Texture in Materials
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Module - 04
Texture representation
Lecture - 09
Pole Figures

Good day everyone. Today, we will start with lecture number 9 which is related to the representation of texture that is our module 4, Texture Representation. So, lecture number 9 is basically on the representation of texture using the Pole Figures.

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So, the concept that will be covered in this course in this class is understanding texture representation using the pole figure.

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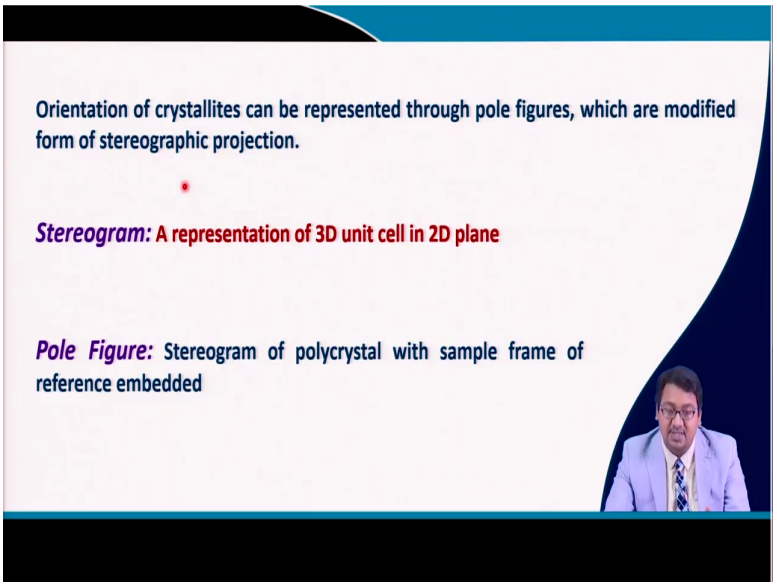

orientation of crystallites can be represented through pole figures and we have told you this and the pole figure is a modified form of stereographic projection right. And, what is a stereographic projection? A stereographic projection or a stereogram is a representation of a 3D unit cell into a 3D sphere to a 2D plane in a form of a stereographic projection, right. So, a pole figure is a stereogram of a 2D stereographic projection of the polycrystalline materials with the sample frame of reference embedded. So, that when we talk about stereographic projection that is the diffraction from a single crystal in a 2D plane. We talk about some standard stereographic projections like 100, 110, 111.

So, we should understand that what do you mean by that? We mean that the stereographic projection has in the center of it 100, 110 or 111 and that is why we call it 100 standard stereographic projection or 110 standard stereographic projection or 111 standard stereographic projection. Now, we can also have a stereographic projection of different hkl planes of higher-order like 1, 12, 123, right, but those stereographic projections will be so difficult because in the stereographic projection we show different poles of various hkl planes. But, the difference of a pole figure from the stereographic projection is that when we say that we are drawing a 100 pole figure; that means, that we are drawing only the 100 poles that are the intensities forming from a polycrystal material at various points inside a stereographic projection with respect to some reference direction which is the important sample reference direction that is we are representing a particular pole say an hkl pole with respect to sample frame of reference and therefore, it is called the hkl pole figure. That

means, then we are representing 100 poles we call it 100 pole figures; when we represent the 110 poles we call it 110 pole figures, and when we represent the 111 poles with respect to the sample frame of reference all of them we call it the 111 pole figures, right.

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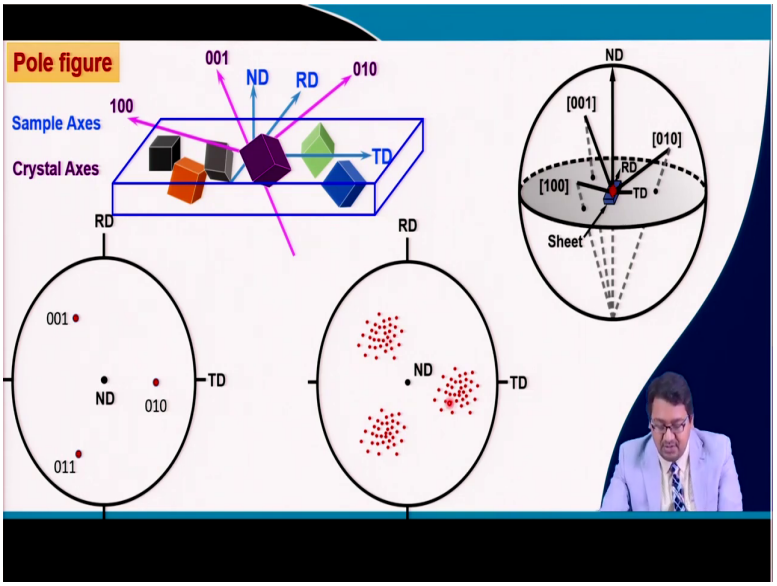

So, that when we discuss the pole figure let us talk about a sample simple sample that has three important sample reference directions, and in this case if you say that we have taken the easiest form of the sample which is available in metallurgy or sheet metal or rolled sheet metal. So, a rolled sheet metal will contain an important sample reference direction that is a rolling direction which is RD.

Which is going out in that direction right look at my pointer and that it has an important plane that is the rolling plane which has to be this one. So, the normal to the rolling plane that is the normal direction, ND is represented like this, and then that 90 degrees to both RD and ND that is TD are represented here. Now, that the crystals which can be present in the sample see this is a polycrystalline material. So, there will be many many grains inside it and a few grains will have some orientation, a few other grains will have some other orientation, right and these grains of a certain orientation may not form together. They may be especially apart, right. Say for example, if we talk about various orientations present inside this polycrystalline material say some of these orientations some of these, some these, some these, some that kind of orientation are present. Maybe say, for example, this orientation the unit cell which is shown in the violet color may have a larger fraction let us say that we have a higher intensity

of this particular orientation present in the material. And, let us say that if such an orientation is there then it is important crystal reference directions are say, for example, 100, 010, 001 and this is very obvious. We took a cubic material say for example, and the important crystal reference directions are the x-axis, y-axis, and z-axis of that unit cell that is 100, 010, 001. And, say for example, if taking this example if we look clearly we have RD towards the top and then if this is the representation of a pole figure and we are putting RD on the top and if TD is horizontally towards the side. So, if we are putting TD on the side and then ND is directly above.

So, if we are putting ND here, then the 100, 010, and 001 are pointing out at three different directions may look up from the above ND like they are pointing out from here, here, and here, right. This is not 011, this is 100, right? So, check for this printing mistake. Now, that is how this three points or three poles of 100 form in the pole figure. that we have this rolled sample inside the 3D stereogram and in this stereogram, we can see that we have put this sample in such a way that it is at the center of this 3D stereogram. And, if there is a small unit cell the same unit cell I have embedded here in red color and you can see that 100 is pointing out this direction. So, it is coming out from this direction and it is poking out from the circumference of the sphere somewhere here, right. The 001 which is coming out in that direction comes out and poking out of the 3D stereographic sphere somewhere here and the 010 is poking out somewhere here.

So, that when these three points are poking out and if this is the point of projection and if we are making this as a plane of projection, then these poles on the sphere on the circumference of the sphere using the ray of light it points out and forms spots or poles in these positions, this one, this one and this one. And, if we take this and draw this particular plane of projection here and we obtain the 001, 100, and 010 projection in a form of spots.

But, that when we are talking about a polycrystalline metal and there are so many grains. So, each so, many many grains may not form the same orientation and produce a single spot like that. There will be some obvious deviation and this obvious deviation comes from many factors that we will discuss later. But, to tell you a little bit that when a plane strain deformation is given and that rolling is a plane strain deformation. So, a plane strain compression is given then what happens is the applied Cauchy stress tensor to the polycrystalline material. But, when the grain deforms it is not only subject to that applied load but is also subjected to the load applied by the neighboring grains in order to keep the

grain boundary continuous. So, the Cauchy stress tensor in various grains differ a little bit and thereby there is a change in the deformation behavior, the strain in the material leading to a little difference in the texture, and therefore, each and every grain does not form a single intensity spot at a single position but has a little deviation. And, therefore, the 100 poles have deviated like this the 010 poles deviate and the 001 poles form in a deviated manner. So, basically, we are getting a spread, and though there is an intensity at the center of these areas.

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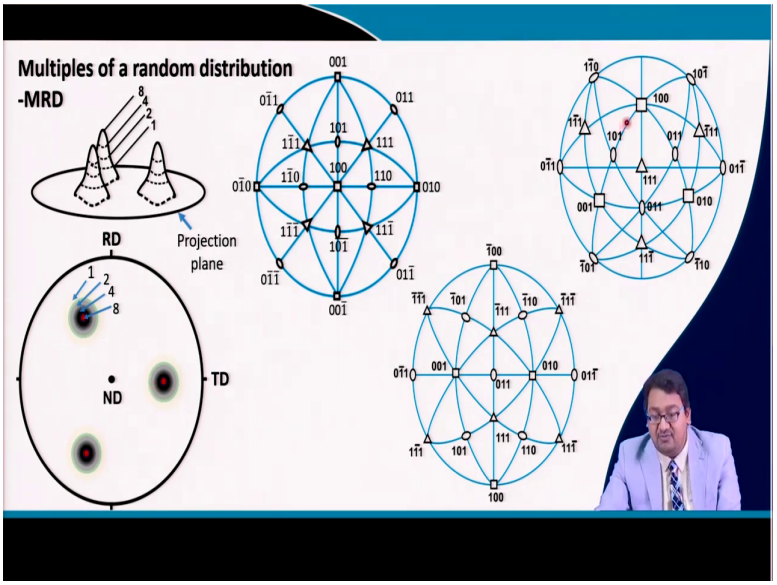

So, what we do is that we use some kind of mathematical function to find out the highest intensity and the lowest intensity position. Say, for example, some kind of a spherical harmonic function can be used to obtain a peak something like that, and then from that spread, we can obtain three peaks and this peak you can see that it has an intensity of 1 somewhere and 2 and 3 and 4 and 2 8 at the point of the peak.

And, thus that in our real-life scenario when we obtain such kinds of poles in this case is the 100 poles we obtain an intensity distribution something like that which is higher at the center and it reduces when it goes towards the side. So, that this pole figure and which shows the only the 100 poles of the polycrystalline material is known as the 100 pole figure. So, that ok if this is the 100 pole figure and how it is different from the 100 standard stereographic projection and that I have shown you a standard stereographic projection of 100 and we have discussed this in quite detail. And, you can see that this 100 pole figure shows a 3-point

symmetry three-fold symmetry and this 100 stereographic projection has a four-fold symmetry, right so, this symmetric to this and this symmetric to this.

So, all these four different quadrants are symmetric and even the smaller quadrant are symmetric. So, that it has a four-fold symmetry whereas, this has a three-fold symmetry. Another difference is that when we see the 100 stereographic projection the 100 is at the center whereas, there is no RD, ND, or TD. When we say 100 pole figure the 100 poles can form anywhere and it is related to the reference system using RD, ND, and TD of the sample, right. So, if we look into a different pole figure like the 10 110 standard stereographic projection and this is the 1 this sorry, this is the 111 standard stereographic projection. Let us look into the 10 110 standard stereographic projection this one and if we look into this 110 standard stereographic projection we will see that it has a two-fold symmetry and you can see that these two are symmetric where or these and these are symmetric.

So, it has a mirror symmetry or a two-fold symmetry, and therefore, that this stereographic projection 110 stereographic projection also does not match with the symmetry elements of the 100 of this 100 pole figure, right. Now, if we look at another standard stereographic projection that is the 111 standard stereographic projection, we find that if the 111 standard stereographic projections 111 pole is at the center then the various poles like the 100 poles or the 110 poles are following a three-fold symmetry. So, 111 is having a three-fold symmetry. So, this standard stereographic projection reflects the three-fold symmetry.

Now, if such a situation is there then maybe we do not know maybe this stereographic projection may superimpose into this 100 pole figure, and maybe these 100 pole figures may match.

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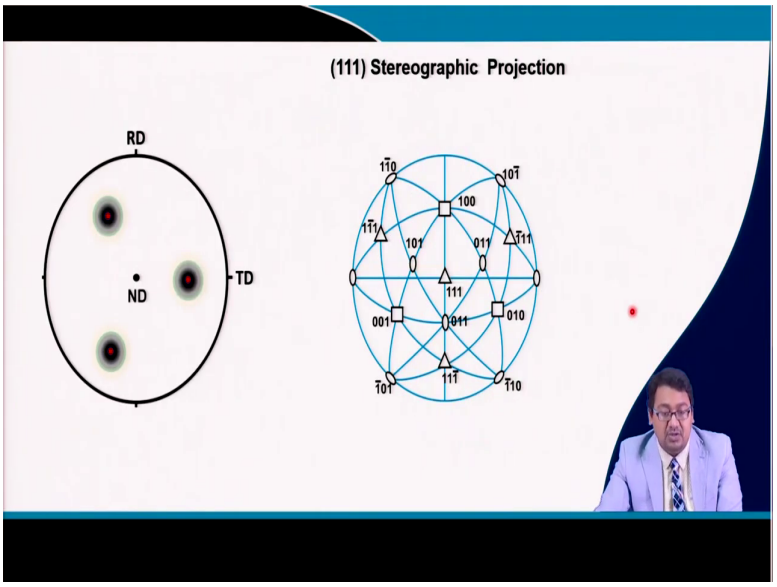

So, what we try to do is that we took the 111 stereographic projection on this 100 pole figure and try to match.

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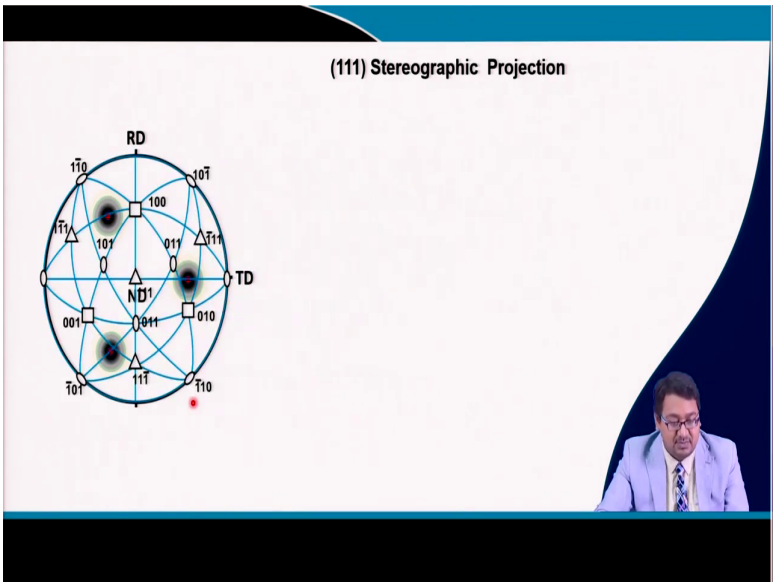

And, we find out that no not none of the points seems to match with the pole figure pole positions of the 100. But, then it seems that maybe if we try to rotate this 111 stereographic projection what will happen and then what we did is that we try to rotate it.

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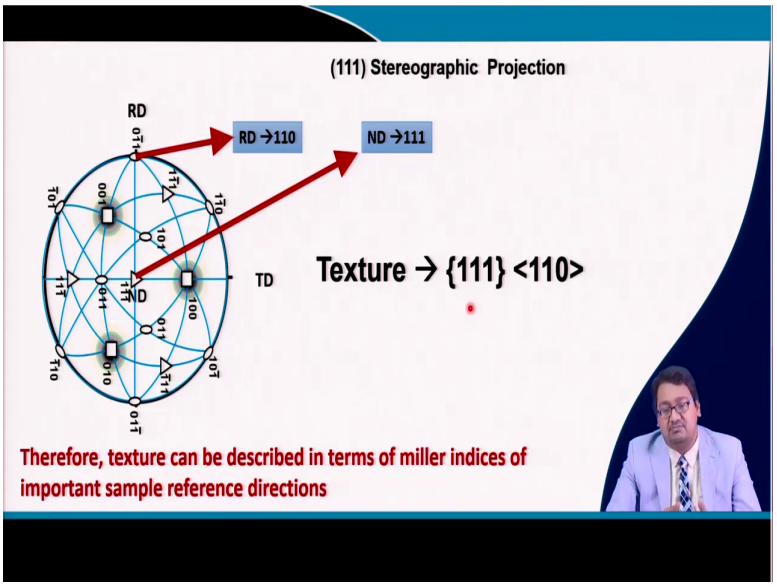

And, we found that if we rotate it by 90 degrees by clockwise right, anticlockwise using the right-hand thumb rule 90 degrees and we find out that the 100s, the 001s, and the 010s. Actually match with the intensities of the poles of this pole figure and thereby we found out that; that means, that when we have this kind of pole figure like 3 a pole figure showing 100 poles with three-fold symmetry and so, symmetric with respect to the center then the center point is 111. So, this indicates that the ND is 111 and the RD is 110. So, this pole figure the 100 pole figure represents a texture that has a rolling plane 111 and the rolling direction 110. So, what I would like to state here is that a texture is represented in terms of pole figures.

And, of course, with respect to other tools like the inverse pole figure or it is represented with respect to 51552 Euler angles or Euler space or orientation distribution function and we will talk about this later or in terms of orientation matrices. But, that simplest form of representation of a texture can be done in terms of Miller indices right of the important sample reference directions or planes, right. So, this is the point that these 3 poles representing 100 pole figures represent the 111, 110 texture.

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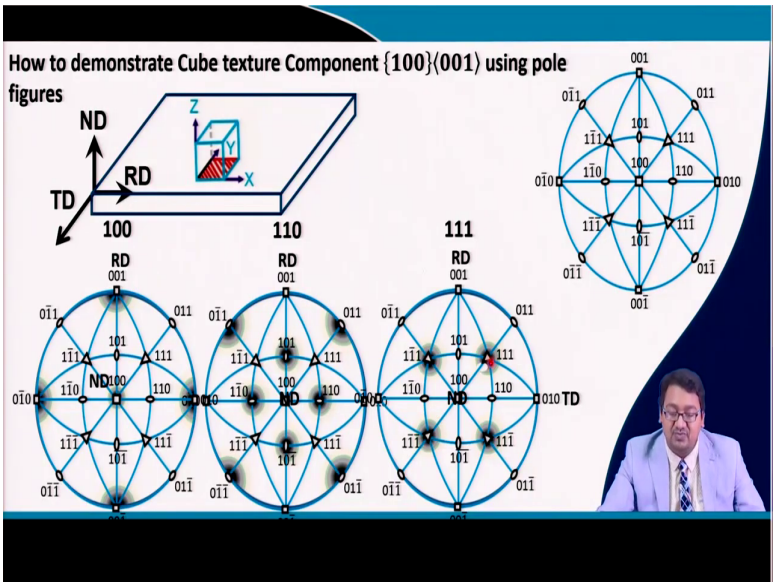

So, there are as I said in the previous class that there are various kinds of texture that may form, and a few of the texture components I am using to demonstrate that how we use it to show it in the pole figure, right. So, let us take the simplest of all the components and that is the cube texture component that is 100, 001, and let us use the pole figure to represent it. Now, that the, if the unit cell is kept, is with a is if the unit cells X, Y, and Z coincides with the RD, TD, and ND of the sample; that means if the unit cells 100 excesses are parallel to the important sample reference direction and in this case as I said that we will take the rolled sample RD, ND, and TD. Then, the 100 poles come in these positions, right.

Now, the 110 poles come at these positions and the 111 poles come at this position. So, that to represent this particular orientation for a particularly flip processed sample the pole figures the 100, 110, 111 pole figures can use to show RD ND and TD. So, TD is kept here RD, ND, and TD. So, all the pole figures sample reference directions are kept the same and then the positions of the 100 poles the 110 poles and the 111 poles can be determined. Now, let us see how easy it is to determine them. Let us say that this is the 100 pole figure and 100 is also at the center we can see that no 110 is at the center or 111 at the center. So, it seems to be that it is related to the 100 stereographic projection, right. So, that here I have shown you the 100 stereographic projections with the center as 100.

Now, to obtain the various 100, 110, 111 pole figures what do we need to do? we need to superimpose this stereographic projection here and then this is for the first one that is to

obtain the 100 poles. So, if the ND is parallel to 100 then the N 0 100 comes at the center, and also as I said that RD is parallel to another 100 say in this case it is 001, then it should come here. So, using the symmetry of the cubic crystal this stereographic projection has formed. So, the other 110 positions this one, this one, this one could be identified. Thus that using this pole figure the only 100 pole figure we can determine the cube component that is 100, 001 in the case of the 110 pole figure. Let us superimpose the stereographic projection and that if the 001s are here and here or here and here then at a 45 degree from these 001s 110 poles forms.

So, here are one 110 poles, another one, another one, another one and you can see that four 110 poles 45 degrees to this 100 and this 001 forms and that we can determine the 110 poles for this particular texture component. Likewise, we can also determine the 111 poles, right. So, you can see that the four 111 poles of the pole figure match exactly with the stereographic projections 111 poles for the single crystal, right. And, this is the way by which the cube texture component 100, 001 can be represented using the 100, 110, 111 pole figures.

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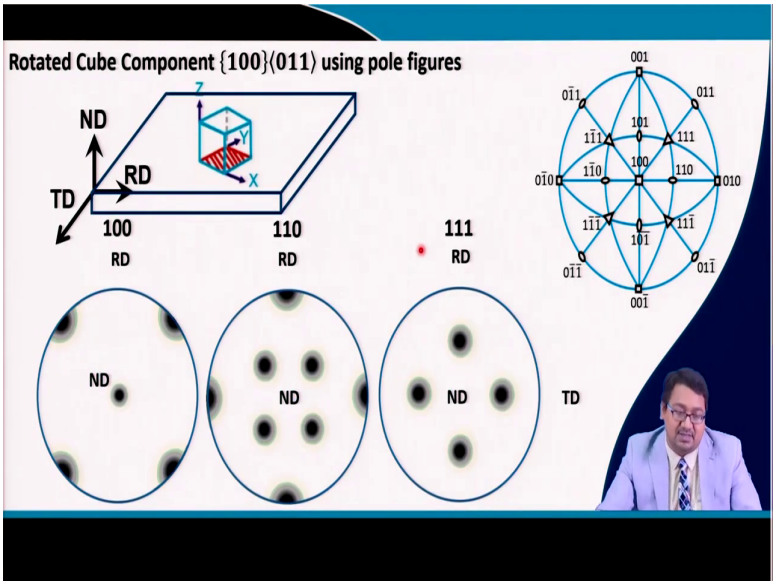

Let us take another example another easy example, a rotated cube component. A rotated cube component has a texture 100, 011 in terms of the miller indices. So, let us see that how we can obtain the pole figure of this. The rotated cube component unit cell looks exactly like this when we represent it over a sample. And, say that RD is in between the X and the Y if we say that that the X is 100 and the Y is 010, then RD is parallel to 110, right whereas, the Z is

parallel to 001. So, they belong to the Z belongs to the family of 100 and the rolling direction belongs to the family of 110 or 001. So, if we superimpose the standard 100 stereographic projection on it because that the Z is along the 100. So, the center of the 100 poles will be 100, right. Now, if RD is along 110 then at 45 degrees to the RD the 100 poles will form. So, these are the poles, right and symmetrically opposite to that the other 100 poles will develop. So, we know the 100 pole figure for this system even without using the stereographic projection, right.

Now, if we are drawing the 110 poles or the 110 pole figure then we found out that RD is parallel to a 110 family. So, RD is along 110, just opposite to it another 110 is there and therefore, at 90 degrees another 110 and here another 110 and there is 110s present at other positions because there are total six 110s, right. So, that in this way 111 pole figures can be determined. But, now we should see that how a stereographic projection can be used to determine it and you can see from the pole figure that this has a four-fold symmetry and it should have a four-fold symmetry because an ND is parallel to Z which is belonging to the 100 families. So, it should be the 100 stereographic projection that could superimpose over it to find out the exact position of the various poles, right.

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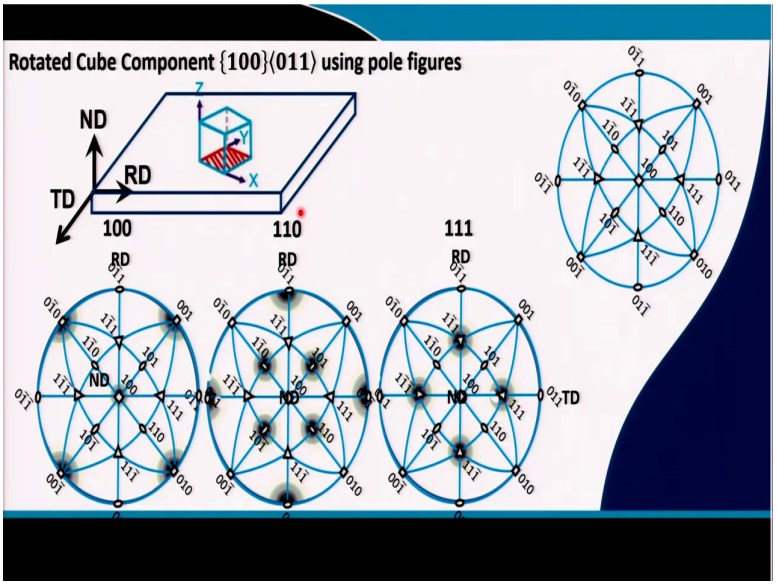

So, let us superimpose them, but that we cannot superimpose them the stereographic projection exactly because in the stereographic projection the top was 100, right. So, what we did is that we rotated the stereographic projection by 45 degrees because the unit cell here is

rotated by 45 degrees. So, that RD becomes parallel to 110. So, let us superimpose this one and when we superimpose this we can see the positions of the 100 poles of the pole figure matches exactly the positions of the 100 poles in the stereographic projection and the same happens that the position of the 110 poles matches exactly with the positions of the 100 poles in the stereographic projection and this happens for the 111 poles too.

So, that this is how a texture of various texture components can be determined and this is how some of the other pole figures are related to some or the other stereographic projections and we are giving easy examples of stereographic projections which are having at the center either 100, 110 or 111. There could be a possibility that such kind of pole figures may exist which does not have 100 parallel to ND or 110 or 111 parallel to ND, but still, such pole figures exist and we sometimes need mathematical tools to solve them. And, therefore, we use software developed for this purpose in order to solve those kinds of pole figures. There are other situations that may have exist where several components not a single texture component, but a number of texture components may form and this is leading to formation of a complex kind of a texture not in terms of component, but in terms of fiber and we will talk about this a little later, right.

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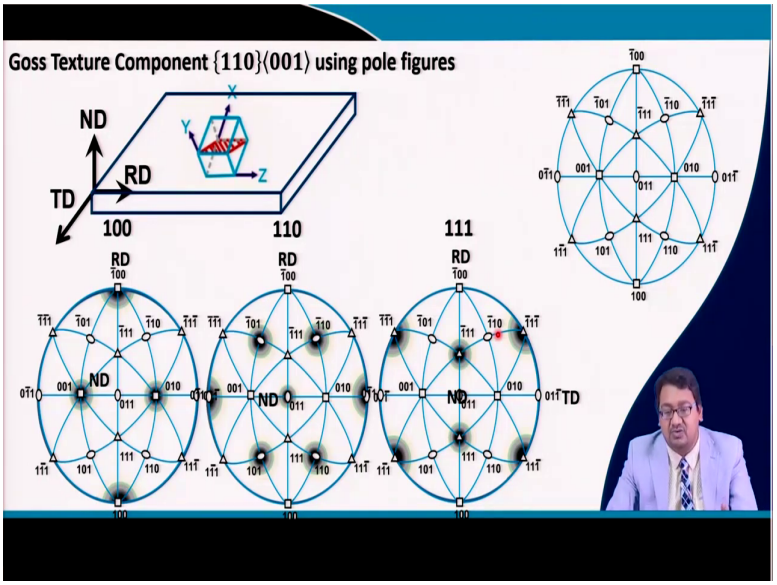

So, let us go ahead and take another example and this is the Goss component and it is a famous Goss component that is used in Fe-Si steel for transformer applications because it has the lowest magnetic resistance and therefore, the lowest magnetic loss. And so, that in this

case, the unit cell is such a way that the n rolling plane is parallel to the 110 whereas, the rolling direction RD is parallel to 001 and that under such situation what happens that the pole figure forms something like this. So, if we look into the 11 100 pole figure this one and we see that we have kept RD here ND at the center whereas, TD here. So, if you look at that we are drawing the 100 poles. So, if what is where is RD? RD is parallel to here 001. So, RD in the RD the 001 poles can be observed. And, so, that the just opposite to it we can obtain another 001 poles, basically this is the 001 bar pole. On the other hand, if you look here in the figure schematic you can see that the two other 100 poles form at 45 degrees 45 degrees to the ND which is 110. And, if such a situation exists then the 10 100 poles may form at 45 degrees from ND, right. and therefore, these poles have developed.

On the other hand, if we look at the 110 pole figure; when we look into the 110 pole figure what happens is that we observe the position of 110 exactly at the center which is basically the ND with respect to that the other poles develop at 90 degrees. Say, for example, if this is one 110 then here somewhere there was this one 100 and thereby at 90 degrees, there will be another 110. So, 110 and 110 are present and the other 110s also develop because of the symmetry, likewise, the 111 pole figures can also develop. Now, we can as we can see that in this case, ND is parallel to 110. Therefore, here the 10 110 stereographic projection can be used to observe the positions of the various poles and we cannot use the 100 stereographic projections because the ND is not parallel to 100, rather it is parallel to 110.

So, let us take this 110 stereographic projection standard stereographic projection and let us superimpose this one over the 100 and you can see the positions where the 100 poles are exactly matched with the positions of 100s of the stereographic projection and the same thing can be obtained for the 110s, right. So, you can see that the 110 poles of the pole figure exactly match with the 110 poles of the stereographic projection and if you look at the 111 planes poles, the 111 poles also match. And, thereby we can utilize stereographic projection standard stereographic projection to see or observe various textures with the help of a pole figure, but in that case, it must have to be an easy component with either 100 110 or 111 as the ND, right.

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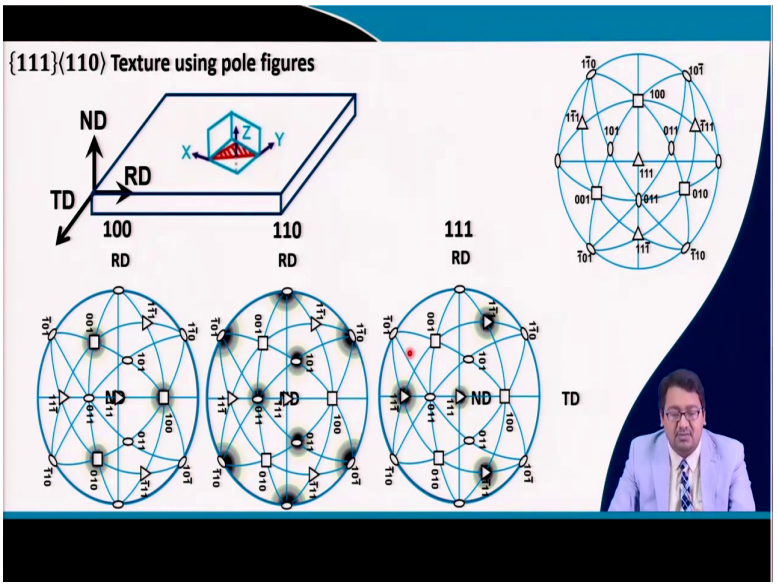

Let us take another example and this is another example of a simple 111, 110 type of texture using a pole figure. Now, if you look at this texture we see this is the texture that texture component that we discussed the most initially and you can see that there is a three-fold symmetry and you can see that when there is a three-fold symmetry it is the 100 pole figure. So, these are 100 poles and that means, that at the center it might be 111 and therefore, if we look at the 111 pole figure you can see the 111 poles and the other 111 poles form at various positions. On the other hand, if you look at the 110 pole figure it also forms and they are also with respect to this 100 and 111. And, you can see these pole figures develop while we do experimentally determine the texture component using either X-ray diffraction or by using electron backscatter diffraction using an SEM. We can also determine this by TEM diffraction experiments, but they are quite difficult to do. So, we use the X-ray technique and the EBSD in a scanning electron microscope.

So, that if we can superimpose the 111 stereographic projection as you might have understood during this process and because it has a 3-point fold symmetry and we have shown it for the 100. So, if we do like that we have to rotate this superimposed 111 stereographic projection by 90 degrees. So, that the poles match with each other, and if you take it beyond for the 110 and the 111 you can see that in both the cases. In the first case, the 110 poles and in the second case the 111 poles match, and thereby for simple texture 1 can use this process to match and understand the relationship of the texture with respect to the

pole figure and, with the Miller indices and how we can use the stereographic projection to determine this pole figures.

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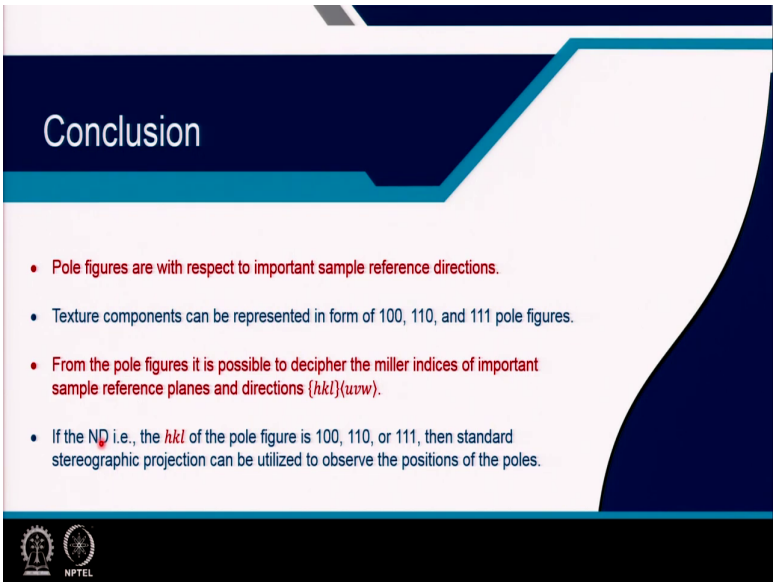

So, we can conclude here that pole figures are with respect to important sample reference directions. Texture components can be represented in form of 100, 110, 111 pole figures where we can show we are showing only 100, 110 or 111 poles right. From the pole figure, it is possible to decipher the Miller indices of important sample reference planes and directions that is hkl, uvw right that is also a form of representation of texture.

If the ND that is the hkl of the pole figure is 100, 110, or 111 that is the standard stereographic projection then this stereographic projection can be used utilized to used or utilized to observe the position of the important sample reference planes and directions in terms of poles, right.

Thank you.