Texture in Materials
Prof. Somjeet Biswas
Department of Metallurgical and Materials Engineering
Indian Institute of Technology, Kharagpur

Module - 04
Texture representation
Lecture - 19
Texture Fibre, Periodicity in Euler Space, Incomplete Pole Figures

Good day to everyone, today we will continue with module 4, which is Texture representation. So, in this lecture which is lecture number 19 we will try to gain understanding related to Texture Fiber in Euler space and Periodicity associated with the Euler Space and a little bit about Incomplete Pole Figures.

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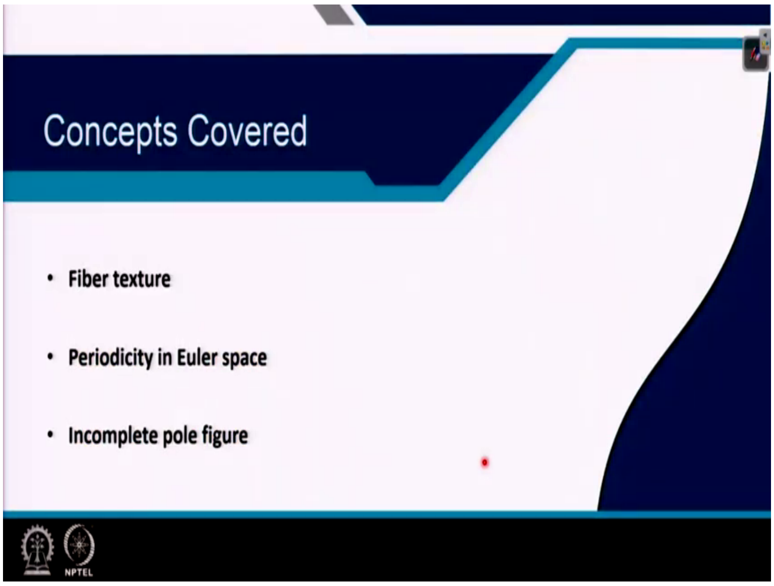

Therefore, the concepts that are covered are fiber texture, periodicity in Euler space and incomplete pole figures; let us start.

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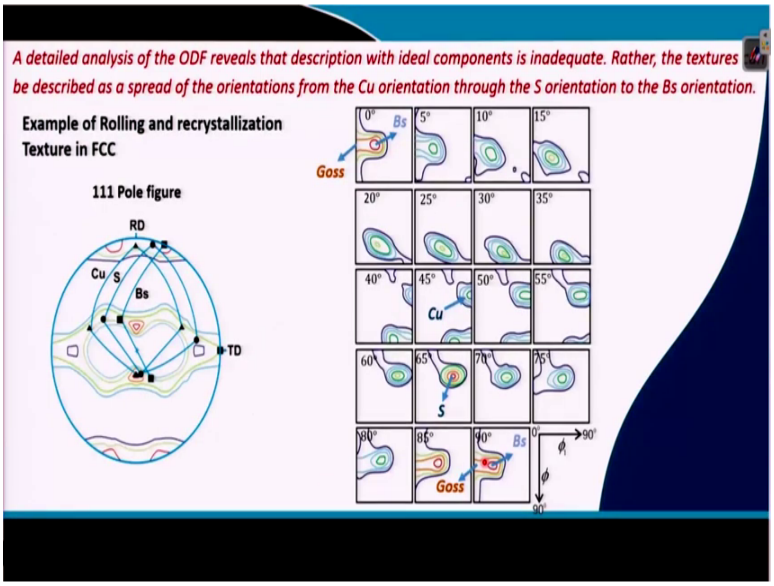

So, regarding fiber texture and regarding fiber texture in both which can be observed in both the pole figures and in the orientation distribution function right ODFs. When we do a detailed analysis of the orientation distribution function that is the ODF, it revealed that the description with ideal components means ideal texture components or ideal orientations are inadequate. Therefore, rather the texture is most actually be demonstrated or described as a spread of one orientation to another orientation. For example, we usually use the example of rolled samples and in this case, I will take the example of face centered cubic material being rolled and being recrystallized.

Therefore, it may be warm rolling has been carried out. So, usually face centered cubic material, we consider say medium to high stacking fault energy material, which could produce general components like copper components, S components and the brass components. So, if we look into such pole figure and we look into the 1 1 1 pole figure and this 1 1 1 pole figure we have seen earlier shows the positions of the copper S and brass components, which are coming a multiple times and this is coming multiple times because of the symmetry of the cubic crystal of course, and we will learn about this in the next lecture.

But here that when there is a copper texture and the S texture and the brass texture they are not coming in terms of individual components but they are coming in form of a fiber and that means, in a kind of tube which are connecting copper S and brass maybe with higher and lower intensities in certain positions right.

So, if we describe this texture in terms of the orientation distribution functions that is phi 2 equal to 0 to 90 degree ODF with a graduation of 5 degrees, you can see the formation of brass component here the Goss component here and then you can see that there is a fiber connecting the Goss and the brass right. On the other hand, if we visualize it what we will find out that from 0 degree to 5 degree; and if we are looking inside this dimension, where inside means perpendicular to phi sorry parallel to phi 2 that is 0 5 degree, 10 degree, 15 degrees up to 90 degrees of phi 2 you can see that this fiber or this component is flowing along phi 2 up to 5 degree and then 10 degree. And then 15 degree and then 20, 25, 30, 35 and its moving right and when it moves down and you can see it goes up to the S component which is forming at around 63 degrees and can be observed from 60 to 65 degrees

So, even at 70 degrees you can observe so, such a spread and the form of tube or fiber can be observed in a orientation distribution function or Euler space much more clearly than that is observed in the pole figure. So, as that ODF's or Euler space gives more complete description of the texture and it is more easier in here to identify when multiple texture components are forming and they are forming fibers right.

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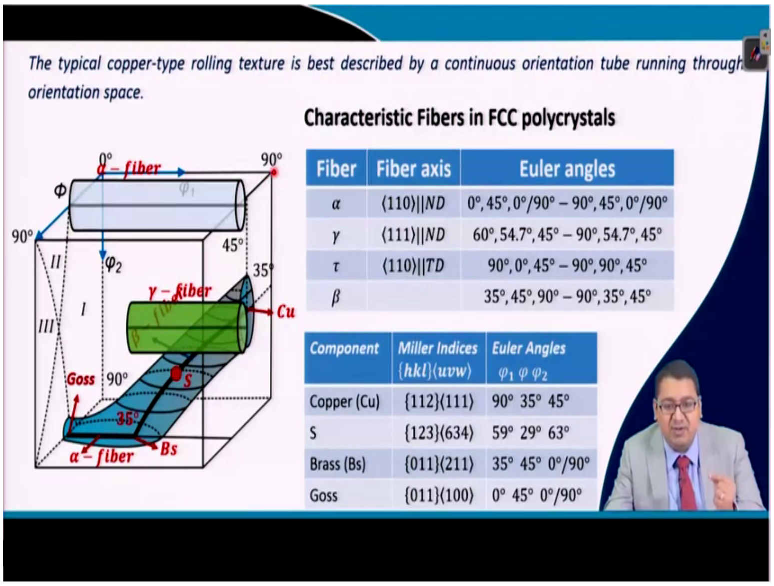

So, let us go ahead and you can see this is a typical fiber texture that can be observed in the Euler space with phi 1, phi, phi 2, which we have plotted all these three axis up to 90 degrees and we will discuss in detail that why we are not plotting phi 1, phi, phi 2 from 0 to 360 degrees each, but we are plotting it up to 90 degrees because just to let that because of the cubic crystal that we are plotting here, the symmetry of the cubic crystal like the 1 0 0 axis has a fourfold symmetry right.

At every rotations of 90 degree you will get the same crystal and you will not you will not recognize that there is a 90 degree rotation right. If you do not know it right and because the because of the crystal position of the motif or the atoms arrangement and its configuration remains the same even after 90 degree, 180 degree, 270 degree rotation and at 360 degree rotation it comes at the original position, but all of these will look like original. Therefore, that this reduces the phi 1, phi, phi 2 section to 90 degrees and there are also other regions of reducing it to 90 degrees and we will look one by one in subsequent lectures. Now that we have plotted phi 1 phi phi 2 from say phi 1 from 0 to 90, phi from 0 to 90 and phi 2 from 0 to 90 here right and that we are showing the typical copper type rolling texture, which is best described in terms of continuous orientation tubes. Which is running through the orientation space and not as kind of component. Typical fibers that are observed in this FCC poly crystals are alpha fiber. Now this alpha fiber is called the 110 parallel to ND. Therefore, it is called either a 110 fiber or an ND fiber right and this ND fiber if we talk in terms of Euler angles, it starts from 0 to 0 degrees for phi 1, 45 degrees at phi and phi 2 equal to 0 or 90 degrees right. So, if you look here if you look here we are showing the partial alpha fiber which are formed in this kind of warm rolled texture form medium to high stacking fault FCC material which is may be aluminium or copper right.

Now, that the alpha fiber is starting from Goss and it is going up to brass and this is the partial alpha fiber that we are showing. So, that if we look closely, the Goss texture forms at phi 1 equal to 0 right phi equal to 45 degrees and then phi 2 equal to 90 degrees right it also forms at if we have given this and it is 0 degree, 45 degree and 90 degrees and it also forms at 0 degree, 45 degree and 0 degree. So, an alpha fiber may form here also. The alpha fiber is the fiber which is parallel to it is parallel to phi 1 phi 1 is a rotation about ND and so, the fiber which is parallel to phi 1 is a fiber which is parallel to ND and is known as the ND fiber right and that in this case the ND axis that is the 110 is constant in this case. So, this fiber is the 110 fiber right.

So, in this case the RD will keep on changing, but the ND from here to here is constant. The same is in this case the same alpha fiber is repeated here and here and you can see that the alpha fiber from here to here has ND equal to 110 or parallel to 110. Now that this is the ND fiber because the rotation is along phi 1 and this fiber is parallel to phi 1. On the other hand, if we talk about another important fiber that is forming and this fiber and this fiber is neither parallel to ND nor RD or TD. ND is the normal direction, RD is the rolling direction and TD is the transverse direction that I have repeatedly explained. When we are considering this fiber it is starting from brass which is it starts at phi 1 equal to 35 degrees, phi equal to 45 degrees right and phi 2 equal to 90 degrees it reaches here if you look here brass which is 111 211 type of component, it starts at 35 degree, 45 degree and 90 degrees.

So, that the brass component is present at phi 2 equal to 0 that is here and at phi 2 equal to 95 degrees that is here relating Goss to brass, Goss to brass to form partial alpha fiber and if this fiber continues up to here that is up to phi 1 equal to 90, phi equal to 45 and phi 2 equal to 90 this is the full alpha fiber right. Now the beta fiber I am coming again that beta fiber starts from brass, which is 35 degrees at phi 1 right 45 degrees at phi and 90 degrees at phi 2. And it goes to S which is 59 degrees at phi 1, 29 degrees at phi 29 degrees and then 60 63 degrees at phi 2. So, and it goes to copper which is again phi 1 is equal to 90 degrees, phi equal to 35 degrees and phi 2 equal to 45 degrees. So, this kind of component which runs from 35 degree, 45 degree, 90 degree to 90 degree, 35 degree, 45 degrees in the Euler space is beta component right in case of FCC crystals.

Now, what we are discussing here? We are discussing the fiber texture, which are parallel to either ND RD or TD right. Therefore, we have given example of fiber texture parallel to ND there could be other fiber texture. For example, gamma texture gamma fiber sorry gamma fiber, which is considered to be 111 parallel to ND texture and that if we look here, this is kind of if the gamma fiber texture is present in the material it will look something like this.

Here the gamma fiber is again partial type fiber texture and it starts from 60 degree, 54.7 degree and 45 degree; that means, it starts from phi 1 equal to 60 degrees, phi equal to 54.7 degrees some something like that and then phi 2 equal to 45 degrees. Then it goes up to phi 1 equal to 90 degrees keeping phi and phi 2 same. So, it’s a fiber which is again parallel to ND because it is parallel to the 111 axis which is parallel to ND and this is also the ND fiber and this is known as the gamma fiber for FCC material.

Now, let us take another example, which is an important example the tau fiber and the tau fiber is a fiber which is the 110 fiber and is parallel to TD.

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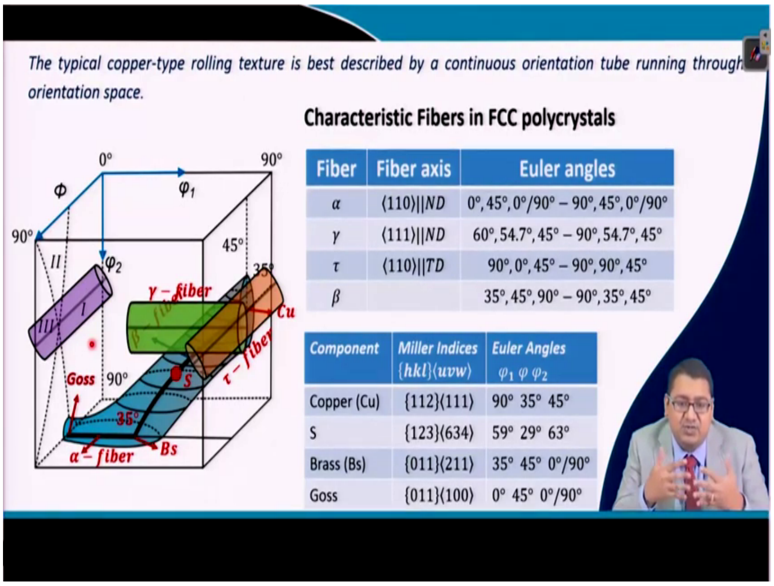

In addition, this means that when this fiber runs; that means, this fiber when this fiber runs, it runs along phi it runs along phi and it is parallel to TD that means, the 1 1 0 axis always remains constant and remains parallel to TD. So, it starts from. It starts from phi 1 equal to 90 degree, phi equal to 0 right and phi 2 equal to 45 and it goes from phi 1 equal to 90 degrees means, it goes to phi 1 equal to 90 degree, phi equal to 90 degree and phi 2 equal to 45 in this. Therefore, it starts from here and goes here and is parallel to phi.

In addition, it is a TD fiber and why it is a TD fiber? If you remember the Euler space what we have shown is that the first rotation is along ND that is phi 1 is rotating along a phi 1 rotation is given along ND right and then the second rotation is given along RD right.

So, if we rotate phi 1 along ND by 90 degrees, then the second rotation which is given along the RD is now RD dash which is rotated by 90 degrees which is TD right. So, the second rotation is actually given along TD which makes the fiber formed parallel to phi the fiber which is forming parallel to phi, but at phi 1 equal to 90 degree parallel to TD. So, this is a TD fiber right. On the other hand, if a fiber which is forming parallel to phi but it is forming somewhere where the phi 1 is 0, whatever phi and phi 2 could be, but the phi 1 is 0 and it is you have you can see that the phi is changing and the phi 2 remains constant right anywhere it could be here or here or here. Now because the phi 1 is 0 the rotation of phi is along RD this kind of fibers which forms at phi 1 equal to 0 are called the RD fiber. So, this kind of fibers are parallel to RD and are known as RD fiber right.

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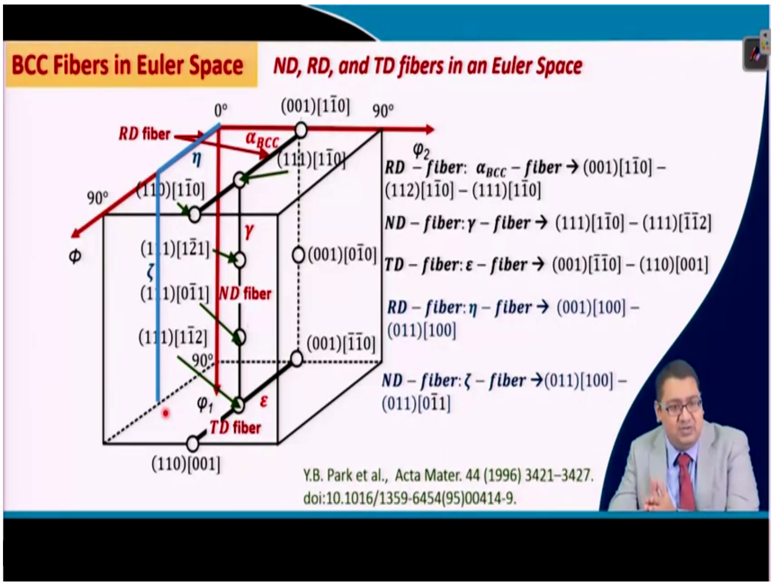

So, let us take this and give example for the body centered cubic fiber textures right in case of Euler space and let us go ahead with the ND RD and the TD fiber right for BCC. Now in this case what we have done we have again drawn the Euler space, but for our easy.

Therefore, to make things easier for us what we have done is that, we have drawn the phi 1 vertically down, phi 2 horizontally like this and phi coming out of the paper right. Now that if this is the Euler space related to the BCC texture and we are going to show you some fiber and show you the nomenclature of the fibers in case of BCC.

So, let us see that what we have studied is that, if the phi 1 rotation is 0, then the fibers which are along phi axis are called the RD fiber and that. So, from 0 to 90 degree this fiber or from here to here this fiber is called the RD fiber because it has phi 1 equal to 0. Now that this fiber is an important fiber in case of BCC and is called the alpha fiber alpha BCC fiber.

We can put the subscript BCC in or in order to distinguish it from the FCC fiber textures. Therefore, it runs from 001, 11 bar 0, which is this component 001, 11 bar 02 111, 11 bar 0 right and in between it has 112, 11 bar 0 and you can add these two ND axiss or the rolling planes a crystallographic plane that is 001 and 111. Therefore, that you can get 112 and you can see that in between somewhere maybe in the middle it has the 112, 11 bar 0 texture components. Here is this alpha fiber and if you continue this fiber up to the end it forms 110, 11 bar 0 and thus this is the alpha with BCC fiber. On the other hand, we can look into the ND fibers and of course, we know now that the fibers, which are parallel to phi 1 are known as the ND fiber and in this case the fiber is known as the gamma fiber and it runs from 111, 11 bar 0 right.

This component 211, 112 bar 1, 211, 101 bar 111, 111 bar 2. So, that the ND is parallel to 111 and thus it's an ND fiber right. When we go ahead and we see that there are other fibers like the epsilon fiber and this fiber is forming at phi 1 equal to 90 degrees right and what happens when there is a rotation of 90 degrees along phi 1 which occurs about the ND axis. The second rotation phi takes place along TD right because after 90 degree the RD forms RD dash which is parallel to the actual TD and therefore, it forms the TD fiber which is the epsilon fiber which runs from 001, 1 bar 1 bar 0 to 111, 11 bar 2 right and then it goes to 110, 001 right. This is the epsilon fiber. Now there could be another fibers right.

In case of BCC there is a an eta fiber and there is a tau or eta fiber whatever you say here and that all both this fiber the eta fiber is a fiber which is parallel to RD it's a partial fiber and therefore, it's an RD fiber it transform 0 01, 100 to 011, 100. Whereas, the fiber which is parallel to phi 1 is the ND fiber again and this fiber runs from 011, 100 to 011 1 sorry 0 1 bar 1.

Now how to calculate back calculate the miller indices that forms in the Euler space and you can calculate that and relate it to this texture fibers and you can find out that whether we have explained it appropriately or not. And you can see that in case of even for the tau fiber where we are saying it's an ND fiber, the ND is parallel to 110.

Therefore, whenever these fibers are there we must understand that when it is an RD, when it is an ND and when it is a TD fiber right.

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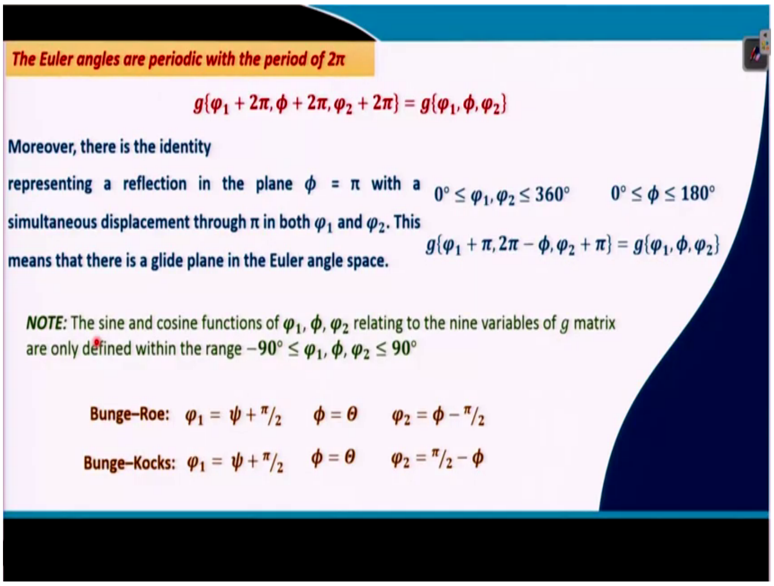

That is all about fibers and now the Euler angles that we have understood and we have done in a lot of detail and we have gone into fundamentals and most basics. We have solved that how it can be calculated and how Euler angles can be related to orientation matrices, Miller indices and we know how to do it. If you have done the previous lectures properly and try to solve them yourself in a using the p in using a piece of paper and pen and you would easily be able to understand that how all pole figures ODF miller indices inverse pole figures and orientation matrices are related right.

Now that if we do not consider the crystal symmetry or any kind of deformation or sample symmetry, then the Euler angles are periodic in nature right and the periodicity of the Euler angle will be of the order of phi 2 right. So, if you rotate the Euler angle the angle moves from 0 to 360 degrees in phi 1 phi and phi 2 and that is completes the Euler angle and it is very obvious to understand that right. We can say from this that then g phi 1, phi, phi 2 is equal to g phi 1 plus 2 pi phi plus 2 pi and phi 2 plus 2 pi its very obvious, but that even in the Euler angles and because of the calculations of the Euler angles there is a identity in it and there is a identity present in the Euler angles and the identity is represented as a reflection; means it is representing as a reflection in the plane phi equal to pi with simultaneous displacement of pi means through pi in both phi 1 and phi 2. This means that there is a glide plane in the Euler angle space. So, the g phi, which is equivalent to g phi plus 2 pi reduces and there, what happens that now the phi is periodic not from 0 to 2 pi it becomes periodic from 0 to pi right pi means 180 degrees right whereas, phi 1 and phi 2 remains periodic in the range 0 to 360 or 0 to 2 pi right. So, what happens that with this because of the presence of this glide plane because of this identity, the periodicity of the Euler space or the Euler angles reduces and g phi 1, phi, phi 2 is becomes equal to g phi 1 plus pi 2 pi minus phi phi 2 plus pi. So, that the periodicity of the Euler space is reduced without considering crystal symmetry and sample symmetry to 0 to 360 for phi 1 and phi 2 to 0 to 180 degree for phi ok. Now we should note that we have found out the relationship between the orientation matrix and phi 1 1 phi 1 phi phi 2 with the help of the equations in the previous lectures. We have found out that how we can use various the 9 g variables few of them to find out phi 1, phi, phi 2.

But that while we are using relating phi 1, phi, phi 2 with this 9 variables of the g matrix we can only identify phi 1, phi, phi 2 in the range of minus 90 to 90 degrees. So, this is the limitation of that calculation. So, you must always keep in mind of that ok. So, that the way we measured and we showed the rotations of the Euler angle or Euler space is with the help of Bunges notation right.

So, the Bunges notation is used because it is automatically being spread out throughout the world and. So, Bunges notation is being used because it is automatically being used and used throughout the world it has spread from Europe to US and other countries which use Bunges, but there are other methodologies of rotations which are equivalently true like Bunge is the rho s rotation and the rotation which was given by Goss. Now, these two rotations there could be earlier papers where the texture has been shown using these two rotations, but most majority of the papers uses Bunges notation. So, that if we have to extract information of the Euler angles and the Euler space, which uses the notations of Roes and Kocks we should know the relationship between the Bunges notation and the notation of the Roes and the Kocks.

Because they are giving the similar kind of angular rotations phi 1, phi, phi 2, but in a different manner, but that is also is true, but that will lead to change in the positions of the components and the fibers formation right. So, the relationship between the Bunges notation and the Roes notation is like this phi 1 of Bunges notation is equal to phi plus pi by 2 where phi is the phi 1 for the Roes notation.

Phi is equal to capital phi for the second rotation and phi 2 is equal to phi minus pi by 2. So, three rotations same, but slightly varied right. In case of Bunge and Kocks notation, the relationship between the Bunge and Kocks is that the phi 1 of Bunge is equal to phi, which is the first notation plus pi by 2 that is 90 degrees the second rotation that is the phi of Bunge is equal to capital phi for the Kocks and the third rotation phi 2 of Bunge is equal to pi by 2 minus phi for the Kocks.

So, there is a subtle difference between all these rotations, but we all follow the Bunges notation which is naturally accepted in the texture community.

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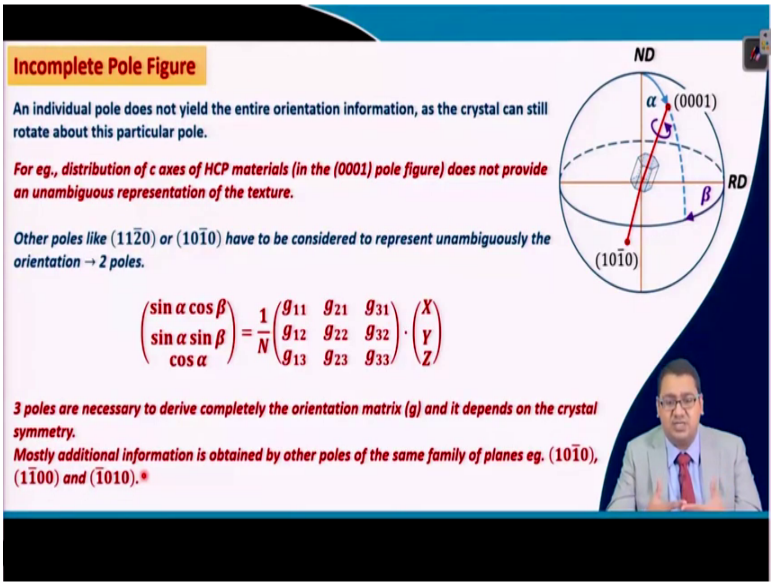

So, that is it all about the Euler space related to fiber and its periodicity. Now I wanted to show this earlier, but I forgot it. So, I have added it in this lecture and that is related to pole figures and that a pole figure is a single pole figure is generally called an incomplete pole figure.

It is it called an it is called an incomplete pole figure because usually an individual pole does not yield the entire orientation information as the crystal can still be rotated in that particular pole.

Say for example, let us take an example of this hexagonal crystal and this figure you have already seen and that in that if we are showing the 0001 pole figure. In addition, we are observing the 001 pole and we can see that it has only one pole or if it has two poles, then it is the reflection of that of the first pole and it is the negative of that pole.

So, its the same pole and it gives information of that pole the presence of that pole with respect to RD ND and TD, but it does not provide an unambiguous representation of the texture because that 1 that 001 pole could be rotated right it could be rotated. Then the positions of the other poles like the 101 bar 0 or the 112 bar 0 becomes un means unambiguous in nature right. Therefore, you we need to show the other poles the other poles like 112 bar 0 or 101 bar 0.

Therefore, we need to show the other pole figure either 112 bar 0 or 101 bar 0. Now to show the full representation of texture. Now these 112 bar 0 poles represents two means three poles which are at 120 degree apart. You can see that we can now observe these three poles and so, using the 1 pole figure of 0001 and another pole figure of either 112 bar 0 or 101 bar 0 we can get the full information.

Now based upon this equation also we can observe that there are three equations that forms in order to solve the information of texture based upon this relationship. So, thus three poles are necessary to derive completely the orientation matrix and it depends on the therefore, it depends on the crystal symmetry. So, most of the time what we are doing here is we are obtaining information additional information by plotting other pole figure means; that means, the other poles and because of their symmetry. For example, 112 bar 0 and 101 bar 0 both are repeated at 120 degrees. So, because of the crystal symmetries. Here we have given 101 01 bar 0 axis, 11 bar 011 bar 00 axis 1 bar 0 1 0 axis which forms at 120 degrees of each other and thus could give additional information of the texture. So, in this case at least two pole figures would be needed.

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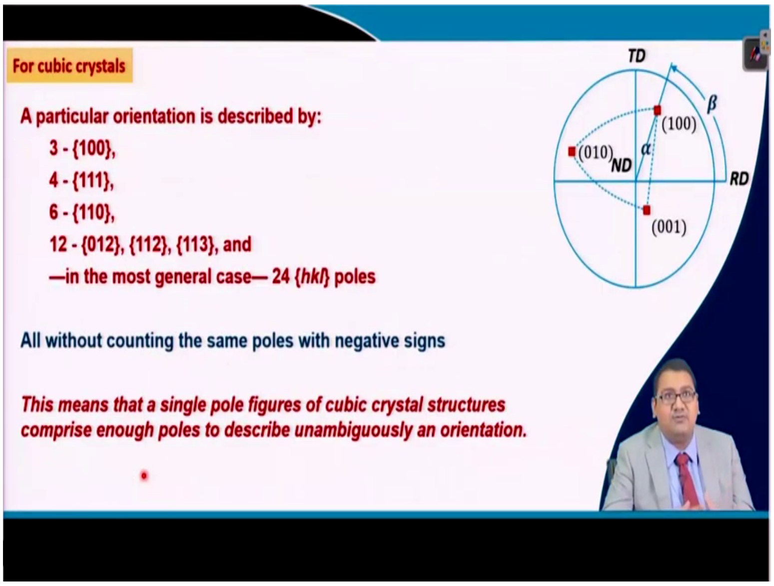

Now, what will happen for the cubic crystals? Now that cubic crystals a particular orientation is can be either described using 100 or 110 or 111 axis right we can even describe it using 1 120, 130, 112, 113 etcetera. Now that 110 has a four-fold symmetry and it has three poles 111 has a threefold symmetry and it has four poles 110 has a twofold symmetry it has six poles, 012, 112, 113 both have 3 12 poles and in general any HKL plane have 24 poles other than this.

So, if we if we means, without if we need three poles to represent a texture a particular orientation then in case of cubic crystal we can plot out a single crystal single sorry single orientation by only by demonstrating a single pole figure right. So, you can see that because 001, 110, 010 are three different poles can be obtained in a single pole figure, we can use the single pole figure of a cubic crystal structure which comprises enough poles to describe unambiguously an orientation.

So, what we are talking about this? In both in case of hexagonal and in case of cubic crystals, we are counting the poles without taking the negative ones right as we I have described in the hexagonal. So, we are taking 100, but we are not considering 1 bar 00 which is exactly opposite to 100 right.

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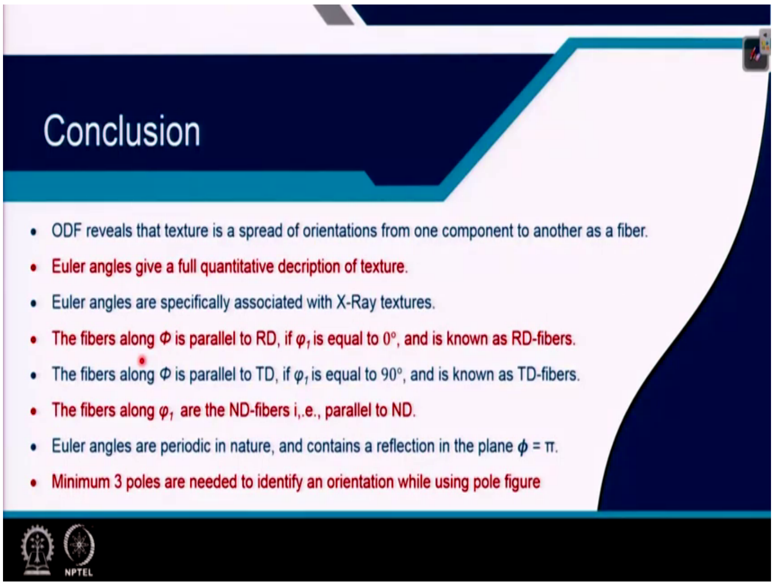

Therefore, concluding, orientation distribution functions reveals that texture is a spread of orientation from one component to another component and therefore, is actually represented in form of a fiber. Euler angles are full quantitative description of texture; yes.

What I have not mentioned, but I have put it in the conclusion is that Euler angles are specifically associated with the X Ray textures because that Euler angle has to give the full complete information of the texture of that particular material therefore, are related to the bulk texture.

So, bulk texture are obtained from X Ray texture measurement using goniometer that I am going to teach you in the coming lectures and therefore, the Euler angles are specifically associated with X Ray textures. The fibers that forms along phi is parallel to RD if phi 1 is equal to 0 and therefore, is known as RD fibers.

The fibers along phi are considered parallel to TD if phi 1 is equal to 90 degrees and it is known as TD fibers. The fibers along phi 1 are always the ND fibers because they are always parallel to ND. Euler angles are periodic in nature; and contains a reflection of a plane in a plane, which is at phi equal to pi and finally, minimum 3 poles are needed to identify an orientation while using pole figure.

Thank you.