Phase Transformation in Materials
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Lecture - 43
Martensite (cont.)

Let us now discuss a bit little about the martensites. As you know martensite is the one of the important constituents of the quenched steels. Therefore, it is important that we understand how it forms, and whether we can control it. As I told martensites actually form during rapid quenching of the steel plain carbon steel or alloy steel, in all cases it happens.

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So, in steels martensites forms like a plates or laths, and as you see here on the optical micrograph. These gray color features are basically martensitic laths in between. White thing is basically written austenite, written gamma, and we term martensite as I told as alpha prime, because it is same as that.

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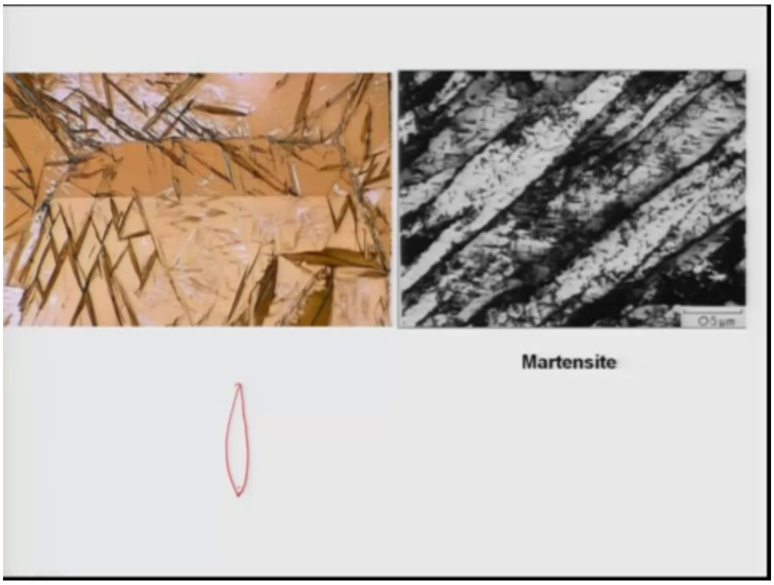

Now, most of this martensitic plates, they start from one on the grain of power austenite and exchanges many cases to the other in boundary. That means, they are pretty long, and they has a shape of a lens, just like these, and because they are (Refer Time: 01:30) and they have finite thickness. So, they are termed as a laths or plates, but question is this, how this transformation happens, when it is steel is quenched from the high temperature to water; obviously, as I discussed, this is an diffusion less transformations. So, atoning movements basically occurs, because of the application of the shear forces and, but this is not. So, simple as we observed as you see, there are plates in the martensites.

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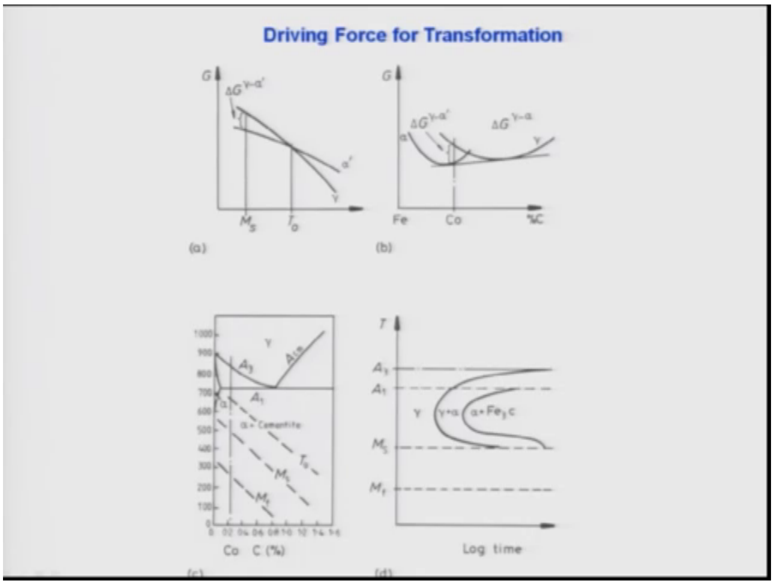

And let us first look at the how the driving force as play for the transformations, then we will get backed into the crystallography of martens transformations.

You clearly see, here this is the left hand side, the C portion of these wave graphs which taken from poto stalling book, shows the relevant personal affairs diagram. As you see this is the eutectoid temperature, known as A 1 temperature, and the gamma phase and the alpha, and by doing proper thermodynamic analysis of martensites and the gamma, because the transformation is from the austenite to martensite. Therefore, if I plot g versus temperature curves as a function of temperature g versus temperature basically for 0.8 percent carbon steel they look like this, as you see here above the temperature T 0 at which the both the curves actually intersect each other. The gamma is more stable, and below this temperature T 0 martensitic more stable.

So; that means, below T 0, it is possible to transform gamma to martensite and. So, it is possible to do the similar analysis for all the steels of different carbon concentrations; like 0.1 to about 1.4 percentage, and then we can obtain the T 0, T 0 corresponds the equally equal free energy points for gamma and the martensites, and that can be plotted, and if I plot that curve, it will look like this, as it is shown here. by this T 0 line, so; that means, below T 0 martensite formation is favorable, why, because finite driving force will be available for austenite to martensite transformations above T 0, that driving force is not available.

As you clearly see that the temperature of T 0 is basically strongly depend on the carbon concentration, as the carbon increases T 0 goes down; that means, the chances of formation of martensites is requires quenching to a lower temperature for high carbon concentration steels, that is very clear because T 0 is the temperature at which both these solid, and both these gamma and the alpha prime; that is austenite and martensites have the same free energies so, but it happens that in many cases, has been found that even if you cool it down below T 0 martensite transformation, does not start, because martensite transformation requires strain, because austenite to machine transformations, as I told in the last class also, will develop plastic strain twinning or dislocation mediator plastic strain.

And therefore, even below T 0 amount of chemical driving force available, it may not be sufficient enough to cause the transformation to happen, and that is why as you see here in all these diagrams, even few of the diagrams we will see later that, there is always two important temperature lines shown; one is the MS other is MF. MS stands for martensitic start, MF stands for the martensitic finish temperatures. So, here the martensitic start temperature is at least 50 to 80 degree Celsius, lower than the T 0 temperature for all carbon. A carbon concentrations in this range and MF is; obviously, much lower.

But remember there is very little chance, or in fact, there is no chance. Let me tell you very clearly that all the austenite will be transformed to martensites, even if you quench directly into liquid nitrogen; that is possibility is very rare. The reason I told you earlier also, because the strain development, if chemical free energy is taken, completely taken you know consumed by these strain. And then there is no driving force available for the further transformation to happen, and this is the reason some amount of austenite is written in the microstructure, and one of the ploy people use in industry to avoid written austenite is to quench many times so that the austenite can be further reduced in the martensitic steels, ok.

So, what is the exact driving force; that is shown on the figure B. You see here for A as a function of carbon concentration. here again I see this is for the alpha alpha prime, basically this one, these left hand side curve and right hand side curve is for the gamma. And therefore, if I have to certain concentration C 0, the distance between these two points is basically what is known as a driving force available. Reason is very simple, that this is the equally equal free energy point; that means, the point at which both the free energies of the alpha and the gamma are equal, and this is the common tension between these two curves.

Therefore, the common tangent will tell you the equilibrium between two phases, and therefore, this distance is what is marked as delta G as a driving force available for the free energies for the transformation of the austenite to martensites. We will come back to this part at part D later, because that is about the TTT diagrams, but it is very clear that this martin transformation is slightly different from the any other transformations. So, that is for the driving force with transformations.

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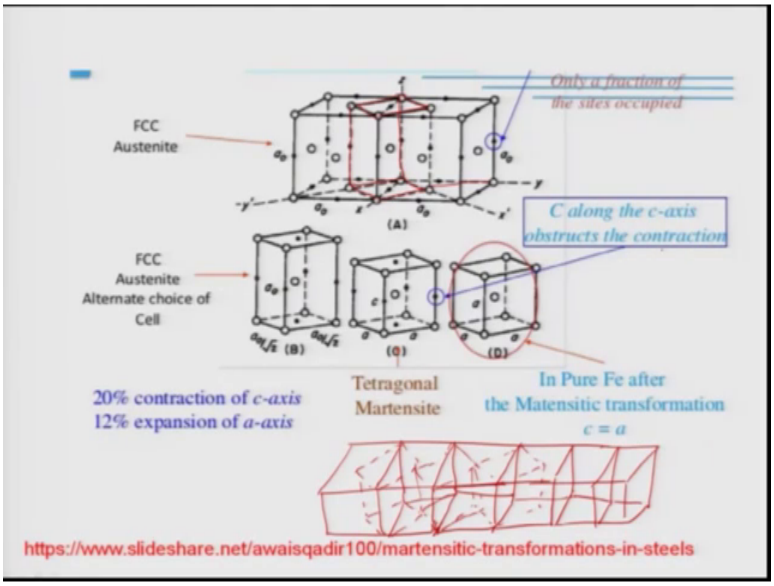

Now, let us see what actually how the transformation happens. This picture is also available in the books of the poto stalling, but I have taken this picture from one of the websites known as slideshare.net. As you see the martensites has a body centric cubic structure. I have been telling you again, it is a body centric cubic structure. on the other hand a parent phase austenite is a FCC structure, and this is a very simple way to generate these polycentric cubic structure or body centric tetragonal structure, rather from the FCC unit cells, and this was done by EC brain long back, as you see this is the construction of the top part the FCC, austenite is shown there, FCC austenite is shown by XYZ, you see here this is the coordinates and the coordinates of the martensite is shown by X prime Y prime Z prime.

Obviously if I have two units cell or FCC austenite sitting side by side we can, I simply join the points like that. We can actually connect the atoms like that. Here also at the bottom and you can get the BC BCT unit cell. This way if you do that you will find that there is actually 20 percent contraction along the C axis, along the z axis basically here and above 12 percent. Next functions along the axis; that is what happens and one can actually do the crystallography very easily. If suppose this is my, this is these FCC austenitic unit cell, that is what you see here FCC energy as a lattice parameter A0.

Now; obviously, if the C axis will remain as A0, but other two axis will become A0 by root 2 or A0 by root 2, because they are the half of the a phase diagonals, that is what is shown. This is the whole phase diagonal are taking half of that so, but if I simply taken bodies FCC iron. FCC iron unit cell, and do the same analysis then; obviously, there been no change and no expansion, or a basically contraction on the C axis; obviously, because iron atoms of similar sizes, there is, no this distinction of the iron atom size is, when it is quenched to from FCC to BCC, BCC structure or a BCT structure; obviously, because they are all similar sizes.

The moment you have carbon atom in the steel, this carbon atoms actually goes and sits in this position. You see here these mark positions of white with black dots; that is why the carbon atoms are sitting, that is they are sitting along the one; that is 001 directions. All the 001 directions will be occupied by the carbon atom at the center positions, and these are the atoms which undergoes shuffling, or rather these are the atoms they undergo, you know basically a movement during these transformation from austenite to martensites.

So, that is one important part you have to remember. It is not the iron atoms which are undergoing shuffling or movements because of this transformation only the carbon atoms were small enough. So, they are easy to move by application of the forces now. So, therefore, if I draw the whole unit cell, let us draw it here. If I draw a large number of unit cell, let us draw it, that I am not going to draw atoms. I am only showing these unit cells here to make it clear to you. So, it is very clear that this transformation can easily happens along these things zones.

So, if I draw only three. Now I can actually generate these unit cells very easily. this is the unit cells you can clearly see there. This is 1 BCT. This is another one; that is, this is the way you can generate many unit cells. There is another one, like that way you can generate. So, what is actually, what is the, a moral of the story. Moral story is very simple that if I want to transform austenite to martensites, what I need to know. I need to simply and simply, basically connect these unit cells and just move little bit. So, it is just like a chain reaction. The cells gets shuffle up, they are originally aligned FCC unit cells, original and FCC unit cells actually simply gets shuffle off, because of these situations; that is what happens.

They are actually getting shuffle up; that means, they are like a pack of cards you are rotating them to the directions, to make these BCT unit cell possible; that is how actually transformation happens, and it is been found a transformation happens at a speed of sound in the most, in the steel, because it requires only distortion of the unit cell, a little bit that is what is required, as you clearly see that this is just like a bent, created from the originally align FCC unit cell. So, that much distortion is required to generate BCT structure in the martensites; obviously, BCT is mainly, because carbon atoms. Carbon atoms as going along these 0 1 directions of the BCC unit cell, and they are the ones which are leading to the contraction on the C axis, and the expansion on the A and B axis ok.

So, that is the main reasons why BCC become BCT structures, but as I told you the C by A ratio; that is the tetragonality, is very small. in case of martensite it is not very high. So, this is also under stable, but the carbon atom is a small, very small in size. So, therefore, distortion it creates along these three axis, will be not very large amount to make the C by A ratio of distinctly much different from one. So, in a pure iron after martensites, there is no difference between the lattice parameters A remains A, B remains B, is only thing the changes is basically these things become A by root 2. So, that is the difference between, because of the carbon atom.

So, carbon atoms actually obstructs, as you said the contractions. although this construction is required, but they sits in such a way that the lattice invariant of the construction with the obstruction happens fine. So, you do not need to understand all those complex stuffs, only thing you need to know that, it is basically happens like a pack of cards in a steel metallurgy. it is very easy to do this transformation; that is why simply by taking a steel and heated to high temperature, and quenching into water immediately transformed it to martensites is very easy.

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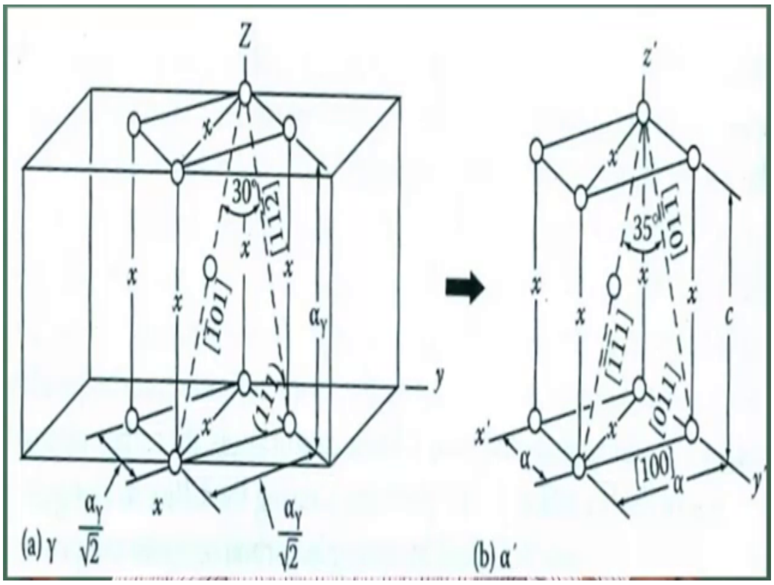

And this is a reason why it happens. Now this is a detail of that, basically it is already there in the books. So, you can actually look at it. these different directions of the crystals. So, that is very easy to understand that, because martensites is forming just by shuffling of the unit cells from the FCC austenitic structure. There must be certain planes, usually parallel to each other that must be certain planes like 1 1 1 1 1 planes in the austenite most parallel to with 1 0 0 planes. Sorry 1 1 0 planes of martensites. similarly some crystallographic directions also will be parallel to each other.

So, depending on the type of steel, people are observed different orientation relationships and that is crystallographically, they are related. So, those plates which you see, they are actually, not exactly. You know completely invariant with respect to the austenite. They are having distinct crystallographic related relationship with the austenites.

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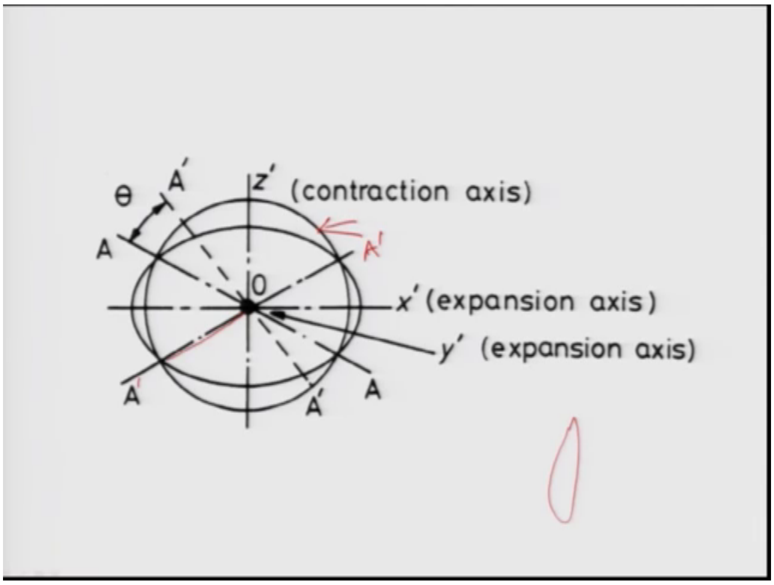

And that is obviously, understandable with the way it transformation occurs. Now let us look at, if I have to consider 2 D, as you see the martensites looks like a ellipse, or basically looks like A in a 2 D. They are looks like a ellipse. How this ellipse actually happens from a circle, that is why the distortion, actually it can be explained.

So, if I plot only one section XZY is shown as a extra X is parties on the. Not on the plane, actually it is all the side of plane. Now if the original circle which is shown here is by this, by this one, this is a circle. So, simply by shuffling the unit cell, what is happens you will see that along all these XZ, as contracted and X has expanded, and Y also have expanded, but there is a direction you clearly see A A A A written AOA along that, there is no distortion happen. Simply this one also you see. Let us write A prime, and this is A, and this is also A prime. So, A A A A prime along these two directions. There is no change of this length; that is the radius of the circle, readable cycle remains same.

And this is observed in the real martensitic structure; that means what although we are talking about the distortion and the shuffling on the unit cells from the FCC to BCT structure in during martin transformation. There has to be a plane, which will not at all undergo any distortion, that plane must exist in the martensitic structure as per this construction is concerned. If we have to retain this, such a kind of, you know this deformation in during transformation. This plane must exit. This is known as lattice invariant plane. The plane which has not undergone any kind of distortion or deformations; that is that plane will exist in the martensitic structure ok.

Let me see whether I have such a kind of picture or not, it is may not be there we will come back to it later. So, this is the unique feature of martensitic steels, although these cells get shuffle up or distorted from the B FCC to BCC structure. There will be plane which will remain undistorted, and that plane is present in martensitic structure. so; that means, what distortion will happen in such a way that negative and positive part of the distortion would cancel out along that plane, and in martensite that plane happens to be 1 O 1 1 O plane. So, 1 1 plane in steels 1 1 O plane basically 1 on 0 plane is basically undistorted plane in the martensitic structure.

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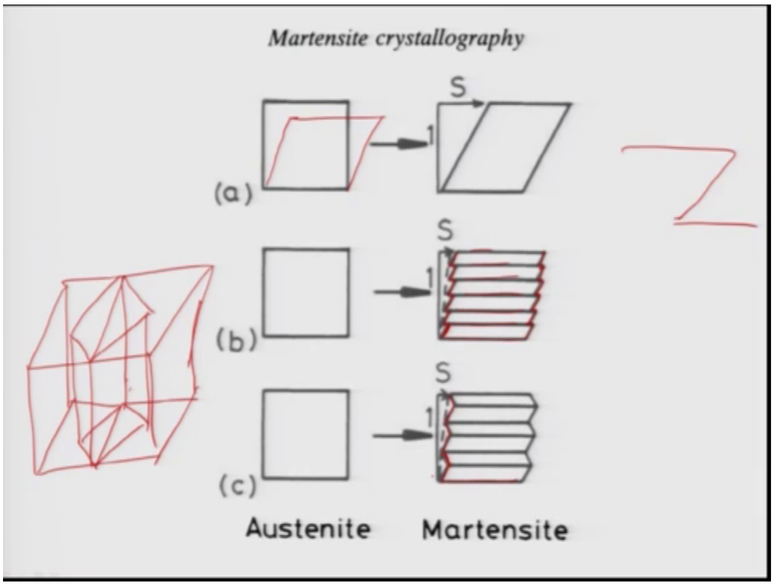

Now, how this exactly happens in the real sense like a pack of cards is shown here see this is the austenite this is mortensites as you know. Let us look at first from this a to a. So, as you clearly seen the this is my case and if I want to create a martensitic structure what I am doing I am basically creating such a kind of a distortion right the whole thing which was lying a, like a nice structure I have shown you again. Let me show it using the two unit cells. Let me draw it here this is easy always to show two dimensional way, it is always difficult. So, I am showing it here itself. So, this was the 2 FCC cell. Let us suppose and we generate such a kind of a martensitic polycentric cubic structure that is there let us assume.

So, we can actually consider these in 2 D like A 1 I have drawn now in order to keep one of the plane lattice undistorted what it will do it will simply retain the plane undistorted you see here this plane is written undistorted. These are DC plane parallel plane it is non distorted, what it has done? It has this, it has basically a created a step here like that you can see here, this is the how it has distort it can be produced. So, distortion happen like that way correct.

So, or in a little bit more visual way you can see here this is how the distortion happens. So, by doing you are creating internal twins automatically. So, you have to keep that undistorted plane driven to be undistorted or undeformed. During transformations this twinning must be done. The twinning is a process to by which this mid plane can be written undistorted. Therefore, twinning is very paramount importance in the martin transformations, and we have seen in the last class also. The twins are basically presence in all the martensitic structures martensitic plates they will be present.

So, that is means what this is, let us just like a shuffling of the cards I am distorting the cards one by one like this way one this, then that is how happens in the real sense in 3 D structures. 3 D will be a little bit difficult to understand or consider that is why in the books also this is shown into two dimensional way, how this can happen, and then comes a 3 D ok.

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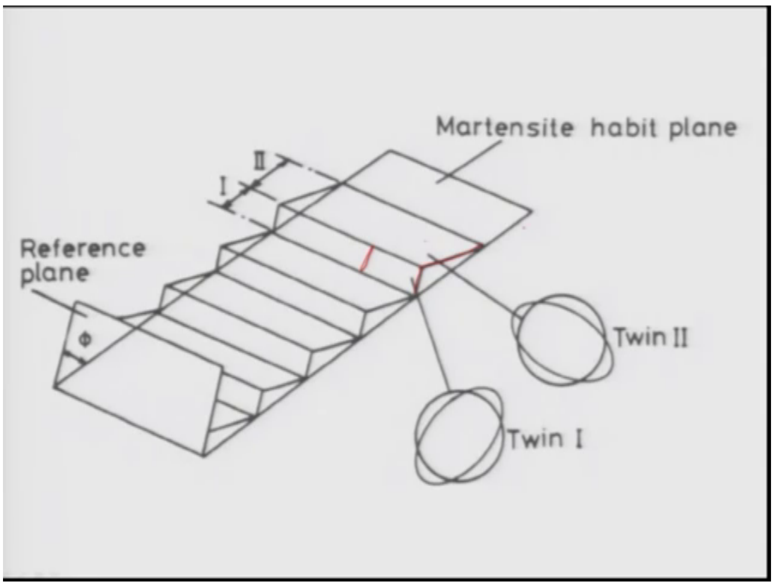

Now, in 3 D this just like that you see this is the initially all the cards were the lying on the plane. Now what I am I am taking a card up and putting like that again I am making a step and taking a card up putting like this.

So, just like that I take a card up put it like this. So, if I want to keep it like this way a certain angle; that is what is shown as here this will lead to between. Now two different configurations are shown here one is there as the card is taken up. So, initially it has a circle lying on the plane and thus you as you the take the card up. So, there this will get distorted just like a ellipse this is a twin one on the other hand the one which is present on this plane this plane this is the one that is also get distorted in the other way.

So, that is actually in 3 D way you can create two sets of twins or two sets of actually twins which in 3 D one 2 D you have seen that there is only one set of prints and 3 D you sit creates two sets of twins to keep this one of the plane undistorted and this reference plane which was basically shown as basically for the FCC structure and you see this is what is known as the habit plane or the plane which has non undergone any kind of distortion. So, keep that habit plane you know intact these twins has to be or have to be created and to show you that a twins do exist ok.

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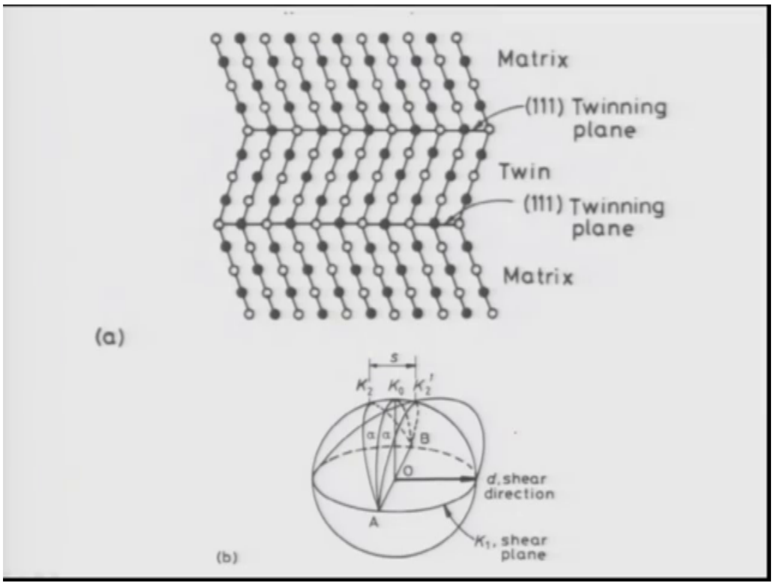

One can do crystallographically also. One can show that this is the twin, where this is the twin configurations ok.

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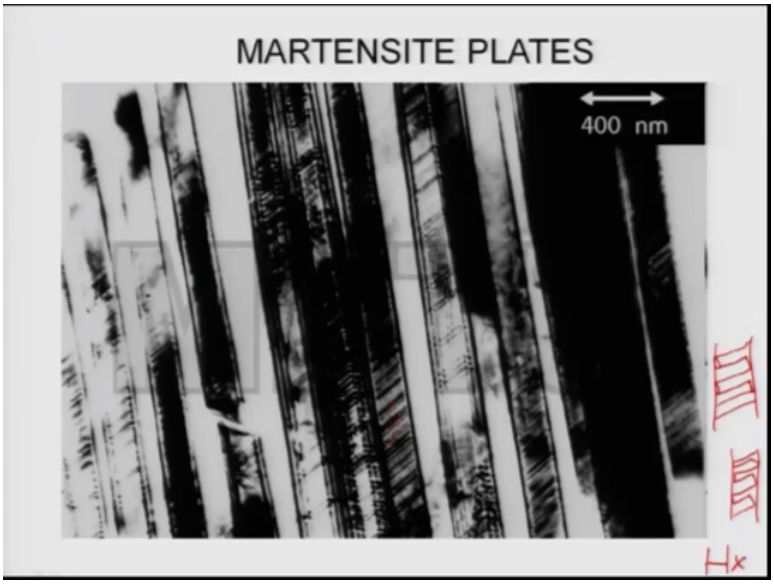

Let us now go to into this, that this is a three dimensional twin relationship among the different martensitic variants that is, let us for the time being. Let us now discuss about that and I showed you in the last class also that the how the twins exist you see that internally these twins exist inside the plates. And therefore, it is same thing like I shown you this is just like a pack of cards you see if I draw it here like that. So, there is a, this distortion happens this is the way things happens.

So, there is a distortion. So, initially this was a flat thing then you are distorting up that is these are visible when it is observe under electron microscope and in tens electron microscope things are actually positions from the original picture. Therefore, you do not see these orientations nicely, but one can actually do better imaging to show that at the end of the plates these twins are aligned at a particular angle they are never actually on like this they can never be like this is not allowed.

They will be always at an angle with respect to that, that is tells you the how the pack of cards can arrange themselves the one thing which I have shown you earlier this picture or even this picture is better that is all actually things happens. So, martensites have a distinct crystallographic feature which is completely different from bainites or pearlite and that is makes them completely unique in terms of the micro structural features important thing for you; obviously, to understand the transformation other than that to detect martensites in the micro structures as you have seen the most of you when you look at martensites in the steals many cases we will be we will be confused with with bainitic plates because bainites and martensitic plates looks almost similar many cases especially lower bainites.

But in martensite there is no carbide phase let us be clear about it martensite has a unique supersaturated body centered tetragonal structure there will be no carbides presence at all because all the carbon is supersaturated in the body centered cubic structure polycenter tetragonal structure. So, that is the unique difference other than that as I told you martensites plates will be appearing like these you see here long needles are elliptical separate plates this is clearly visible in a optical metallography and it is better actually to do optical metallography then scanning electron microscope microscopy on the martensites under certain martinet plates are very fine which is not we rarely observe martenite plates should not be. So, fine that it has to be seen under the same.

But they are normally observed in optical metalloograph micrograph very easily ok.

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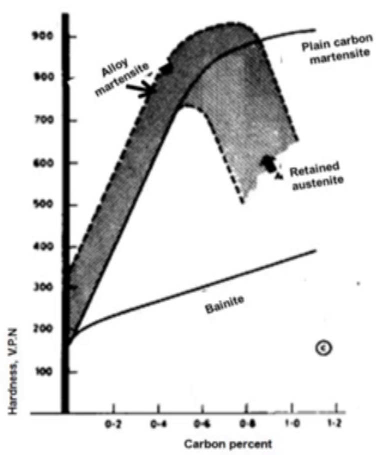

So, that is the important part of martensites and I as I shown you I discuss you most of these features and this one also I have discussed and. So, therefore, upon knowing all this stuff it is important that we should also know how the martensitic nucleation happens. See martensites nucleation as I told you in the books also they are given let me just read out the books that particular proportion is very easy interesting part ok.

A single plate of martensites it still grows in 10 to the power minus 5 10 to the minus 6 7 seconds just like a microseconds to it is full sides at the velocities approaching the speed of sound using resistivity measurements to monitor the growth of the individual plates of martensites sequentially in iron nickel alloys it is founds to be 800 to 1000 meter per second. That is done by (Refer Time: 26:16) at all so; that means, what growth is rapid it just like a blink of eye a martensite plates grows from one part of the grain to other part very important aspect is the nucleation and now nucleation of martensites is distinctly different it is not same as we can think about it ok.

So, that nucleation will just discuss in the next class a little bit about it; obviously, to discuss nucleation of martensite it will take a separate course altogether, because first of all let me clarify it in the books, or even your you know courses teachers will never say that martensites can nucleate. In fact, I still remember my days when I was just starting my bachelors if I tell that my teacher has told that martensite involves (Refer Time: 27:10) problem a nucleation people used to laugh at me ok.

But even in the books you will see there is a particular portion theories of martensitic nucleation; that means, what nucleation is evidently more important martin transformation than the growths very clear because the growth happens at the such a high speed it is just like A 1 almost like a 800 2000 1100 meter per second it is extremely high in a small sample so; that means, what in a fraction or in a basically if microsecond the whole transformation is finished done that is expected because quenching the steel from the high temperature to the water immediately everything is we will be avoid and that was actually happened to martins who discovered these phase.

So, but as I told you that reason we discussed a growth the crystallography are things is that martens transformation involves shear that is that is the plates gets arranged in a different manner. Therefore, there is a involvement of the shear forces will leads to leads to basically shuffling of the plates shuffling of the atomic planes. So, these strains has important role to play in martensitic nucleation and that is what actually that is why the martensite unique transformation requires cooling down at least 50 to 80 degree Celsius below T 0 temperatures.

As I discussed with you that is the reason, because the strain which is built up because to start a transformation is to be taken care by the excess chemical driving force or the basically chemical free energy difference between the austenite parent phase and the product phase martensites that is what is important.

So, let us discuss in the next class that is will be clear to you.