Defects in Materials
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Lecture - 29
Twinning – 1

Welcome you all to this course and defects in material. So, far we have looked at point defects and then looked at the defect called dislocation. The dislocation is the one the movement of which gives or which is responsible for plastic deformation in the material correct. Suppose by some means we assume that in some materials dislocations are not able to move that easily then is there any option for deformation to occur that is what we have to look at it. Or is it that plastic deformation by this movement of dislocation is that only option that is the question.

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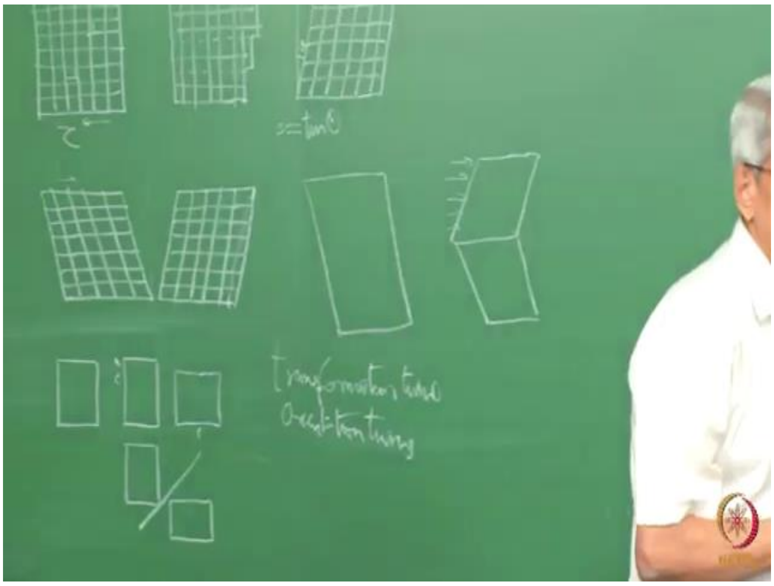

So, let us first look at how deformation propagates by dislocation then we will come to the next topic, which is what is the other alternate mode by which deformation can propagate. Suppose, we take a solid block like this in which we assume that dislocations are presented different regions. When these dislocations under the action of a stress which is being applied, these dislocations come out of that sample surface then there will be a small microscopic step will be generated, when the dislocation has come out of it. This means that the shape of the sample has changed that is what it is.

Here what is essentially important is that which one should understand is that you consider this region, you consider this region, what has essentially has happened it remains the same. This region has it undergone any deformation no overall shape changes there, but this shape change is brought about by movement of dislocations in some specific planes that means, that the deformation is not homogeneous, but the deformation is heterogeneous that is what it happens that brings about the shape change. And generally these steps and or normal experimental techniques which are available for observation of the dislocations or observation of the microstructure, we will not be able to see the steps only the overall as if the whole shape has changed that is how we look at it, and that dislocations may be uniformly distributed at so many regions. So, it appears it is macroscopically, it has homogeneous deformation, but microscopically the deformation is still inhomogeneous.

Student: (Refer Time: 03:32).

Macroscopically, it appears homogeneous. Microscopically, when you look at it from this region nothing has happened, this region nothing has happened. So, it is inhomogeneous deformation that is what it gives rise to appearance which is macroscopically because at the resolution which we look at it looks like homogeneous.

Now, what is the other option by which this material can deform? Suppose, it is not able to move dislocations are not able to move, the choice which it has is that when you apply a stress, either the material can fracture to relieve the stress or there is an another mode in which it should deform. That is we assume that case that where the whole region has deformed like this, it was this region, it has been homogeneously sheared to this shape. Essentially, what has happened is that. And another thing which you consider is that when you it has homogeneously sheared because the deformation appears to be now homogeneous, because here it is heterogeneous. Here, we if we try to find out what that angle is this angle S will be equal to tan theta this angle that is what the shear we define; that means, that every point the shear is proportional to the height at which we are considering. So, it is a homogeneous deformation.

In this deformation, suppose we assume this case that we have because so far we did not consider any crystal structures. Now, let us look at some crystal structure within this. In this case, if we look at it when a homogeneous deformation takes place, now all these regions have undergone some deformation every unit cell also has gone under goner (Refer Time: 06:06) deformation. Whereas, here if you consider it by this movement the crystal structure is being preserved, once dislocation has gone through nothing has happened. Whereas, here there are shape changing in for particular angle of shear, the shape change occurs in such a way that crystal structure is being retained. If such a thing happens that sort of deformation we call it as twin, that is by a movement of a homogeneous deformation, we have gone into an another orientation, so that its able to observe the external applied load, the energy put into the some observe the load and deform this itself.

We can consider it in another simple way, because if we consider this structure, suppose let us consider a structure like this. It will be easy to visualize and understand to this structure, we are applying a shear simple shear. Then now you look at these two essentially by application of a shear homogenous shear the shape, which was initially like this it has been transformed to this shape. Now, you look at the orientation this crystal, it has oriented in a different way, but the crystal structure remains that same that means, that it has gone to another orientation. These sort of deformation is called which takes place in material by homogeneous shear is called as twin. So, we have looked at external shape. Now, we are considered the units cell also. So, only the orientation has changed. This sort of deformation becomes very important. So, what essentially has to happen is that

Student: If more energy.

Exactly that means that when slip is very difficult in the material, twinning will occur that is the condition. So, if slip is requires less energy if it can occur then twin formation does not occurs deformation by twin does not occurs. When slip is inhibited then deformation by twinning occurs. The cases which it can happen is that suppose we deform a sample lot of forests dislocations are there, then the glide dislocations, find it extremely difficult to move, but the external stress which we are applying that stress is being increase continuous pressure it is putting onto the sample, then some of these regions can deform by twinning.

So, in many materials, where slip takes place at the end of the deformation, when the strain is very high, where dislocations find it very difficult to move, and under those circumstances twinning can occur. Is it clear? That is one. Then one more factor which comes if material we take a polycrystalline material, if it has to deform uniformly without fractures occurring in that material then five independent slip systems are required for deformation to take place this is called as a von-Mises criterion. Many materials like FCC, FEC, we have five independent slip systems are there. Like HCP metals like zirconium or titanium, there are only four independent slip systems are there that means, that by movement of dislocations only four slip systems are there. But if the material deformations has to maintain the material continuity, one more system, mode of deformation is required, in such cases the twinning becomes another mode another independent mode of deformation. So, in those material also, we observe like zirconium and titanium twinning could be observed frequently when we try to deform the sample.

Suppose, we assume that the twinning is not there, the material will like a brittle material it would have fracture very easily. Having said so far about twinning a very simple way, now let us look at a little bit in detail about the crystallography of twinning. What can we understand the science of these twins. How do we define a twin from a crystallographic way? If we have one crystal is there, by a symmetry operation that is any of the symmetry operation, if an another variant is being generated of that crystal these two will be the relation between them is essentially called as a twinning relation, that is what I am written here.

When a crystal is made up of parts that are oriented with respect to one other according to some symmetry rule, the crystal is said to be twin, these regions are. So that means, that twinning need not be by a mechanical means, it could occur other ways also when crystallization takes place, when from solid to liquid when the transformation takes place; even in solid-state transformation, we can have regions which are related by twins. What are the symmetry operations which we know they are reflection, rotation and inversion, all these symmetry operations if crystals are two crystals are related by these operations, we can say that they are twin related that is common rule for twinning is this is what essentially it is. All the three are possible, and all these type of operations have been observed.

Let us try to understand how the crystals will look like when these sort of deformation takes place. What is the simplest example, which we can take up of a reflection twin?

Student: Mirror image.

Mirror image, which we can take it one is our body itself, across this one, if we take it around this axis externally, we are related by mirror symmetry. So, this half and this half are twin image of the twin related. Other way in which we can you assume the case this a just a hypothetical case. Suppose across, this is not related by reflection, it is by rotation then what will happen, how will you look like, one eye will be here, another will be at the back correct, so that sort of operation also if one that is also related by twin.

Then contact between this area, where the twin and twin region meet. Suppose, you assume that this itself is assume it to be a crystal which is there like this, when load has been applied, this part remains like this, this part has deformed and reach the mirror image. So, this plane where they join together this is called as the composition plane that is where the twin and the un-twin region meets or this is also called as the twinning plane. So, essentially across this plane, everywhere a homogenous shear has been applied that is how this deformation has occur. I mentioned that twinning need not occur due to deformation also, but due to nucleation also, especially in non-cubic systems this sort of process occur. This is one example, which I had given here if you look at it the unit cell.

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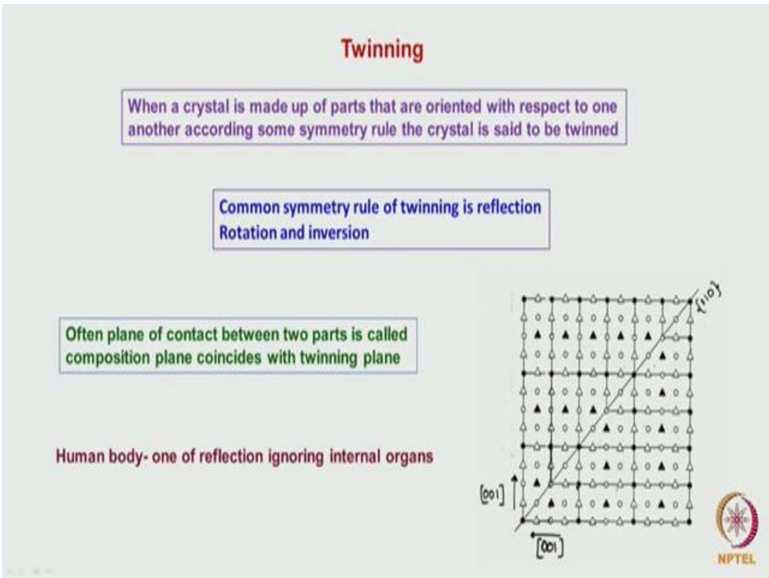

Now, here is like a this is one unit cell, this is an another unit cell. This is nothing but a tetragonal body centered tetragonal unit cell, its projection which is being shown. If we look across this plane, across this plane both of them are twin related. This sort of process can occur during nucleation, example we can take it. Suppose, a material at a high temperature is FCC; from FCC, it undergoes a transformation at low temperature to tetragonal structure. And let us assume that when this transition, this transformation is occurring, the A lattice parameter remains that same A and B, the C lattice parameter as increase.

Then if you just look at a two dimensional analog initially which is essentially an FCC structure, it has now become slightly this is the C-direction. The crystal can form when it is nucleating in a single crystal, in some region you can form with the C-axis along the C-axis of the FCC in one are the cubic system in one, it can form with its C-axis along the A-axis in another you can form with its C-axis along the B-axis. That means, the three possibilities are there all the three can occur all the three possibilities can will occur simultaneously at different region, but one of them will occur at a particular time at particular region. Suppose, such a transformation has occurred, when they come and join together, when the transformation takes place during time.

Then if we look at this structure and a structure which is forming in another region with these when they join together across one interface like this here. These two are related by a mirror that is precisely what is being shown here is that here C-axis is in this direction; in this one the C-axis is in this direction. Then across the interface, now you see that there are later by twin. As if this whole unit cell we had given a shear and deformed it homogeneously to bring it from this structure to this particular structure, this aspect of it we will now consider.

So, essentially what we have seen it is a there are many ways in which shear could be that is many ways in which twinning could occur in the material, not only by deformation, but during phase transformation also twinning could occur when the twins which occur due to phase transformation, we call them as transformation twins or orientation twins. These are all the two because one orientation variant is there another one which is oriented in a different way, but the crystal structure remains that same. They could be related by a reflection, or they could be related by a rotation, or they could be related by inversion.

Let us just concentrate on this FCC lattice itself. Suppose, here with the C-axis as found here if an another one forms with a C-axis along this direction this cubic unit cell. But since the symmetry is being maintained ABC we cannot distinguishes the correct because of which whether C- axis is in this direction or C-axis is in this direction as far the structure remains cubic it remains identical, we cannot distinguish them. That is what it happens in the case of a normal transformation when FCC itself is there when different nuclei form.

Whereas, when a transformation occurs where we are able to distinguish the C-axis then we can immediately notice that this nucleate, we can distinguish them by looking at it telling them on which direction the C-axis form we can identify them. And then we can find out what is the symmetry relationship by which these two are related. If they are related by the symmetry relation, then we call them as twins that is how we have defined the twins now.

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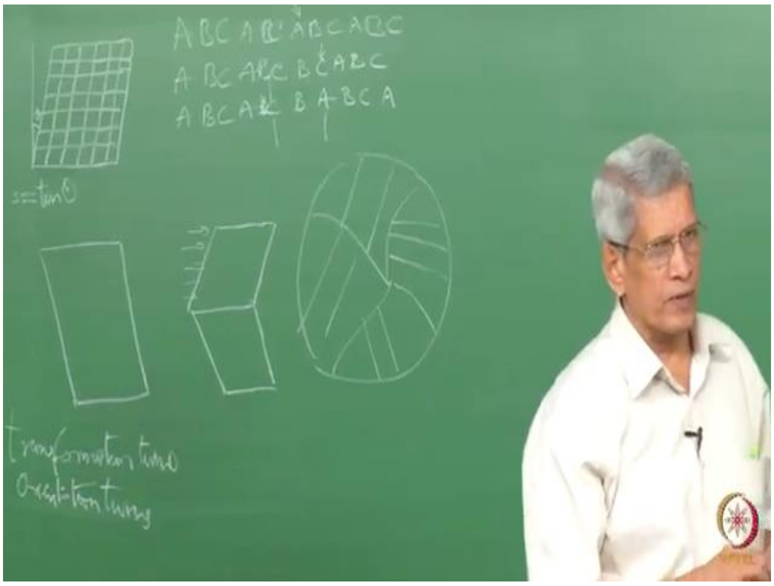

Here, I am just showing taking an FCC lattice how twinning is occurring. The stacking sequence in FCC is ABC ABC ABC in a perfect stacking sequence correct.

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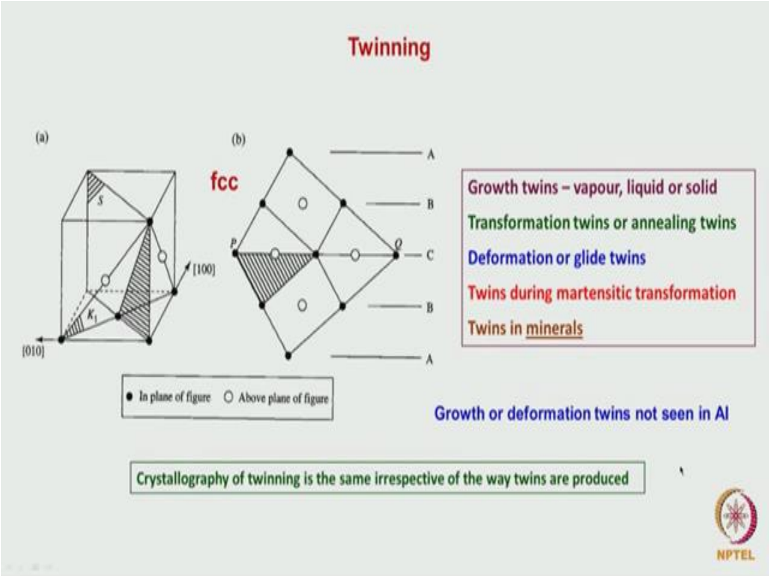

In this lattice, if I apply a homogeneous shear that is the plane which is here ABC, these are all what has been shown here is a 1 1 bar 0 projection on that plane is being projected. These ones if you look at it this is 1 1 1 plane, this is another 1 1 1 plane, this 1 1 1 plane only the projection is being shown in that 1 1 bar 0. This is A; this is B; this is C. See if by A by 6 1 1 2, if I move the next plane which is an A plane which has to come, it occupies a position which is corresponding to B another one corresponds to position A. So, this is what we can do that.

If I introduce a stacking fault here now it will become ABC ABC, this will become B, this will become CABC like that it will go. Now, if I introduce a fault in the next plane that is then what will happen a stacking sequence changes to ABC ABC B C becomes ABC A like this it goes. Now, across this if you see here ABC here CBA correct, the stacking sequence as reversed. The same thing when we look at the projection of the crystal in 1 1 bar 0 direction, now we can say that these are related by a reflection mirror symmetry is there. So, these two regions we can call them as twins or this small region is essentially a twin which has formed within them that is when the falcon sequence reverses then we can say that the twin is form. But this is a visualization of the same stacking sequence of the crystal that is what we have shown here. Is it clear? This we had shown that by moment of a partial it can occur.

Now, the next question comes is that that means that partial means that the material should have a low striking fault energy. Only if a low stacking fault energy is there then only this sort of a shear can occur and twins can form that is one criterion. A materials which have low stacking fault energy what has been seen is there especially. Suppose, we take gold, evaporate it and allow it to condense on cold substrate. When it condenses, it has been seen that lot of twinning occurs these are called as micro twins that it is a growth only is taking place.

This is because since the fault energy is small twins that when the by stacking one layer on top growth takes place. Sometime stacking sequence instead of b atom coming a position c atom can come to a position and like that it can happen it can reverse again that means small, small regions you find that in the growth or twin related. This happens from vapor to solid, liquid to solid as well as in solid-to-solid transformation also. These sort of that solid to solid transformation which we can think of is take copper, gold, we cold roll it, we anneal it at a very high temperature.

If you look at the anneal sample what do we observe in the grains which are connected like this between them we find large sub regions like this which are related these are all twins, which we call it as annealing twins, that is from the completely deformed region. When a defects free dislocation free regions are growing the atoms are arranging itself in such a way that sometimes the stacking sequence is changed. Those regions we call it as annealing twins. Then twins can occur during or glide twins, the deformation twins we call them.

Then another is that when martensitic transformation takes place, they are also to accommodate that strain twinning occurs within the material. In addition to it, in most of the materials where the slip is difficult their hard materials, if you look at the microstructure of those materials when they have solidify or minerals if we take it and look at it we find that many of the minerals plenty of twins will be there. These have formed during solidification are under extreme pressures under which they are subjected to do under within the earth under which this sort of transformation might have occur.

So, what we have done is we have briefly looked at what are the ways in which twinning can occur. In aluminum, if you look at it, twins does not form at all. The reason is that the stacking fault energy is very high, so whenever one layer of transfer even during growth when it happens fall do not form. This I believe could be due to the reason that if you look at one layer the hexagonal packing layer is which is ABC their stacked on top if I take an a layer there is a B site and a C site is there to which the atoms can go and occupy. This is just pure probability by which they can occupy. But if when that occupies it forms a crystal structure also, the layer we need them also will have an influence on what sort of a structure because if any stacking fault is form in FCC that is nothing but a unit cell of HCP. That means, that the HCP structure should also be the energy, which is required to form them should be very small then only this sort of a transformation can occur.

Suppose, the energy is high that structure which it forms has got a high energy then it would prefer because this a thermodynamic condition which we are applying it that it would prefer to remain in the FCC stack that is what it happens in the case of aluminum. When fault energy is high stacking fault grown form, so deformation twin is not seen, not even a growth twin is seen that means, that that the type of annealing twins which are seen in the. So, anneal microstructure of either copper or gold those things, we do not see it in aluminum.

Whatever be the way in which these twins are twins have form, what is the mechanism by which twins have form that is something which is a common crystallography which is involved in that that remains that same. What we would try to look at it, we first look at this crystallography of twinning.

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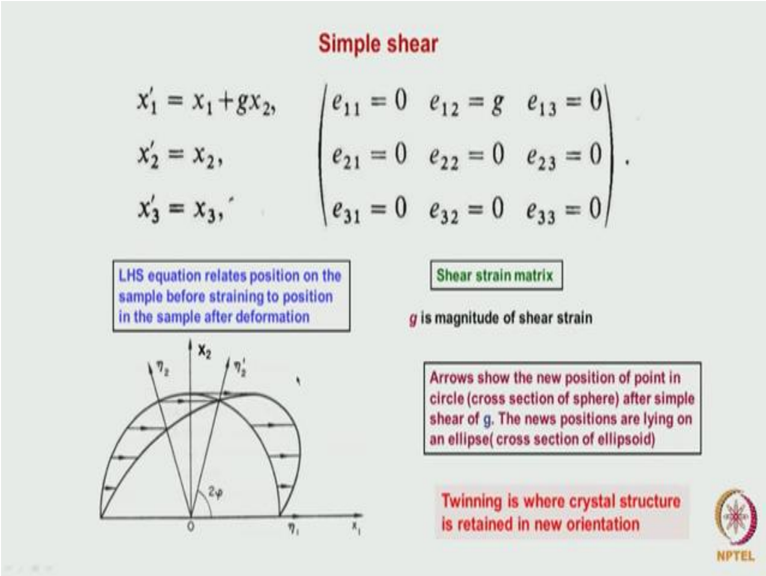

Let us just look at a simple shear. In a simple shear what we do is only that if you look at the strain tensor, which is being given, it is only one direction we are giving and simple shear. What is being shown here is that we assume that the original shape of that sample we assume it to be hemisphere. This hemisphere when we apply this shear, what we are applying it is called as a simple shear.

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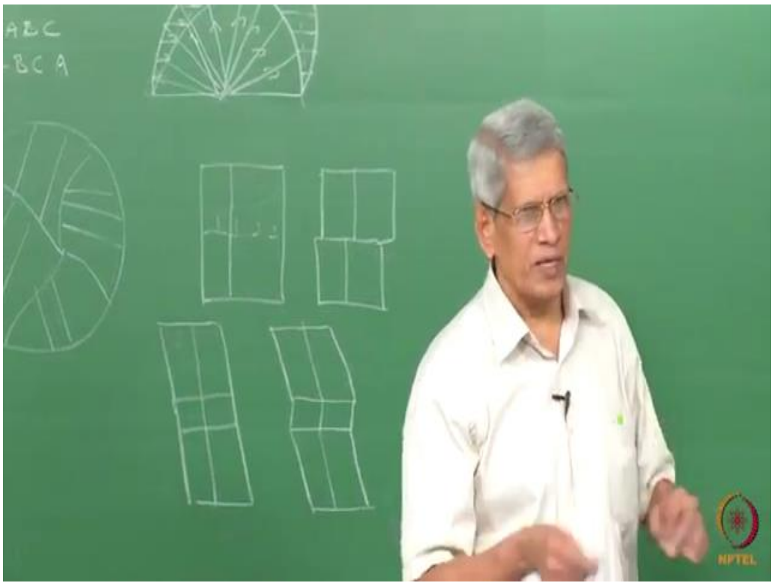

But it is a homogeneous shear; that means, that every region will be deform proportional to the height by that multiplied by the height multiplied by that tan alpha that is the way the displacement will takes place. When such a thing occurs the way this will become because at this region, they are joined together because the strain has to be 0, as the height increases. So, essentially what we can see is that this is how it happens correct then here like this each point this is what we had shown here.

Another interesting observation in these is that there is at one particular point that is from the center if I look at vectors, which are joining to the surface, I can look at these sort of vectors. After shear, this vector has changed to another vector, you take from here when it has deform to here this vector has now become at this point, that is the vector length is not the same. So, there is a distortion of the vector is taking place. But at this point, the deformed one from where from it has after some deformation from here to here when it has come, the vector length remains the same that means, that in this sort of a pure shear, one of the property is that there is one direction which is on distorted, but it is rotated.

Student: (Refer Time: 32:09).

Yeah, so it is just rotated like this, but all other planes let us under. So, this is only a direction, which we are considering it with respect to. Suppose, we consider to be part of as surface which is essentially a cut essentially cylinder, since shear is being applied lets a plane which is passing through this. This plane if you consider that plane also remains rotated, but undistorted, but here there is one plane is there which remain neither rotated nor undistorted.

So, there are two types of planes are there. After the deformation there is one particular plane which remains join together that is called as the composition plane or the twin plane, over which the materials are the deformed and the un-deformed region is meeting because you assume that this is the other part of it. So, this part with respect to it when a deformation takes place it has change, so, this is the plane over which they are joined together, but there is a plane as well as a vector we can see that both of the marketing rotated. That means, that there are two planes that they are which even after deformation the plane remains that same as that of the original plane. This is a property of homogeneous shear.

When whatever be the amount of shear which we are applying suppose the shear becomes very small this would have become like this it would of a happens, then the vectors which are there may be this vector and this vector are different plane. That means, that these inherently a property of this a homogeneous deformation, but for some deformation some strain when that is the shear from here to here. So, if here to here is what the displacement and this height if we take the ratio of it that will automatically give what is the simple shear which we are applying, the magnitude of the shear we can calculated. Not only that for a particular value of the magnitude of the shear, when this change takes place, it goes from one orientation to another orientation which is identical to it when such a thing occurs. Then we say that twins have formed are they have twin related that because they are related by some symmetry operation that how we can considered it is by a, that I will come to it now. Is it clear?

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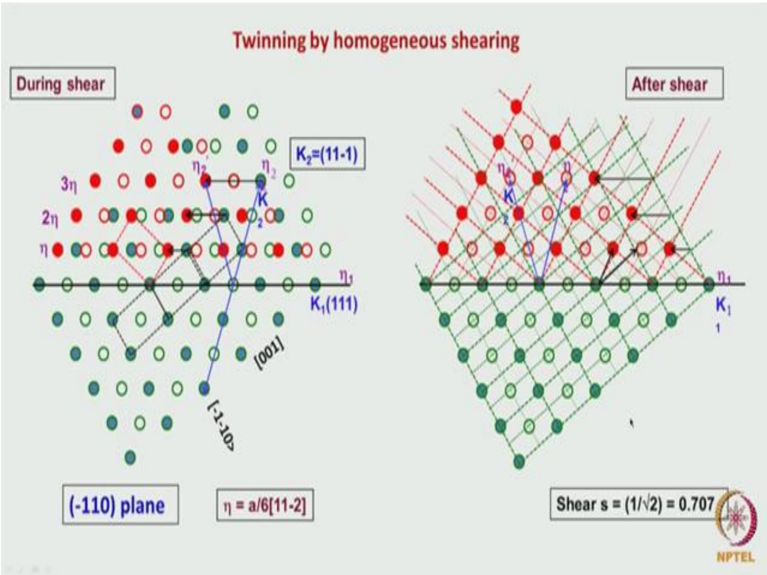

I have just looked at a crystal structure this is an FCC lattice the same as what I had shown here. This is the plane which I considered it is a K 1 plane these are 1 1 1 plane all are 1 1 1 planes I could have chosen any one of the 1 1 1 planes. And similar to these this is the other 1 1 1 plane in the lattice. You forget the red atoms, you consider that this is the lattice which is there. Across this 1 1 1 plane; above this plane in all other 1 1 1 plane in this direction which is 1 1 2 direction 1 1 2 bar direction this specific one. I am shifting it every atom by a by 6 1 1 1, a by 6 1 1 two bar that means, that this atom is shifted by that vector it comes here that is what I had.

When I shift give a shift to this atom all the layers above will also shift by that same way. Then in the next layer again I give another eta, it is equivalent to deforming the second layer by 2 eta, eta is the shear vector which is being given on every layer. When I do that, this atom will move from here to this position, this atom will move from here to this position, this atom moves from here to this position, this will move from here to this position like that each of them are moving to different position.

Then when I give it in the third layer this is 3 times eta it moves from here to position which is identical to a original one. That means, that when we looked at the stacking sequence ABC this has become from the A layer as going to B layer then B layer has gone to C layer then here the C layer has gone to an A layer. So, the stacking sequence have change. If you look at this one this is during shear what happened, so every layer has undergone a shear eta, 2 eta, 3 eta that is with respect to height the shear is taking place that means that this is a homogenous shear which is occurring in the material.

And what I have shown here is just the projection of it. Now, if you look at it after the transformation these sort of as cell here has transformed to this sort of a cell. Now, you look at these two cells, they are related by reflection, across this plane that means, that these two structures are twin related.

The same thing I have just shown it a different way where I have removed all these a atoms because here I had shown both the position before shear as follows after shear this makes it little bit difficult to imagine. Here I had shown only the lattice the structure is being shown, not the atoms and now when the transformation has taken place now we can see that these two are twin related. And essentially we can see that this vector from here to here has been transformed from here to an another identical position. This is the vector, which is rotated, but not distorted. And here this is the plane which is the K 1 plane these called as the composition plane, and the shear is being always given simple shear in this direction homogeneous shear which we are giving it. So, it generates in the deformed N that is this plane K 2 plane which is called is the plane which has also rotated, but undistored.

So, these four terms are very important in understanding twinning crystallography that means, that there are two planes are there which are undistorted by deformation, they do not know undergo any transformation, but only they undergo a different orientation change. Similarly, two directions are also there. And if we look at what is the shear vector which corresponds to this for this FCC lattice is we can calculate this it will turn out to be 0.707. So, this is a very high shear. Only for this shear twin related structure will be formed for these planes; for and some other plane if you consider it may be a different shear vector, which will be required.

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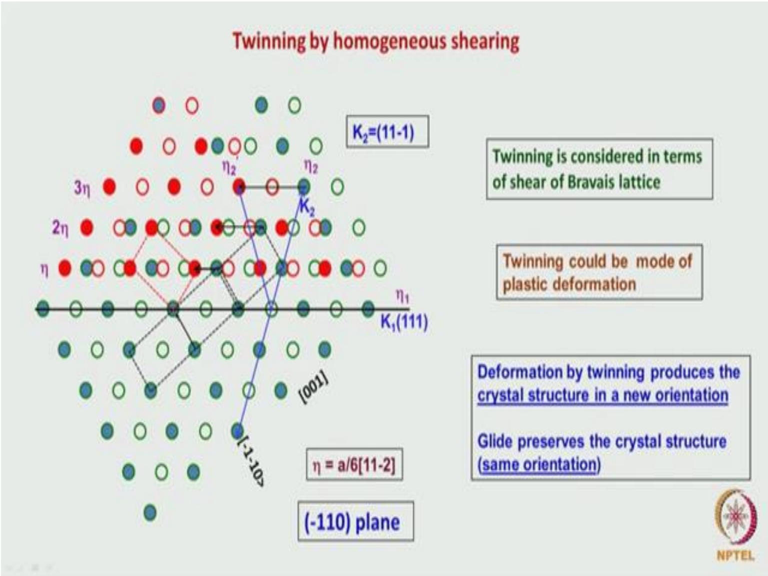

So, that is exactly what I had shown here. But the tie what is the lattice which we have considered here this lattice is a Bravais lattice. We should understand that it is a Bravais lattice, which you are considering it. And twinning is considered always in terms of shear of the Bravais lattice. And this mode of deformation also can occur in a material. So, whenever material has to deform it has cut two modes in which it can deform one is by shear or by twin. There is a third mode of deformation which is there is like a viscous flow very high strained deformation like when you fire a bullet or a explosion takes place, what is the mode which is the material will deform. Then we call it as some shear band propagation that is as was the material has become highly viscous like a fluid and it deforms that is the third way that is the turn extreme rate of deformation. Otherwise under normal conditions of deformation, when we do that these are all the two modes with by which the materials deform. Is this clear?

And another also be is that by this homogenous deformation which we have introduced it here, we have generated this is one orientation, another orientation which we have generated of the crystal. And these two are related by a symmetry operation. Here we considered as across this plane, it is.

Student: Mirror reflection.

Mirror reflection. But if you look here with respect to this direction if I take it that is perpendicular to this if I take a direction and give a rotation of the world structure I could get the new structure. It is related by rotation also 180 degree rotation. And in this direction like for example, here around this direction eta 1, if I give an 180 degree rotation, what will happen this from bottom one the top one will be form. So, these are related by both reflection and rotation, and that terminology which is used these this is called as the compound twin, this will come back to it. Just wanted to show that here many types of twin process occur together that many types of symmetry operation by which they are related. But all need not exist may be by only one symmetry operation related also it is a twin that is what is seen in most of the non cubic systems that we will take up later some examples and look at it.

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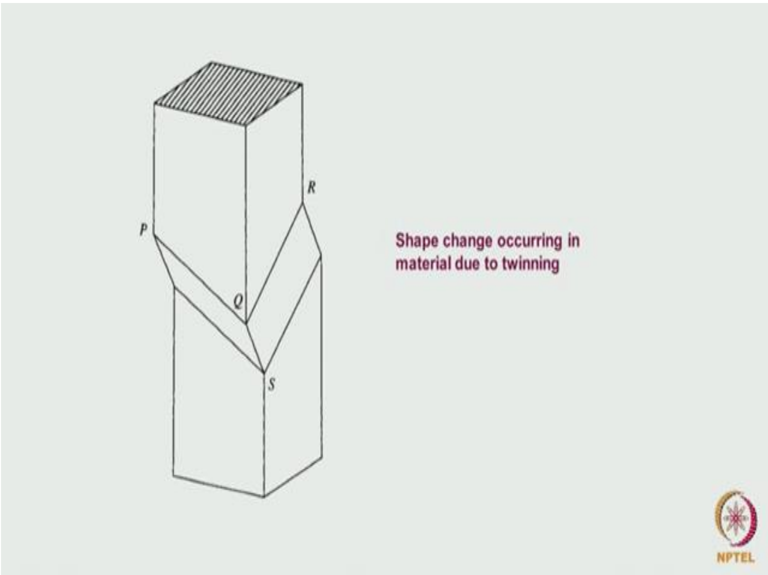

Before we do that if you look at a material, how does it look like when a deform it. If a material deforms by twin are assume that a material is deforming by slip. Suppose, this is the shape of the sample, lot of dislocations have passed through the sample, various this made of form and there pass through it. Then the material would look like this way, externally we can see this correct this is how with that stuff it happens. How this can be verified whether it is occurring or not is that.

Suppose, under sample I draw a line; now polish sample I draw a line before I am deforming the sample. Then it has deformed by slip which is taking place in this line then what it will happen, this line will be like this, this line will be shifted by this, these lines will be gap it will occur that means, the deformation is discontinuous. If the deformation is continuous they should have tilted they should be join together that does not occur, this is one way.

Let us take the case when the material deforms by twin like this is the region, where the twinning is taking place, assume that within this band. When twinning is occurring then what will happen is that the rest of the regions remains in that same position, this is what it happens. There is a overall a shift which has taken place. So, from this direction, how much is the shift, it is getting tilted we can find out what is the macroscopic strain which is involved. And in this suppose, I have drawn a line what would have happened, after twinning when this happens, this line also would have but continuity is being maintained this is one way in which we can immediately find out whether it is twinning or slip. But the same thing can happened for martensitic transformation also which I will be talking about when I talk about magnetic transformation maybe after a few lectures.