Texture in Materials
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Module - 10
Texture in FCC, BCC and HCP materials
Lecture - 53
Texture in HCP Polycrystals - III

Good afternoon, everyone. Today, we will be continuing with Texture in FCC, BCC and HCP Materials, that is module number 10. This is lecture number 53, where we will be learning, continue to learn Texture in Hexagonal Close Packed polycrystals, and this is part III.

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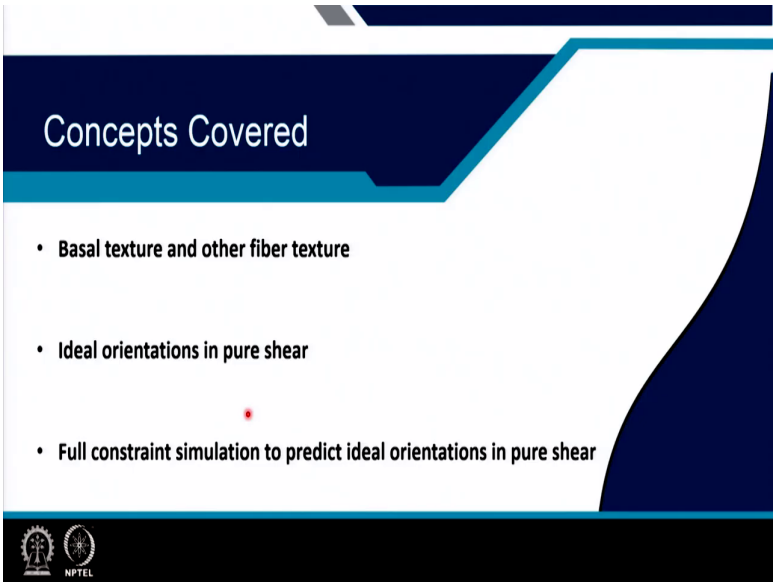

The concepts that will be covered here are various kinds of texture that will include basal texture and other fiber texture formation. Second, ideal orientation in pure shear in case of hexagonal close packed material focusing on magnesium. And how a full constraint simulation is used to predict these ideal orientation in the pure shear condition, using the condition of you know free end torsion.

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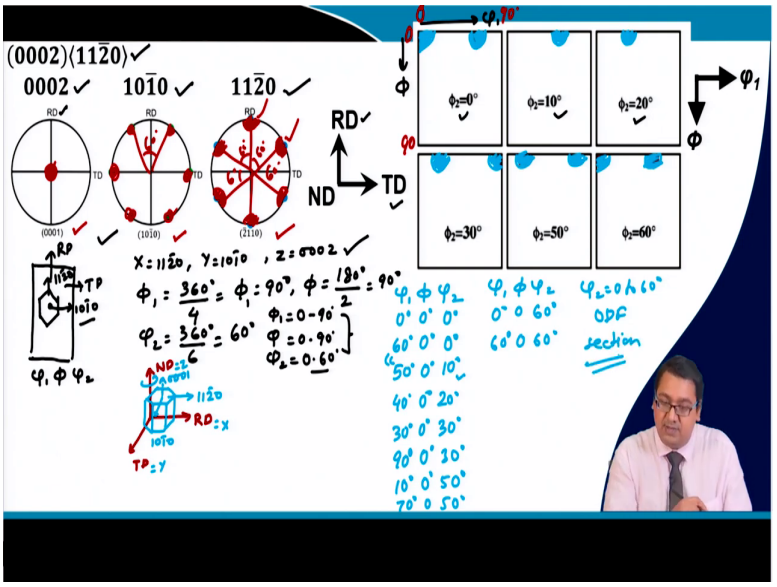

So, if we look into, let me take the pen, from the beginning itself. If we look into a texture, a texture, which is called 0002, 112 bar 0, we can see that if the RD is in the top direction vertical, the ND is coming out of the center and the TD is on the right hand side horizontal, then the 002. Which is showing the rolling plane basically, right should comes should come at ND, right.

If you see it will form somewhere here, right. On the other hand, the 10, 112 bar 0 is the rolling direction of course, so h k l u v w, hkil u v t w Miller Bravais indices. So, this is the rolling plane, this is the rolling direction. So, if we look into the 112 bar 0 pole figure, this is the 0002 pole figure, this is the 101 bar 0 pole figure, and this is the 112 bar 0 pole figure, right. So, if we look, so when we looked into the 002 pole figure we see that the 002 pole is at the center. Now, if we look into 112 bar 0 pole figure, you will see that the 112 bar 0 should be at RD. So, it should form somewhere here, right. And of course, then, because 112 bar 0 axis forms at 60 degrees to each other because of the six-fold symmetry about the 0002 axis that is the c axis, right. So, the c axis is here. So, the 112 bar 0 axis should each will be at 60 degrees to each other, right, something like this.

So, the angle between these is basically 60 degrees, each one of them, right. Now, 101 bar 0 is always at 30 degrees to the 112 bar 0 axis, right. And they also have a six-fold symmetry. So, they will form in between these two, right in between these two, say for example, here somewhere. And in between the other 112 bar 0 axes or poles, so they will form somewhere

here, here, here, here, and here and they also will be at 60 degrees to each other, right. Now, this is a situation if I would like to show you by drawing this situation, this is a situation where if I take a rolled sheet which is something like that with RD here and TD here and ND going you know out of this screen. Then, the unit cell will look something like this from the top, right.

The unit cell will look such that the 112 bar 0 is in this direction, whereas, the 101 bar 0 is in this direction. And this is the situation of for this particular texture condition, right, where the texture in terms of the 0002 pole figure 101 bar 0, 112 bar 0 will look as it is shown here. Now, if we would like to draw the ODF sections and here it is drawn we are seeing that one intensity has come here, here, and the other intensities are being shown at various positions, right. Now, how this intensities have developed at that certain position?

We can see that for this situation, the hexagonal closed packed structure has a Miller Bravais indices where there are 3 axes a 1, a 2, a 3, with 112 bar 0 type directions and one axis perpendicular to this 3 a 1, a 2, a 3, that is 0002 direction has to be converted into an orthonormal coordinate system. And let us take in this situation X equal to 112 bar 0, Y equal to 101 bar 0, and Z equal to 0002 for our convenience.

Now, in some research work, X has been taken as 101 bar 0, Y as 1111 112 bar 0, Z as 002 is also correct, but we are taking the convention where X is 112 bar 0, Y is 101 bar 0 and Z is 0002. Now, you see there are phi 1, phi, phi 2 section, this one is the phi 1 section and this is the phi and we are showing the phi 2 sections, right phi 2 equal to 0, 10, 20, 30, 50, and 60 degrees. Now, if we look into say for example, let us look into phi 1.

So, phi 1 is basically you know 360 degrees where it is a, so it has to be superimposed by the sample symmetry which is deformation symmetry. We are giving a plane strain deformation which is a rolling. So, the sample symmetry has been reduced by 4 so, phi 1 equal to 90 degrees. Now, phi we will come later. Let us say what happens to phi 2. Phi 2 is the crystal symmetry, the rotational symmetry. It has six-fold symmetry, so I have to divided it by 6, so it becomes 60. So, phi 2 we have to see from 0 to 60 degrees, whereas, phi, now, phi is basically 180 degree because of the identity present in the phi 1, phi, phi 2. You know Euler space, and there is a two-fold symmetry definitely in an another plane apart from the which is perpendicular to which is parallel to the c axis and then this becomes divided by 2 and becomes 90. So, we can see that phi 1, phi, phi 2, now, has converted into you know 0 to 90,

0 to 90, and 0 to 60, right. So, if you say that phi 1, phi, phi 2 has been converted from 0 to 360, to 0 to 90, 0 to 90 and 0 to 60, right. So, within this phi 1, phi, phi 2 we have to show the texture.

Now, if we look into the situation where the texture is basically 002, 112 bar 0, and if we try to plot the phi 1, phi, phi 2, right, let us draw the rolling direction the transverse direction, and ND, and the crystal structure to our convenience. So, let me do it as per my convenience. So, let us say let us say that this is RD, then this becomes TD, and then this becomes ND, right. And let me take another colour, and draw the you know unit cell based upon this situation. And I am trying to draw this in three-dimensions, so that one can understand in a proper manner how the texture basically works.

So, this is the unit cell that is an hexagonal unit cell, that I am drawing here. Mind my drawing if it is not good. So, this is a direction which is 112 bar 0 of course, right, which is parallel to RD. This is a direction which is 101 bar 0, which is parallel to RD sorry TD, and this is the direction 0001 or 0002 which is parallel to ND. Now, for the texture 002, 112 bar 0, you will find that the crystal structure is aligned with respect to X, Y, and Z, where X is equal to RD, and Y is equal to TD, and Z is equal to ND, right. So, there is no further rotation required to make this crystal structure aligned with respect to RD, TD, and ND.

So, if we try to plot phi 1, phi, phi 2, let us say phi 1, phi, phi 2, we can see that phi 1 can be 0 degree, then there is no need to rotate the phi which is 0 degree. And then phi 2 equal to 0 degree is the crystal structure is already aligned with the you know reference system of the sample. So, under this situation 000 is present here, right. So, you see this is 0; let me change the colour for a bit. So, this is 0 to 90 for each case, and this is also 0 to 90. So, this is phi 1, this is phi, let me change the colour again. So, the position of the first phi 1, phi, phi 2 is here.

Now, if you see for this same phi 2 that is 0 degree. If I rotate phi 1 by 60 degree, the rotation of phi 1 by 60 degree means the rotation along ND as 0001 is parallel to ND a rotation by 60 degree using the right hand thumb rule, right will bring another 112 bar 0 parallel to RD, right. So, rotation by 60 degree can be given. And thereby, if we look into the 60 degree section you will see another intensity of the same texture 00 to 101 bar 0.

Now, if we take this for phi 2 equal to 10 degree section then you will see that for if I rotate phi 1 by say for example, 50 degrees and then does do not rotate the phi. That is keeping it 0 degree then we have to rotate phi 2 by 10 degrees again to make a total of 60 degrees. So, you

see that what I am doing I am rotating along ND which is parallel to 001 by phi 1 by 50 degrees, and then again by 10 degrees which is basically same as this. So, this is equivalent to this, and therefore, at phi 2 equal to 10 we will be able to see another you know texture component.

But now the other component are at an angle 60 degree away from phi 1. So, 50 plus 60 becomes 110, which is cannot be shown at phi 2 equal to 10 degree section because it is more than 0 to 90 degree of phi 1, even minus of 60 degree makes it minus 10. So, it is not shown. So, only one component is visible at phi 2 equal to 10 degree. What happens for 20 degrees? For 20 degrees it becomes 40 and the situation remains same where 40 plus 60 is 100, and 40 minus 60 is minus 20. So, only one component will be visible at phi 2 equal to 20 degree.

Now, what will happen at 30 degrees? 30 degrees will have a phi 1 rotation of 30 degrees phi 1 30 plus phi 2 30 equal to 60 degrees. Here you will see that at a position of 30 degree there is another texture component formed in the orientation distribution function, section, phi 2 equal to 30 degree. So, if we add 60 degrees to phi 1 this becomes 90 degrees, 0 degree and 30 degree. So, another component could be observed. Similarly, if we go for 50 degrees then it has to be 10 degrees and addition of 60 degrees to 10 degrees becomes 70 degrees, 0 degree and 50 degree, so two components, right.

And at phi 2 equal to 60 degrees again phi 1 equal to 0 and at 60 degrees the components develop. So, in this way, the 0002, 112 bar 0 type component is visibly observed in the phi 2 equal to 0 to 60 degree ODF section, right.

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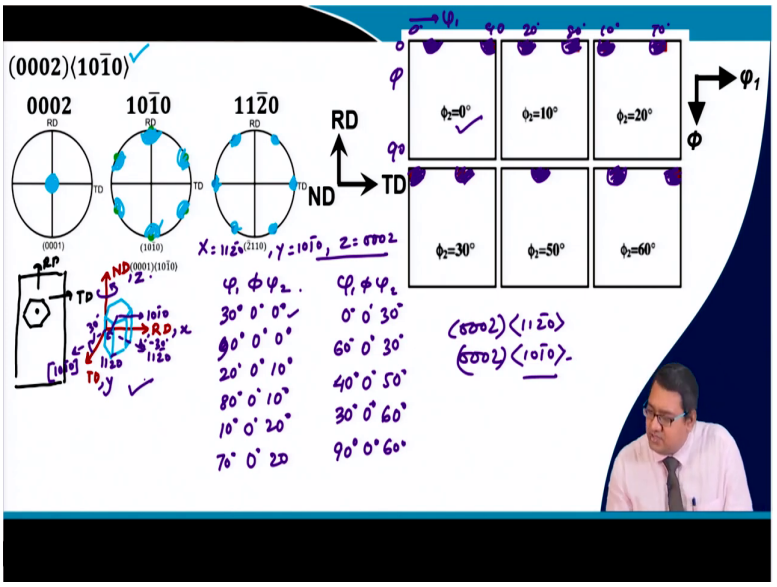

Now, if we look into the other texture component which is 002, 101 bar 0. The situation is little different. Here the 0002 pole figure if you see of course, it is the intensity is at the center, that is at ND. The intensity at RD is should be 101 bar 0. So, the intensity is here.

Based upon the symmetry of hexagonal crystal, the other intensities presents are here, here, here, here, and here, right and therefore, the intensities of 112 bar 0s are at 30 degrees to 101 bar 0s will be present somewhere here, here, here, here, here and here. So, this texture, if we look into this texture, you will see that in this case if we look into the rolled sample sheet keeping RD, TD, and ND intact, in this case, the crystal structure basically looks something like this.

Now, when the crystal structure looks something like this, if we try to draw this, if we try to draw this in the three-dimensional way, similarly as we did earlier this is RD, this is TD, and this is ND, right. And in this we draw this particular crystal structure. Now, it will be little different from the one we drew earlier. In this case, it will look something like this. Bear with me, of my way of drawing may not be so good, ok. But these are very difficult to draw even in this way.

So, this is the hexagonal structure, right. And if we look closely TD, let me take another colour, so that it is becomes more visible to you. TD is parallel to 112 bar 0 in this case, and RD is basically parallel to 101 bar 0 in this case, right.

Remember that in this case also X I have taken 112 bar 0, Y I have taken 101 bar 0, and Z is again same which is 0002. Now, if we try to plot you see the phi 1, phi, phi 2 here, the crystal structure is basically such a way that RD is parallel to 101 bar 0, where RD is basically X, right and TD is basically Y, and ND is basically Z, now RD has to be bring parallel to 112 bar 0, right.

Now, if we do a right hand thumb rule rotation along ND, and that rotation has to be 30 degrees along phi 1, this will be, this will you know rotate the RD by 30 degrees, right. So, it will rotate the RD something like this by 30 degree. And it will bring it you know parallel to 112 bar 0, one of the 112 bar 0, and it will rotate the TD by 30 degrees, right. So, this is 30 degree and this is again 30 degree, and it will bring this TD to 1 any one of the 1 101 bar 0 axis, right.

So, by rotating phi 1 by 30 degree keeping phi 0 degree and phi 2 0 degree, we will get the first position of the texture component at phi 2 equal to 0 degree section for phi 1 0 to 90 degree phi 0 to 90 degree, right.

So, let us say that this is 30 degrees. Now, if phi 1 the at phi 1 equal to 30 degree, if a component is present then due to symmetry of six-fold symmetry of the hexagonal close packed system along the c axis, another phi 1 will be present at 30 plus 60 degrees, right. Sorry 30 plus 60 degree, which makes it 90 degrees. So, it will be present somewhere here, right.

If we take phi 2 equal to 10 degrees, then it is just a repetition, so we have taken 10 degrees. So, 20 degrees plus 0 degree plus 10 degree that is you see 30 degrees, and then you see 10 degree 0 degree 20 plus 60 that is 80, right. So, at it will form another component at 20 degree? So, let us say it is 20 degree and another component as somewhere as 80 degrees. Now, for 20 degrees, it will form something at 10 degrees and at you know 70 degrees, so 10 degrees and 70 degrees. At 30 degrees it will form somewhere at 0 degree. So, it you can see and it will again form at 60 degrees because of the symmetry six-fold symmetry.

At 50 degrees you see it will form at 50 plus, see it is so tricky. So, at 50 degrees, you will see that it will form at somewhere, where it will form? It will form see either it forms at phi 1 equal to 30 degree or it forms at phi 1 equal to 30 plus 60 degrees which is 90 degrees. Even the addition of phi 1 plus phi 2 remains either 30 degrees or 90 degrees.

So, in this case, you will see that at 50 degrees if I add phi 1 plus phi 2, it cannot be 30 degrees. If it becomes 30 degree then it becomes phi 1 equal to minus of 20 degrees which is away from this phi 1 value which is from 0 to 90. So, if we see that phi 1 plus phi 2 equal to 90 degree has to be taken, and then it becomes equal to 40 degree. So, you will see that this will form somewhere here.

At phi 2 equal to 60 degrees, you will see that either at 30 degrees it will form which is 30 plus 60 which is 90 degree or it will form at another position. Because if you rotate because of the six-fold symmetry addition of 60 degrees, if you do to the phi 1, that means, 90 degrees, 0 degree and 60 degree it will again form here.

So, if you look into this two examples of 0002, 112 bar 0, and 0002 and 101 bar 0, you can see that how the pole figures developed for this particular texture component and also how the ODFs developed by simple geometrical rotation of RD, ND, and TD with respect to the hexagonal crystal structure.

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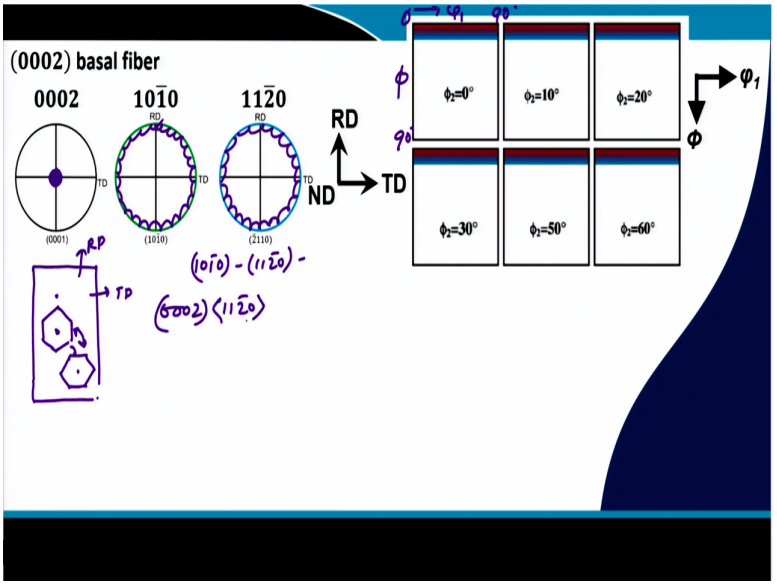

Now, if we look into the 002 type basal fiber. Now, what does it mean by the 0002 type basal fiber? It means that if there is a sheet present in the material, and if this is RD, and if this is TD, and if this is ND, then the hexagonal crystal structure may form like this or may form like this or rotated along the c axis by any angle in between them, right.

So, the along the RD and the TD, both 101 bar 0 and 112 bar 0 is present. Only the position of the c axis that is the basal pole or the 002 is fixed and that is a pole. The position of the 101 bar 0 is basically radial and it is present throughout the pole figure something like this.

Now, the texture is basically a kind of prismatic fiber and sometime it is also called as 101 bar 0, 10, 112 bar 0 type fiber texture. Now, this texture basically looks like a fiber in phi 2 section that is 0, 20, 10, 20, 30, 50, and 60 degree section as shown here with phi 1 0 to 90 degrees and phi 0 to 90 degree here, right, for each of this 6 cases.

Now, if we look how this type of fiber forms, just remember that if we take this 101, sorry 0002 and 112 bar 0 type texture. So, this is known as the 101 bar 0, 112 bar 0 fiber texture.

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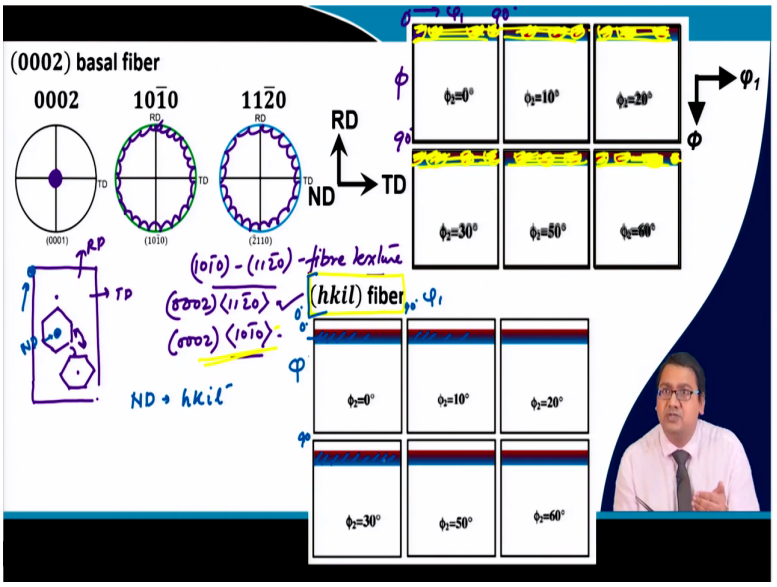

If we want to plot the phi 2 sections, 0 to 60 degree sections as being plotted here with phi 1 from 0 to 90 and phi from 0 to 90 in the horizontal and the vertical directions. We will have to see that this 101 bar 2 basal fiber has been formed from 0002, 112 bar 0 type texture component as well as 0002, 101 bar 0, type texture component and all the texture component keeping 0002 intact and varying the prismatic direction from 112 bar 0 to 101 bar 0.

So, if we look into this particular texture component, so it has formed from this position here; let me take another colour for better visibility. So, say for example, in this position and in this position, right and in this position as we have seen in the previous slides, right. Superimposition of the 101 bar 0, right, this one will form at these positions which are for

various phi 2s, right. The presence of other axes apart from 101 bar 0 and 112 bar 0, other prismatic axes will lead to the formation of the total fiber like this, right. So, this is the 0002 basal texture fiber.

Now, if we see that the fiber, if we look into the hkil type fiber, let me change the colour, you will see that the fiber which was forming exactly at phi equal to 0 section, phi equal to 0 for various phi 1 and phi 2s. Now, it is forming at a certain angle, right. So, it is forming at say this is phi and this is you know phi 1 and every time the phi 1 is from 0 degree to 90 degrees, phi also is from 0 degree to 90 degrees. If at a certain theta of phi, at a certain angle of phi not confusing it with any other theta or something. So, at a certain angle 2 phi of phi, if a fiber is forming like this this fiber becomes a certain hkil fiber.

This indicates that the ND, the ND which is coming out of this sheet the ND, right, which is coming out of this sheet is now not parallel to the 0002 axis. It is not parallel to the c axis, but the c axis is at a certain angle to the ND, right, making the fiber and that angle makes the ND parallel to hkil you know axis. So, the hkil fiber with different values of l can form at various position by varying phi and a fiber which is constant for a certain phi is this one, right.

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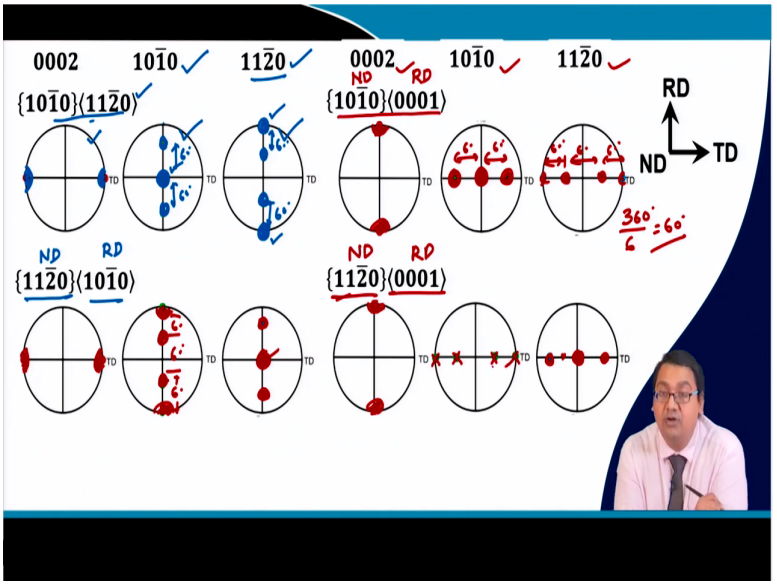

In this way, in this way, there could be various other texture components that can develop in hexagonal close packed material. A paper by Huang and Wang, shows a detailed description of these texture components. One can read it for knowledge. So, here is the one you see.

Here is 101 bar 0, 112 bar 0 type texture component, and the first one is the 0002 pole figure, the second one is the 101 bar 0 pole figure, the third one is the 112 bar 0 pole figure. We can see that the ND is at the center, right coming out of the paper. So, 101 bar 0 is parallel to ND, therefore, it must form somewhere at the center, right.

On the other hand, the other axis of 101 bar 0 will also form, but it will depend upon two issues. What is the position of 112 bar 0? It is at RD. And secondly, that at c axis the hexagonal close packed structure has six-fold symmetry. So, if we look into the 112 bar 0 pole figure you will see that these are the positions of 112 bar 0 poles, and these are at RD, right. So, 101 bar 0, 112 bar 0 component will show 11, 101 bar 0 at the ND, 112 bar 0 at the RD.

And the other components of 101 bar 0, and 112 bar 0 will depend on the six-fold symmetry. So, it will this the other components will form at 60 degrees and 60 degrees, right. Thereby the other components of 101 bar 0 will also form at 60 degrees to the ND.

If the component are present along this axis that indicates that the c axis is perpendicular to this 112 bar 0, 101 bar 0 axis, will form at these positions, right. So, one can determine the pole figure 000 to 101 bar 0, 112 bar 0 pole figure, if it is asked for the component 101 bar 0, 112 bar 0.

Similarly, if a component 112 bar 0, 101 bar 0 is given; that means, 112 bar 0 is parallel to you know ND and 101 bar 0 is parallel to RD. So, we can immediately say, ok ND is 112 bar 0 which will be here, right because this is the 112 bar 0 pole figure, whereas RD which is 101 bar 0 will form here, right.

Now, based upon the symmetry as I said, the other 112 bar 0 axis will be at 60 degrees to the 112 bar 0, this 112 bar 0, whereas, the other 101 bar 0 will form again at 60 degrees to the 101 bar 0. So, 60 degrees, 60 degrees, and 60 degrees, right. If this is the position where 101 bar 0, and 112 bar 0 poles are forming, then the c axis will form perpendicular to it at these positions, right. So, in this way, we can found out 112 bar 0, 101 bar 0 you know pole figures, pole figures for this texture component.

Similarly, if we look into this 3 pole figures for the texture which is 101 bar 0, 0001, then 101 bar 0 will be parallel to ND and 0001 will be parallel to RD. So, if we look into ND, 101 bar 0 will be here, right. And if we look into RD, 0001 will be here. So, we at least know these

two components. And we know that the positions of the other 101 bar 0 and the 112 bar 0 will be relative to the c axis and will have a six-fold symmetry. Therefore, the 101 bar 0 components will form here and here that is at 60 degrees to the first point and the 112 bar 0s will form in between them that is here, here, and here all will have a 60 degree which is because of the six-fold symmetry. So, 360 divided by 6 equal to 60 degrees, right.

Now, if we look for another example which is 112 bar 0, 0001. So, this is ND, it is at the center, this is RD, these positions are here parallel to RD. The positions of the other 112 bar 0 are at 60 degrees and in between the positions of 101 bar 0 is in between so, here, here, here, here, all 60 degree apart.

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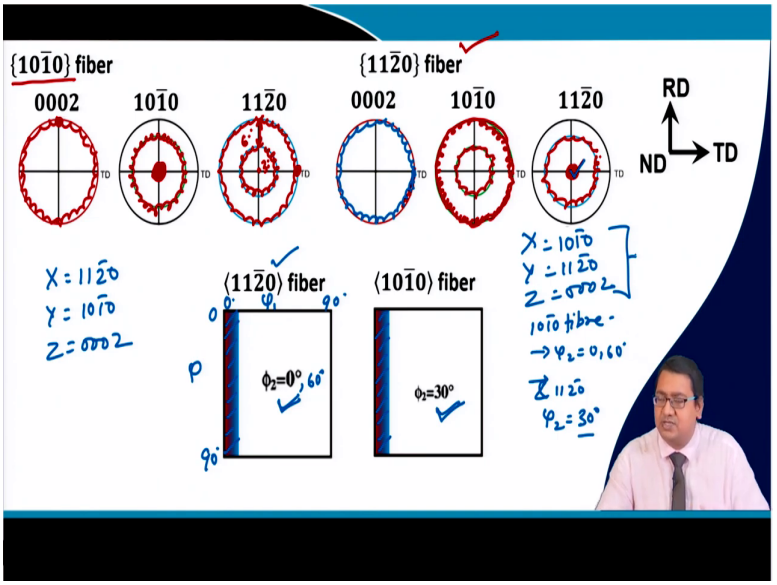

So, the fibers can also be represented in a similar manner. So, if we are looking into the 101 bar 0 fiber; that means, that this fiber and this is a symbol for a family of planes. So, the fiber is present parallel to ND. So, it is present here.

And the position of the another 101 bar 0 should be at an angle 60 degree because of the you know six-fold symmetry and will be somewhere here and this will be because it is a fiber, so it will form throughout axially. The positions of 112 bar 0s will be at 30 degree from the center which is here, right.

And again at 60 degree from this position, right, so will be exactly at the periphery, right. So, the distance between the center and this is basically 30 degrees because the that is the

distance between 101 bar 0 axis and the 112 bar 0 axis. Whereas, the distance between these two fibers this distance is basically 60 degrees because that is the angular distance between two, 112 bar 0 axis, right.

So, if 101 bar 0 is present in the center, then 0002 will always be at 90 degrees to the 101 bar 0 will always form at the periphery like this, right. To understand this, remember that this that we are talking about a poly crystalline material and where 112 bar 0 poles are perpendicular to the 0002 pole. So, for the poles of 002 the grain for which the pole of 002 is here, the 112 bar 0 poles are somewhere here, ok.

So, if we look into the 101, 112 bar 0 fiber now, the similar situation exist, only thing is that now the 112 bar 0 is at the center. From the symmetry another 112 bar 0 at 60 degree will develop here. In between these two fibers 101 bar 0 fiber will develop here, and at 60 degree at the periphery somewhere here, right, right.

And similarly, as the 112 bar 0 axis is perpendicular to the 002 axis therefore, the 0002 fiber will form exactly at 90 degrees from this 112 bar 0. You see I am taking a different colour to show this from this, 112 bar 0 fiber axis. So, it will form somewhere here.

Now, both these fibers 101 bar 0 fiber and 112 bar 0 fibers usually are shown in the phi 2 equal to 0, 30 degree and 60 degree section. Here we are showing the phi 2 equal to 0 and 30 degree section, in case of phi 2 equal to 0 degrees 0 degree section phi 1 is from 0 degree to 90 degree.

Phi is from 0 degree to 90 degree. You can see that I have shown the 112 bar 0 fiber forming at phi 2 equal to 0 degree section; that means, it will again repeat and form at phi to equal to 60 degree section. This is the situation for which X I have taken 112 bar 0, Y as 101 bar 0, Z as 0002.

And that is why at phi 2 equal to 30 degree section 101 bar 0 texture fiber has formed, right. So, the fiber texture, the texture fiber 101 bar 0 or 112 bar 0 is looks something like this, right. In case, I take X equal to 101 bar 0, Y equal to 112 bar 0 and Z remains the same 0002, then the phi 2 equal to 30 degree section will show the 112 bar 0 fiber and phi 2 equal to 0 and 60 degree will show the 101 bar 0 fiber.

Note it down that 101 bar 0 fiber will be shown then at phi 2 equal to 0 and 60 degrees, and 112 bar 0 fiber will be shown at phi 2 equal to 30 degrees. Then, because of the symmetry and the way we have taken the orthonormal you know converted the hexagonal system into orthonormal coordinate system, with X, Y, and Z of the crystal structure equal to 1, means changed it into unity.

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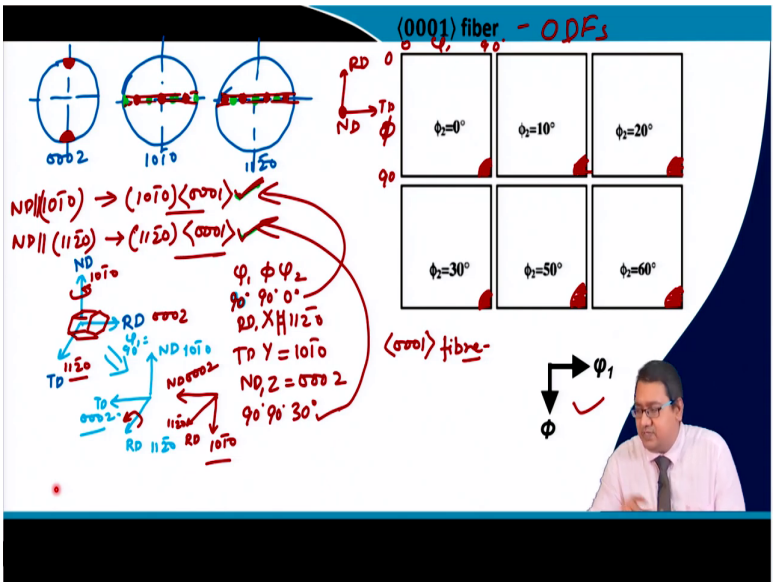

Now, if we look into another fiber which is known as the 1; sorry the 0001 type fiber axis, and this is a fiber, if you see what we are talking about is the directional fiber 0001. And if we look into this fiber, and if we look into the texture formation for this fiber, let us look into the 0002 pole figure, the 101 bar 0 pole figure, and the 112 bar 0 pole figure. And pardon my you know diagram. Please bear with me because may be not very good, but I am trying, ok.

So, you see that if we have this 3 different pole figures and let me change the colour for you know better visualization, we see that if this is you know RD, this is TD. And this is ND, coming out of the screen as usual then the 0001 fiber will definitely form at RD because this is an RD fiber, right. So, it will form here the components will develop here 0002 components. Now, where the components 101 bar 0 will develop, right. Now, if it is, now if it is you see if ND is 101 bar 0, if ND is parallel to 101 bar 0 axis, then the 101 bar 0 will develop at the center. And it will develop at 60 degrees to it. And the 112 bar 0s will develop at somewhere at 30 degrees, right to the one 101 bar 0s.

Now, on the other hand, if ND is parallel to 112 bar 0. So, what I am talking about, in case of this situation, we are talking about 101 bar 0, 0001 type texture component that we have seen in the last slide. And in this case, we are talking about 112 bar 0, 0001 type components, right. Let me change the colour for this one. So, let me take say green colour. So, this is green colour.

So, in this case the 112 bar 0 will form somewhere here and at 60 degrees definitely because of the symmetry. So, the 101 bar 0s will form somewhere here, here, and you see here maybe. So, if we look that if the texture is the 0001 type fiber along RD, then the situation is such that this basically is rotating from you see different planes 101 bar 0, two 112 bar 0 and therefore, it will form something like this, right.

Now, if we look into the texture of this situation in terms of ODFs, and as I said that phi 1 equal to 0 to 90 in this case and phi equal to 0 to 90, and this is same as shown here, right, this is phi. So, if we look closely, let me draw a diagram which gives an idea of the system.

Let us say this is RD, and this is TD, and this is ND, as shown in the last case. And let me do a change in take a change in colour to draw the crystal structure. And if we draw something like this, I hope that it is understandable. Sometimes it becomes little difficult to understand. My drawing is crap. Let me erase and draw it again. This is better understandable. So, the situation, say for example, where RD is parallel to 0002, and ND is parallel to 101 bar 0, and TD parallel to you know 112 bar 0 is shown here. Now, if I rotate along phi 1, phi and phi 2, we start initially by rotating along phi 1. A rotation of phi 1 by 90 degree along ND will bring, you see, sorry you see the RD. If we do a 90 degree rotation by phi 1, what will happen? The ND remains at the same position, whereas the RD goes here, right and the TD goes here.

So, now if you see the ND remains parallel to 101 bar 0, right, the RD becomes parallel to 112 bar 0 whereas, now the TD is basically parallel to 0002. Therefore, we may need this is 90 degree, right. So, we may need another rotation. And this time the rotation has to be along phi, that is the RD rotation. And if we do an RD rotation by the right hand thumb rule what will happen that, ND will move here let me, ok. No issues. ND will move here because TD will move down and RD will remain the same, right.

Now, that means, the RD remains along 112 bar 0, ND has come along 0002, and TD is now along you see 101 bar 0. So, as I said that usually in our case, we are taking X equal to 112

bar 0, X basically is the RD, right and Y is equal to parallel to 101 bar 0. So, this is TD, right. And ND which is Z equal to 0002. So, this configuration is confirmed after a rotation of 90 degree along phi 1, 90 degree along phi, and 0 degree along phi 2.

So, the situation of the texture component which is basically 101 bar 0, 0001 this is this one is fulfilled by phi 1 equal to 90, phi equal to 90, and phi 2 equal to 90. Now, if this is also true for this one then the same component will form at phi 2 equal to 30 degrees at phi 1 equal to 90 and phi equal to 90. So, it will form here. So, this is a situation where for this one, right. This is a situation for this one.

Now, if it is a one, 0001 type fiber then this component will develop at every phi, and therefore, can be shown like this like a fiber from phi 2 equal to 0 to 60 degree section. So, this is a very fundamental idea that I tried to develop in you regarding the development of you see the how we observe the texture in terms of pole figure and ODF in case of hexagonal close pack structure material, right.

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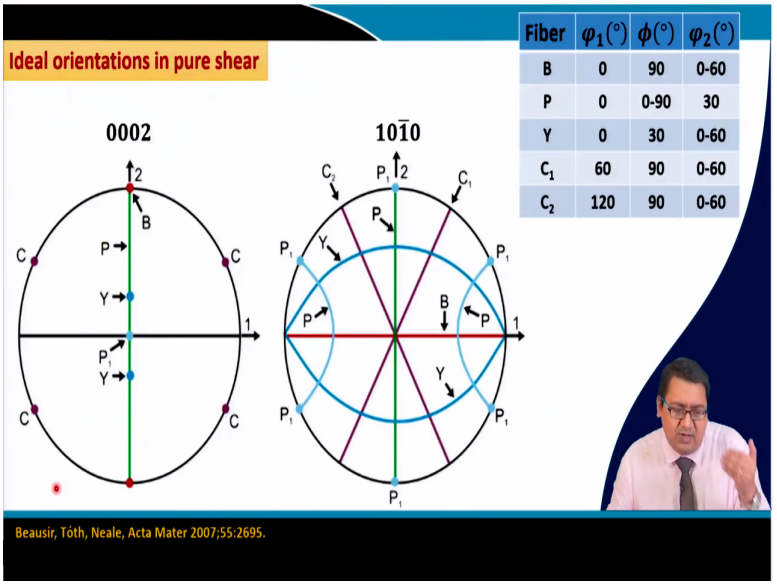

Now, if we look beyond, there are various work related to understanding the hexagonal close pack structure texture development. One of the very nice work is by Beausir et al. And it is to understand the ideal orientation by you know while pure shear is given to the material hexagonal close packed material, and this was the case of magnesium. And this was the case of experimental studies as well as simulation studies where you see the shear is given along this direction.

And when such a shear is provided along this direction, various types of texture components developed. One of the; and all these components forms in terms of fiber. Here is the 0002 and 101 bar 0 section. And we to let you know that here in this section X is basically 101 bar 0, Y is basically 112 bar 0, and Z is basically 0002 in compliance with the research paper this one, right.

So, you can see this red coloured fiber, this is known as the B-fiber. It forms even the phi 1, phi, phi 2 were found out phi 1 equal to 0, phi equal to 90, and phi 2 equal to 0 to 60 degree. The other fibers like P, Y, C 1, C 2 fibers also developed, and all these fibers basically developed because of the presence of various kind of slip activities in magnesium, when shear is given to magnesium at a temperature nearly at 253 degrees, 50 degree centigrade. Because at this temperature most of its slip system will become activated and the magnesium or the magnesium alloy will not deform by deformation twinning, right.

So, the B-fiber basically is related to the basal slip system, right the P-fiber that is the this fiber, right. This fiber is related to you can see that, one can see the P-fiber also in green here, right. So, the P-fiber is here also so, P-fiber which forms due to the formation of because of the prismatic slip system. Whereas, Y-fiber, that is this fiber, right this fiber, the component in terms that fiber in terms of component could be observed in 0002, X pole figure also. So, Y components could be observed here. So, this fiber forms due to the during the deformation due to pyramidal a type slip system.

On the other hand, C 1 and C 2 type of fiber are shown in violet. Here C 1 and C 2 fibers have been shown. These fibers forms because pyramidal c plus a 1 and pyramidal c plus a 2 type of slip system.

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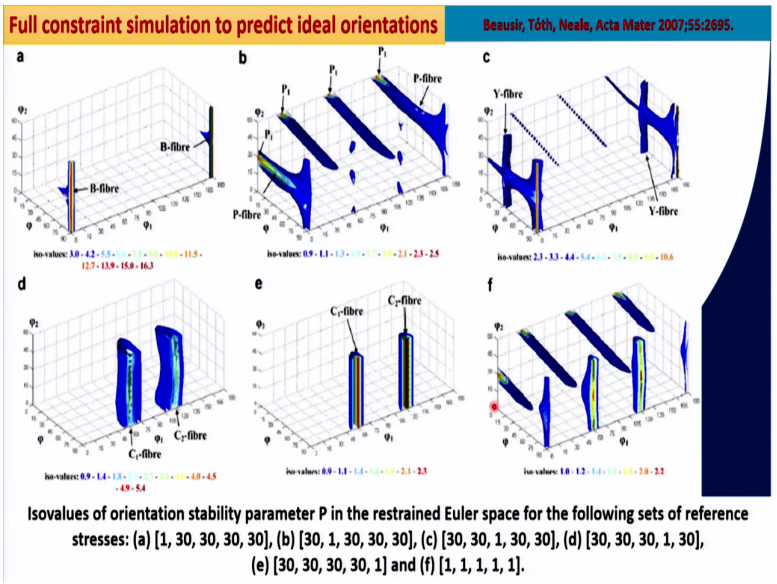

Isovalues of orientation stability parameter P in the restrained Euler space for the following sets of reference stresses: (a) [1, 30, 30, 30, 30], (b) [30, 1, 30, 30, 30], (c) [30, 30, 1, 30, 30], (d) [30, 30, 30, 1, 30], (e) [30, 30, 30, 30, 1] and (f) [1, 1, 1, 1, 1].

Now, in order to prove this, what they did is that they carried out a full constraint simulation to predict that these ideal orientations have come from that particular you know basal slip system or prismatic slip system and pyramidal slip system.

So, using, you know what they did they used isovalues of orientation parameter P in the restrained Euler space for the following set of references. So, what they did? For you know they used the resolved reference shears stresses that is the reference critical resolved shear stress for the first one is for basal, the second one is for prismatic. The third one is for pyramidal a, the fourth one is for pyramidal c plus a 1 type and the fifth one is for c plus a 2 type of slip system.

And they found out that when the basal system is having the lowest CRSS ratio; that means, when we activate mostly basal slip, then the B-fiber forms at this position of the three-dimensional Euler space where this is phi 1, this is phi 2, and this is phi for all the cases shown here. In case, when the prismatic slip is activated, you can see that P-fibers developed in this positions. Whereas, in case when the pyramidal a type slip system is activated different fiber that is the Y-fiber becomes more activated.

On the other hand, when the prismatic c plus a is activated in d, 30, 30, 30, 1, 0; 1 means the CRSS of prismatic c plus a 1 type is kept the least and then this C 1 and C 2 fibers are activated. Whereas, in case of you see when the prismatic sorry the pyramidal c plus a 2 type of slip system is activated, these two slip component you know texture component or texture

phi was developed. So, when all the 5 slip systems are activated then the texture fiber that developed looks like this.

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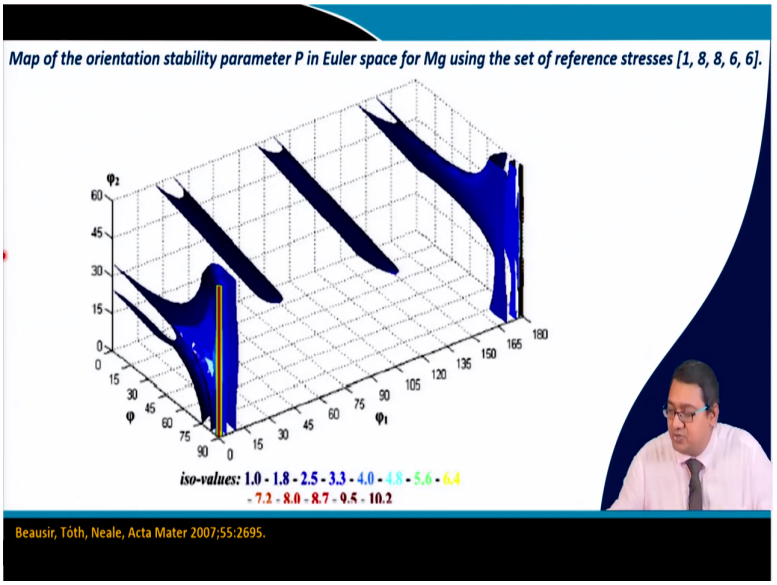

And this is a situation of the texture fiber that is usually obtained in case when magnesium is deformed by pure shear and in the reference shear stress is 1 is to 8 is to 8 is to 6 is to 6 for basal 1. Look at my cursor 8 for the prismatic type, 8 the third one is for pyramidal a type, 6 and 6 are for pyramidal c plus a, 1 and 2 type of slip systems.

So, this is a work by Beausir et al. There are couple of papers. One who knows want to know more into hexagonal close packed 'material structure deformation' behaviour, please go through it. We can conclude that from this lecture.

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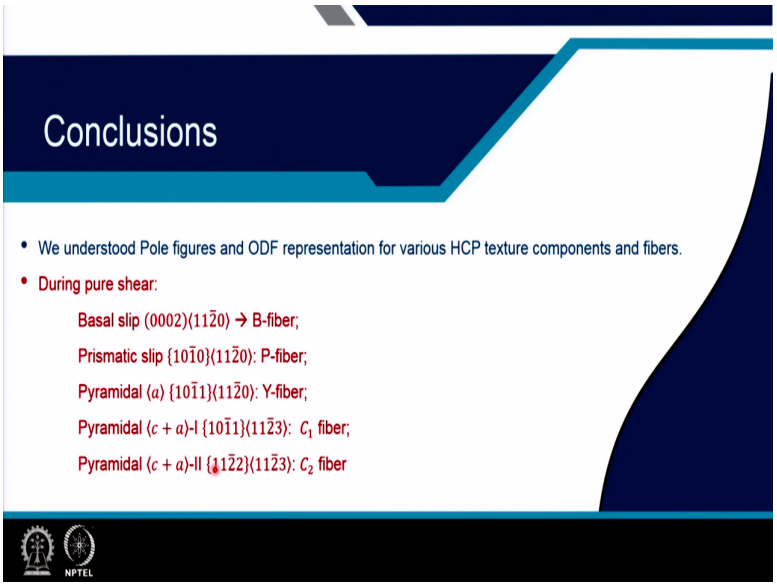

That, we understood the pole figure and the orientation distribution function for various hexagonal close packed, means various texture with of hexagonal close packed structured material. So, and we also understand that during pure shear, the various fibers B-fiber, P-fiber Y-fiber, C 1, C 2 fibers, they developed because particularly because of the basal slip, prismatic slip, pyramidal a, prismatic c plus a 1, and prismatic c plus a 2 type of slip systems.

That is all folks for the FCC, BCC and HCP texture revolution. And we will continue our journey. And in the next class, we will go and understand Annealing Texture Evolution. Thank you so much.

Thank you so much.