Texture in Materials
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Module - 08
Texture evolution during phase-transformation
Lecture - 41
Phase Transformation Texture and Bain Strain

Good afternoon, everyone. And today we are starting with module 8 which is Texture evolution during phase transformation. This is lecture number 41, Phase Transformation Texture and Bain Strain.

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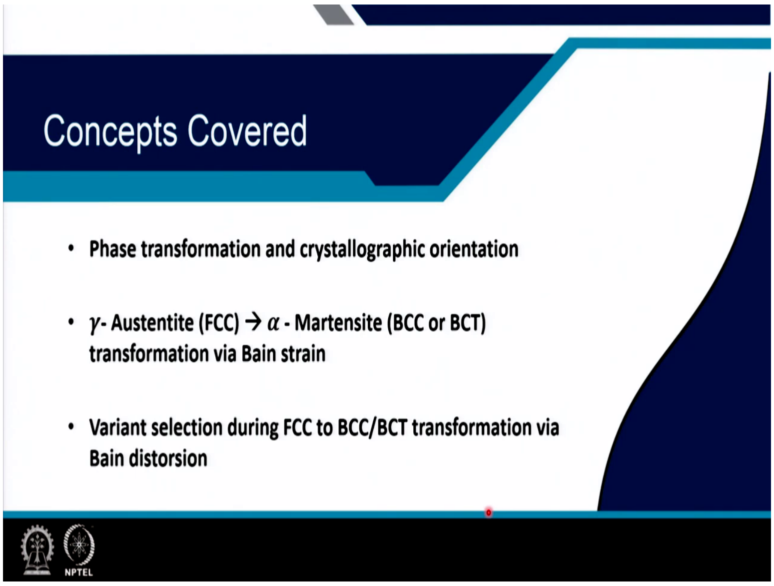

In this lecture, we will cover the concepts that are phase transformation related and crystallographic orientation first. Then we will go into specific austenite that is gamma austenite which is FCC to alpha prime martensite which is either BCC or BCT depending upon the carbon content transformation via the you know phenomena Bain strain. And then, variant selection during FCC to BCC or BCC transformation via this Bain distortion will be covered.

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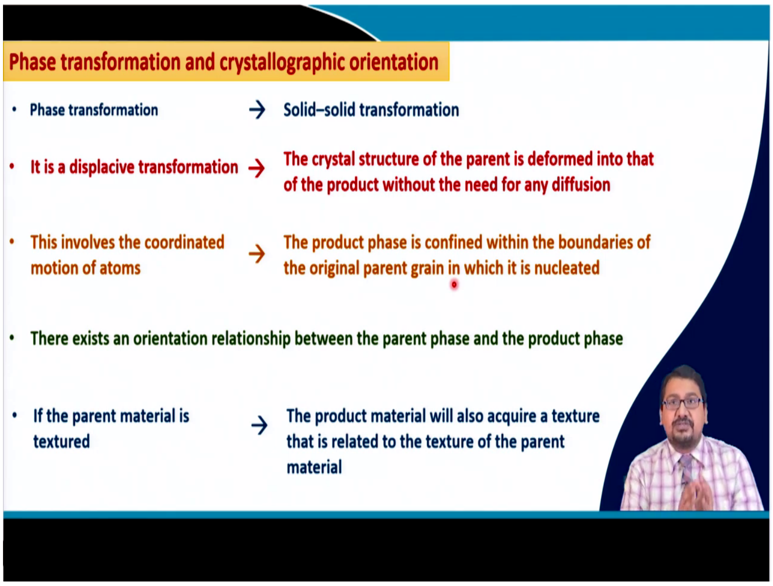

So, if we start with phase transformation and we have all gone through the course of phase transformation in metallurgy and materials engineering. So, phase transformation always involves a crystallographic relationship that leads to if we have a certain parent texture, then it the texture goes to the product phase that is as I said in the earlier slide that if the phase transformation is taking from gamma austenite which is FCC to alpha prime martensite, then this phase transformation involves you know the relative you know orientation relationship which decides the texture of the material.

So, if gamma austenite is initially textured, then the alpha prime martensite which is either BCT or BCC will be textured. If we go into the fundamentals of phase transformation, we know that it is a solid transformation. And if we know, then also it is a displacive transformation and it is not a diffusion-based transformation. So, the crystal structure of the parent is deformed into that of the product phase without any need of diffusion. So, this phase transformation basically is a coordinated movement of atoms, right.

So, the product phase is confined within the boundaries of the original parent grain in which it is nucleated. There exist always exist an orientation relationship between the parent phase and the product phase. So, if the parent phase is textured, then the product phase will also acquire a texture which is related to the texture of the parent material.

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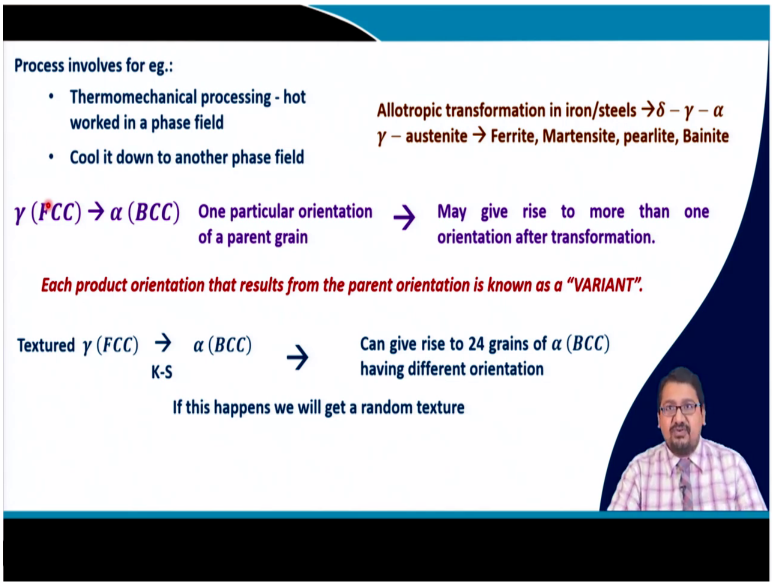

So, the process that are involved in phase transformations are for example, something like that in under a high temperature, a thermo mechanical processing takes place. For example, if we talk about steels. Then at say for example at a higher temperature, that means at a temperature where gamma austenite is present that is the FCC structure is present, the material is rolled and then it is cooled down to alpha ferrite or alpha prime martensite forms during cooling.

Then the relationship between the texture which was formed during the hot working of gamma austenite can be transferred into the alpha prime or alpha structure of the steels. Now if the temperature is much higher, it could be the delta ferrite which has been hot worked upon right.

So, the process that involves are thermo mechanical processing at hot temperatures that is hot worked at a certain phase field say for example, delta phase or gamma austenite phase and then, it cools down to another phase field which is basically say for example if it is delta ferrite to gamma austenite and then gamma austenite to alpha ferrite.

So, allotropic transformations in iron and steel from delta to gamma to alpha or gamma austenite to alpha or alpha prime which are ferrite, martensite, pearlite, bainite usually takes place and that takes place using an orientation relationship right. So, gamma FCC as I have shown here to alpha BCC, ok.

So, if the parent material that is the gamma FCC contains a certain orientation ok, then this may give rise to more than one orientation during the transformation and that is theoretically. And we will look into this matter more deeply because of the crystal symmetry may there could be more than one orientation from the gamma austenite to alpha BCC phase that may form.

Now, you see that each product orientation that results from the parent orientation to the product orientation is known as a variant. Now, in this particular example gamma FCC to alpha BCC if we consider that Kurdjumov Sachs relationship is occurring during this cooling down procedure and during the phase transformation to gamma to alpha, there could be 24 grains of alpha having different orientation that could form from a single gamma grain.

And this is because of the crystal symmetry that we have explained in detail in previous class, but if we I we will also discuss this later in this phase transformation lectures. Now if this situation arises, then we will definitely get random texture.

When we are you know say for example, rolling the material at hot working at a phase field of gamma austenite and then when we are cooling because a certain texture will develop and then when it cools each of this texture components different grains having same texture. Almost same texture will convert into 24 different crystallographic orientation leading to form almost a random kind of texture.

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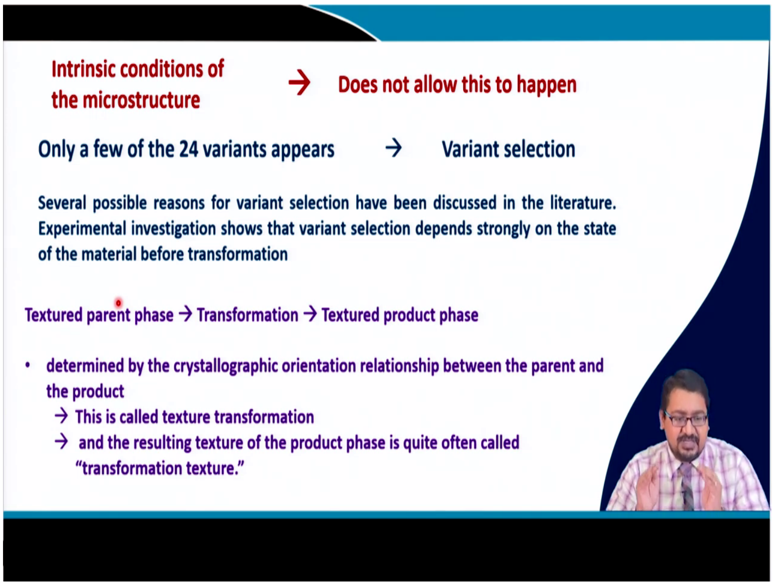

But you know because of the intrinsic conditions of the microstructure, that means when we have deformed the microstructure at the hot working condition, we have given some kind of a quasi-stress tensor to the microstructure right. So, it will have in certain direction a compressive stress another direction it will have a tensile stress and this will vary in various direction. So, such kind of stress state inside the microstructure will not allow the material to form all the 24 variants during this phase transformation to for example gamma austenite to alpha prime martensite or alpha ferrite.

So, there are several possible reasons for a certain variant to be selected which forms during the phase transformation and not all 24 variants form and they have been discussed in various literature, various you know publications regarding to phase transformation in quite a detail. Now, in experimental evidences shows that variance selection strongly depends upon the state of the stress in the material before the transformation and during the transformation, right.

So, a textured parent phase during phase transformation will not form random texture almost all the time and it will have a textured parent phase by orientation relationship. Therefore, it will have a certain variant selection. This is determined by the crystallographic orientation relationship between the parent and the product phase. So, there will be a certain relationship between the parent and the product phase crystallographic relationship.

So, this kind of phase transformation in which leads to you know a relative formation of orientation or you know relation between the parent and the products orientation is called Texture transformation. And the resulting texture of the product phase is known as transformation texture or coated as transformation texture.

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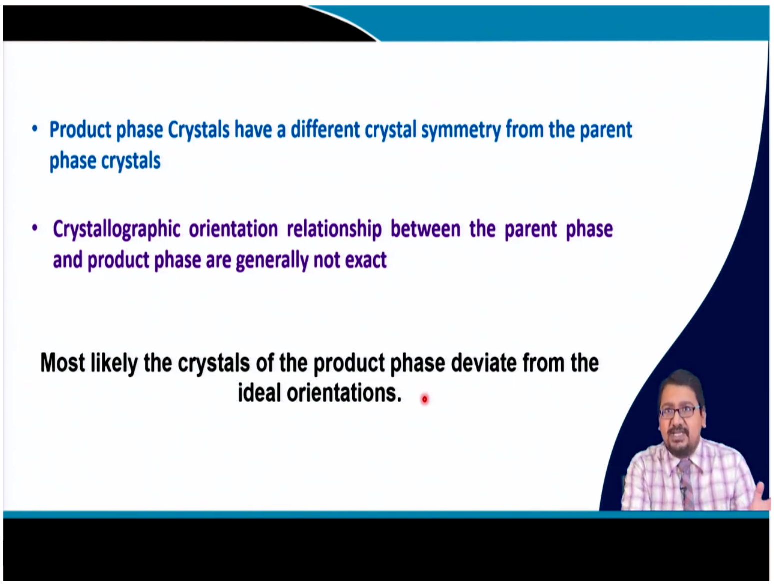

So, product phase crystals always will have a different symmetry than from the parent crystal. Now, you see when gamma austenite which is FCC is forming BCC, even though most of the symmetry element of FCC and BCC are same, but still few all the symmetry element will not match. Sometimes the orientation phase transformation occurs from BCC to HCP.

So, product phase crystal has different crystal symmetry from the parent phase crystal. And so, the crystallographic orientation relationship between the parent and the product phase may not be always exact and it will vary. For example, as I said FCC to BCT martensite, the symmetry elements of BCT is quite different from that of FCC and therefore, the exact relationship that ideally can be derived will be different from the actual ones that will form.

Now, we will discuss this fundamentally in detail in the upcoming slides and in the next lectures. So, the most likely the crystals of the product phase basically deviate from its ideal orientation.

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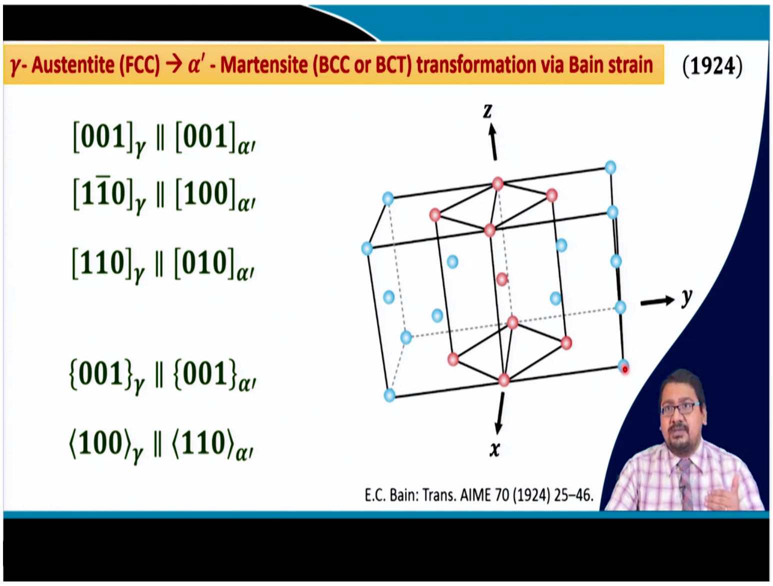

Now, let us talk about this austenite gamma austenite which is FCC to alpha prime martensite which could be BCC or BCT depending upon the carbon content in the steel, the transformation of these two via the Bain strain. So, Bain in 1924 found out that the transformation between the gamma austenite alpha 2 alpha prime martensite occurs by certain relationship.

He found out that if the initial crystal structure is gamma austenite which is basically FCC and here we are showing two crystals of FCC structure, then during deformation phase, transformation will occur from this FCC to BCT structure and we have deliberately you know colored the atoms connecting this BCT structure with orange color instead of blue.

And we can see that you that from this crystal structure which is initially FCC, a rotation of the crystal keeping the z axis same and the rotation of the crystal in such a way that the initial 1 1 0 for example in this direction, right converts into 1 0 0 or 0 1 0 and the initial 0 1 0.

Basically, of the gamma the austenite converts into 0 0 1 of the martensite. So, the relationship that exists during this transformation can be given by either this or this relationship. So, if we look into the above relationship, it is that in the z axis, the 0 0 1 of gamma remains parallel to the 0 0 1 of alpha prime, right and which can be schematically seen and visualized in this figure whereas, the 1 1 bar 0 gamma.

So, let us say it is say this is 1 and this is 1 bar. So, this one converts into 0; sorry 1 0 0 of alpha prime, right. So, this is also so this line and then 1 1 0 of gamma which could be this one or this one is converted into 0 1 0 of alpha prime. Now, this relationship could be written in terms of planes and direction also.

This we have written here in terms of direction and here we are showing this in terms of plane. So, we can say in terms of plane that the plane 0 0 1 of gamma remains the 0 0 1 plane of alpha prime, whereas the x or the y plane that is the 1 0 0 of gamma or the 0 1 0 of gamma becomes parallel to the 1 1 0 type plane of the alpha prim.

Now, if we look into this Bain strain related austenite to martensite transformation, we can find out that there is always a stress associated with this transformation. So, the or there is always a strain associated with the trans this transformation because you see that when the gamma is converting into alpha prime, the this particular direction 1 0 0 type direction of alpha prime is actually almost tries to match within half of root of the direction that is this diagonal direction which is root 2 of the lattice parameter right.

So, there will be always a stress associated with this kind of transformation and if we try to calculate, this stress ideally ideal stress associated with this transformation.

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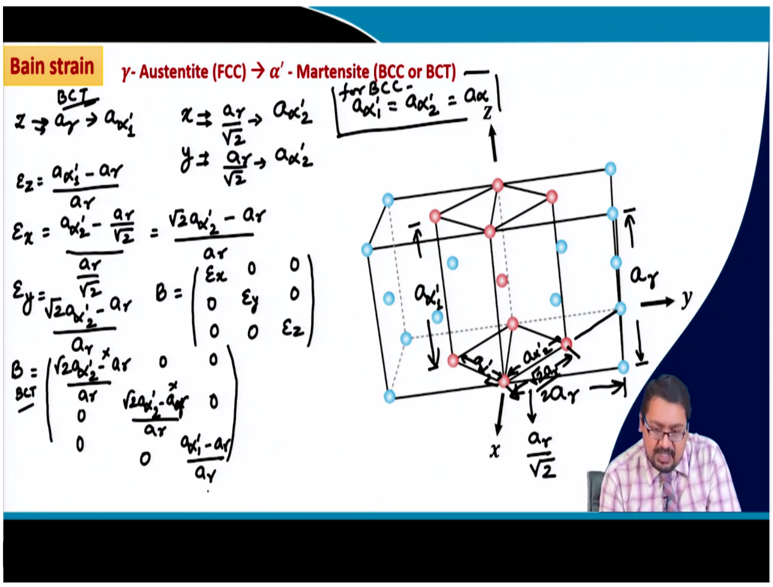

Let us try to see the amount of Bain strain that evolves during this transformation and you see that if during this transformation z becomes from the lattice parameter of gamma. If it becomes the lattice parameter of alpha prime along the z direction let us say it is 1. So, let us say that if this portion, this direction is alpha of sorry let me take the eraser.

If this is the lattice parameter of the gamma phase and which converts into the lattice parameter of the alpha prime phase. So, let us say the lattice parameter of the alpha prime 1, right because the gamma austenite is converting into the alpha prime martensite which has BCT structure in the x direction. If we talk about this particular diagonal and then this is also the lattice parameter of austenite is this one. So, if we look into half of this diagonal, this is equal to root two times a gamma by 2 right. That means, this equal to a gamma by root 2.

So, in the x direction a gamma by root 2 basically converts into a alpha dash 2 and in the y direction also a gamma by root 2 basically converts into a alpha bar 2 because in the x and the y direction, it is same. So, a gamma by root 2 actually becomes equal to a alpha prime 2 right and this also converts into a alpha prime 2, right.

Now if we say that there is a strain in the x direction, in the y direction and in the z direction and if we plot the strain along epsilon z, then this will be equal to a alpha 1 alpha prime 1 minus a gamma by a gamma. If we find out the stress along sorry along e x equal to a alpha prime alpha prime 2 minus a gamma by root 2 by a gamma by root 2, right.

So, this becomes equal to root 2 a alpha prime 2 minus gamma by a gamma and it will be the same for the y direction, right that is root 2 a alpha prime 2 minus a gamma by a gamma, right. Now, if we say that the Bain strain b is if we write in terms of matrix and if we see this, we can say that it is equal to epsilon x 0 0, there is no shear strain. So, epsilon y 0 0 0 epsilon z, right.

Now, if we are putting this value of epsilon x, epsilon y and epsilon z here, so we are talking about BCT here, right. In case of BCC what will happen? a alpha prime 1 will become equal to a alpha prime 2 and it will become equal to a alpha right for BCC, right. Now, let us put the value of b in terms of these values which we calculated.

We will see that it will be equal to root 2 a alpha prime 2 minus a gamma by a gamma, rest is 0 right. Rest is 0 and here also in this second quadrant, second term root 2 a alpha prime 2 minus a gamma by a gamma here also 0, here also 0 and here it will be a alpha prime 1 minus this is gamma ok a gamma by a gamma.

Now, if we if we look into this equation and this is for BCT, this is for Bain strain for BCT. We can see that in both this, in this and in this case, the strain will be positive because it is root two times alpha prime 2 minus sorry root 2 times a alpha prime 2 minus a gamma in case of x and y, but in case of z it is only alpha a alpha prime 1 minus a gamma which is a negative because alpha prime 1 will be certainly lower than the alpha sorry a alpha prime 1 will be certainly lower than a gamma.

Now, let us say that let us try to you know prove it hypothetically ok. So, if we consider the BCC structure instead of PCT.

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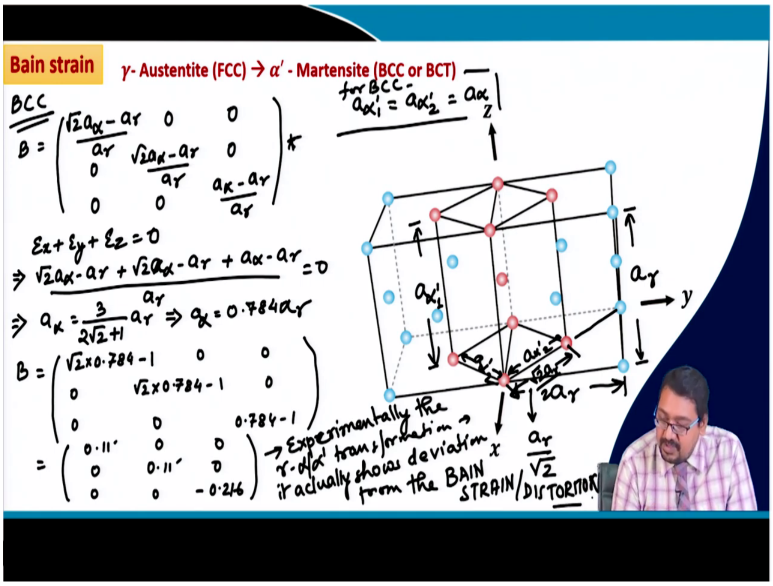

If you consider the BCC structure then this Bain strain b which we have calculated in terms of BCT where a alpha prime one and a alpha prime two representing the lattice parameter of the BCT crystal structures are different and now a alpha prime 1 and alpha prime 2 becomes equal to a alpha.

So, the Bain strain in case of BCC will be root two times a alpha minus a gamma by a gamma 0 0 and then 0 and then again root 2 a alpha minus a gamma by a gamma and then, 0 and then 0 0 a alpha minus a gamma by a gamma, right. So, obviously root 2 a alpha minus a gamma is positive whereas, a alpha minus a gamma could be negative and let us say hypothetically the change in the volume during this strain is constant.

Then you can say that epsilon x plus epsilon y plus epsilon z is basically equal to 0 and we can put this values of epsilon x epsilon y and epsilon z to be equal to root 2 a alpha minus a gamma plus root 2 a alpha minus a gamma plus a alpha minus a gamma. And in all the cases, it is divided by a gamma equal to 0 and this shows that a alpha becomes equal to three times 2 root 2 plus 1 a gamma and this could be a alpha equal to 0.784 a, sorry a gamma right.

And if we are putting this value of a alpha in this equation, then we can get the Bain strain to be equal to you know root two times 0.784 minus 1 0 0, then 0, again same root 2 multiplied by 0.784 minus 1 0 and then, this is also 0 and here it is 0.784 minus of 1. So, this becomes equal to 0.11 which is a positive strain 0 0 0 0 1 1 0 0 0 and minus of 0.216.

And we can clearly see that there is a Bain strain involved. Of course, this is a hypothetical calculation where there is it involves with the positive strain in the x and the y direction of the newly formed BCT structure whereas, in the z direction it is negative. So, because of the strain when we look experimentally, the gamma austenite to alpha or alpha prime transformation it actually shows deviation from the Bain strain or distortion ok.

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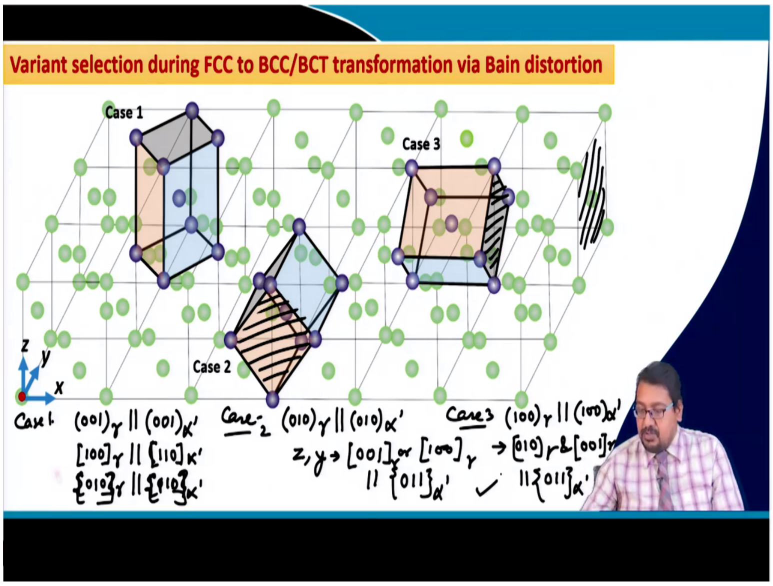

So, if we look further into this you know Bain strain and its variant selection. Then we will see that there could be three possible ways in which the FCC that is the gamma austenite can convert into alpha prime martensite or alpha ferrite via this kind of Bain strain or Bain deformation. Let us consider this crystal in which the green colored atoms are arranged into an FCC crystal structure.

That means, it shows a gamma austenite crystal structure. Now if we look clearly that in case of case 1, the if we say that ok this is x, this is y and this is z. So, in case of case 1 which is here the 0 0 1 that is the z direction right or the let us say the z plane, the 0 0 1 of the gamma austenite remains parallel to the 0 0 1 of the alpha prime martensite or alpha ferrite structure.

In both these cases, you see the 1 0 0 of gamma becomes parallel to you see 1 1 0 of alpha prime, right. So, also the 0 1 0 becomes parallel to the some other 1 1 sorry kind of alpha prime. So, it is better to write this in terms of you see family of direction. In case of case 2, what will happen? One can see the transformation has taken place in such a way that the plane which is 0 1 0 of gamma which is you know this particular plane drawn in oranges color is parallel becomes parallel to the 0 1 0 of the alpha prime.

Whereas, the other directions that is the z and the y directions which comprises of 0 0 1 or 0 1 0 basically becomes parallel to the type direction of alpha prime. In case of case 3, you can see the plane which is basically this one right that is parallel to the x axis, this one shaded in grey in case of gamma austenite, this is 1 0 0 gamma becomes parallel to 1 0 0 of alpha prime whereas, the other two direction is that is 0 1 0 of gamma and 0 0 1 of gamma becomes parallel to you see some 0 1 1 of alpha prime.

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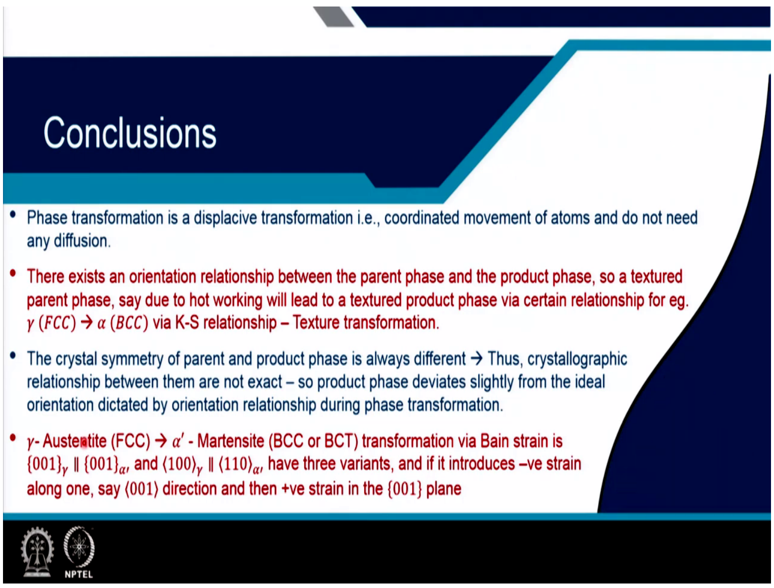

So, in this case and let me correct it. So, this is 1 0 0 right. So, in this lecture what we found out that phase transformation is a displacive transformation and requires a coordinated movement of atoms and does not need any kind of diffusion mechanism or thermally activated mechanisms, right. So, there is basically no need of any climb or cross-slipping climb of edge dislocation or cross-slipping of screw dislocations, ok.

Now, there exists and orientation relationship between the parent phase and the product phase. So, a textured parent phase say which forms during the hot working condition will lead to the formation of a textured product phase via a certain orientation relationship. For example, as we said gamma FCC to alpha BCC via base transformation or via you know Kurdjumov Sachs kind of relationship and this is known as texture transformation and the product is known as transformation texture.

So, third the crystal symmetry of the parent and the product phase may not be same. They are always different and thus the crystallographic relationship between the parent and the product phase could not be exact. So, there will be deviation from the ideal situation and this the product dictated by orientation relationship between the phase transform ideal relationship for the phase transformation may deviate right in actual situation.

So, gamma austenite FCC structure to alpha prime martensite BCT or BCC or alpha ferrite transformation via the Bain strain is basically given by two planes which are parallel 0 0 1 planes of gamma become parallel to the 0 0 1 plane of alpha prime or alpha martensite.

And the direction which is away from that different one's that is the 1 0 0 of gamma or 0 1 0 of gamma becomes parallel to 1 0 sorry 1 1 0 of alpha prime or 1 1 bar 0 of alpha prime, right and both will be occurring at the same time. They have these three variants that can form. So, one more important thing is that the Bain strain involves in negative strain along this z axis, this axis say now 0 0 1 direction and has the positive strain along the 1 1 0s that is in the x and the y direction. And that is it for today's lecture.

Thank you very much.