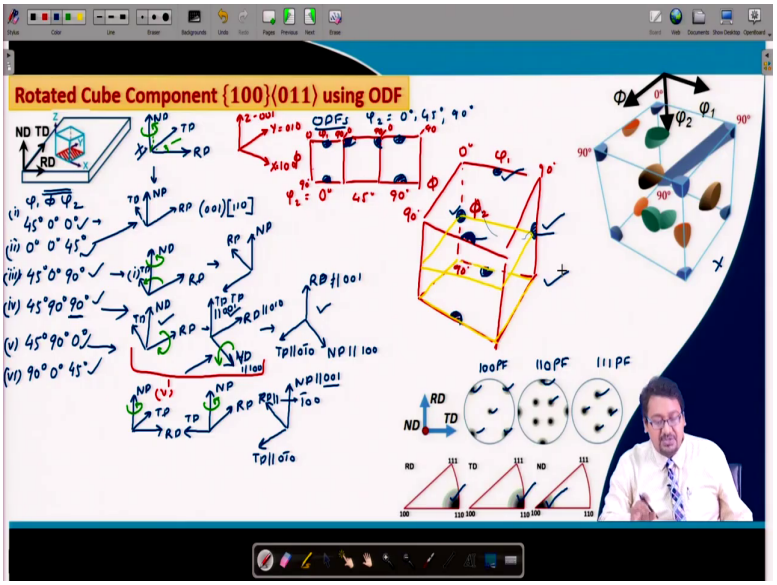
**Texture in Materials**
**Prof. Somjeet Biswas**
**Department of Metallurgical and Materials Engineering**
**Indian Institute of Technology, Kharagpur**

**Module - 04**
**Texture representation**
**Lecture - 15**
**Euler Angles and ODFs (Contd.)**

Hello, everyone. In today's lecture, we will continue with the Euler angles and ODFs and we will continue understanding how we represent texture in terms of Euler angles and Euler space.

(Refer Slide Time: 00:44)




So, in today's lecture we I will start with showing the rotated cube component, right. We have observed the rotated cube component R in the earlier lecture and the rotated cube component is 100 011 component and it looks like this as shown here that the RD is on the RD, TD and ND of the rolled sample is given that is the important sample reference directions. X, Y and Z are the important crystal reference directions representing X by 100, Y by 010 and Z by 001. Therefore, the position of the cube components are a rotated cube component are not shown here, but I will try to demonstrate it. So that as in the earlier example of the cube component we have kept RD TD and ND of the sample reference system like this.

In this case also we will keep it the same, but that in this case the position of the crystal axes that is the X 100, the Y which is 010 and the Z which is 001 are somewhat like this; that is, it is at 45 degrees to RD and TD that is X and Y are at 45 degrees to the RD, right. Now, if we consider to observe the first component along phi 1, phi, phi 2 we can notice that if we rotate along ND by 45 degrees, then we are rotating the specimen axis by ND using the right hand thumb rule like this by 45 degrees to rotate the RD here and the TD somewhere here, right. So, that if we look after the rotation the ND remains at the same position whereas, RD is somewhere here and TD is say somewhere here, right at 90 degrees.

Now, if such a situation then RD is along 010 whereas, ND is along 001. Therefore, this texture which is 45 0 degree, 0 degree forms at a position where the Miller indices must be 001 RD 110, right. Therefore, if we draw if we draw the ODF Euler space let us start with drawing the Euler space right. And the same Euler space that I have drawn earlier I am drawing it here with this axis phi 1, this axis is phi, and this axis phi 2, right phi 2 axis and this is 0 degree, 90 degrees, 90 degrees and 90 degrees, right. Now, if we look into this what we can see that, that if we give a 45 degree rotation along phi 1 that is a 45 degree rotation along ND we can get the cube component and the position of this cube component will be let me show it using the blue color and this is here right. So, this component forms at phi one equal to 45 right phi equal to 0 and phi 2 equal to 0 section ok.

Let us go ahead and say that if instead of giving phi 1 phi 1 phi rotation of 45, 0 and 0 if we give 0, 0 and 45 degree rotation, then also the similar rotation will take place and then along ND and thereby the position of the rotated cube component will form at 0 along phi 1, 0 along phi and at 45 degree, right along phi 2 right which is this one. The third situation that can happen is that if we rotate by 45 degree along phi 1 that is the first and the second; first case that is the first case ok. And, then if we rotate by 0 degree along the phi and then again if we rotate by 90 degrees along phi 2; that means, if we are taking this component and rotating along say you are taking this RD, ND and TD which is here.

And if you are rotating ND by 90 degrees along phi 2 that is the phi 2 rotation then what happens the RD goes to TD right the RD goes to TD and TD comes out like this ND, RD and TD. So, RD becomes parallel to 1 bar 00, where TD becomes parallel to 01 bar 0 and ND remains parallel to 001. So, we could keep the specimen reference directions parallel to the important crystal reference direction 100s. So, 45 0 90 degree component will form at 45, 0 phi equal to 0 and phi 2 equal to 90 degrees and that is here. Now, if we look at the 4th

situation where we can see that if we rotate by 45 degrees 90 degrees and 90 degrees then what will happen that we are taking this one right ND and here was the TD and here was the RD. So, we are rotating using the right hand thumb rule by RD by 90 degrees which will make the RD will remain the same and the ND will be somewhere now like this and the TD will go up, right.

So, this is the 90 degree rotation and then what will happen that if we rotate again along ND by phi 2 equal to 90 that is this rotation right hand thumb rule, right, then what will happen that this will become RD will become here and TD will become here and ND here. So, that this time RD is parallel to parallel to 001 whereas, TD is parallel to 01 bar 0 and ND is parallel to 100. This is also a position of the rotated cube texture component. So, this is at 45 degree to phi 1, 90 degrees to phi and 90 degrees to phi 2 and therefore, we can show this point sorry using this blue color here, right. Now, let us take the 5th position and the 5th position is little what you can say that little may be tricky that is 45 degree, 90 degrees and 0 degree.

Now, that in case of the 4th this thing I have given a rotation of 45 degree along phi 1, 90 degree along phi and then again 90 degree along phi 2, right. I forgot that just by 90 degree rotation along phi that is for the 5th situation that is if we include only this two and this becomes the 5th situation, that is, that in this case after the phi equal to 90 degree rotation, the ND is parallel to 100 the RD is parallel to 010 and the TD is parallel to 001.

So, this situation also exist at phi 1 equal to 45 degree phi equal to 90 degree and phi 2 equal to 0 degree that is this position. So, that we have found out 5 positions and now, we have to find out the one which is a little tricky. So, in this case what we need to do we have to give a rotation of 90 degree along phi 1. We take this particular thing and then we give a 90 degree rotation along ND and it can be shown like this ND, RD and TD is the initial situation of the specimen axis and we are giving a 90 degree rotation along ND which is phi 1 rotation and then it will become something like this ND RD and then it will become TD, right. So, the position of ND, RD and TD has changed.

Now, if I do not I cannot give any rotation along RD because if we rotate along RD then ND and TD cannot anyway become anywhere near parallel to the specimen axis 100, 010, 001, right. So, we will not give any rotation along RD rather we will give a rotation of 45 degree at phi 2 along ND. So, what we will do? We will give a rotation of 45 degree and when we

will give this rotation of 45 degrees what will happen. ND will remain at the same position whereas, the RD will change and it will become here and the TD will form here. RD this one which becomes parallel to 1 bar 00 TD becomes parallel to 01 bar 0 and ND becomes is always remain parallel to 001.

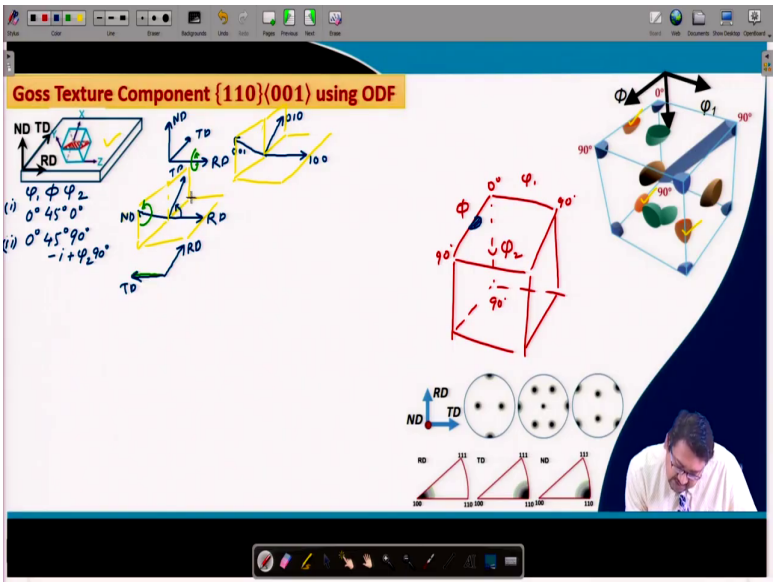
So, this situation can be observed at phi 1 equal to 90 degrees, phi equal to 0 degree and phi 2 equal to 45 degree that is this position. So, you can see that the positions of the rotated cube texture component can be observed in the Euler space and this position can be described in terms of the 100 pole figure. The 110 pole figure and the 111 pole figure and the positions of the rotated cube component can be observed for the 111 poles here and we have discussed this for the 110 poles here and for the 111 poles here, right. Now, that the rotated cube component has the rolling plane parallel to 100 that is the ND parallel to the 100 axis or the 010 or the 001 axis. So, 100 axis family; so, it can be shown here. The RD is parallel to 011.

So, it can be shown parallel to 110 and if we cross multiply 100 with 011 we will see that the TD axis is also in the family of 100 110 axis. Therefore, the TD can be shown here and we have discussed this. So, now, using the Euler space can be represented in terms of ODFs right, ODF now the positions where the fiber sorry the rotated cube component have formed. The rotated cube component has formed at phi 2 equal to 0 degree section right phi 2 equal to 45 degree section right and 90 degree section, right. So, we need not need to show all the phi 2 sections in this ODF and we can just show these three sections, right.

So, this is 0 degree, phi 2 equal to I am making 45 degree and this is for the 90 degree section and this is 0, 90 and this is again 0 and 90 and this is again 0 and 90 for the first, second and the third orientation space and this is also 90 for all of these boxes. This is phi 1 section, this is phi section for all of these boxes and we can observe the position of the rotated cube component here which is related to this one and for this one we can observe it here and the other two components can be observed from this phi 2 section let me show you the section this section. And, therefore, its position can be observed here and here. So, this one, this one and this one, this one.

So, on the other hand the phi 2 equal to 90 degree section which can be shown here, right and in that case also we observe the position of the rotated cube components here, right. So, one can observe the Euler space and can calculate the position of the components in the Euler space and this is another example showing rotated cube component.

(Refer Slide Time: 17:16)




Now, let us go ahead and observe this situation for the Goss component and the Goss component you can see that similar to the rotated cube component. We will be showing the specimen axis in terms of RD, ND, TD whereas, the sample axis in this case is 100 which is the X axis say or Z axis whatever it is.

The X axis parallel that is the we will consider it as 010 and then the Y axis we will consider it as 001. So, to just make you understand it is something like this right. So, this is one plane and this is another plane. So, the components are like this right. Now, that the position of the Goss texture components were shown in the Euler space that we demonstrated by these orange components, right these components, right.

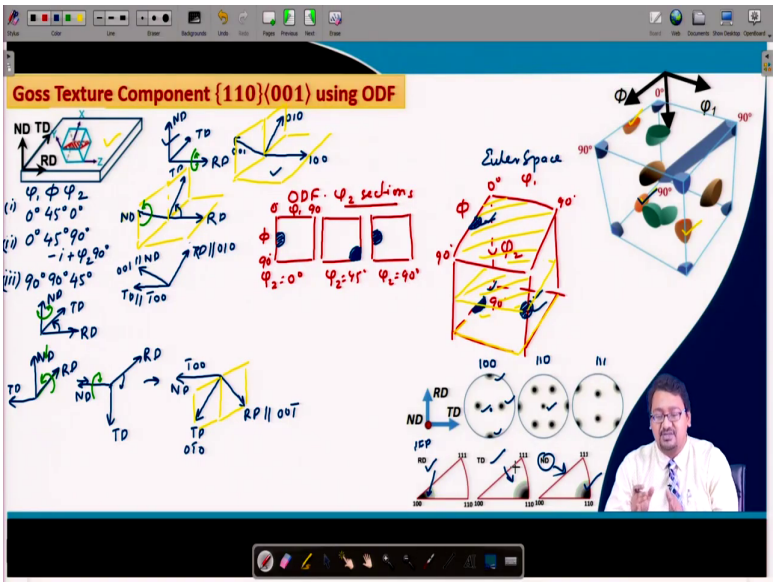
These are the Goss texture component the Goss texture component is 110 parallel to the rolling plane and 001 parallel to the rolling directions, right and it will look similar like this as shown in this figure and can be demonstrated like this. Now, let us consider the situation where we are going to find out the Goss texture and so, the situation 1 is that if we rotate; if we rotate the specimen axis by phi 1, phi, phi 2 say we rotate initially by phi 1 by 0 degree and this is the 1st case.

And, then if we rotate phi by 45 degrees because phi rotation is along RD and therefore, we are giving a 45 degree rotation using the right hand thumb rule and which is like this right. So, this is the rotation that we are giving along RD and therefore, what will happen that the RD will remains the same and TD will go a little above like this and ND will go here, right.

If it is following this same just the yellow color I am showing to demonstrate the 3-dimensional nature of the construction right. So, that TD is now parallel to 010 the ND excuse me ND and the TD. So, TD is parallel to 010 the ND is now parallel to 001 and RD is parallel to 100. So, the position of the angles phi 1, phi, phi 2 could be traced to 45, 0, 45 and 0. Therefore, if we make the the Euler space here again 0 degree, 90 degrees, 90 degrees, 90 degrees and this is phi 1, phi and this is phi 2, right.

So, the position can be traced for the Goss texture component and that is 0, 45 and 0; so, 0 and along phi 1 and 45 along phi and 0 along phi 2. So, the position is this one, right. So, if we take the second situation and then what we just know that if 45 degrees can go phi at phi then at phi 2 if we rotate by 90 degrees then the texture the similar texture can be obtained. So, what we are doing we are taking this first one and adding a rotation at phi 2 equal to 90 degrees, right. So, how we will do so? We will take this we will rotate it by 90 degrees and when we it will be done, what will happen? The TD will go somewhere sorry somewhere here and the RD will go somewhere here. So, this is TD after the rotation. So, the rotation is taking place like this. So, the RD is going to let me delete and make it once again for clarity.

(Refer Slide Time: 22:35)




Therefore, ND remains the same, the RD goes to TD and the TD goes to opposite of RD right. Therefore, under this situation the ND remains parallel to 001, the TD that was sorry I have written it wrongly that earlier it was TD and now, it became RD remains parallel to 010 and the TD becomes parallel to 1 bar 00. So, we have traced the specimen axis from the Goss

texture component to the position where the important specimen axis are parallel to the important sample axis and thereby this position 0, 45 and 90 degree is also the position of the Goss texture component. Now, what is 0, 45, 90 degree so, phi 1 0 45 along phi and 90 degrees along phi 2.

This is the position and so, this is the position that we have shown earlier. Now, the 3rd position of the rotated cube is if we rotate phi 1 by 90 degrees and let us take this first one ND, TD and RD and let us rotate by 90 degrees by ND and then what will happen? Then RD will go. Sorry. Let us use the perfect color RD. ND will remain at the same position RD will rotate like this and go here and TD will rotate and come here by 90 degrees. Therefore, this is the first rotation and then again if we rotate along phi by 90 degrees. So, what we are doing? We are doing a right hand thumb rule rotation along RD and thereby the RD remains at the same position RD and the ND is rotated somewhere here and the TD is rotated here.

Now still we have to rotate to go to this position. Therefore, the sample has to rotate still to go to the specimen axis. Therefore, if we rotate by ND along by 45 degrees so, using right hand thumb rule this one. So, right hand thumb rule and thereby the rotation will take place such a way that RD will rotate somewhere here and TD will rotate somewhere here, right. So, instead of drawing it here let me remove this slowly and let me draw it separately.

So, ND remains the same and RD and TD are forming something like this right TD and RD, right. In order to for you to realize the 3-dimensional nature of this construction I am drawing this yellow color and then that RD is parallel to 001 bar TD is parallel to 01 bar 0 whereas, ND is parallel to 1 bar 00. So, this position 90, 90 and 45 degrees can be seen in the in form of the position phi 1 90, phi 90 and phi 2 equal to 45. So, these are the position where the Goss texture components develops. Now, you can see that the Goss texture component which is the 110 001 texture components can be observed in the Euler space like this, right in this positions. Therefore, instead of showing them in the Euler space what we would like to do is that we show that in terms of ODF at phi 2 sections, right like the other ones. So, what we will do is that we will draw important phi 2 sections.

We see that the Goss texture is observable at phi 2 equal to 0 degree section, it is observable at phi 2 equal to 45 degree sections and phi 2 equal to 90 degree sections and then if this is 0 degree for phi 1 to 90 and the same for the other ones and this is phi from 0 to 90 and same

for the other ones, the positions of the Goss texture components can be seen as if you say for example, we sliced along phi 2.

So, this is the first slice and so, the component can be observed here which is this position. On the other hand, when we do the second slicing at 45 degrees that is this slice, right the component is observed somewhere here which is this position right this position and I am showing with a large spread as usual will happen in case of real life scenario. On the other hand, for the phi 2 equal to 90 degree section the slice is actually the lowest one here and the position is here which can be shown here.

One can see that the symmetry of the cubic crystal always will show that phi 2 equal to 0 and phi 2 equal to 90 degree section will show the exact same component at the same positions and this is related to the symmetry. The position of the Goss texture components in terms of pole figure and inverse pole figures are already discussed and see in terms of the pole figure here we have shown to compare for you the positions for the 100 poles.

And, you can see that it shows a 2-fold symmetry because the ND is here and the ND is 110 which has a 2-fold symmetry and you can see the 110 poles to where at the center you can see the position 110 as ND and here is the 111 pole figure. So, one can observe from all this pole figure a 2-fold symmetry, at the same time one can observe the inverse pole figures and as the Goss texture component has 110 parallel to the rolling plane that is the 110 axis parallel to the normal direction.

So, you can see it is position here at 110, so, the ND inverse pole figure. On the other hand if we look at the rolling direction which is 001. So, the RD pole figure inverse pole figure shows its position here and then a cross multiplication or cross product of 110 cross 001 gives the position of TD which is here. So, we see that one can relate the inverse pole figure, pole figure and the Euler space and can find out the position of various texture components.

Of course, these are easier ones by simple rotation using the geometry of the sample axis and with and the crystal axis just the rotation should follow the Euler's angle principle given by the Bunge that is the Bunge's way of rotation phi 1, phi, phi 2 so that the specimen axis could be rotated and go to the crystal axis of that particular kind of texture and in this case what we have shown here is for the Goss texture. Earlier we gave the example of rotated cube and cube texture and that is all for this lecture in the today's class.

Thank you.