Texture in Materials
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Module - 06
Microtexture measurements using EBSD technique in SEM
Lecture - 35
Analysis using the TSL-OIM Software

Good afternoon everyone, we are continuing with the Module 6 which is Microtexture measurements using the EBSD technique in SEM. So, today is lecture number 35 and we will do understand how a measured you know EBSD map or a measured Kikuchi patterns are basically Analyzed using a TSL-OIM Software by this software basically belongs to EDAX, AMETEK limited.

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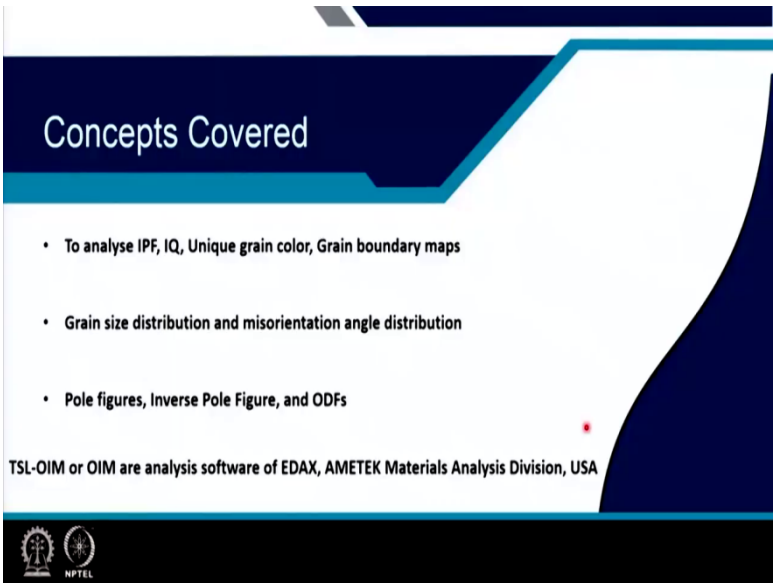

So, the concepts that will be covered in this lecture are how to analyze the inverse pole figure map image quality map unique grain color map grain boundary maps, how to characterize grain size distribution, misorientation angle distribution and how to find out pole figures, inverse pole figures and ODFs.

So, TSL and OIMs are analysis software which belongs to EDAX, AMETEK materials analysis division of USA. We have this software procured in IIT Kharagpur and I will be using that same software to give this information to educate you guys.

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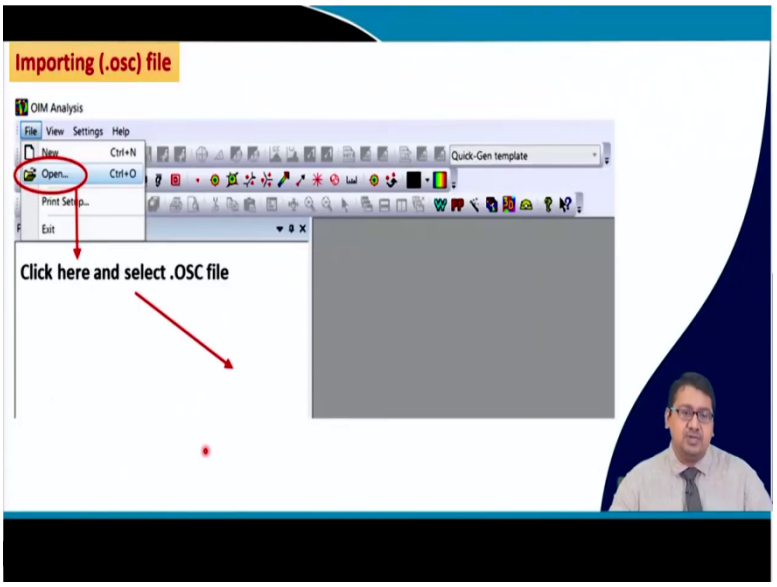

So, you see that in EBSD which is you know mounted with a TSL EBSD detector the measurement software of TSL OIM gives a file when we do an EBSD scan the file name is basically dot OSC file and this OSC file is basically obtained from the measurement.

And the OIM analysis software TSL OIM analysis software basically looks something like this, it has few buttons and one can have more options with the help of a right click right. Now you see when we look into this file we can open a file and we can import that measured dot OSC files.

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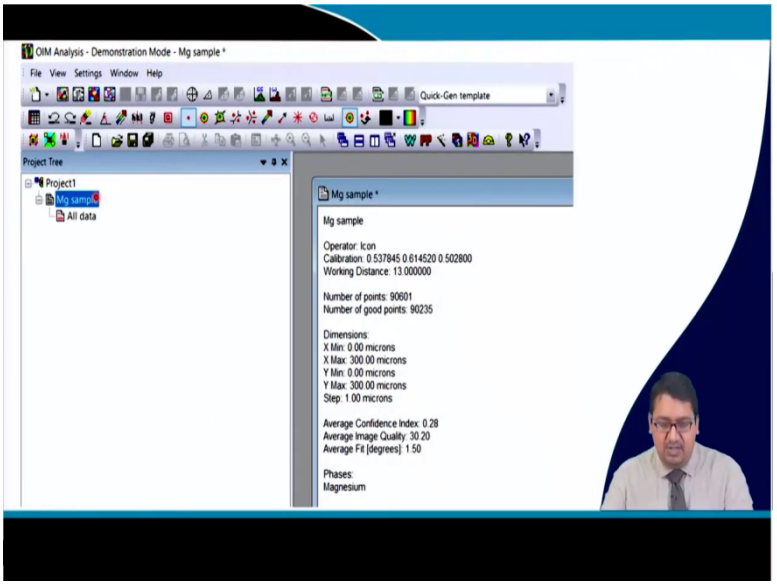

And when you we are in this case you we are looking into a magnesium sample and we are taking it when we do open a file a magnesium file you see the sample name is magnesium sample. And when you open it we see something like this project 1 which contains magnesium samples and it contains all the data of that sample right. And now when we do it what happens that we have a lot of options here you see, this is the option where if we click here we can obtain you know inverse pole figure map.

If we click here we can obtain image quality map or pattern quality map, if we click here we can obtain unique grain color map, if you click here we can obtain you know grain boundary map which will show various boundaries of the grain, low angle boundaries, you know g and bs or high angle boundaries that is grain boundaries on the other hand we can just obtain.

You know a pole figure or an inverse pole figure you know directly yes of course, not a computed one, but a discrete pole figure or a discrete inverse pole figure and then we can get a grain size distribution by clicking here or a misorientation angle distribution by clicking here.

So, there are various you know options which can be utilized and there are more options inside it which can be utilized to solve a research problem related to a certain sample that has been scanned by EBSD. So, if you look into the magnesium sample that were obtained from that measurement file magnesium sample dot OSC. We can get initially an information about that file and that file contains the name of the sample magnesium sample you see operator is icon.

So, the icon is a machine calibrations working distance 13 mm, number of points that are taken is 90601; that means, this is the number of points taken to measure that particular sample area that is the number of times the electron beam fall and the Kikuchi pattern was obtained right in which the number of good points are 90235; that means, the rest of the points does not you know yield a Kikuchi pattern from which the half transformation could not be obtained right.

So, you see here more dimensions of the point X starts from 0 microns and X finishes at 300 microns Y starts at 0 micron and finishes at 300 microns. So, a large area can be scanned also not very small area this one. So, 300 microns into 300 microns means 0.3 millimeter into 0.3 millimeter was scanned, the step size used here is 1 microns the average confidence index

was obtained to be 0.28 of course, it is not very high, but usually in case of materials poly crystalline materials like magnesium which have low atomic number.

They have you know a higher interaction volume leading and they are very difficult to do you know EBSDs when we if we do EBSD on materials like stainless steels or nickel or copper it will yield a much higher confidence index than magnesium samples. Now the confidence index in case of TSL softwares are good if it is greater than 0.08 preferably 0.1 it can be taken into account.

Because as per experience in case of magnesium alloys particularly I have seen that a confidence index greater than 0.1 can be easily taken into consideration to understand what is happening in that quantitative microstructure. So, the image quality is 30.2 the average fit is 1.5. So, we get all the information of that sample information of that measurement right. So, the measurement information are all given here.

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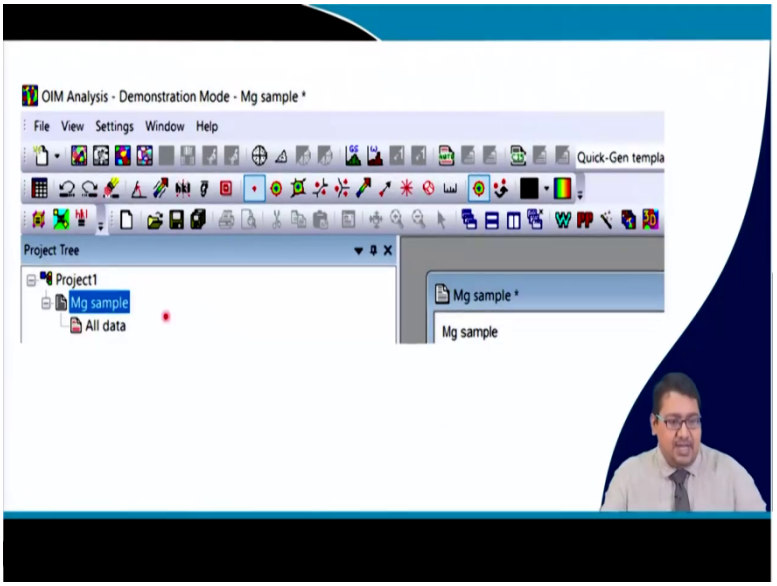

So, if we take this magnesium sample and if we click here right this then we can obtain the you know image sorry the inverse pole figure map. On the other hand if we click in the magnesium sample.

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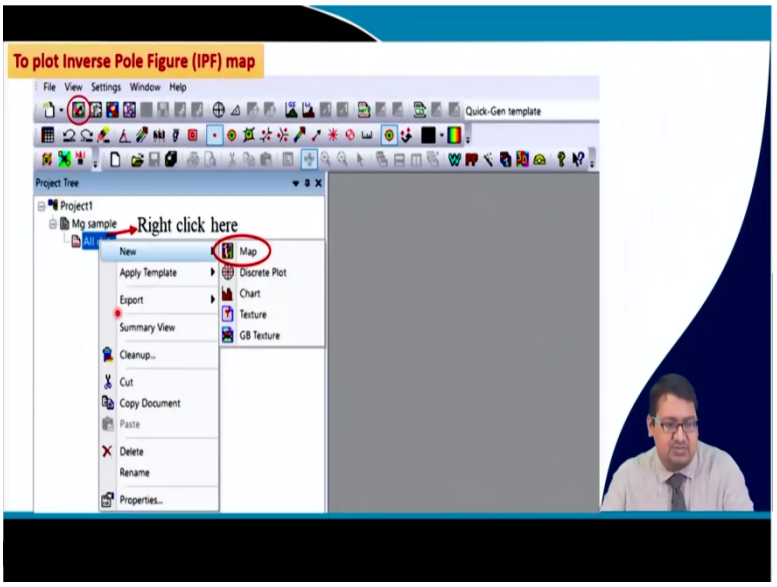

In this all data right click here and get a new and the same map here then what will happen that in a more elaborate way it will be shown.

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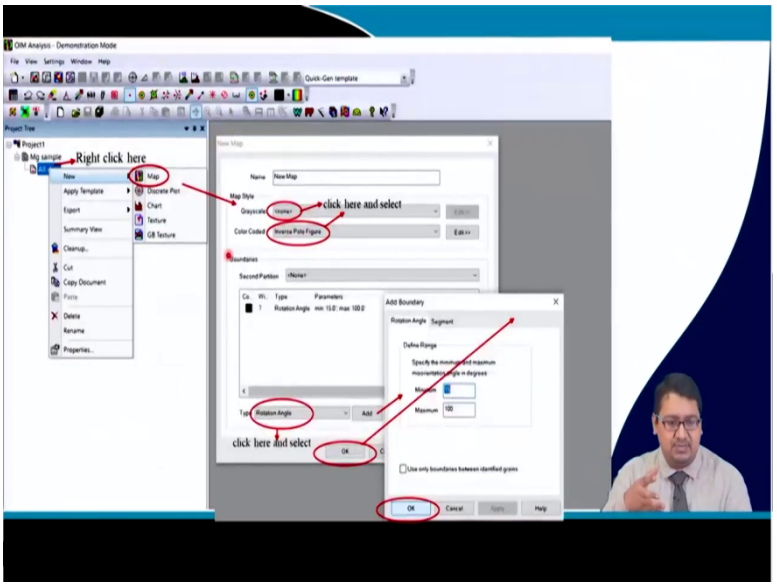

So, how? It will open up in windows something like this in which you will have the map style which will contain a grayscale map and a colored map. And in the colored coded map if we open this portion from here you will see a lot of information means the lot of different types of map that can be plotted.

So, let us take the inverse pole figure one and in the grayscale map we can put none, sometimes we can merge the inverse pole figure map with the grayscale map which is basically the image quality map to see the contrast difference in the microstructure at various strained and unstrained region, but in this case let us say that let us take just the inverse pole figure map.

Secondly, when we take the inverse pole figure map, it shows the color of a grain with respect to its orientation which is defined by the you know triangular color code right and this triangular color code we have defined and we have discussed a lot in previous lectures so I am not going into it is just that particular color of the grain defines its orientation.

So, in order to distinguish between the grains sometimes if the color difference is not that much, we can take a rotation angle and say that ok we take a rotation angle from if we click here there will be various options coming and in which we can take a rotation angle. And then we go to add and then add that rotation angles right. So, we can add say 15 to maximum this is magnesium.

So, it has a maximum misorientation of nearly 98.2 or something. So, we can also click on the segment to increase the thickness of the boundary in order to make it observable for a person right maybe make it more prominent and we will do an ok.

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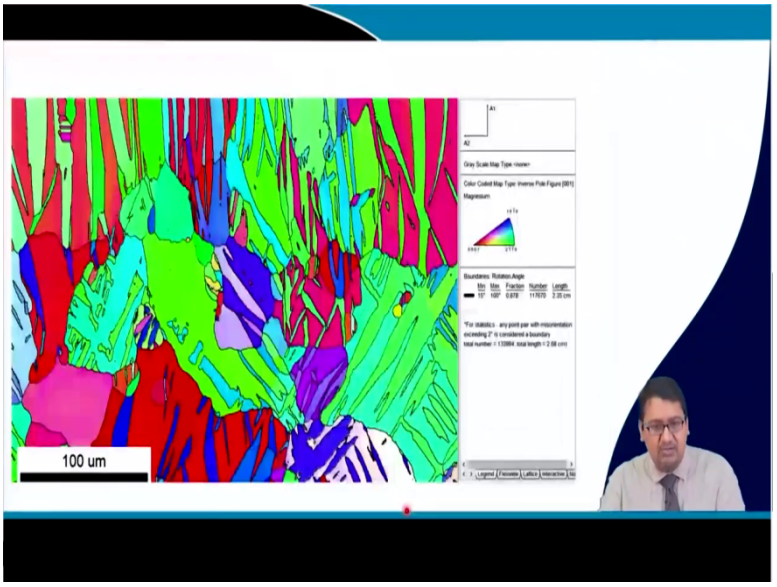

And while we do an ok like this we can obtain this inverse pole figure something like that and you can see this particular inverse pole figure that we have taken it has 3 it has 300 cross 300, but I am showing a little smaller area where you see that this particular image contains a lot of twins in it.

So, the magnesium we can see that magnesium that was actually deformed at a very small strain; however, say a strain of I think 0.1 or something and then it developed a microstructure which looks like this and we have the grain boundaries from 15 degree to maximum and which divides this grains and we can see the whole microstructure.

Here is the you know the triangular inverse pole figure color code which indicates the positions of the 0001 112 bar 0 101 bar 0 as red, green and blue color and therefore, we can say ok.

This is its normal to the screen and it is basically you know 0002, this blue twins have axis normal to the screen as 101 bar 0, this green grain have an axis normal to the screen as 1 0 sorry 2 bar 110 right. So, we get the information of the microstructure, we get the information of the specific texture and so, if we look into the interactive microstructure and if we click on the lattice if we can get the information of the lattice from any point we can we click.

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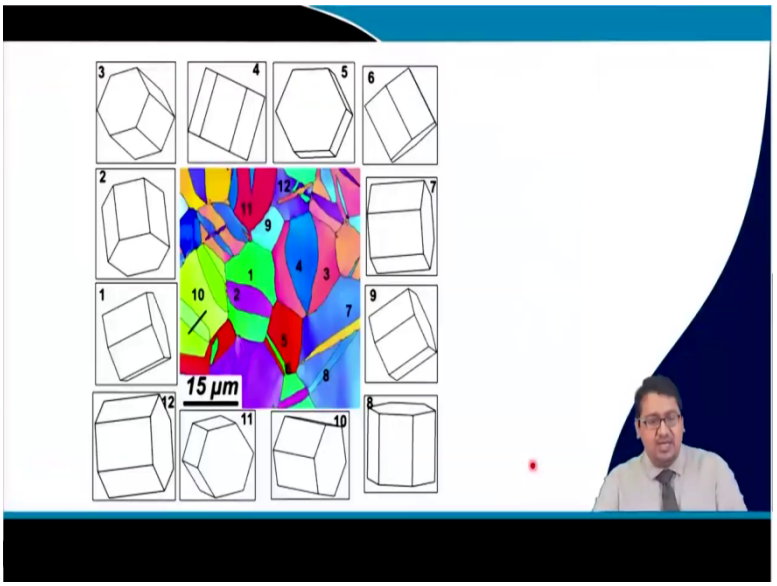

So, here is an example that if we click on here we see that the lattice looks like this, if we click here then we can see the lattice looks like this, if we click here you can see the lattice

looks like this like that. We can see the unit cell corresponding to the RD TD ND like as we have already told that when you put the sample in the EBSD we all already know where is the RD and where is the TD and we tell the software and the hardware that how we are putting the samples.

So, that it can you know it knows that where is the RD or where is the TD that is where are the important sample reference direction and based upon which it can you know find out the unit cells and the orientations definitely.

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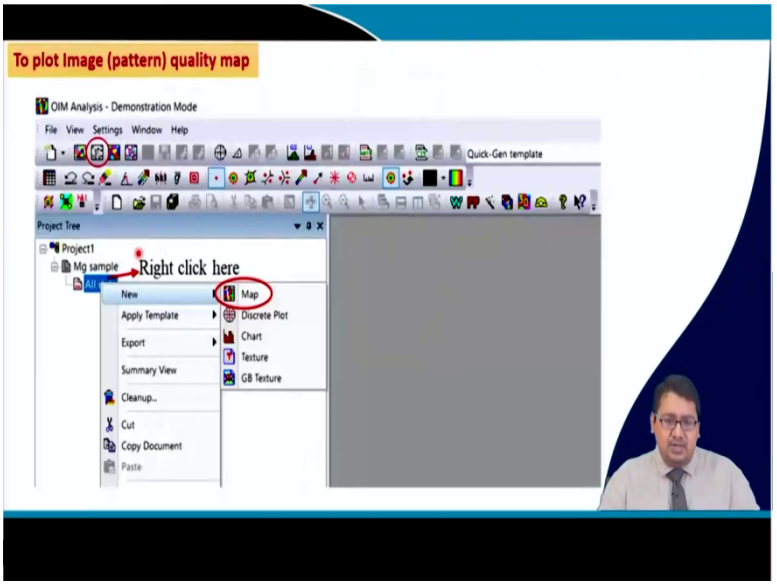

So, not only the you know inverse pole figure maps could be obtained, but also the pattern quality map or the image quality map could be obtained. So, either we can click directly here and we can obtain the pattern quality map for this particular sample or we can right click to new and map and then obtain the same screen and from the drop down menu instead of inverse pole figure map we write pattern pattern quality or image quality map and we get the image quality something like that.

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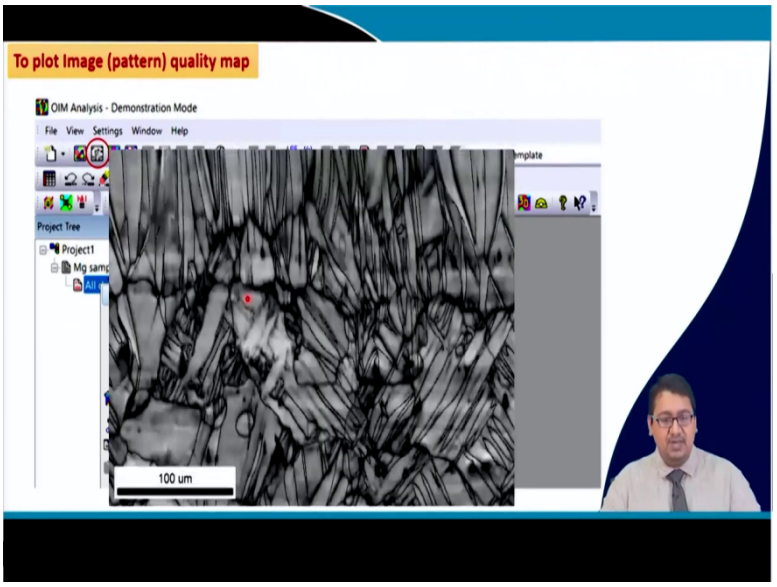

And you see that the image quality map contains areas which are darker and which are lighter, one can see that the grain boundaries become so darker whereas, the other part of the areas become so lighter. So, the pattern quality map depends as I said depends upon the diffuses diffusiveness of the Kikuchi pattern whereas, whenever the Kikuchi pattern is sharp it gives a lighter pattern quality whereas, wherever the Kikuchi pattern is diffused it gives a darker image quality right.

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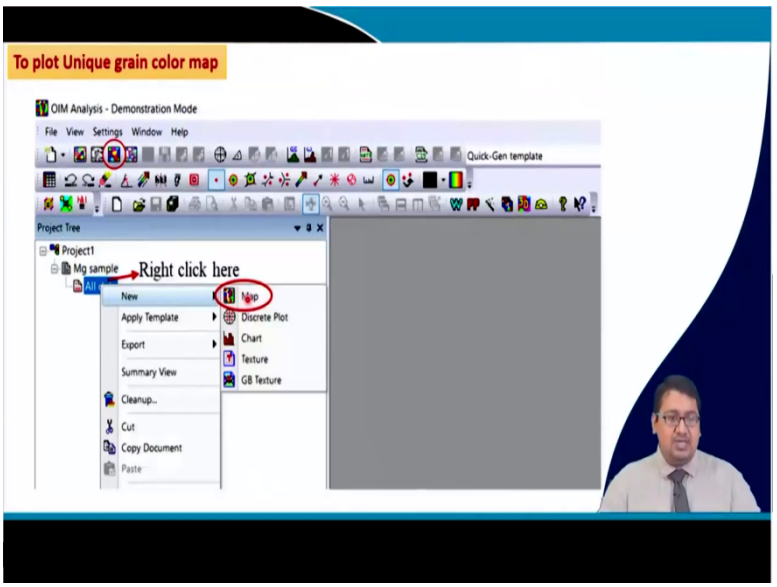

On the other hand similarly one can get a unique grain color map. So, each grain is colored independently of its orientation it just shows different grains in a different color and one can do it by directly left click here or right click and get the map from the drop down menu instead of IPF map or image quality map one can select the unique grain color map and get the unique grains like this right.

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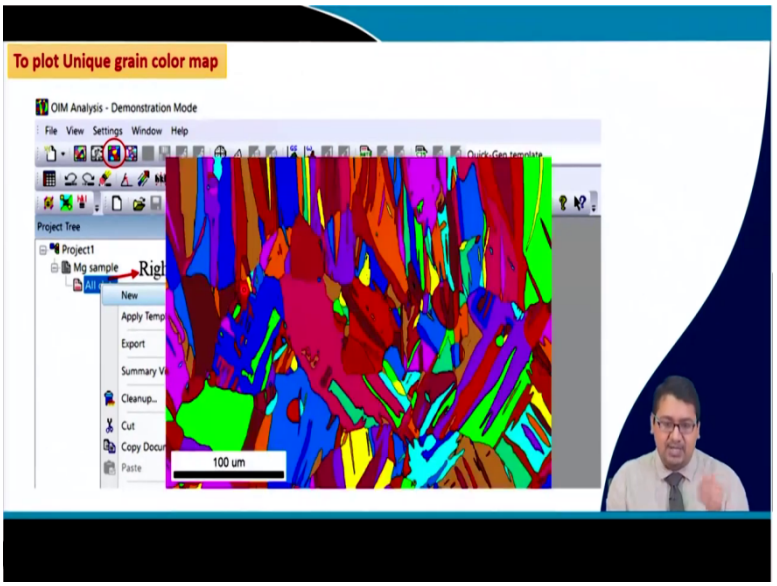

So, these colors of the grains does not represent the orientation, but it is just randomly colored in order to show you how the microstructure will look like and in a color form right.

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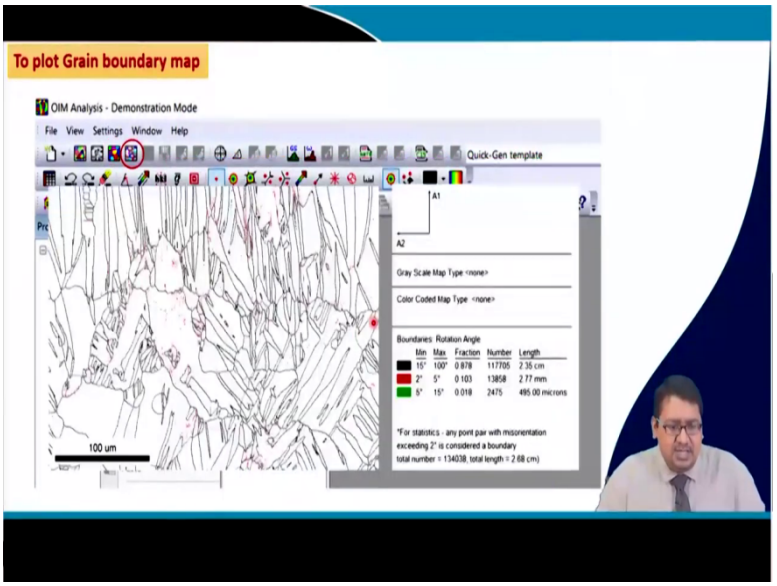

Thirdly we can have the grain boundary map, this grain boundary map will give the you know the boundaries of this particular microstructure. So, here you see that we have divided you know the boundaries at as the black boundaries are 15 to maximum 100 degree and then we have the red boundaries which are 2 to 5 degrees and the green boundaries which are 5 to 15 degrees.

This indicates that there are very few red grain boundaries are present and there are fewer green boundaries are present which indicates that the geometrically necessary boundaries present in this microstructure is quite less whereas, there are lot of you know 15 to 100 degree boundaries which indicates that most of the microstructure contains high angle grain boundaries.

Now the point is that we have not shown here, but we can even distinguish the twin boundaries because these twin boundaries will have certain orientation you know relationship about certain axis. So, it will have a certain axis angle pair and say for example, in case of magnesium most of the magnesium that deforms they form you know extension twinning which is rotated by 112 bar 0 about 112 bar 0 by 85 degrees approx.

So, it forms a boundary which has an axis angle pair which is 85 angle axis pair which is 85 degree and the axis 112 bar 0. So, one can even determine that axis angle pair. So, let us go ahead I am not showing that one.

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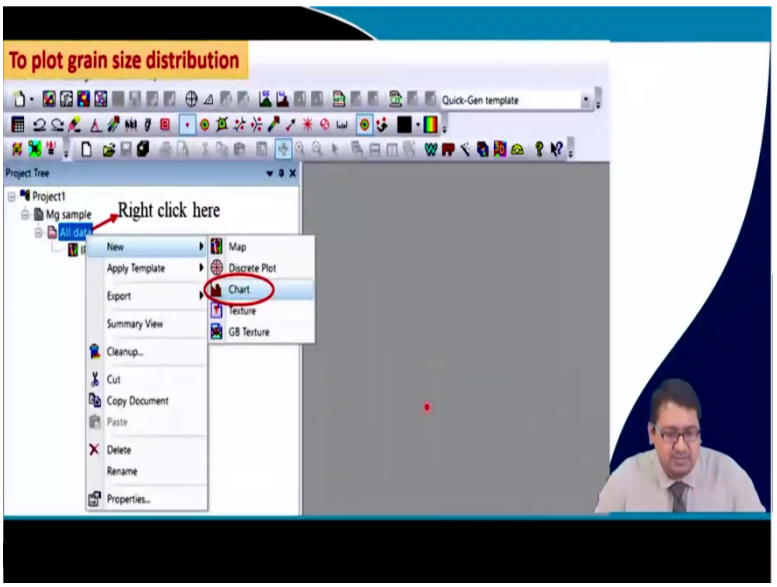

On the other hand we can take that micro structure and we can plot the grain size distribution. So, one can directly click here and obtain the grain size distribution right and it will give you the default grain size distribution in grain size diameter which is I also prefer that one. So, otherwise we can do a right click here, go to new, go to the chart instead of the map we can go to the chart.

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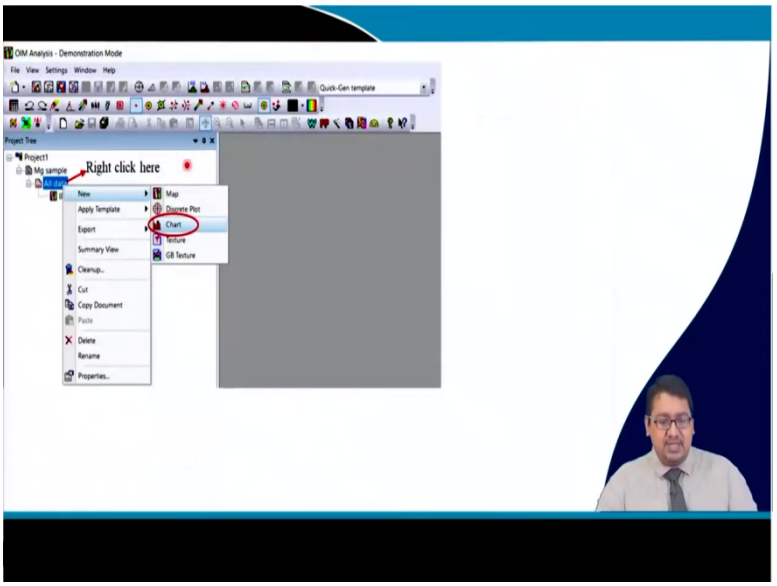

And then a window like this will come up right.

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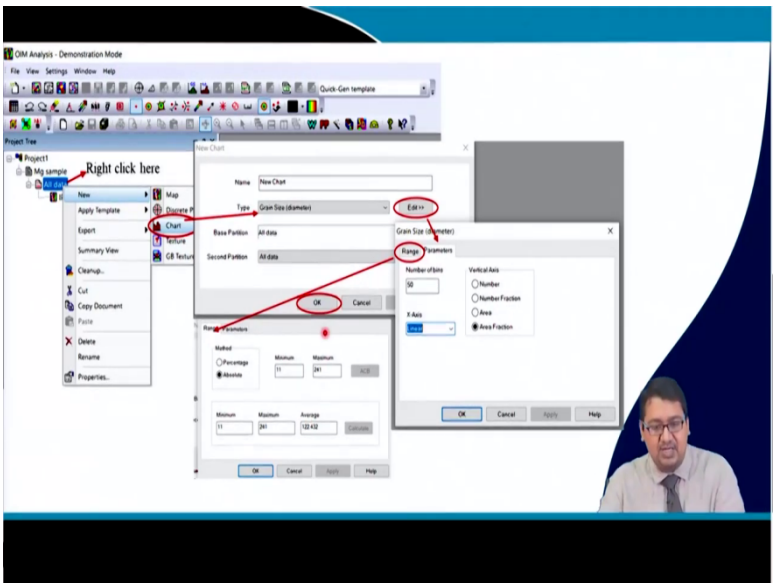

And in this window you see we can get the drop down menu where we can take the grain size in case of diameter and if you like to edit it we can edit the range of the grain size and the parameters of the grain size. So, let us edit the parameter of the grain size say for example, we say that the number of beans that we are taking is 50.

So, in the default case it remains always 20. So, let me let us keeps 50 and then we can take the vertical axis as number of grains or the number fraction of grains or area of grains or area fraction of the grain and I always prefer to show grain size by the area fraction method and so, we can do an ok otherwise we can also do a range change.

So, we can see the range and say that ok we will give the range in terms of percentage or we will give in absolute values. So, we will say let us say I prefer absolute values and we are giving absolute.

So, one can even see that the minimum grain size that is obtained in that particular magnesium sample is 11 and the maximum grain size is 241. So, even the software can calculate the average of these grain size and which comes out to be 122 approx and if we do an ok here we can get a grain size distribution something like this.

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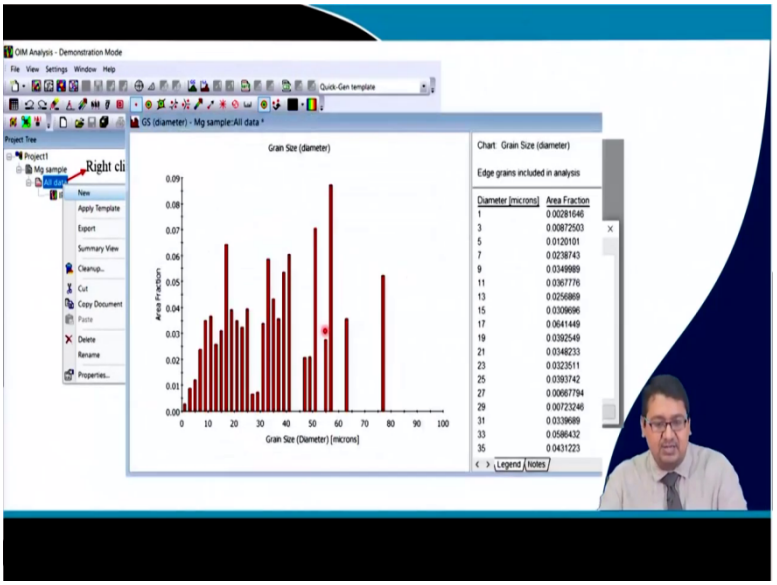

We will not only this kind of a curve, but we will also give get the information of that if the diameter is in the range of 1 micron then the area fraction is this much if it is from 1 to 3 micron the area fraction is this much like that we can get the whole information which can be

exported in the excel file and then we can also get the information of the average grain size in terms of number fraction measurement and in terms of area fraction measurement.

I will always prefer to use area fraction measurement because area fraction measurement considers the larger grains area fraction in terms of its you know area. So, basically the even though it gives a higher estimation of grain size for example, we want to produce a nano structured material and we are deforming it and in case of number fraction we are saying that average grain size comes out to be say 100 nanometer.

However, if we look into the area fraction we found that maybe the average grain size is 500 nanometer in terms of area fraction. So, I know that most of the industries use this 100 nanometer to show that ok we have achieved a 100 nanometer grain size, but it is more appropriate to say that the grain size is in the range of 500 to 700 nanometer, which is like 0.5 to 0.7 microns.

So, using area fraction actually an overestimation of the grain size is obtained which is basically more appropriate in terms of you know a comparison with the mechanical properties of the microstructure and other stuffs right other research and scientific stuff. So, you see that we can obtain the grain size distribution where the X axis is basically the grain size in terms of diameter microns and the Y axis is basically the area fraction like that we can obtain this information in terms of number fraction or area or numbers right.

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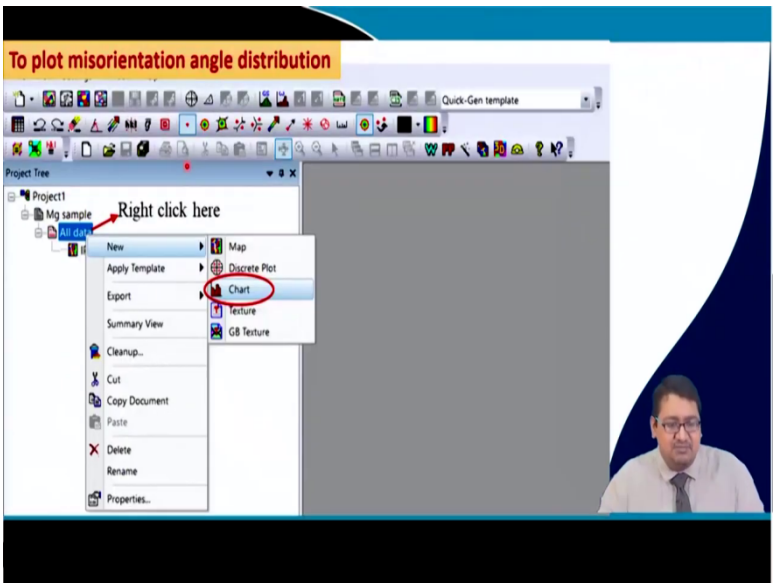

On the other hand if we take this same chart.

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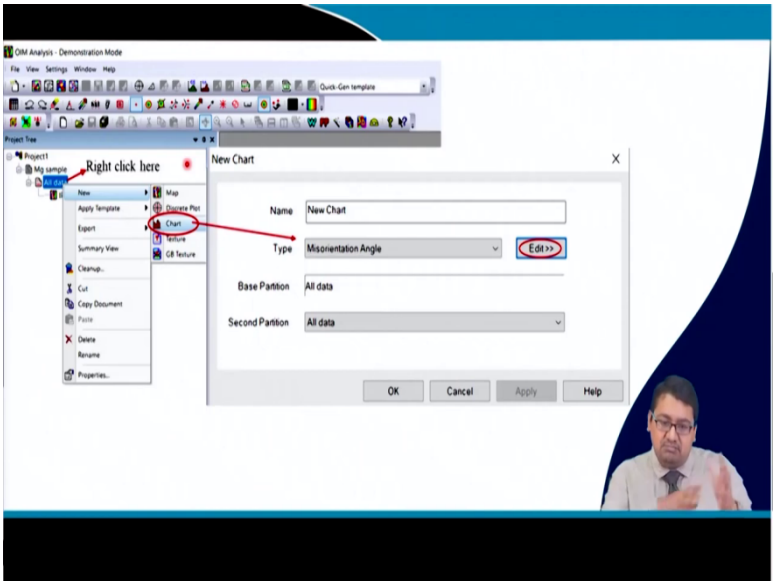

And you know get this you know the same if we click on the chart and we can get we can take the drop down menu instead of the grain size distribution we can take the misorientation angle we can go and edit it.

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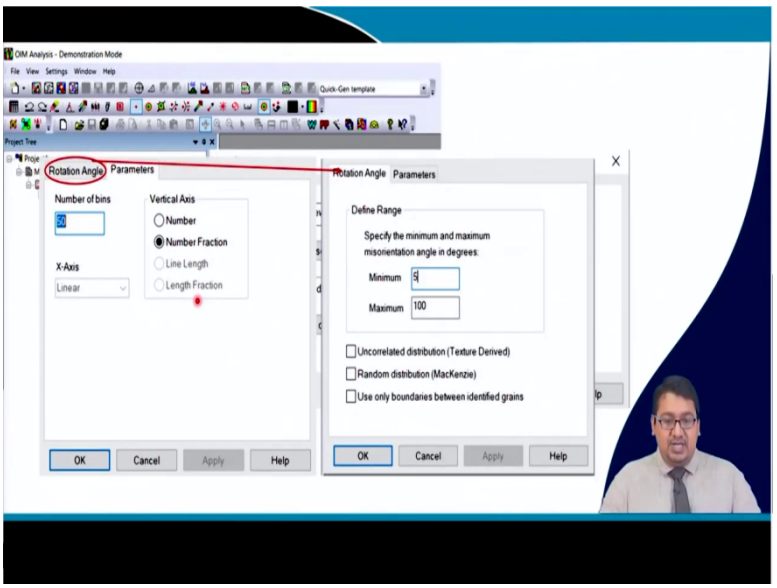

And we can say that ok I want the parameter like same like 50 and here you see that when we are determining the misorientation angle distribution we can get the number in the number

fraction, also sometimes we can get the length and the length fraction, but in this case it is showing lighter; that means, we cannot determine here.

Now, if we take this if we look into the rotation angle and we see that when we are looking into this misorientation angle distribution we can say that ok we will see from minimum 5 degrees to the maximum or you can say ok from minimum 2 degrees to maximum or we can say that no we will we are only going to see the high angle grain boundaries which are you know 15 to 100 we can.

So, this grain size sorry this misorientation angle distribution that we will be showing here will be a correlated distribution; that means, it will only show those misorientations between two adjacent pixels right. So, a microstructure that has been computed using EBSD measurement that is a quantitative microstructure and it will compute the G matrix of one pixel and another pixel which is which are adjacent and only the misorientation of those you know adjacent pixels will be calculated so that will be a correlated distribution.

On the other hand one can also find out you know tick here and get the uncorrelated distribution that is a texture derived distribution which will be certainly different because now the spatial relationship between the two pixel adjacent pixel will not be there. So, a pixel is taken and the misorientation between all the other pixels will be calculated for that particular texture.

On the other hand if we tick here and we can get the information of the random distribution; that means, if it is not a textured material so one can say that one can get the McKenzie plot. So, I will ask the students to go and check what is McKenzie plot ok.

So, and on the other hand we can use the you know only those boundaries which are between the identified grains, but yes this two are sufficient and if we do an ok here and then go back and do an ok here what will happen that we will get the misorientation angle distribution.

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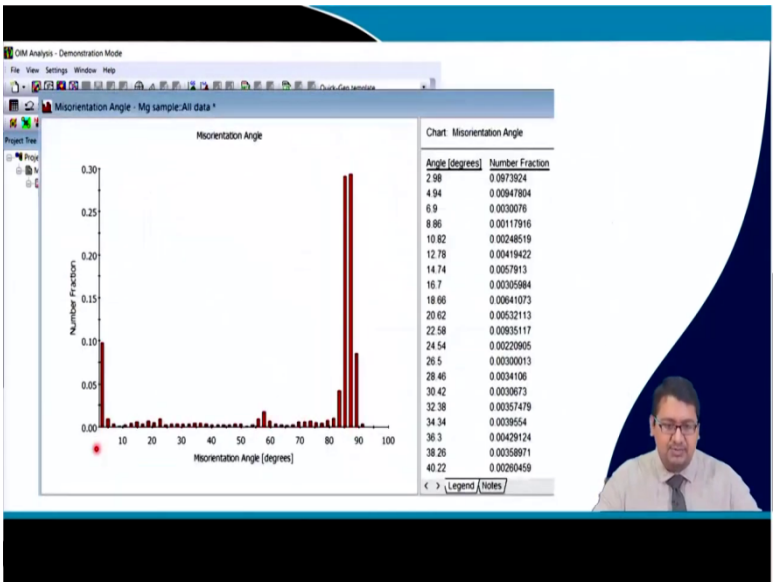

So, we will not only get this curve or plot we can we will also get the information of the angle that ok up to 2.98 the number fraction is this much up to 4 point from 2.98 to 4.94 this much like that the whole information up to the maximum you know miss orientation angle. And you can see this grain size distribution the X axis gives the angle misorientation angle in degrees and the Y axis is giving this in terms of number fraction.

Now you see that as I said this particular material if you remember the inverse pole figure map just go and go back to the slide and see what is the inverse pole figure map looks like it and also go to the grain boundary map and see there is very less fraction of low angle grain boundaries right here. So, the GNB geometric necessary boundaries are actually so low.

So, though it is higher you see the boundary which is starting from 0 to 10 to 15 degrees you see that there is a small fraction point one fraction of the boundaries which is mainly low angle boundaries which are geometrically necessary boundaries and then you see there is a flat response of the presence of you see random boundaries.

There is a small peak here you see and there is a large peak here and this large peak you, what we can see here this large peak corresponds to something around 86 87 degrees this basically corresponds to the angle this basically corresponds to the angle that has formed due to the formation of extension twinning which has a rotation angle pair with respect to an axis 86 or 87 degrees along 112 bar 0. So, this is also called 101 bar 2 extension twins.

So, a large portion of the microstructure basically consists of this extension twinning and you can see that how much fraction it is. If we take this line it is 0.3 this line it is 0.3 so, 0.6 and then if we calculate this lines also. So, it will increase its intensity to 0.7 or 0.75.

So, about 0.75 fraction of this microstructured this microstructures grain boundary is basically the twin boundary which will be a special boundary definitely right. So, it will have these will be definitely have you know have a coincidence site lattice and therefore, these are coincident site lattice boundaries.

Now in order to prove that these are coincident side lattice boundaries one can even draw an angular IPF map I am not showing it here for the angle 86 degrees with a certain deviation plus minus 3 degrees and can see that the intensity of the triangular inverse pole figure angular map for 85 degree is highest at 112 bar 0 or near to it, which indicates that this is a special boundary with a specific angle x sphere.

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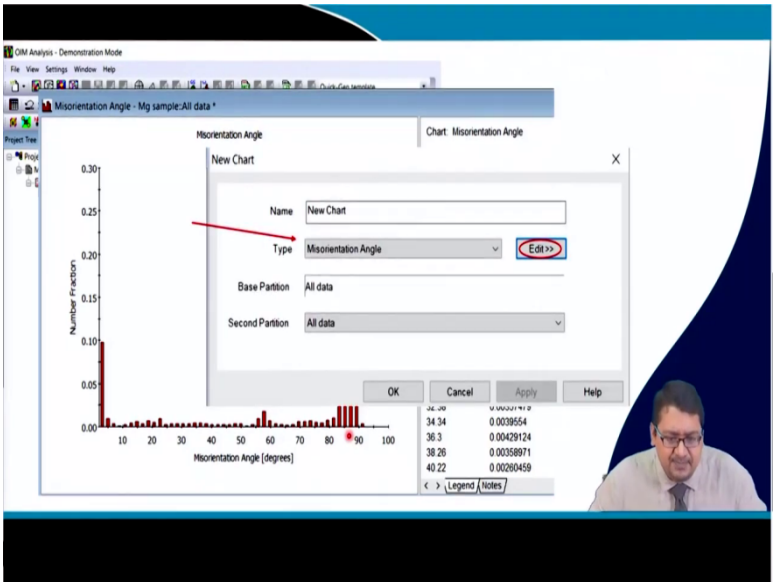

Now, if we look into this misorientation angle and edit as I said.

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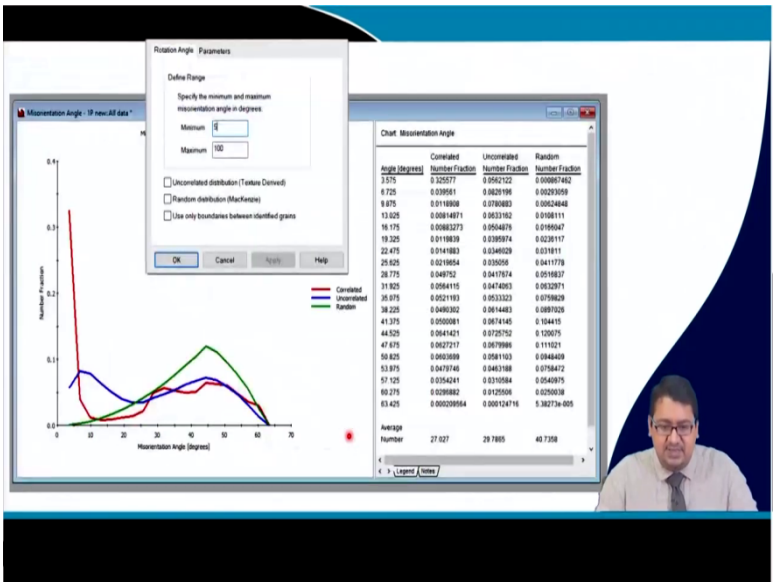

And we can we tick on both uncorrelated and the random, apart from the misorientation angle you know bar chart if we see this in terms of the plot like this the bar chart will come up to looks something like this right and if we look into the you know McKenzie distribution it will come and look like this if we look into you know the uncorrelated texture derived that is which has no spatial relationship it will look something like this.

I hope that you would not get confused here because where I am showing this misorientation angle map this misorientation angle map this relationship is for a different you know material and for a different sample. So, it does not show a peak here at 85 degrees or somewhere right.

So, you see this is just for an for example, and showing that how TSL basically computes the information that is obtained from the EBSD and how we can utilize it to solve our problems in the research scientific and industrial field right.

So, not only this curve we can get the information in terms of angle correlated number fraction, uncorrelated number fraction, random number fraction and then we can even plot this information using excel or other things and one can get and you can also do various calculations related to your problem to solve these scientific problems of yours right.

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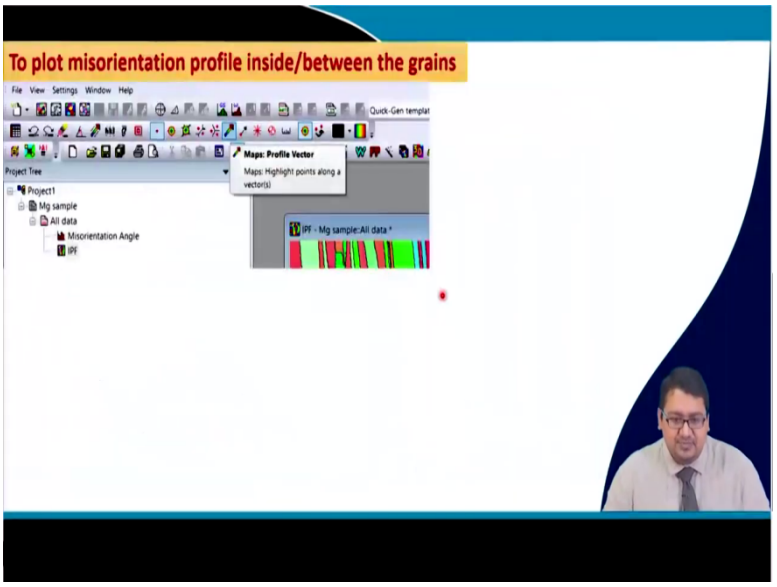

So, not only we can see the misorientation angle distribution, correlated, uncorrelated, random McKenzie we can also obtain you know the misorientation plot inside and between the grains. So, in order to do so, what we take, we take this the what you call the software page and we can click directly here right. So, it gives a map for the you know profile you can allows you to map the profile vector ok. So, it will ask you to highlight the points along this vector.

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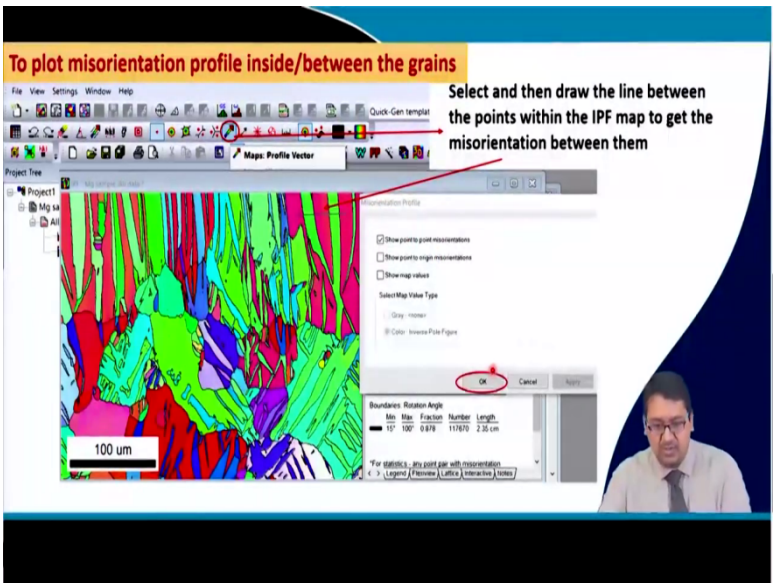

So, say here is this microstructure the IPF map and I say that I am highlighting the points from here to here right, you can see this faint line that which we have highlighted. Now after we have highlighted we it I will we will be asked by the software that what do you want means, you want to show the point to point misorientation or you want to show the point to origin misorientation.

So, depending upon our requirement we will show either point to point or point to you know origin and let us in this case let us see tick here and do an ok here to see that what we can obtain.

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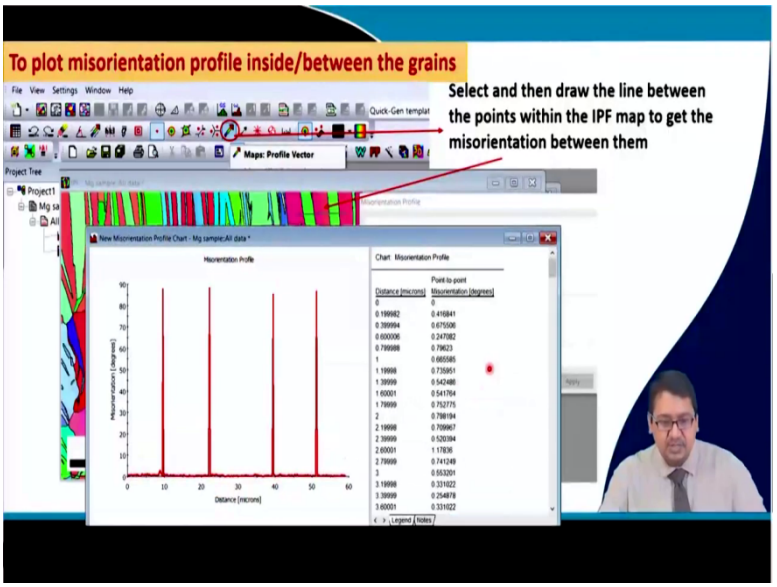

So, if we look we have obtained point to point misorientation and when we are looking into this you know line and you can see that the pink grain is converting into green and then pink and green and pink right. So, there is a considerable amount of orientation difference so, mismatch of the orientation between them. So, the misorientation that will be coming out in this line you see will be having no peak and suddenly very high peak up to 87 88 degrees and then no peak and so there will be 4 peaks.

So, 1 2 3 4 peaks could be observed and each of these peaks are in the range of that 84 85 87 90 degrees which is basically the shows that is this are twin boundaries with 85 degree peak and if we look into the axis of these boundaries it will come up to be 112 bar 0 and the software can also show that this axis is 112 bar 0 by the same formulation of the angular inverse pole figure of course, I am not showing it here how to calculate it.

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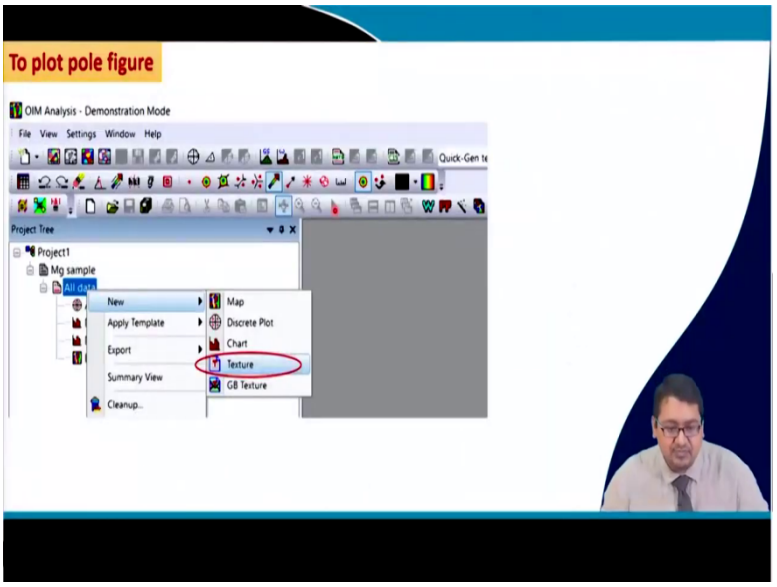

So, apart from that if we look this is that was the microstructural things that can be computed using this EBSD related TSL OIM software, on the other hand one can compute the pole figure right. So, let us come to that measurement of texture micro texture how it does. So, one can compute the pole figure.

So, if we look into the pole figure either we can get directly click here and get the discrete plot of the pole figure for a certain HKL plane the lowest HKL plane may be and then on the other hand one can do take the all data go to new and instead of map and chart go to the texture and once you go to the texture a window something like this will open.

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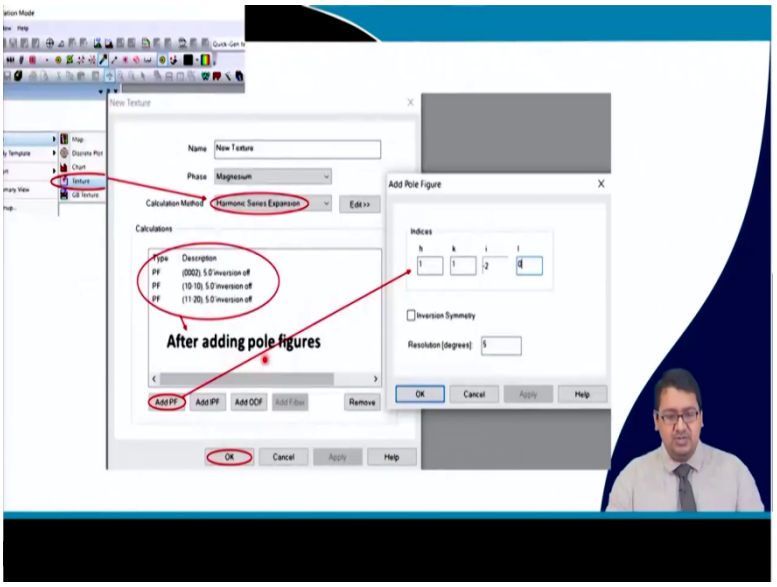

Now, if we want to plot the pole figure what we can do, we can go here we can say that ok I want the calculation method there will be various method discrete binning, harmonic expansion series expansion and let us take the harmonic series expansion for example, and then let us add pole figures right. So, if we add pole figure say we are adding first 0002 and then we are adding 101 bar 0 and then we are adding 112 bar 0 right and we do an ok and thereafter if we do an ok.

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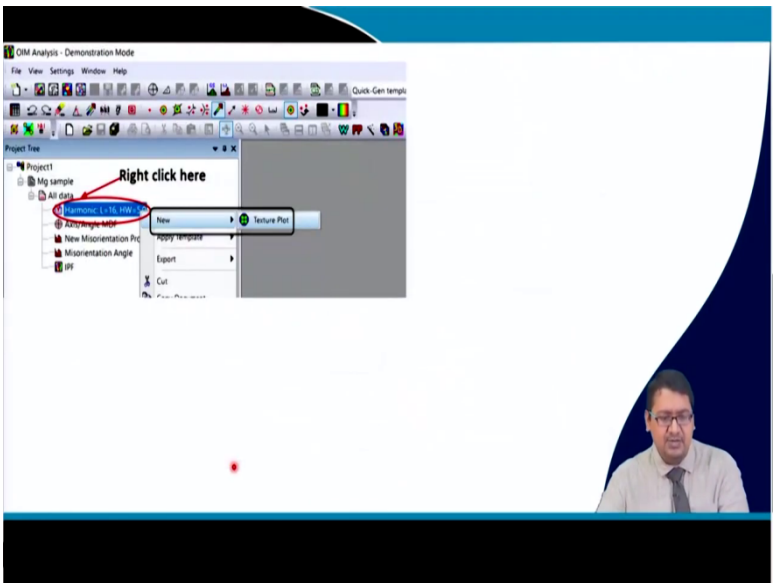

Here what will happen, we will it will do a calculation. So, it will take some time for the software to calculate the pole figures and thereafter another you know point harmonic function with L equal to say the number of times it has iterated the harmonic expansion function in this case we have iterated it 16 times I like to iterate it more than this and I like to keep it 22 it gives a better I think texture plot. So, from here if we click we get right click we get a new texture plot information and if we click on the texture plot we will get a window something like this.

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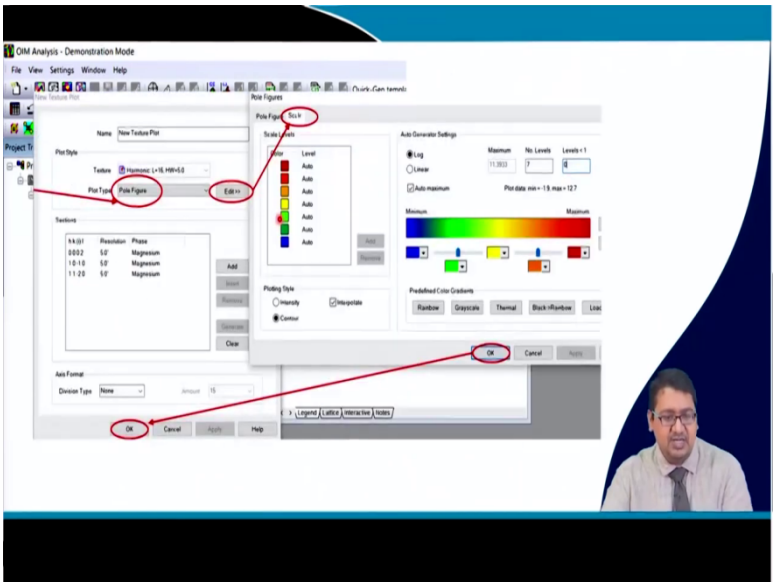

So, the window will show that what you want to plot? We want to plot the pole figure it will show the harmonic expansion function has calculated up to 16 iteration with an H W of 5 and if we go and do an edit, we can do an edit of a scale where we can say that ok we want this in log scale or we want this in linear scale and then the number of levels we say this levels are in MRD right as I said multiples of random distribution.

So, the level 1 is basically random and less than level 1 is the intensity is positions which are less than random right. And of course, in a textured material in some position the intensity will be very high then in some positions definitely the intensity will reduce to less than random right.

So, levels less than 0 levels less than 0 are put as 0 because we do not want to see the levels which are less than levels less than 1 is kept 0 and because we do not want to see the levels

which are less than random right, we want to see the levels which are intensified more than random to see the orientation or the texture information right.

So, let us say we have taken 7 levels and we can show this 7 levels in terms of a rainbow type color which I prefer sometimes because its easy to distinguish and then one can say that ok we will plot only intensity contours or we can plot you know pole figure plot.

Now, if we take the contour and if we take rainbow and if we take this 0 and this number of levels and maximum can also be you know what you called maintained or you know manually controlled, if we untick this auto minimum and as we can see that the plotted data will have a maximum intensity of 12.7.

So, one can say ok maximum can be kept as 11.3 or one can say that ok I would like to keep maximum like 10 or I want to keep the maximum MRD as 9. So, after doing this we do an ok and then finally, we do an ok here to find out the pole figures.

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So, you see in this case as I said that we have measured 3 pole figures 0002 101 bar 0 and 112 bar 0 and in this case when the software basically plots the pole figure, it plots the pole figure in terms of A 1 and A 2 and one can you know have the preference; however, to put the A 1 and A 2 with respect to how the samples are sample is means put into that SEM chamber right based upon the direction in which you are putting.

So, in this case the A 1 is vertical, A 2 is this side horizontal and you see that the software has used the right hand thumb rule to do it because you see A 1 to A 2 along ND right which is A 3 in this case and say for example, the software knows that A 1 is rolling direction and A 2 is the transverse direction, in A 3 which is coming out of the screen is the ND.

Now we can observe the intensity points where the intensity of the orientation is higher and the no intensity points are present where the intensity is lower than 1 and you can see that we can have the values of the intensity with indifferent color and we can distinguish now that ok.

That this intensity about 8.809 like will be somewhere inside these positions right inside this positions and as I said that while we have plotted this pole figure we can also take an option to you know see that if the deformation is you know orthorhombic then we can take you know or it is triclinic. So, we can take triclinic symmetry, we can orthorhombic symmetry or we can take the you know axial symmetry.

So, in this case when you have plotted we have not taken any sample symmetry of the material and we have just considered this to be triclinic. So, there are options in this software to change this triclinic symmetry into orthonormal or axial symmetry. For example, if you are looking up the texture of an extruded material from the extruded direction then the axial symmetry can be utilized to get the more better information right.

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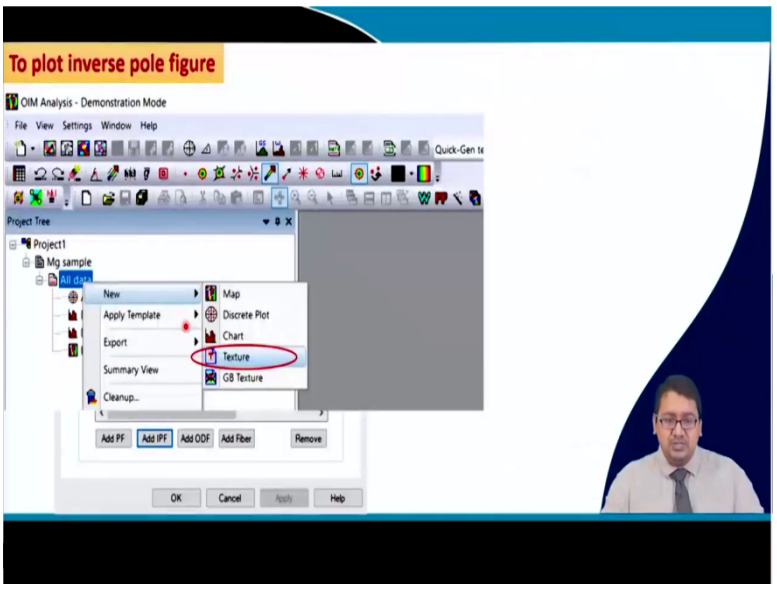

So, apart from this pole figure one can also measure the inverse pole figure and the same thing the same you know place where the all data is right clicked and then new texture.

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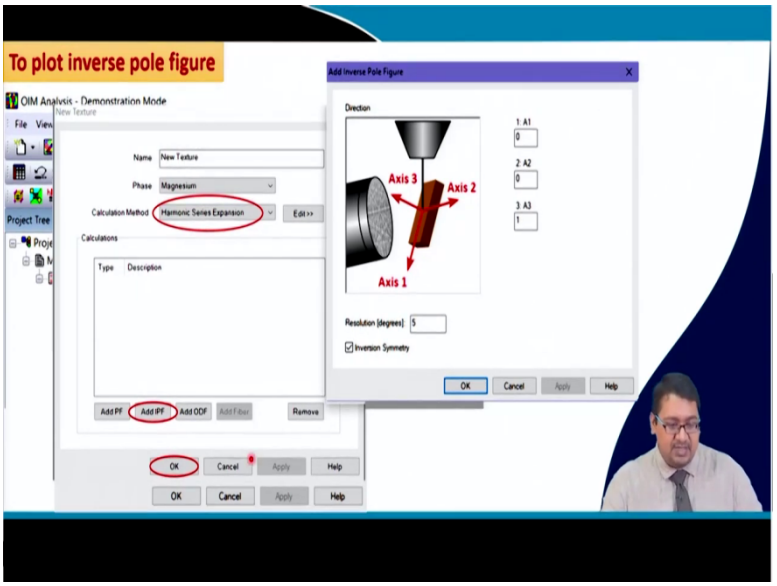

And then it is clicked and a window such occurs we are using the harmonic series expansion as usual and instead of adding the pole figure now we are adding the ipf. So, when we click on the IPF we get an information something like that and it is saying that this is axis 1, this is axis 2 and this is axis 3.

So, if we are kept this if we know that this is RD this axis 1 and if this axis 2 if we know that this is TD and this axis 3 if we know as ND then if we are putting 001; that means, we want to see the inverse pole figure with respect to RD right A 3 sorry A 3 means axis 3 that is ND and then if we want to see the inverse pole figure with respect to A 2 which is axis 2 that is TD and then if we want to see the inverse pole figure with respect to axis 1 then we will put 1 here.

So, we will put 001 for ND, 010 for TD and 100 for RD and we will use the inversion symmetry, so that it knows that it is symmetric inversion. Now, therefore, we will tick here and then if we do an ok here and finally, do an ok here what will happen, it will calculate and then similar to that which obtained which was obtained in the pole figure one a harmonic expansion or something like that will be shown. So, if you click on it, it will show new and then texture plot.

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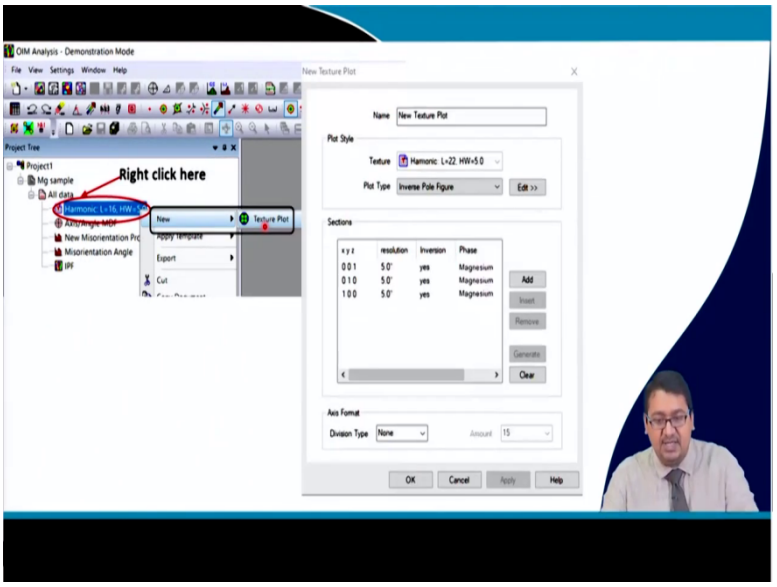

And then it will give the information in terms of this you know window where we will see 001 010 110, resolution is 5 0, inversion we have taken yes, phases are magnesium this is inverse pole figure. So, we can either edit the contours and scale and all these things or we can plot it directly and we can say that you see that 001 is respected with respect to z which is ND 10 sorry 010 with respect to TD and 100 is for respect to you know RD.

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So, here are the you know inverse pole figure that is obtained. So, this is 001 inverse pole figure that is the ND inverse pole figure, this is the 010 pole figure which is the TD inverse

pole figure and this is the 100 pole figure which is the RD inverse pole figure. And you can see that all this inverse pole figures have their intensities of the sample with respect to the crystal reference system as opposite to that of the pole figure right.

So, these are the crystal reference systems and the intensity of the ND is shown here, the intensities of the TD is shown here, the intensities of RD is shown here right are shown here right.

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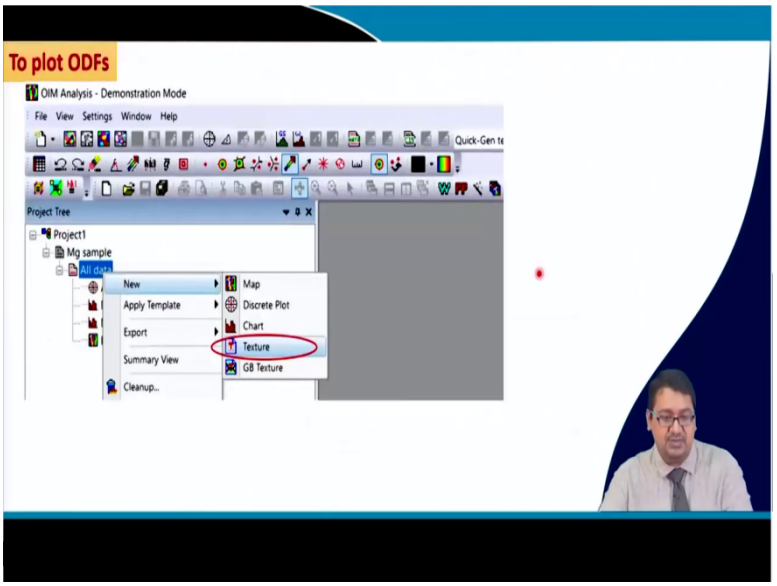

So, finally, if we would like to plot the Euler space or the Euler angles and we definitely plot them in terms of orientation distribution functions which is ODFs we take the same you know path where to we will do a right click go to new and you know click on the texture.

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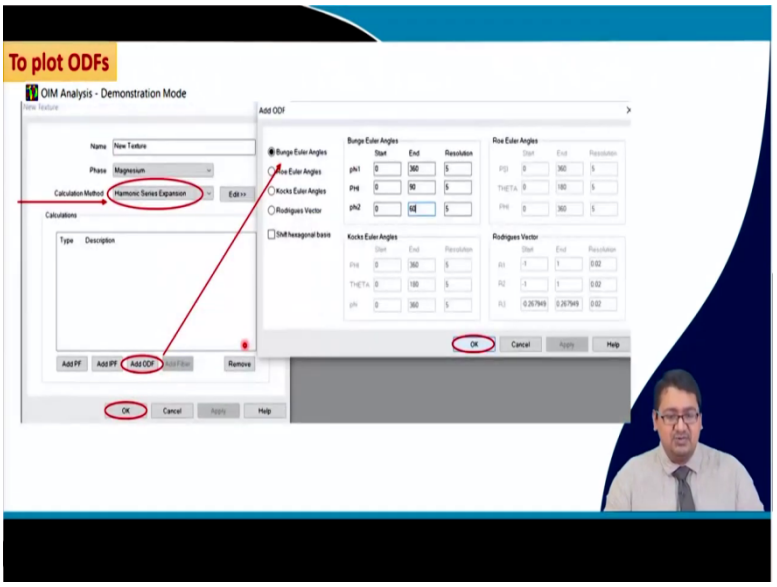

And when we click on the texture the same window will open, but this time we will click on the orientation distribution function we will take the harmonic series expansion. And then we will we can have we have the you know we can use Bunge Euler angle, we can use Roe Euler angle, we can use Kocks Euler angle, we can find out Rodrigues vectors, but we will use the Bunge Euler angle to because it is used most widely and most of the researchers and engineers they are familiar with the Bunge Euler angles.

So, you see phi 1 0 to 360 phi can also be taken from 0 to 180 as I said, but we are taking phi equal to 0 to 90 and this is because of the symmetry and then phi 2 0 to 60 this is also because of the you know symmetry of the crystal. So, because of the symmetry of the HCP crystal we are taking phi 2 equal to 60 because 6 fold symmetry of the HCP crystal we are talking about magnesium 360 divided by 6 becomes equal to 60 and there is one mirror plane a separate mirror plane which is dividing the phi from 180 degree to 90.

So, here we will be plotting phi 2 sections in case of magnesium we can like in other material we can get phi 2 sections from 0 5 degree 10 degree 10 15 degree like that up to, you know how many means up to 90 degrees or whatever is suitable. So, but in case of magnesium mostly 0 phi 2 equal to 0 and 30 degree is shown and that is enough to show the texture, phi 1 is from 0 to 360, phi is from 0 to 90 and if we do an ok here.

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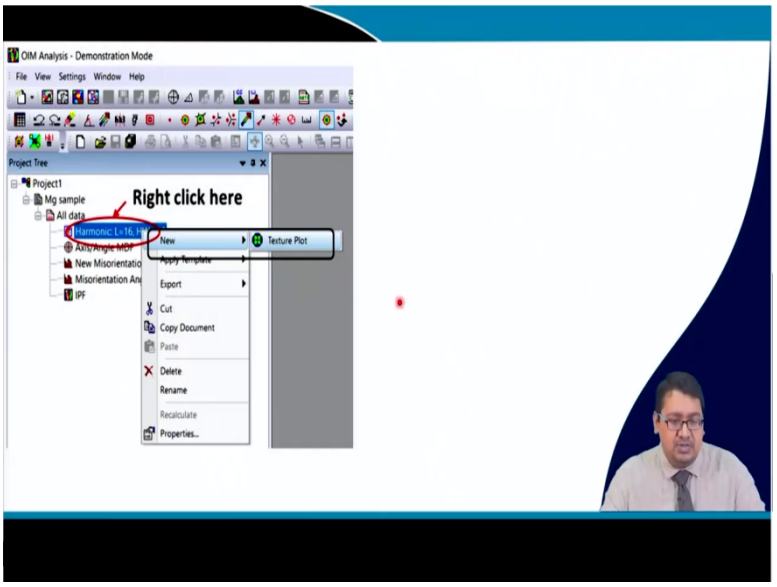

Then it calculates and go to the same position we have to right click new and we can we have to go to the texture plot.

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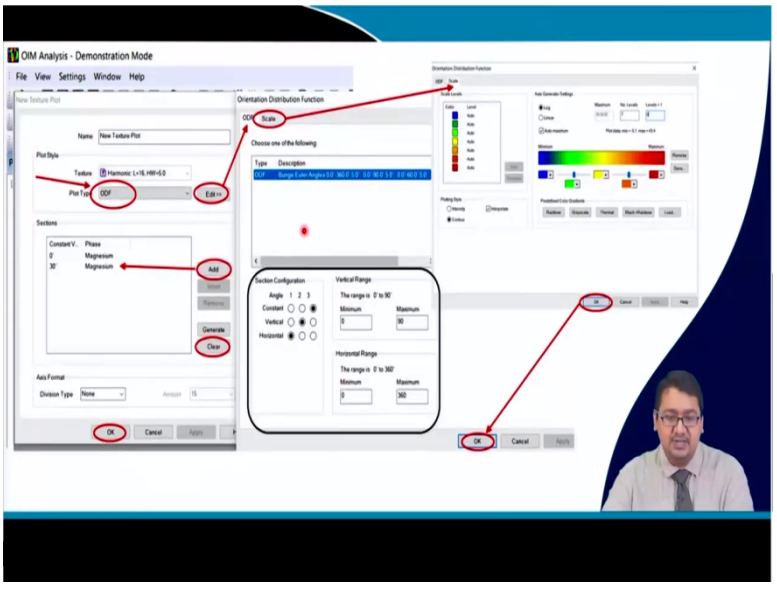

If we click here it will give an window something like this. And the window will tell us to either add or remove and so as I said we will only plot 0 to 30 degree we will add and put phi 2 equal to 0 and 30 degree.

And if we look into if you if before we plot if we try to edit it, we can edit the scale and as I said in case of the pole figure we can edit it log, number of levels and levels which are less than 1 which we will keep it to 0 and then you can use rainbow grayscale or whatever scale thermal in order to plot this you know pole figure intensity sorry orientation distribution functions intensity and then we want to you know plot phi 2 sections right.

So, if we want to plot phi 2 sections we can see there are angles 1 2 and 3 which indicates phi 1 phi and phi 2 so, 3 is phi 2. So, we will kept 3 which is phi 2 a constant and then we will keep phi as vertical and phi 1 as horizontal. So, the vertical range that is the range of phi is basically 0 to 90 degree as we have said, the horizontal range becomes 0 to 360 degree because we are not taking any sample symmetry in this material and we are using triclinic symmetry right.

In case of ortho normal symmetry it will become 0 to 180 and sometimes it may also become 0 to 90. Now, if we are adding only two phi 2 section 0 and 30 degree phi 2 section and if we are doing an ok here what we will find we will get something like this.

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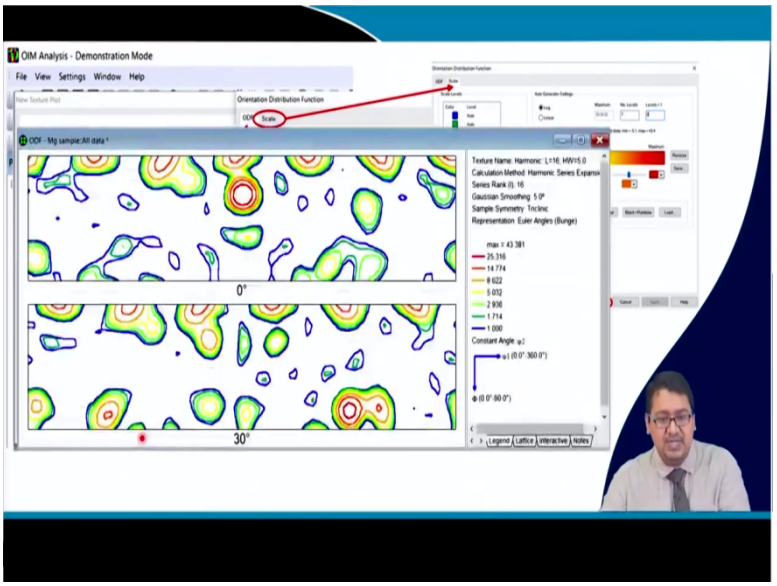

So, we are getting here two orientation distribution functions for phi 2 equal to 0 section and phi 2 equal to 30 degree section, where the horizontal axis is phi 1 the vertical axis is phi the horizontal axis is starting that is the phi 1 is starting from 0 to 360 degrees, the vertical axis which is phi is starting at 0 degree and finishing at 90 degrees.

We can see that how the different intensities are forming in this material at phi 2 equal to 0 and 30 degree just to give you a brief information why we are taking 0 and 30 degree because most of the time what happens that during deformation, the deformation is accompanied with recrystallization. So, deformation forms deformation texture and recrystallization leads to rotation of the orientation by certain angle.

And in the later lectures I will show you in case of magnesium or in case of hexagonal crossbar material how this kind of situation takes place such rotation leads to form certain intensities at phi 2 equal to 30 degrees and therefore, these 2 phi 2 equal to 0 section and phi 2 equal to 30 degree sections are important to be observed in case of hexagonal close packed material mainly. This is not only the complete picture the complete picture also I should say in order to show you the complete picture I should say.

That not only the ODFs has to be shown in terms of phi 2 equal to 0 or 30 degree sections or phi 2 equal to 0 5 10 15 20 30 degree section it can be shown in terms of phi section or phi 1 section depending upon the requirement of the research or the you know the information we want to take up from this orientation distribution function or Euler space.

One can see that the intensities of the Euler's this ODFs are shown from 1 to 25.36. So, the red ones is 25.36. So, we can see that this position or these positions will have the highest intensities and the positions where there are no you know contours those positions will be having lower than 1 intensities that is the texture intensities in this positions are basically lower than the random.

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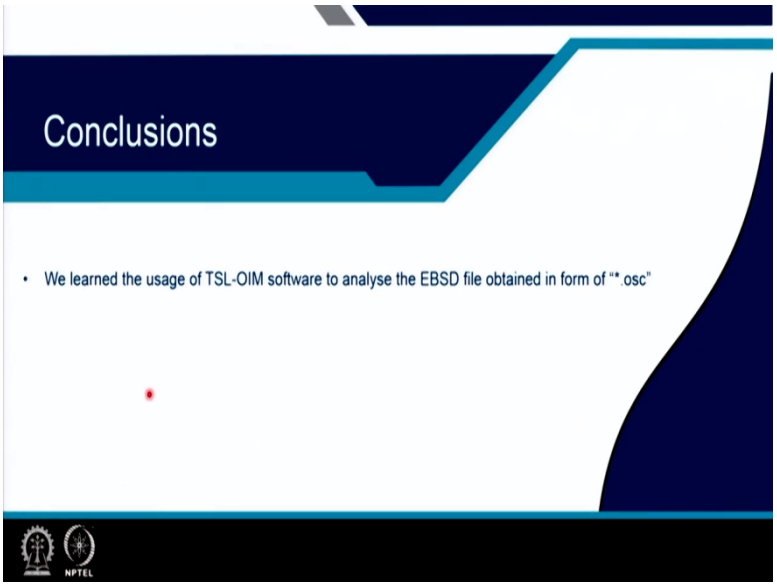

So, this is all for today's class. So, we can conclude that by you know if we learn the usage of TSL OIM software, we can analyze the EBSD data which is obtained in terms of OSC to obtain various kinds of information that I have shown like inverse pole figure image, quality map, texture, in terms of pole figure orientation distribution, orientation inverse pole figure and also we can get microstructural information like grain size distribution, misorientation angle distribution.

And in and there are more you know integral details that can be obtained like you know grain orientation spread, grain kernel average misorientation, G rod grain rotation orientation deviation and there are many other features which can be utilized from the software where you can use it to solve the problems related to your research in you know on texture and evolution of texture and its correlation to mechanical properties electrical or semiconductor properties whatever. So, thank you very much for this for your consideration, take care bye, bye.