Defects in Materials
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Lecture - 32
Martensitic Transformations – 2

Welcome you all to this course and defects in material. In the last class, we discussed about martensitic transformation, some of the experimental observation and some aspects of crystallography of martensitic transformation. Let us recap a little bit of what has been done in the last class.

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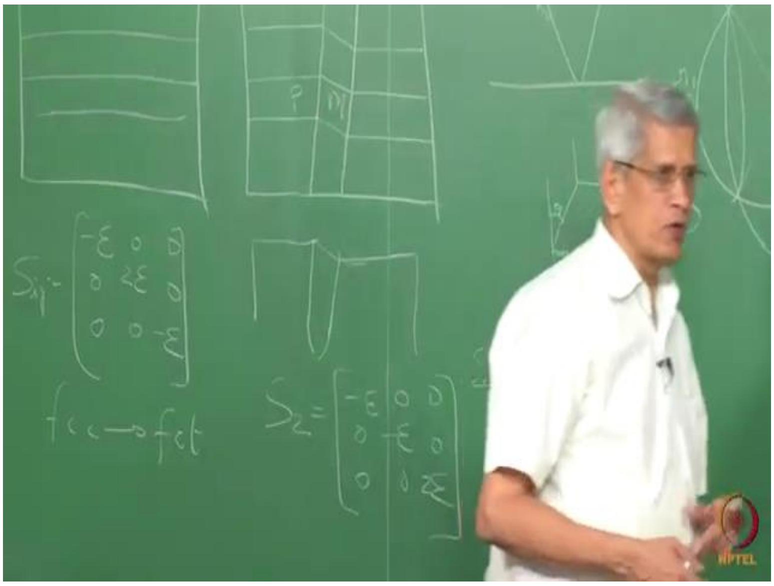

As far as the experimental observations are concerned, what essentially happens is that if we take a sample, and the sample is well-polished sample if you put a lines, scratch mark on the surface of the sample, you have just drawn some scratch marks like that on the surface of the sample and then do a heat treatment. Then portray of the sample after the heat treatment in a optical microscope then you suddenly find that in that sample, the simplest case which we can consider is that there is one line which comes. And these lines define that this is the way these lines are getting deflective.

These lines the observation of the sense there are some characteristic features which we can observe one this is an experiment in which we have taken the sample to high temperature and just quenched it. So, immediately after the quench sample, so there is not much of time for diffusion to take place, we find that a crystal structure when we do an exact crystal structure has changed. And then we observe that there is an orientation relationship between the parent or the matrix and the deformed and are the transformed region.

The next observation which is being seen is that there is an interface which has been generated, across the interface these lines have changed the direction, it maintains continuum at this point is a continuous line. So, these indicates that this looks quite similar to what has been observed in the case of a twinning which is essentially a homogeneous transformation. The twinning can be considered as a strain induced homogeneous or a strain induced transformation, so it is crystal clear homogeneous deformation which has occurred.

Can it be considered in that way that is how this question arose? Then another aspect of it if we look at it is that till this interface this line remains straight that means, that whatever is the transformation, this is parent this is whatever is the transformation which has occurred, they effect of the transformation is not there under parent side. There are no strains, which are being accommodated. And since the lines are continuous across the interface that means that this has this is a un rotator undistorted plane which we call it as a habit plane of the martensitic, these are all the observations which we have.

And the same samples are first if you try to look at it from the side wise view you look at it we essentially see that this is the way essentially the martensite looks like that means, that the surface relief has come in this region and this are continuous one. So, on the basis of these observation, since the features look similar to twinning it was start that whether it can be considered as a deformation induced change in crystal structure or not that is essentially what has been there that is why I had introduced this into this course because this course is essentially about defects in material correct. So, that question which raises is why martensitic transformation which is a phase transformation, because it has lots of similarities with that of deformation.

How did we go about to understand this crystallographic theory of martensitic transformation since its similar to twinning, twinning can be considered as one where a simple homogeneous shear if we give it the entire theory of evolution of twin microstructure could be explained that I have taught in one or two lectures, one should refer back to get.

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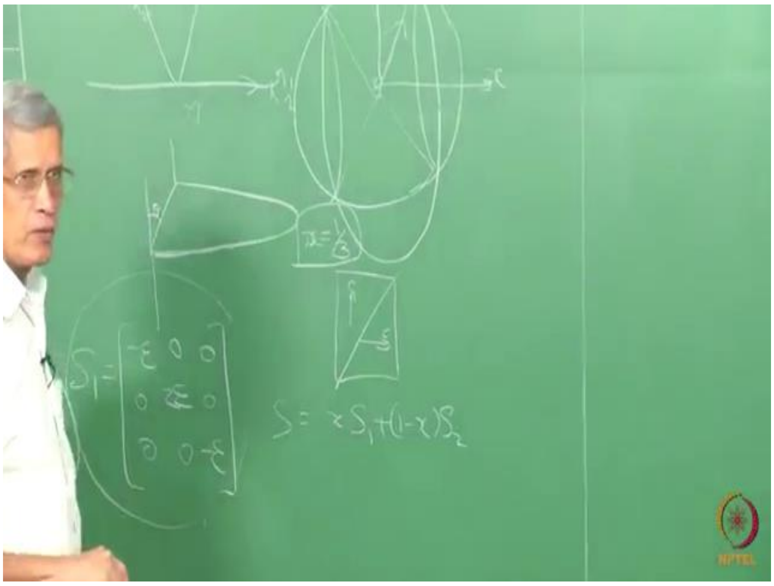

What are the essential features of a twinning transformation essentially between the twined and the untwined region? This is the matrix and that is a plane which called as a k 1 plane which is a plane which is unrotated and undistorted which we call as a composition plane. And then there is another plane which is their k 2 plane which is essentially the plane gets rotated, but not distorted. And there are some directions also there eta 1 which is the twinning shear direction in this k 1 plane. Similarly, here also there is another direction eta 2, which is the direction which is rotated, but not distorted correct. And that simple shear essentially is that from here to here, some twining shear G has been given.

This could be easily observed looking at how if you look at the surface of the sample this is how the twined. So, if you measure this angle if this is the composition plane then we can find out what the twining shear of the simple homogeneous shear which we are applying. Exactly the same theory can be used here, but only thing, which is important is that when for twining we have looked at this theory that is a simple homogeneous shear. Simple homogeneous shear can be considered as giving an elongation in one direction to a volume of a material and then a compression in a perpendicular direction, which is equal and opposite to it, then giving some rotation, so that it is being brought back to the original one.

But in the third direction when we consider it there is no strain which is involved. So, the strain is involved in only two axis, the third axis there is no strain. The same theory is being applied here also. But generally what happens how do we go about and do it in a transformation, you take a crystal structure of the sample parent matrix, and then in that choose a unit cells on which by applying a small deformation along different axis that is the total strain which we involved in this a straining of the lattice. Use that lattice which has minimum strain, so that it transforms to the product microstructure that is the product phase.

And then we can find out that correspondence between the lines and directions between the parent and the matrix. And if strain is involved in all the three directions then what happens if you take a sphere of the sample and then apply strains homogeneous strain in all the three directions, it becomes like an ellipsoid. This ellipsoid intersects the sphere the along that is if you take at this ellipsoid intersects essentially along yes two circles on the circumference. That means, that we have only here vectors from here to here, that is a vector which is common to both of them that means, that there is only an undistorted vector is there, but not a plane.

But what we require a plane that like a k 2 plane for which what has to be done is that if we can apply some strings that is if this is x y and this z-axis is perpendicular to the board. If you apply some strain, which we call it as a lattice invariant shear which would be either slip or twin. Then what we can do it is that that strain can be made 0, then we can find out a plane which is rotated, but not distorted that way the same theory could be applied to find out that plane which is common this plane we call it as the habit plane that is how the whole theory of martensitic transformation goes.

And then we considered a case in zirconium, where in the third direction the strain that is lazier direction is negligible, so that we can apply that twining the theory for homogeneous deformation to explain the results. So, the orientation relationship which we found out was matching exactly with what was expected, and the habit plane which was derived on the basis of the deformation which is given to the unit cell which is chosen to go from beta phase to hcp phase we could identify the habit plane. And the experimental lops of habit plane matches with that that is a very simple case.

The next is that we talked about lattice invariant shear, so that we can apply and make strain in one direction 0. Let us consider a case which has been done in the case of a martensitic transformation in one alloy that is indium, tellurium. Here if the transformation is from fcc to FCT that means, that fcc structure we take it along the c directions site elongation or a compression in there that is e by a ratio changes, so it becomes a FCT. This transformation occurs at around 20 percentage composition atom percentage transforms from fcc to FCT on cooling at around 60 degree centigrade. What is the interest in this transformation? Here the phase which forms that FCT phase the two variants which we can form they are twin related the matrix and the transformed phase become a twin related variant. Then the other one also which happens is that using a combination of these twin related phases, we can make the condition which is required for application of the homogenous simple shear.

Let us look at it how it has been done. In this, what is it being done that FCT structure can be produced by expanding along the c direction by 2 by 3 percentage and contracting in the other two directions by 1 by 3 percentage. Because to apply the homogenous shear what we require is one direction there should be a contraction and the perpendicular direction that should be expansion that is what is required. If you notice carefully in all the martensitic transformations that is exactly what is happening. In the third direction that may be a contraction or an expansion, but on one plane, there is a contraction and expansion is there of equal and opposite magnitude.

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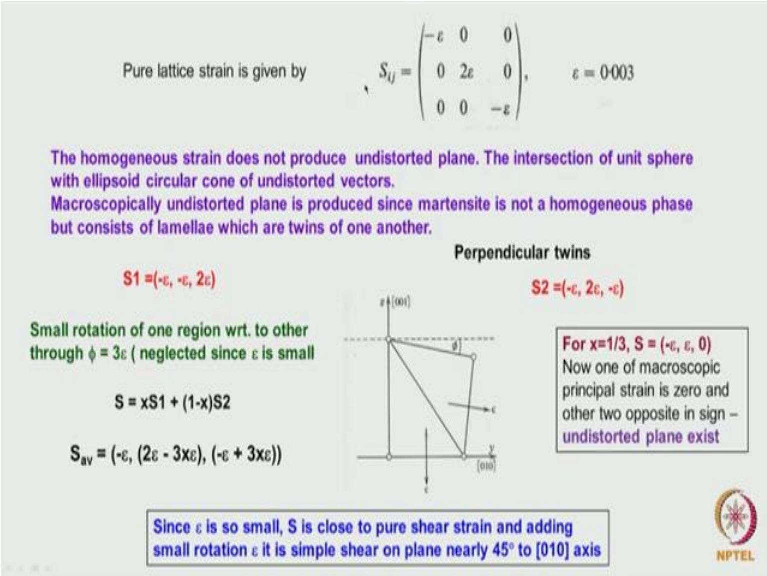

Here since we mentioned that two-third is the expansion and other direction contraction. Now, if we look at the strain matrix, but if you look at these lattices from fcc when it has come, the strain is there in all the three directions. Two directions, if you look at it there is only a contraction and the third direction is an expansion. So, this does not satisfy the condition for a homogeneous shear to take place this transformation correct. Then how can we reach stage where a homogeneous deformation theory could be applied. If you take one variant of it, this is exactly how the because this direction what has happened is an expansion which has occurred you take one variant where expansion this is are written as S 1 because where is in the c direction there is an expansion. Because when crystal undergoes a transformation from fcc to FCT, it is instead of pulling it along the c direction, suppose we try to pull it along the a direction or the b direction, then also the FCT structure could be done.

So, essentially three variants could be there. Another variant has got a this one what we are concerned is where it has been pulled along the b direction fcc structure. Then for this structure, this is how the strain matrix becomes; for the other structures, the strain matrix becomes. And these two if you look at the structure, if they are formed independently onto area regions of the crystal in a single crystal, and they come and join together, they will be twin related because the c direction is perpendicular to each other with an interface in between. So, essentially this will look like we will have a interface with one crystal coming like this, the another crystal forming like this with one c axis sit in this direction, another the c axis is the perpendicular direction that is essentially what is being shown here.

When the transformation takes place, since the c axis has changed a little bit. When they come and meet along the plane there will be a slight distortion will be there this is the angle which is being shown corresponds to that. If these two twin related variants are forming, we consider this as a one whole unit, what will be the total strength for this system now, that how we can consider it. This is the strain corresponding to this variant, variant one; this is the strain corresponding to a various two.

If you take some volume fraction of it we assume that volume fraction x which we take it the total strain can become x into S 1 plus 1 minus x into S 2, so that you know. Now, our aim we know the what the value of these strains which we know if you can find out the value of x, which will make the total strain for this system to be minus epsilon in one direction, epsilon in other direction, and in the third direction it is being made 0.

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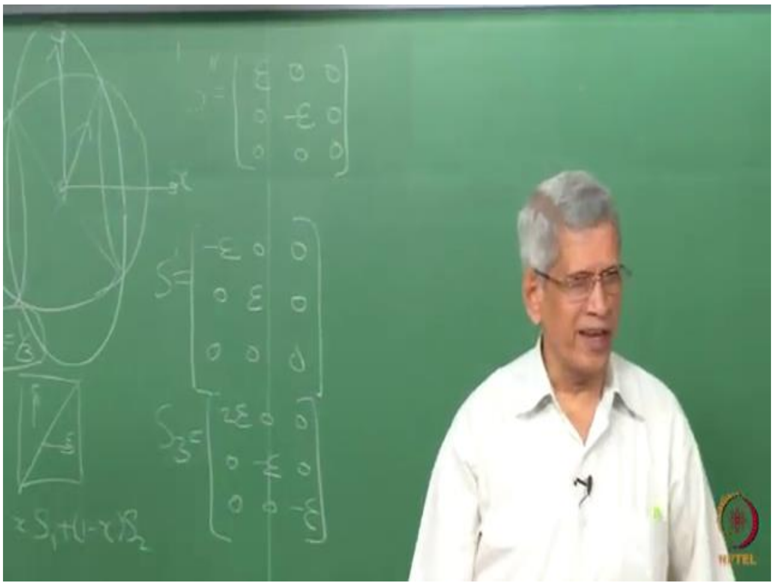

This for a value of x equals 1 by 3, if you choose this fraction of the twin variant, then it turns out that this s matrix becomes. So, when a twin related variant forms now what we are observing this is that both matrix and that twin we can find out how much is the twining which is required, so that the strain matrix of the region becomes, the condition which is ideal for application of homogeneous simple shear theory.

Now, we can find out because in this matrix, if we try to find out what is going to be if you consider a sphere of this material before transformation, after this strain then the transformation occurs it goes into an ellipse side. We can find out only a invariant direction, but not a plane. But for this system as a whole now we can find out an invariant plane correct that is exactly what has been done. And this plane turns out to be at 45 degrees that is 1 1 0 type of a plane for the two variants which are being considered.

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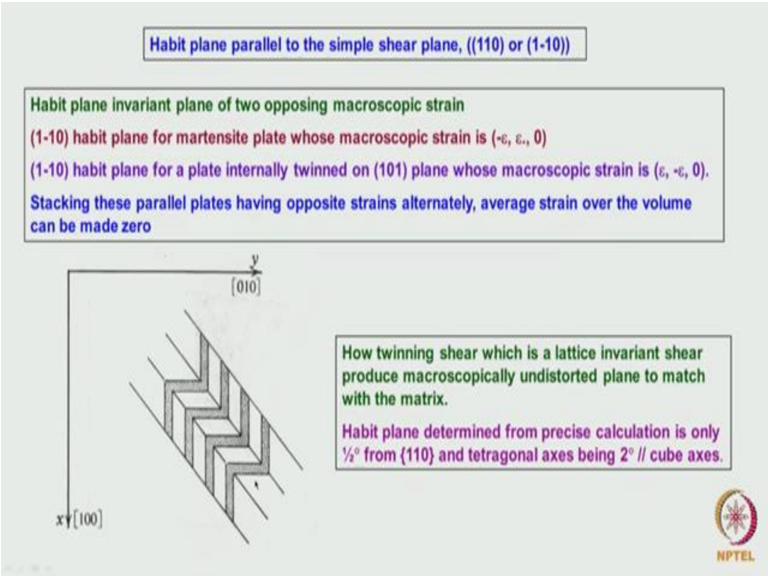

This is exactly what is being shown here. So, when we consider planes like this, if you consider a variant the invariant plane which turns out to be there are two possibilities which are existing either it could be 1 1 bar 0 plane or 1 1 0 as well as 1 1 bar 0 planes both possibilities are existing, both it can choose. We assume that it has chosen one with which a region has transformed into where like for example, you consider this region where it is an alternate parent matrix parent matrix it is going to be there. Actually this adjacent region what we consider it is either since we have considered a transformation which involves and another variant. And similar thing can be considered because here we took S 1 and S 2, there is another S 3 is also there in S 3 the matrix will be two the strain matrix will be correct.

So, if we choose the other combinations also we can find out what is the region which is required between choosing these two variance, so that the strain becomes net 0. If you do that in the case which is considered here and with 1 1 bar 0 is the habit plane this, I will leave it as an assignment which you can work it out then it turns out that the microscopic strain is epsilon minus epsilon 0.

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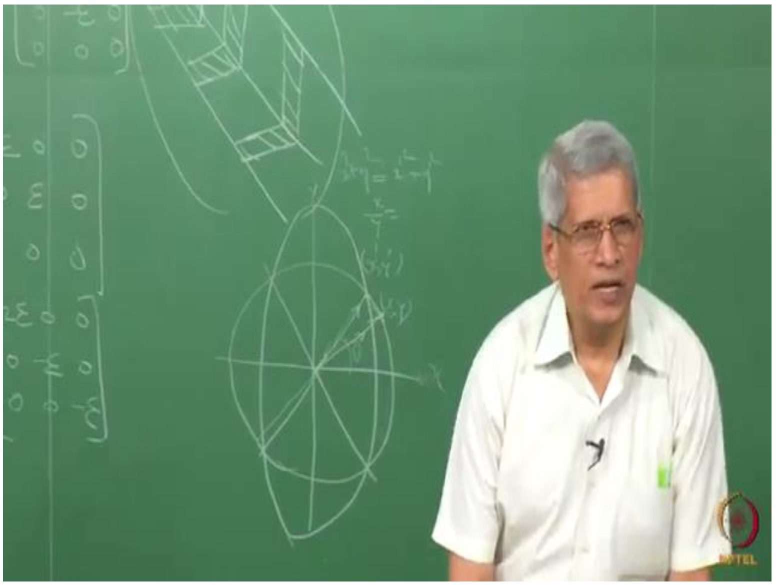

Or here we have got one string this is S dash, I will put it this I will put the other one has S 2 dash equals. Suppose, these two regions come adjacent to each other, what will happen to the total strain of that region that will turn out to be 0. That means, that if we have one region where twins of form like this, there is an adjacent region, these two variances in that twins have formed like this. If you take these two combined region, the total strain turns out to be 0; that means, that by choosing this sort of a combination not only they get internally twinned the way this plates form is like that they are parallel to each other. So, the total strain becomes 0 in this whole of the sample. In fact, this has been observed in many of these ordered alloy is a very common feature, which one can see this sort of a microstructure that is exactly what is being shown here.

You see that again the third variant comes like this if it continues like this, these are all essentially a plate type of a martensitic transformation. And since there is a small tetragonal destruction some of the tetragonal access here will be rotated by a very small angle, even that angle also we can calculate knowing the how much tetragonal destruction. So, when we find out the orientation relationship, this much rotation also will be seen from the position of the diffraction spots corresponding to matrix and the martensite.

What is the take home lesson from this transformation is that by choosing combination of martensite and its transformed region, the strain in a particular direction for the whole region could be made 0. This is exactly what happens in the case of many transformations, where the strain along different directions are not very small on substantial. The best example which we can think of is martensite in iron carbon alloys.

So, essentially first we considered the zirconium alloy where along one direction the strain is negligible which we can assume it to be 0. Then we considered a case where the strain is not 0 in all the three directions, then how choosing a combination of how choosing the generation of twin, we cannot make the strain in a particular direction 0 that is what we have done. Now, we will consider the case of iron carbon martensite, where strains are quite substantial how do we go about.

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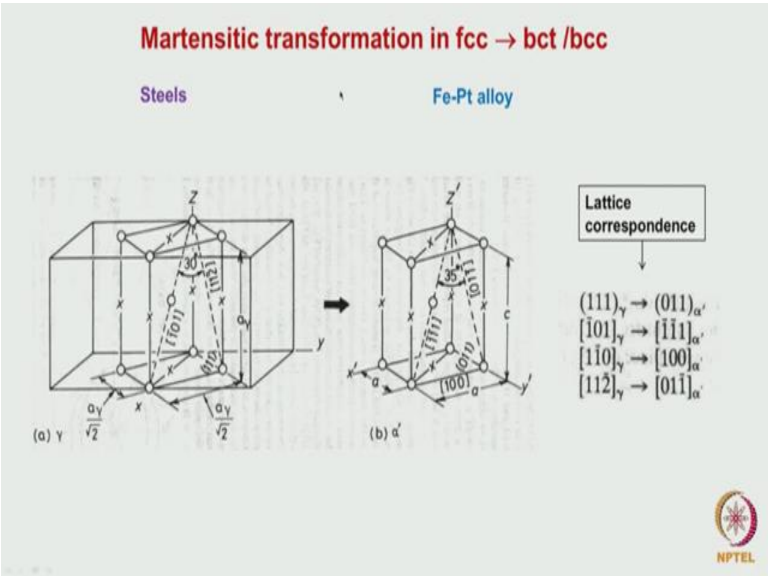

Let us look at the martensitic transformation. Iron at high temperatures about 900 degree centigrade is in fcc this transform to bcc ok below 910 I think to bcc structure martensite degree. Most of the time that iron contains carbon, so since the carbon is within that sample, it is not able to come back to the bcc structure, the carbon got stuck at different positions that transforms that changes the unit cells along whichever direction that carbon is stuck that there is a slight tetragonal distortion. So, it becomes a body centered tetragonal structure.

So, here what we have considering it is that as I mentioned that how do we go about to understand the crystallographic theory. First choose a unit cell, which contains the same number of atoms per unit cell as in the case of the transform matrix, and that is what we have done here considered 2 fcc unit cell. And then if we take 1 1 0 directions, and the c direction, these three directions because this three are perpendicular to each other this can form a tetragonal unit cell with one atom at the center which is going to be there. So, this has become now where body centered tetragonal structure.

And as you know fcc can be considered as a body centered tetragonal that is in the body centered tetragonal one the c by a ratio becomes root 2 correct 1.40, that is here this c and this is a, the c by a will be 1.404. We have one atom at the middle this lattice because now it the anywhere not close to a bcc structure. How we can bring it close to a bcc structure? If we give a deformation in this direction to reduce that dimension and give a corresponding increase in these two directions, we can bring it to an bcc structure. And if we look at that here this is the bcc structure or the bct structure which is being done, this type of a transformations seen not only in steel, in iron platinum alloy also which is an ordered alloy these sort of transformation is seen.

We will not talk about this we will only consider these steels, there is a just practically of more important. And if we look at the coordinate system here, this will be 1 1 0 type of a directions which are going to be the a and b axis; and this direction is 0 0 1 in terms of fcc. Here if we consider the same direction becomes in bcc one will be 1 0 0, another will be 0 1 0, another is 0 0 1. If you look at the plane, these two planes are common right, so that is what essentially are these plane if you look at it this is the plane which is common because it is a close packed plane here in fcc corresponding to that the plane which turns out to be here is 0 1 1 alpha prime. Alpha prime is martensitic bct structure. We know that in bcc the close packed plane is 1 1 0 type. So, we have a correspondence between the close packed plane of the fcc transform to close packed plane of the bcc correct.

Then let us look in this plane the directions 1 bar 0 1 direction here the specific direction that turns out to be 1 bar 1 bar one. So, closed pack direction in fcc is 1 1 0 type that turns out to be the close pack direction in a bcc structure that is one. And another is if we take this one 1 1 bar 0 that turns out to be close to 1 0 0 that direction, and 1 1 2 bar turns out to be 0 1 1 bar. There are two types of relationship orientation relationship whenever in martensitic steals which has been observed one is a k s relationship, another is a n s relationship; one of them will have this and this particular one another will have this and this particular one or this and this particular one. So, essentially orientation relationship comes from this correspondence matrix itself chosen.

But when we have given some deformation what will happen there will be a slight rotation of these planes also will take place because this is without rotation we are considering it. When we consider a rotation the slight tilt will take place because of that between these planes some tilting metal have been there that is essentially equal to one rotated from one by a sum that tilt angle that is what we see in the orientation relationship, the small differences also. The crystallographic graphic theory of martensitic transformation could explain all these differences exactly, this much is clear. So, we have a correspondence relationship.

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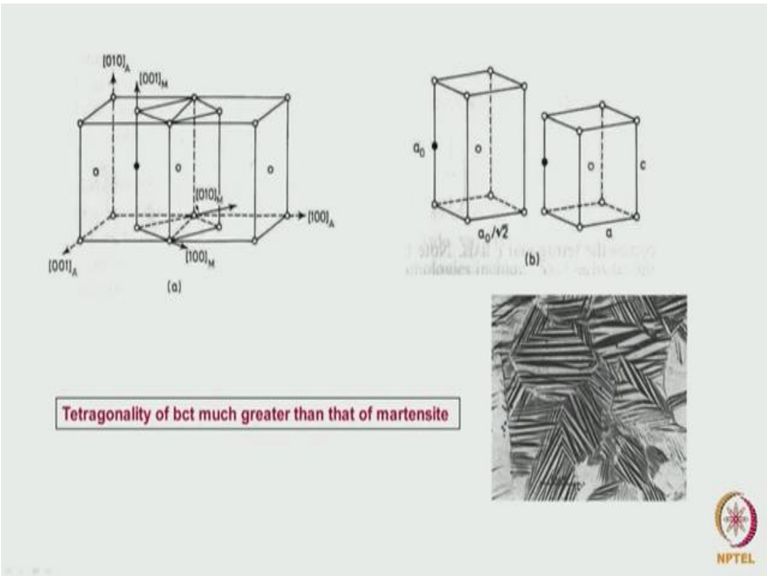

Now, that is exactly what is it being shown. And typically when this sort of martensite is a plate martensite which comes which is essentially a twin related structure. As I mentioned that why twinning is required this twinning is the one, which is responsible for compensating further to make strain in one direction 0.

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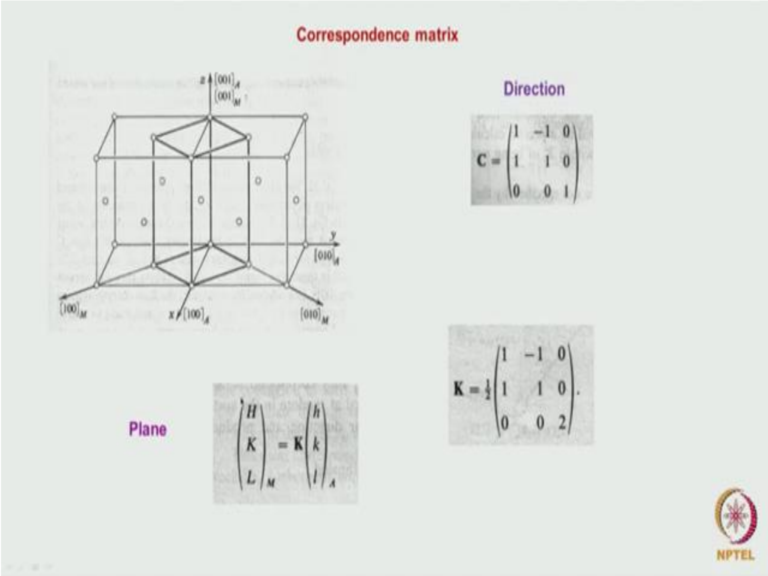

This essentially we have already considered this is the correspondence matrix, which one has to draw to go from hkl of one structure to another structure. These lattice correspondence matrices and all we have considered when we talked about coordinate transformation. So, in iron martensite, what happens to this structure, which is a body centered tetragonal unit cell within that fcc matrix. If we gave 20 percentage compression along 0 0 1, and the expansion about 12 percentage on the other two directions, we can transform this into a ellipsoid correct no not ellipse, this transformation makes it into a bcc structure.

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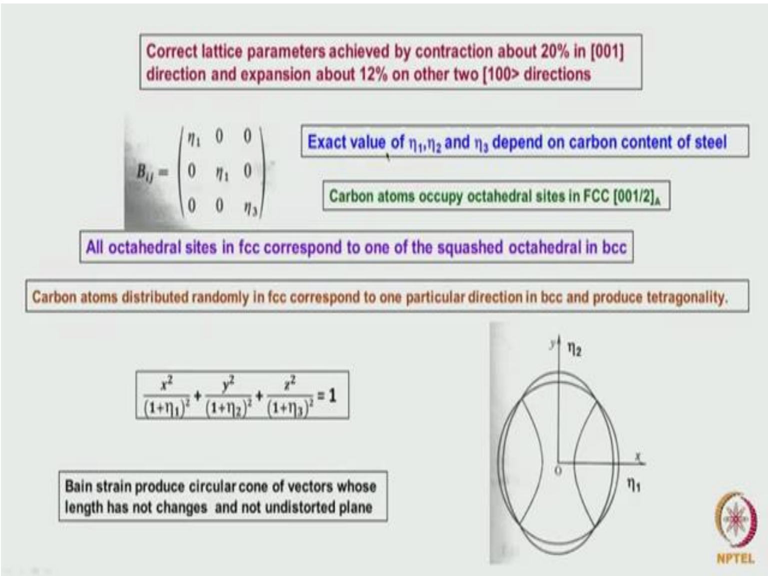

So, this is the strain matrix which we have done. And this value of eta 1, eta 2, eta 3 that depends upon the carbon content in the material it changes. And we know the position which carbon atoms occupy is octahedral sites right. Now, we see. Then if this is the strain the ellipse side which we consider what will be the a, b and c axis of the ellipse side that 1 plus eta 1 is going to be in the x direction, what will be the a axis this will be 1 by 1 plus eta 1 in the y axis, and 1 plus eta 3. As a general formula if you write this is the way you write to represent the equation to an ellipse. So, these distortions are normally called as that Bain distortion, this you may have studied in iron martensite this terminology which is used. These, essentially a homogeneous shear which is being given in all the three the shear which is homogeneous shear, which is given in all the three directions.

So, essentially as I mentioned if this is a case, when a sphere and ellipse side intersect there is what we get is only a vector which is unrotated and undistorted. The locus of this vector essentially traces a circle on the surface, two circles which are tracing, and these vectors are originate from the origin. So, essentially the surface of this which the locus of these vectors generate that surface is a cone, it is a curved surface and if we make that if eta 1 equals minus of eta 2 and if on the z direction, we can make this train somehow 0 by applying a lattice invariants shear, whether it is slip or twinning. Then what will happen is that we will be able to identify two planes that is those planes become or it will be a two circle which will be intersecting the sphere and the ellipsoid, those circles are nothing but the locus of all the vectors, which are undistorted.

Using this transformation, now if two vectors that is two strains, which are applied one is nothing but the negative of the other and equal in magnitude. And this will give rise to a plane which is common to both of them, but this plane how do we generate this plane it is essentially suppose we take a point here on this sphere that let us just consider that. That is since we have elongated in this that is compressed in this direction to the point here using the compression it will be shifting to some point here correct then we are pulling it in this direction. So, the displacement of this point final position will be from here it reaches. Originally, this point is corresponding to this vector. After that sphere has been elongated by applying tension in one direction and compression in another direction, this vector has reached this point. So, this vector essentially what has happened is rotated, but not distorted.

And since in the third direction the strain is 0, this will correspond to this will be lying on a plane. So, we have two planes which are there. And this is the original plane in which this vector was lying this corresponds to a matrix that means, that if we try to rotate it back from here to here we will be able to generate the two planes which are matching with each other that means, unrotated and undistorted planes could be generated. That plane if their habits plane of the martensite or we call it as invariant plane that is invariant plane. That plane is nothing but this one here what we are seeing it is known optical microscope the trace of the plane on the surface of the sample.

Then we know the coordinates we assume that this is the x y coordinate we know how much is the strain, which is being given, so that we can find out the displacement in this x direction this displacement of y direction. So, the x dash and y dash, we can find out. Since, the vector remains identical, the magnitude of the vector, x square plus y square is be equal to x dash square plus y dash squared, that x dash squared is in terms of x, y dash squared is in terms of y. So, we can find out the ratio of x by y we can get from this equation. This x by a ratio gives this angle theta. So, now, we know since we know the directions these specific directions we can find what is the direction which is going to be at particular one, and the plane which contains that direction, then we can identify using stereographic projection what is the plane that is how this habit planes are identified. What are the types of habit planes, which has been seen in iron martensite depending upon the composition of the alloy.

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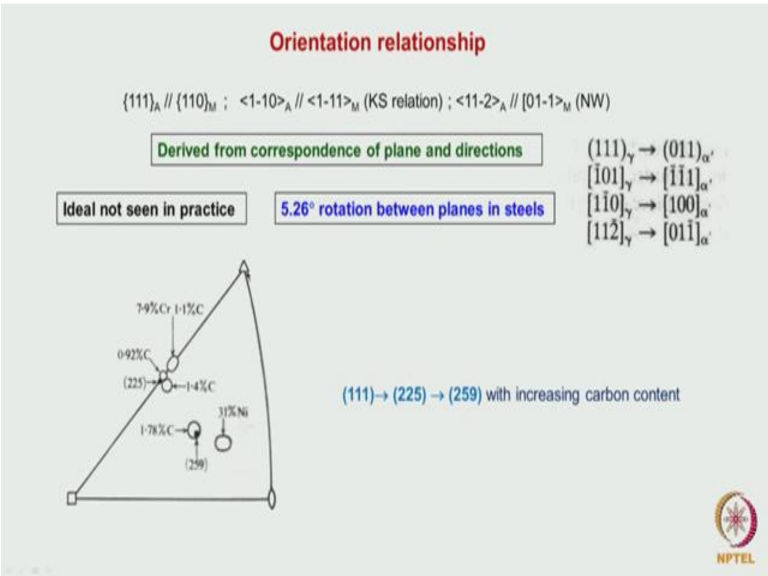

When the carbon concentrations are small essentially, the habit plane is seen it to be 1 1 1 type. And then it changes to 225 habit plane. So, if you look at this an irrational plane correct a high in that is plane we call it as an irrational plane. And the then when the carbon concentration changes to 1.78, it is around 259, these are all the habit plane which has been. So, when we put this much amount of carbon one could calculate the strain which is going to be there in the lattice. Correspondingly one could using this crystallographic theory of martensitic transformation, one is able to identify and find out what is the exact habit plane.

Then the orientation relationship which are being seen which are determined using diffraction patterns taken in an electron microscope from the matrix that is from the austenite and the martensite one can find out the orientation relationship. And the rotations which are being generated which are being predicted by the crystallographic theory, exactly these rotations also could be the rotations observed rotations matches with their predicted one. So, this is success of this theory.

But this theory considers the initial structure and the final structure, and then we look at it that if it undergoes the use of path, how exactly the type of habit plane, which will be generated. And what is the angular relationship, what is the orientation relationship which will exist between the martensite and the austenite. And also what sort of rotations which are there between the various planes and directions stable. But still there are a lot to be understood about this. There are lots of cases where one is not able to predict also, but it has a large success. And way we call this theory as phenomenological theory. The reason essentially is that we do not know what the path it takes place the initial and the final one we look at it and place to match the theory is able to explain the experimental observations.

Now, the next question which comes is that here if you look at let us come back to the original optical micro microscopic figure with which we started. Since, this looks like a continuous line can it be and since there is going to be a surface relief like a twining, can we find out because this shows that some strain as if can it be considered that some sort of a strain which is introducing into the lattice. What is the surface relief which we measure from which can we find out the macroscopic strain. Because it shows that in this direction that is a homogeneous deformation that is why it is a perfect line continuous line otherwise there should have been if any slip as taken place there should have been a discontinuity should be seen. Since, we do not see that that is how we can understand.

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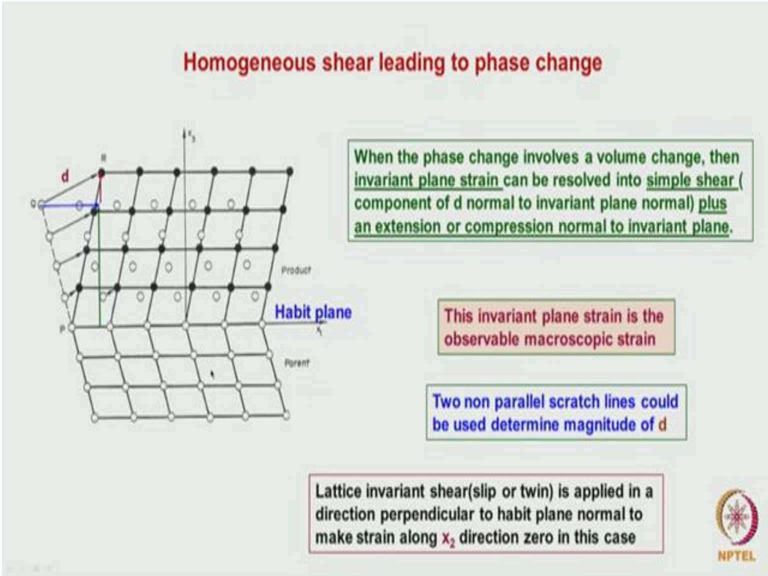

Let us look at this figure. This is the parent lattice; it is a two-dimensional projection of the parent lattice, simple cubic lattice which is being shown. These atom positions open circles represents the position of the region which before undergoing the martensitic transformation. So, what does martensitic transformation means? That by a homogeneous shear that is from here to here, here to here we are showing this displacement. This has undergone a transformation from one structure to another structure. And this shear is a homogeneous one because if we measured the displacement and we take this height then we will find the ratio of it is constant everywhere. So, the shear is homogeneous.

And another thing which has happened is that the volume of the unit cell has increased or it could have decreased also that means, during the transformation the volume is not being preserved. So, from what is going to be this shear this is what the one which we are able to observe is correct. If this is the surface of the sample this is what which will be the angle by which this tilt is taking place. This strain which is called as the invariant plane strain this can be resolved into two ones, one a simple shear in this direction plus an expansion or contraction as strain in this going to be there in the direction which is perpendicular to it that is the displacement which corresponds to when it is a simple shear and this is the displacement when the lattice is getting expanded, that is what the total displacement. Then correspondingly, we can find out the shear also these are sum of both of them together. This is what we are able to observe on the sample surface.

How we can find out like we have if it is a single crystal this sort of a transformation takes place. Similar to this suppose we have drawn another set of lines like this plus few many line that also would have undergone some sort of a transmit that if you know how much is there shift, this one this is a simple from geometry. We can try to find out what is going to be there microscopic strain that angle by which it is tilted, we can find out that corresponds to the observable macroscopic strain. And then in the third direction, if we consider it, in a martensitic transformation, we have considered only it is a two-dimensional figure suppose in the third direction also some change is going to be there. How we can account for the change in the third direction as we mentioned, it could be done by introducing lattice invariant shear, which is nothing but either a slip or twin along the c axis direction.

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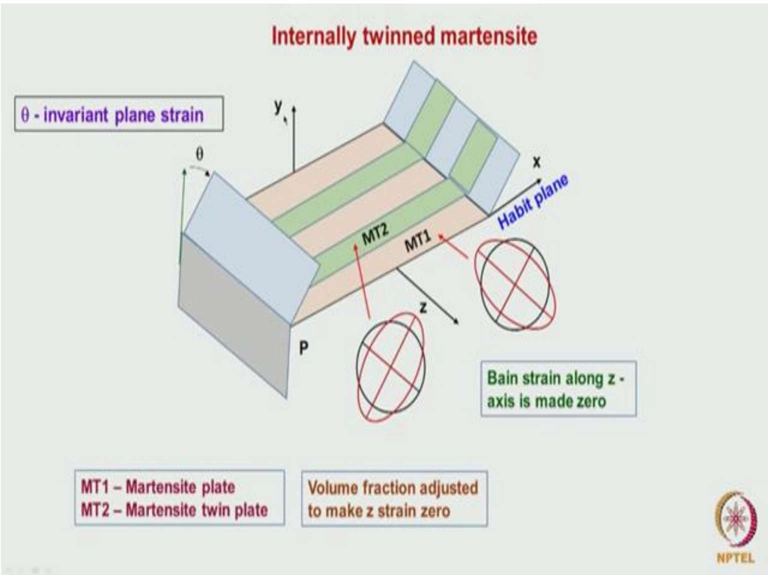

That is what essentially is being shown here. This is the x direction which is the habit plane, this is the y direction this is a martensite which has formed and it set invariant. So, I am calling in MT 1 at MT 2. This is with respect to a parent; this is how that tilt which has come. If you look at MT 1 with respect to a original parent lattice this is we are assuming a region which is a suffers sphere that gets transformed with respect to axis in this particular way.

In the twin variant, there also before twining has happened, the parent variant remains the same right, but in the twined one the directions will be different. So, now, the this the way in which is elongated. If you compare these two here an elongation is in this direction, the same direction it is a compression. Here where compression has taken place that is an elongation. So, these two together what will happen in this z direction. We will have a net strain which is going to be 0 that can be obtained by controlling the volume fraction of the martensite phase, and the it is twin, that is what we considered in the case of a the fcc to fct transformation.

And this is how from this figures one can understand how the strain that is in z direction or the third direction is being made 0. This is the same thing could be done by introducing some slip also that is where that many of the samples we find that lot of dislocations will be seen within the (Refer Time: 49:58), they are generated to accommodate for the strain.

So, now using this model, we can and not only that using this crystallography theory, depending upon the strains which have to be applied in the three directions to go from the parent crystal structure to the martensitic crystal structure, we are able to tell what sort of lattice is invariant shear which is required. Especially in the case of twined martensite, the volume fraction which is being predicted by theory it has been observed that the same volume fraction the experimentally observed volume fraction corresponds to the same value. So, this is one of the great success of this theory.

Then the orientation relationship, which is predicted exactly the same relationship could be obtained in most of the cases, then the habit plane which is calculated that turns out to be the same habit plane which is experimentally determined. But these habit planes, we should understand that they are high index plane or we call them as irrational habit plane. Essentially, what we have to consider here is that one of the experimental observation is that in this type of a thing, we observe that suppose we allow a region to transform like a normal diffusion transformation. Then after a deformation has taken place shape changes occurred then we allow some surface fraction to bring it to the original shape and introduce it into it.

When we introduce it back into it what essentially is happening is that the strain it will try to relax. So, the strain is accommodated and the matrix as well as the precipitated; whereas, here that does not happen. The reason essentially is that from the cryptographic it is clear that the plane gets rotated then by rotating the plane we are able to and then put it back matching with the original plane, which correspond to a undistorted plane. So that means, that when the martensite is introduced here which is microscopy to observable shear, the perfect matching is obtained here, but on the matrix side the effect is not being done by rotating the crystal that is the surface relief which is coming the strain is getting accommodated. So, on this side of it right up to the interface absolutely there is no strain. So, this feature also this cryptographic theory is able to explain.

So, there are many aspects of martensitic transformation which has to be considered like nucleation of martensite, the energies which are involved, then there are (Refer Time: 53:35) martensite, martensitic transformation which has been studied in various systems. And there are many crystal systems we observe surface relief similar to this, but they are not martensitic transformation, there are various case are there. Those part will be covered by somebody else, when phase transformation is being covered. So, here what I have done is covered whatever is the crystallography of martensitic transformation which is relevant for the case of defects in material how the defect interaction how defects introduce strain.

So, with these essential features of martensitic transformation from a strain point of view straining of the lattice, we have considered. We will stop here. In the next class, we will discuss about different types of interfaces, because we know that interfaces of the ones which do not allow which act as an obstacles to movement of dislocations. And when they act as an obstacle that will give rise to increase in strength of the material work hardening all this behavior depends upon the type of interfaces which we are. So, we will talk about the different types of interfaces in material that is interface are also a defect in materials. We will talk about it in the next few classes. We will stop here now.