Thermo-Mechanical and Thermo-Chemical Processes

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Lecture-13
Crystallographic Texture

Hello friends continuing with our crystallographic texture discussion, today we will discuss about texture representation using pole figure or {hkl} <uvw> representation or orientation distribution function (ODF). So, I will show you that how you can use the idea of a stereographic projection to develop pole figures and then how to understand the ODF, what do we mean ODF and so on.

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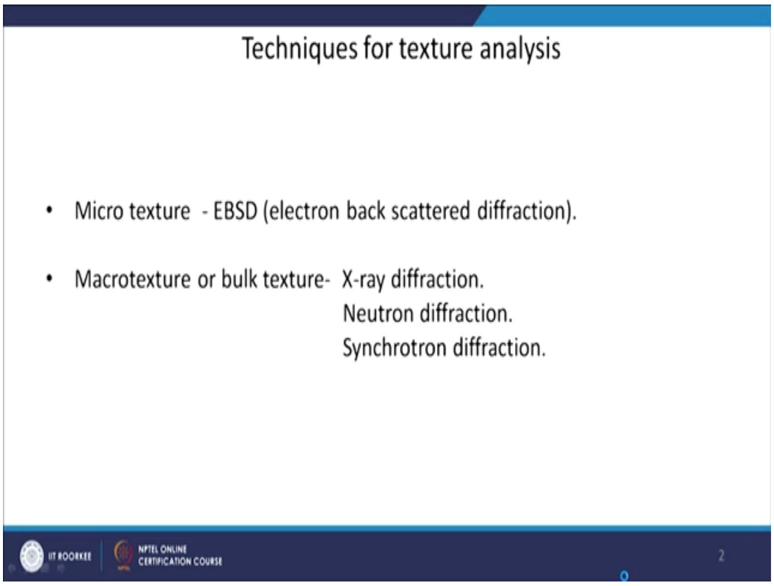

So, before going any further these are the techniques texture measurement and analysis. One is what we call as electron back scattered diffraction which is also called as EBSD and in this you measure micro texture means at microstructural level.

Then you have macro texture or what we call as bulk texture that means, over a bigger volume you measure texture in this case. So, in this category you have X ray diffraction. If you want even better measurement in a bigger volume you can go for neutron diffraction or synchrotron diffraction. So, these are the macro texture or bulk texture and EBSD is at microstructural level so we call it as micro texture because the area covered is small and at the same time because we are dealing with electron, the electron penetration within the material is usually very small.

So, the amount of volume it covers depth wise in the material is also very small whereas, X-rays can penetrate more, synchrotron and neutron diffraction even these radiation even penetrate the penetration is even more so, there you get the bulk volume information and that is why we say macro texture or bulk texture.

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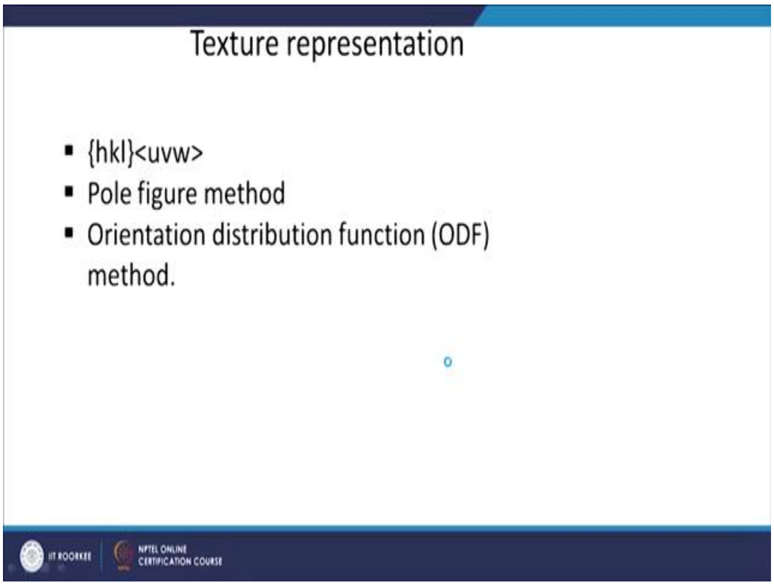

Texture representation already we have seen this that you can do texture orientation representation by {hkl} <uvw> symbols or through pole figure or orientation distribution function so, we will look each one by one, {hkl} <uvw> we have already seen once I am just giving a quick review here.

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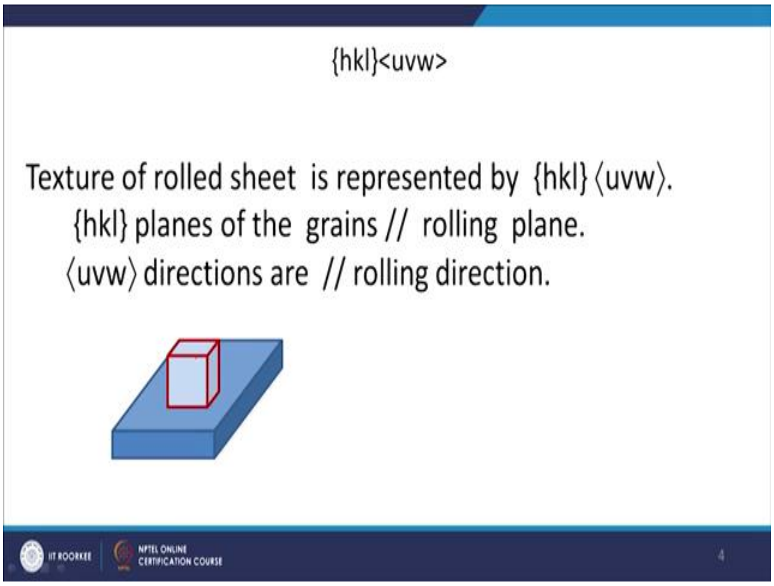

So, if I want to suppose in a particular grain the unit cell is oriented like this (refer to above figure). And let me give you the sample geometry first, so this is my RD rolling direction, this is my transverse direction TD and normal to this rolling surface is the normal direction ND. So, these are the three orthogonal sample symmetry and, in this cube, let us say this particular direction, this one is 100 this one is 010 and this going up is 001 (refer to above figure). So, you have sample geometry and you have crystallographic axis.

So, if I want to represent the orientation of this particular grain in which the unit cell is oriented like this (refer to above figure), then as we have said the hkl plane of the grains parallel to rolling plan is the 001 plane.

Or you can also say that the normal to this particular plane 001, that is parallel to ND. So, you can say the normal to hkl plane is parallel to ND. So, these two statements are same. So, we can see that the 001 plane is that which is parallel to the rolling plane and the uvw direction which is parallel to rolling direction, so, we can see that 100 is the direction which is parallel to RD. So, for this particular orientation, I would say that my texture or my grain orientation is {001} and <100>.

So, this is the grain orientation for this particular unit cell. Suppose if I have rotated by 45° this particular cube then what will happen? My 110 direction will be parallel to RD. Suppose if I rotate 45° on 001 then what will happen the cube will be such that the 110 direction now is parallel to RD. So, again plane will be same 001 because the same plane we are rotating about 001 here and the direction the 100 will go at 45 °.

So, the 110 will become parallel to RD. So, now just by rotating the unit cell our grain orientation is changed. So, like this I can represent in terms of {hkl} <uvw>.

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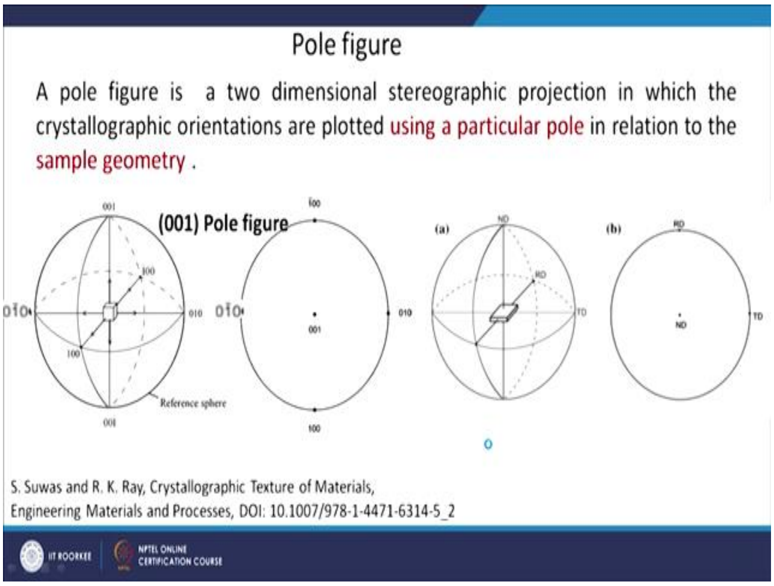

Now coming to for pole figure, it is similar to a stereographic projection. If you remember when we were plotting stereographic projection for let us say 001 standard stereographic projection what we did is we put 001 normal such that that it was hitting the top pole and it was projected exactly at the centre of our projection. And then we have plotted all the other poles with reference to that.

So, we plotted all the 110 poles or 111 poles. So, there we did not restrict any pole, we have plotted all the poles. Now, when we talk about pole figure, we are interested only in a particular pole. So, when I say pole figure, why it is different from stereographic projection though the construction and the concept is same that we are only interested in a particular pole here. And we will use the sample geometry as the reference for plotting.

So, for example, this is a 001 pole figure (refer to above figure). So, when I say it is 001 pole figure, I am only interested in the 001 poles. So, if you compare with stereographic projection, this particular one (refer to above figure), you will see that there are no other poles plotted here, only the 100s are plotted. So, that is why I am calling this as 001 pole figure. Now, right now, I have not mentioned any sample geometry here. But when I'm going to plot the pole figure, the geometry will be something like this (refer to above figure).

So, you have a rolling direction here, the normal direction is just hitting the top pole so, it is exactly at the centre and the transverse diffraction is at 90° to both RD and ND. So, this is the sample geometry and now with reference to this we will be able to tell what is the orientation of each grain. So, like we did just for {hkl} <uvw> similarly, you can do in pole figure that this is my sample geometry, this is my RD, ND and TD with reference to this example.

If I want to plot 001 pole figure where the 001 are lying right now? So, for example, this particular orientation which is shown here (refer to above figure), so, my 001 will be of course, lying on these locations. Let us say we take the same orientation as shown previously, so, 001 is going and hitting the top. So, of course, it will come exactly the centre, then 100 will go in the bottom.

So, this is 100 and 010 will go here (refer to above figure), this becomes $0\bar{1}0$ and these become $\bar{1}00$. This is the orientation of this particular unit cell with reference to our sample geometry. So, whenever I say pole figure it is very similar to stereographic projection only difference is that we are now plotting a sample geometry on the projection. When we were discussing stereographic projection, we were just plotting in terms of north, south, east and west taking the analogy from the globe.

But now, we are going to impose the sample geometry on the stereographical projection first, second thing is that we will be on the interested in a particular pole and that we will write that we are interested in this particular pole and only that pole will be visible on the stereographic projection.

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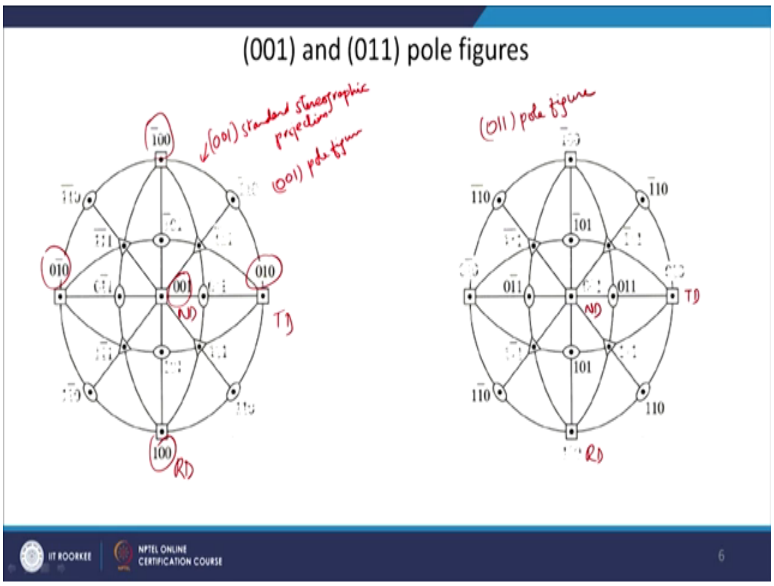

So, just to give you an example here (refer to above figure), we have taken a stereographic projection here which is 001 standard stereographic projection. Now, I want to convert it into a 001 pole figure. So, as I told you, that if I convert it into a 001 pole figure I would not be seeing any other poles. So, I'm just removing them here. I have removed all. So now only the poles which you can see are the 001 poles.

So this will be a 001 pole figure ,all the other poles I have removed. You would not be able to see other poles here. Suppose the same thing, same stereographic projection but I am now interested in lets says 001, I want to convert it into a 001 pole figure then what I will be doing, I will be removing all the other poles.

So, this is what is the meaning of pole figure and now I can also super impose the geometry here for example, I can say this is my RD TD ND, if I am interested in that. So, this is the whole idea of pole figure and now we will use this idea to show couple of texture orientations. For example, you have one orientation what we call as cube orientation.

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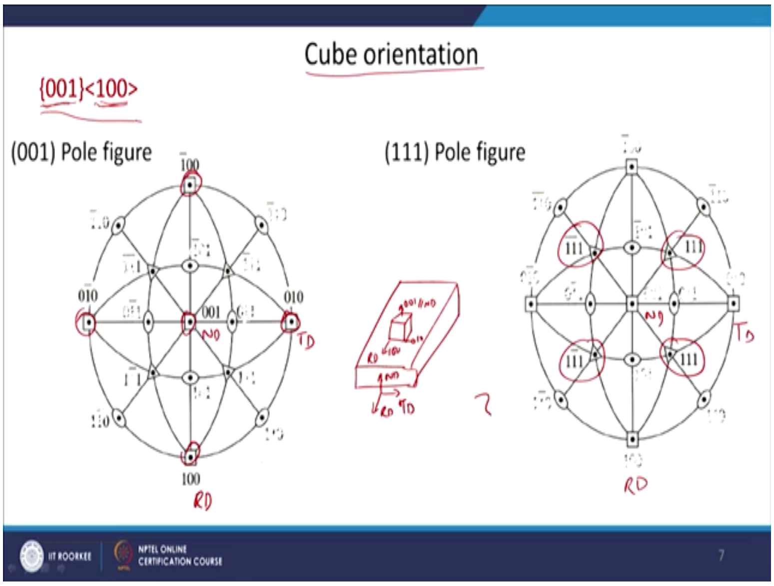

It is very simple orientation already we have seen in terms of {hkl} <uvw>, 001 is parallel to the rolling plane and 100 is parallel to rolling direction. That kind of texture component is there. So, this is my rolling direction, this my transverse direction, this is my normal direction and on this my cube is there (refer to above figure). So, this is the 001, this is 100 and this is 010, this is parallel to ND and this is parallel to RD (refer to above figure).

So this is the orientation, how it will look on a 001 pole figure? It will be similar to this (refer to above figure). So, I am just putting my sample geometry here RD, TD and ND and for me all other poles will go now. So as I just showed you all these poles will not be visible for me. I will erase them. So, now if I have a cube orientation for my grain, and I want to plot a 001 pole figure then that pole figure will look like this (refer to above figure). So, very nice symmetry will be visible to you.

For the same grain orientation here at orientation I am plotting the 111 Pole figure, then my all other poles will go. So, only these four poles will be visible in this symmetry. So, this symmetry will be very clear. You will have these four poles at this particular angle for this orientation. And of course, this will be your RD TD and ND. So, for the same orientation, I can plot different pole figures. So, if you get a 111 pole figure you should not worry about that it is some kind of 111 orientation, the orientation is still is 001 100 only we have plotted the 111 pole figure and from understanding of a stereographic projection we know that where these poles will come and what will be the angular information you can always get using the Wulff net and that will follow whatever is the angle you have calculated using cos θ relationship.

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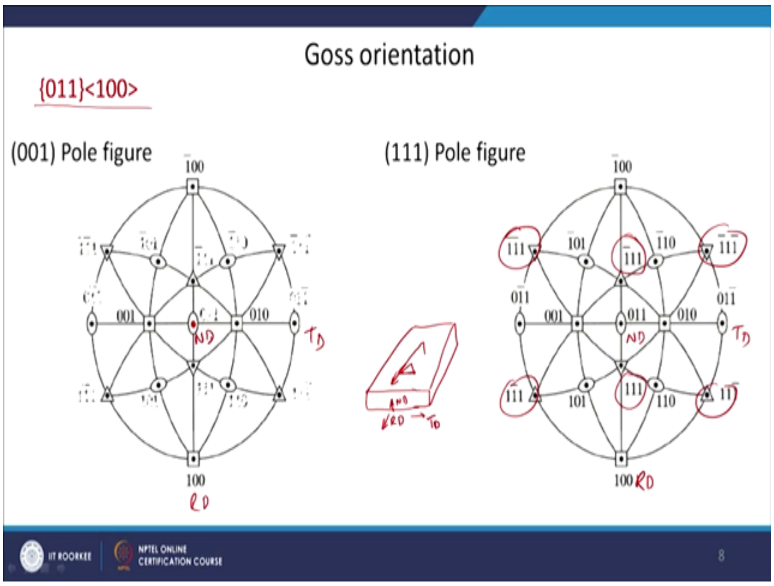

There is another very important orientation called Goss orientation. The orientation has this information (refer to above figure). The 011 plane is parallel to the rolling plane and the 100 direction is parallel to rolling direction. If I may try to show you the orientation here, it will look something like this. The 110 plane will be parallel to this and the rolling direction will be parallel to 100 (refer to above figure).

So, when a 001 plane is parallel to RD, so its normal we will go and hit the top pole. So and its projection will be exactly at the centre. And if I am now plotting a 001 Pole figure for this orientation. So, now, you can see I have taken a 001 stereographic projection here. And I want to show you that how the pole figure will look like. So, I am removing all the other poles other than 100 types (refer to above figure).

So, you can see that only these particular poles are shown. And if I am looking at a 111 Pole figure of the same grain orientation, I will remove all the other poles here and I will keep only the 111 poles. So, you should be able to see only the poles, which I am highlighting here (refer to above figure). So, in a 111 Pole figure if you see a symmetry like this, you should be able to understand that it is a Goss orientation, which has a 011 at the centre and the 100 is parallel to rolling direction.

So, this will be your RD TD and ND. Similarly, this will be your RD TD and ND (refer to above figure). So, I am keeping my sample geometry like this. And looking at how the unit cell is oriented with respect to the sample geometry, that I am plotting in the pole figure. Now, as already I have told you then there is another concept to show the orientation and especially when you have axis symmetric processes.

For example, rolling is not axis symmetric process you have straining different direction, but for example, you are doing a wire drawing operation or an extrusion operation there the strain is symmetric. In the direction of the extrusion or wire drawing, if you see in the diametrical or around the circumference the strain will be uniform throughout the circumference or in the radial direction. The strain will be uniform in the 360 ° direction. So, this is what we call as axis symmetric processes.

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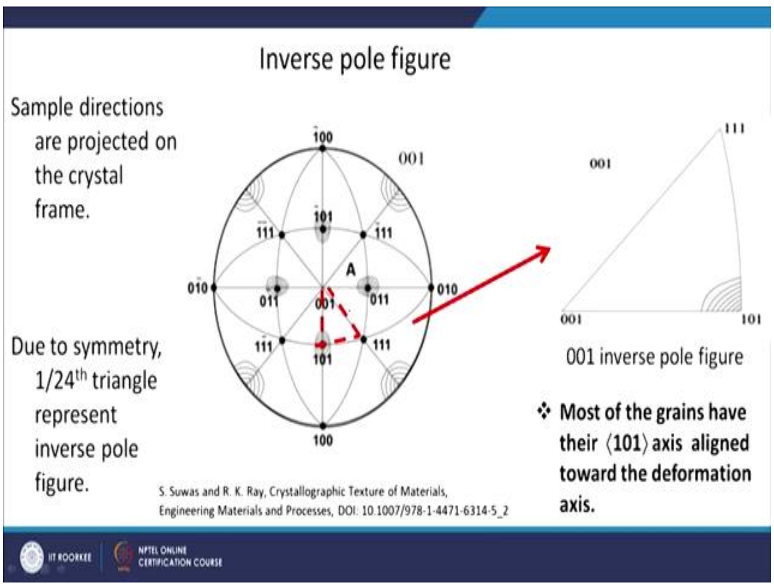

And then in that case, you can easily plot only the inverse pole figure. What do we mean by inverse pole figure? So, you can take this one particular triangle (refer to above figure), there are 24 triangles and all are symmetrical. So, any one triangle I can take and that I am plotting here. So, you can see that at 101 you have more intensity. So, when there are large number of grains which are oriented with this kind of orientation, you will see that there are large number of points falling on these particular poles.

And that is how you get the texture information through pole figure. So, as you can see if I take this (refer to above figure) triangle you can see here that there is a more intensity around 101 and this is the standard triangle we are taking 001, 101 and 111. So, this is how you can plot an inverse pole figure map. So, all the sample directions are projected on the crystal frame.

So, you can see that here, we are not saying that whether RD TD ND, we are fixing the crystal frame. So, 001, 101 and 111, this is what we have fixed and now we are looking at that how the ND direction which you can also call as 001 direction or I can call it as ND direction that how the ND direction is oriented with respect to this reference frame.

So, this slightly just an opposite of what we do in pole figure where we have fixed the sample geometry and we are looking at that how the unit cell is oriented whereas, in this case we are fixing the crystal frame and we are looking at how the ND is oriented with respect to the crystal frame. So as you can see that most of the grains have their 101 axis aligned toward the deformation axis (refer to above figure).

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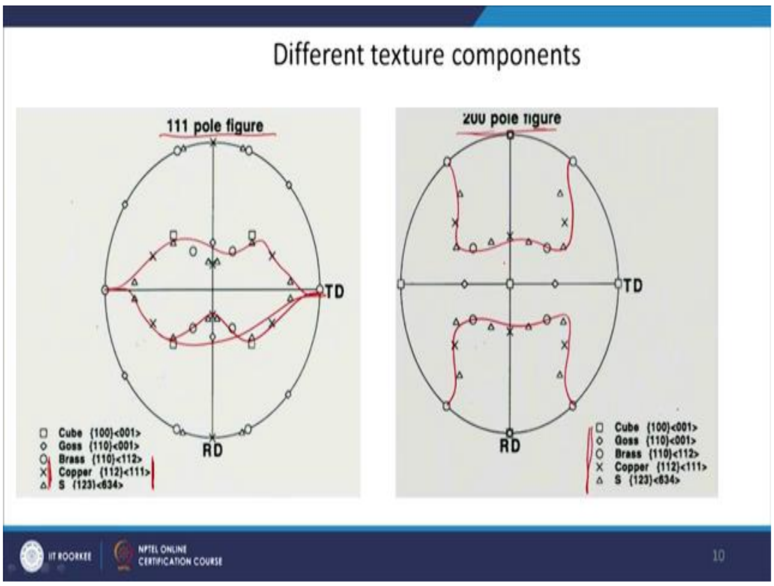

Now, there can be different texture components can be shown on the pole figure already we have seen two Cube and Goss. So, those two are also shown here (refer to above figure). Then there are some more here Brass, Copper and S. And there are different symbols are used for that which are shown on the pole figure where these will be there. So, if you are plotting a 111 Pole figure you will get an information like this (refer to above figure).

If you plot 200 Pole figure for the same orientations, you can see that the arrangement has changed obviously, because we are now looking at the 200 Pole figure or 100 pole figure both will be parallel. So, this is how it will be depicted and when you look at the pole figure you will see some this kind of arrangement.

So, if you see this kind of intensities on the pole figure, large number of grains oriented like this then you know that these are the texture component which are projecting on the pole figure. Now, the problem with pole figure is that you can only show two angles, one is from the centre how much far the pole is there and other is how much it is rotated from the RD for example, how much it is rotated from the ND and how much it is rotated from RD.

But we know that because we are dealing with a three-dimensional space here, there has to be three angles to actually give you the complete information about orientation. So, for that some drawbacks which are there with a pole figure can be solved using an orientation distribution function. So, that is the depiction of orientation in a three-dimensional Euler space.

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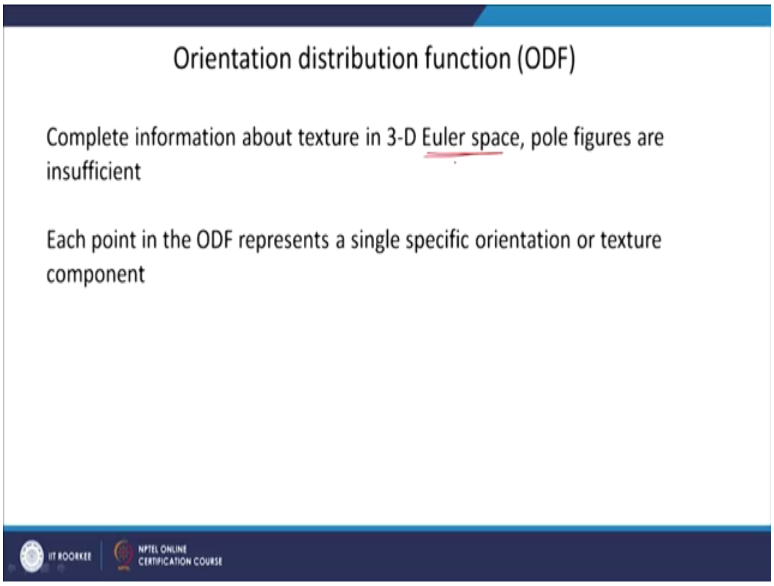

We will see what do we mean by Euler space or Euler angles. ODF is that each point in the ODF represent a single specific orientation or texture component. So, I will show you how do we understand ODF, but before going there, I will first show you what do we mean by Euler space or Euler angles.

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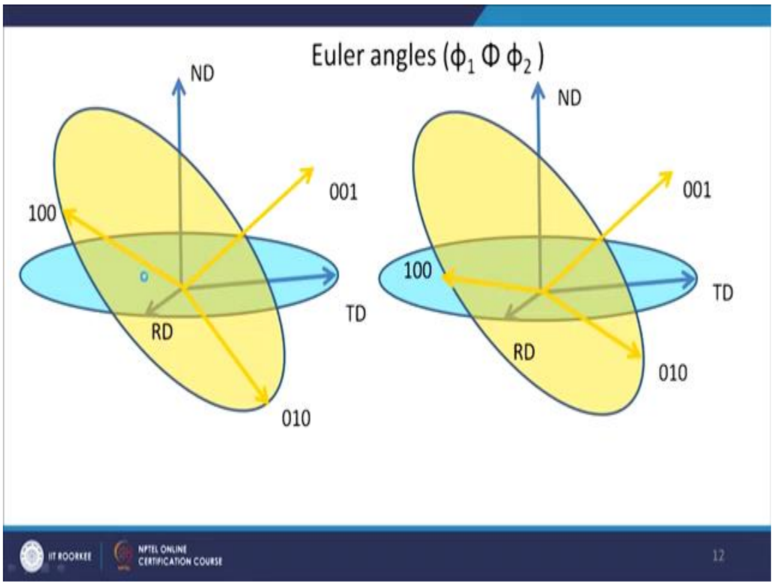

So, basically it is like this (refer to above figure) you have two frame, one is your sample frame which is RD, TD and ND and there is another frame which is your crystallographic axis. So, you have 100 axis 010 axis and 001 axis. So, now, as you can understand that my unit cell is not aligned with the sample geometry, it is a randomly oriented in the space. So, now I want to know that how much off it is aligned with the simple geometry.

So I want to bring it back to the sample geometry and whatever rotation I will be requiring to do that, that will be the information about the about the orientation of that particular unit cell. So, there is a sequence which we follow to do this you So, you have three angles here, one rotation is Φ_1 angle, then you have Φ and then again Φ_2 angle. These three angles will be there. So, two frames are shown here blue one is for sample. So, you have these two axes 010 and 100 in the plane and one 001 is perpendicular to this plane. So, this is how this is oriented. So now, if I want to bring it into coincidence, what I will do, I will first give a rotation on 001 for example here (refer to above figure).

But how much rotation I have to give. So, that will be decided by how much this 100 is at angle with this RD TD plane. So, the rotation will be such that that when I am giving a rotation like here (refer to above figure) then it will be rotating like this. So, this disk also will be rotating. So, when it is rotating then this 100 axis will ultimately fall on this RD, TD plane and whatever is the rotation required that I will note down that I have made this many rotation. Let us say it is Φ_1. So, once this 100 axis is on the RD, TD plane, which is this now second image here (refer to above figure), so, my 100 is now lying on the RD TD plane. So, now it is very, once this is lying on the RD, TD plane I can easily bring the 001 axis parallel to ND because any rotation I am going to give in the same sample geometry, it will be there will be a true angle between the ND and 001.

So, any rotation if I give this will bring this parallel to ND. So, I know that how much rotation I have to give I have to give a rotation on 100 now so that this comes and become coincidence with the ND, so let us say that is my capital Φ.

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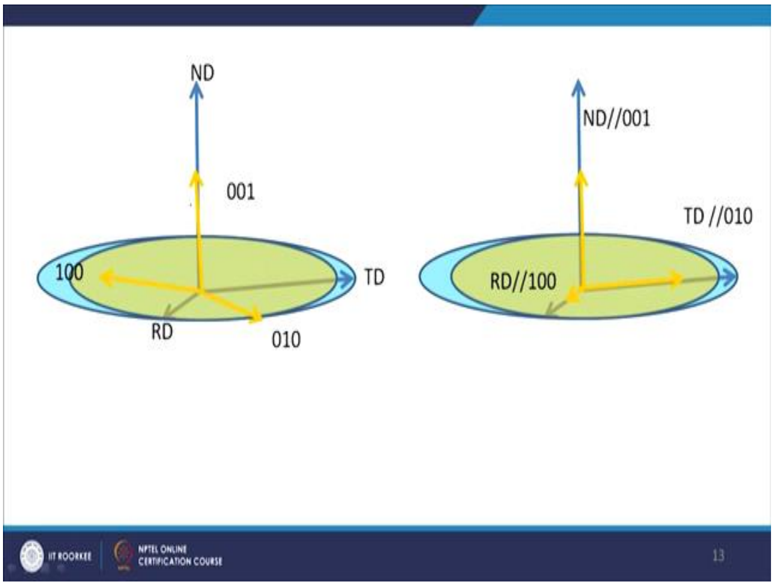

So now my 001 is parallel to ND, but it is still 100 and 010 are not parallel to RD TD. But since now, my these two are aligned and both these two directions are in the same plane of sample geometry, I know that how much rotation will be required to bring 100 and coincide with RD and 010 coincide with the TD. So that one that lets say we call it as Φ_2. So, these three rotations if I give, I will be able to bring the unit cell from whatever orientation it is in to the sample geometry rotation.

So, that defines the orientation of this particular unit cell. So, now, you can see that I have three angles. So, I can now create a three-dimensional space using these three angles, which is what we are doing here (refer to below figure).

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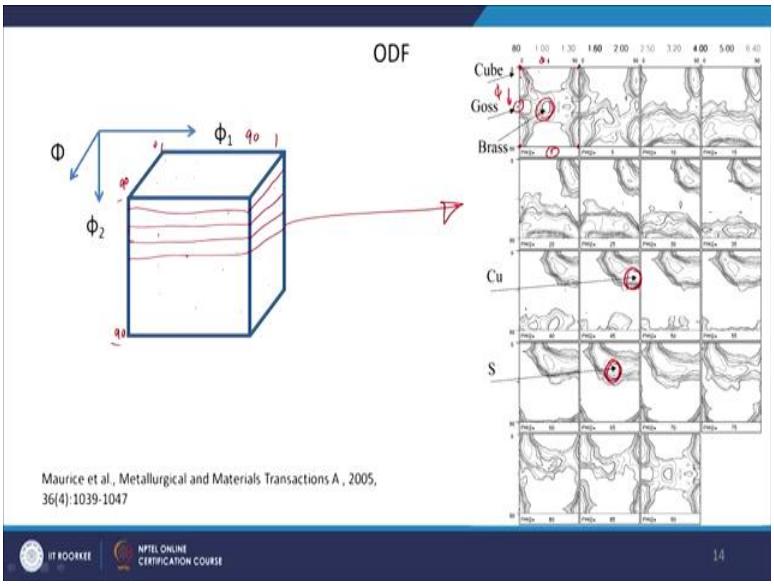

So, you have Φ_1, Φ_2 and Φ, three-dimensional Euler space. And in any point in this, we will have some Φ_1, Φ_2 and Φ. So, that will be the orientation of that particular grain. Now, looking at a three dimensional space will always be a difficult prospect. So, what we will do is we will take slices from these three-dimensional spaces, let say at 5°. So, we will take the slices and, in the slices, we will see that whichever orientations are falling on that will be shown here (refer to above figure).

So, you can see that this is 0 to 90 Φ_1, then this is 0 to 90 Φ and Φ_2 is taken at different intervals 0°, 5°, 10°, 15°, 20° and up to 90°. Few texture components which we have already seen you can see it here also.

So, the cube will be already in the same sample geometry because in cube, the 001 is parallel to the rolling plane that means it is parallel to RD and 100 is parallel to ND. So, already cube is in the same orientation, you do not require any rotation to bring the two in the coincidence because they are already in the same reference frames. So, that is why you will see that for cube you have Φ_1 as 0, Φ also as 0 and Φ_2 already we are taking the 0 slice here.

So, cube will be at these (refer to above figure) locations. Goss will as I told you that it is 110 plan that means I have rotated the unit cell by 45°. So, it will be somewhere, where you have 45° angle in Φ. So, like that the brass will be somewhere, copper will be somewhere here and another texture component S will be somewhere here. So here, different texture component can be now shown on the ODF. So, now I can get all the texture component information from the orientation distribution function.

So, this is how you can use different representation of texture to understand that how the grain is oriented or If more than one grains are oriented then I can get intensities like these contours (refer to above figure). So, these can be plotted as discrete plot also you can show as points or you can do some kind of interpolation using some mathematical function and then you can plot contours. So, the when the contours are more or their numbers are more that means that it is much more intense.

And that will be able to give you the particular information about the texture. So, I hope you are able to understand all this texture representation. So, in next class we will look at few typical texture which is produced in the material because of deformation or recrystallization.

Key words – Stereographic projection, Pole figure, Inverse pole figure, ODF.