCC unit cell, I am not going to put atoms into it, these are my corner atoms, right. These are my corner atoms and these are my face centre atoms, right. So, these are the corner and face centred carbon iron atoms. So, carbon atoms obviously will be sitting in the interstitial places. Now, I can apply stress, I can apply shear force like this, distort the lattice in such way I can form this. So, let me remove some of the atoms then you can see it very clearly, these atoms. So, now you can see, I have generated a unit cell like this. So, what I will do is I will make it thicker, so that you can see it properly.

So, you can see, this is the body centre tetragonal unit cell, this is body centre, but tetragonal is, because this side and this side, these two sides of equal length, although they are looking different length, but they are equal length. So, you can understand this is a diagonal, face diagonal, so face diagonal should be equal length, but this one is the side of the unit cell. So, that is why, one of the axis which is, suppose this is z-axis and this is x and this is y. So, one of the axis is elongated because of this transformations. So, what we have done? We have not asked the atoms to diffuse; we have asked the atoms that their shuffling positions just like shuffling of playing cards.

So, by doing that it create a unit cell, which has some body centred tetragonal structure and this tetragonality is very small. You know, in a tetragonal unit cell a is equal to a, but not equal to c, correct, or a equal to b rather not equal to c. So, therefore most important factor, I mean, tetragonal cell is the c by a ratio, which tells you the tetragonality of the cell here. It is very small, it is may be 1.02 or something, very, very small. So, there is a small difference, very small difference in the c, length of the c axis as compared to a axis, but this is the way the transformations happens.

Now, question is this, so that means what? We are distorting the unit cells and this happens in like this. If a line number of FCC with cell setting like this. So, this happens when flipping. So, flip, flip, flip. So, all the unit cell will get changed and this can happen with the speed of sound, that is, that is, (Refer Time: 12:27) martensite transformation is so fast. You take the sample at 950 Celsius temperature (Refer Time: 12:32) change in water, immediately the steel gamma will transform to martensite. That means, the rate of transformation is just like a speed of sound inside the steel that is very high, speed of sound is very high. Then, why this happens, speed of sound? Because what you need, you need basically to flipping the cell, unit cells, you flipping the unit cells just like that from this position to this position; that is easy to understand. Everybody can understand this, that is, what actually lead to formation of different domains.

But if you look at carefully there are two types of deformation happen in such transformations. One, which will lead to change of cell or change of crystal structure, one which is leading; change of crystal structure means, from FCC to BCT. The way I have shown is phi by 1 and this transformation is known as, you know, homogeneous plane steel. This transformation is done by homogeneous plane strain, plane strain. You understand the strain in which the one of the component, third component is not present, that is called plane strain situation. So, that, that means, you have a plane strain situation in which the crystal structure gets change from the FCC to BCC or BCT.

So, and in this case what happens? For the plane carbon steels there is a 20 percent compression along the c axis and 20 percent tensile stress, tensile strain along the x and y axis. So, along z axis there is 20 percent compression, it will be compressed. On the other hand, along the x and y axis there is, there is 20 percent tensile, sorry, 12 percent, let me write down. So, along 20 percent is the composition stress along z, but tensile stress of 12 percent along x and y. This is the amount of strain applied and this strain leads to chain of crystal structure. Just by flipping atoms you can change this crystal structure, correct.

So, we know, but people who have investigated a lot this martensitic transformation in steel, they have found, you know, although we are changing the crystal structure by applying strain or by, because of shear force there is a plane in this whole structure, which will remain unrotated or undistorted even after transformations. So, this unrotated or this unrotated or unchanged or undistorted structure is known as habit plane. So, let me just draw it very nicely, already it is very difficult to do.

So, this plane here, as you see here, these two unit cell have rotated, rotated this way, but this one has not undergone any rotational transformation, any distortion. So, this is known as habit plane. This is gamma, untransformed gamma, this is also untransformed gamma, this is the martensite. So, in the martensite one of the planes will remain undistorted or you know, no change of the shape or whatever positions, that is what is, known as habit plane. So, this plane does not undergo any kind of distortions. So, thus you need not to keep this plane distorted. You need certain deformation to happen because you are already deforming the whole crystal, right. You are changing the shape of the crystal; you are changing the shape of the crystal from FCC to BCT.

So, and within this martensite, within this martensite one of the planes is remain undistorted. How it is possible? That is only possible when you have, having somewhere else the strain is applied to accommodate, you know, the strain because of the effect of the, because of this plane and that is can be done by the (Refer Time: 17:01). Although it is very difficult for you to understand or for you to visualize, but that actually happens in the real steel and that strain, that thing, that is what is known as, you know, to keep this unrotated crystals in the same position. We need to apply the sleep or twining that is why you see, I will show pictures also, that is why you will see lot of deformations, twines in the martensitic planes. And this deformation twine is to accumulate the strain, which is required to keep this plane undistorted.

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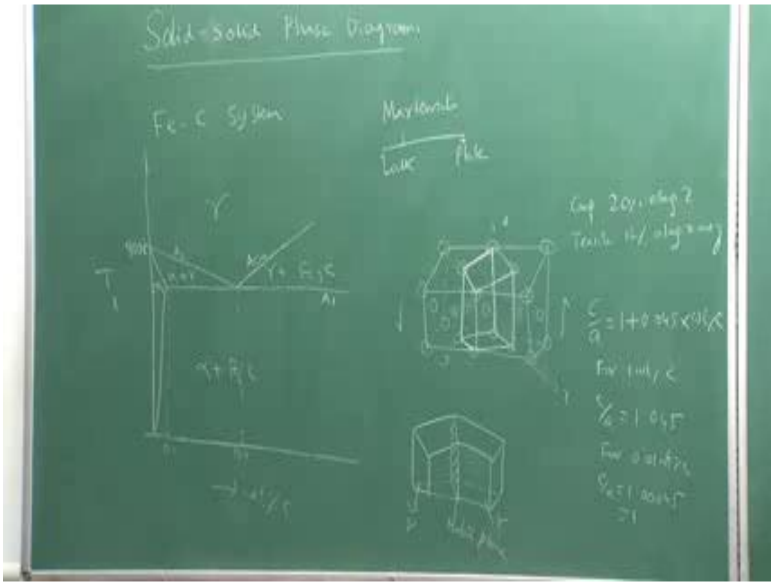

Well, few important aspects before I finish this lecture. We are going to discuss more on martensite in the next lecture also. One is, that the c by a ratio which I told you is, basically depends on carbon percentage in the steel. This is how it is.

So, c by a is basically 1 plus 0.05 into weight percent of carbon steel. Suppose you have 1 weight percent carbon steel. For 1, 1 weight percent carbon steel, c by a is 1.045, that is all. There is very small difference between c by a ration. So, when carbon concentration is very low, suppose carbon concentration is 0.01 percentage or 0.05 percentage, let us calculate it, 1.01 percentage of carbon, this will be, c by a is basically 1 point, this is 1, 1, 1, 1, 4, 5, it is nothing but 1.

So, that is why, for very low gamma concentration steel, you produce BCC not BCT structure. You produce BCC structure, not body centred tetragonal, a body centred cubic structure. That is one thing you must remember. 2nd important thing you must remember is this, that this transformations starts with specific temperature for a particular steel. It cannot start in any temperature. Like for pearlite, the transformation starts any temperature below A 1. For martensite, it starts with a temperature is known as M s temperature, all s, this is what is called martensitic start temperature that depends on the carbon concentration steel and it ends with the temperature known as M f. So, therefore, this is the temperature ends in which the marten transformation happens (Refer Time: 19:27) and this temperatures will be very low. For plane carbon steel this is about, M s is about 200 degree Celsius temperature and if you add, you know, alloying element this can go up little bit.

So, in the next class I will give you the formula, the, the formula of M s temperature, which will depend on compositions of the different alloying elements in the steel that is one thing. Second important thing is transformation is athermal in nature, is known as athermal. These are the terms you will, you will listen in steel metallurgy, this transformation is athermal in nature.

What does this means? That mean, that means, if I cool the sample below M s, suppose if I cool it somewhere there below M s, transformation will happen spontaneously as usual, but you know, it will not depend on any further decrease, cooling rate or sometime that is what is known as athermal or rather I can tell you in very nice way, this transformation is basically independent of time, yes. So, if I cool it down, the steel below this M s temperature somewhere here transformation will depend independent of time. It is not dependent on time unlike pearlite transformation. Pearlite transformation depends on time, you know, it has a rate.

So, here it depends on the temperature below, M s, that is all if you cool it down below M s, it will transform and. So, if you cool it down below M f, it should basically transform fully into martensite, all the gamma grains will transform into martensite, but that does not normally happen. That is one thing we should remember.

We will discuss more on this last thing, which I will like to tell you is, that this transformation, this martensite transformation, martensite has two morphology, one is, one is lath, other is plate. This is the two morphology of martensite and these morphologies will depend on what kind of steel you are looking at it, like this one, I showed you here, you see here, these are the plates in this picture. This is the optical microwave, which I am showing here. You can see here, these are the five gamma grains: 1, 2, 3, 4, 5 gamma grains.

You can even see the boundaries and the martensites are formed like a, like a, like a tree branch or leaves of the tree. They are actually called laths, laths of martensite. On the other, here you see they are plates. So, these are the two typical morphology martensites.

In the next class we will discuss more on the martensites and I will tell you the basic theories behind it, martensites because martensite transformation is very important for steel metullargy.

Thank you.