Texture in Materials
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Module - 06
Microtexture measurements using EBSD technique in SEM
Lecture - 36
Analysis using the AZtecCrystal Software

Good afternoon everyone. And, today we will be continuing with the module number 6 which is Microtexture measurement using EBSD technique in SEM. And, this is lecture number 36, in which we will try to analyze texture data EBSD data, obtained from EBSD measurement in you know oxford instruments you know EBSD detector. And, the file we will try to analyze it using the AZteccrystal Software, which is of oxford instruments.

And, now it is this is the latest software by oxford instrument for EBSD measurements and analysis and is available in their website which is oxinst dot com.

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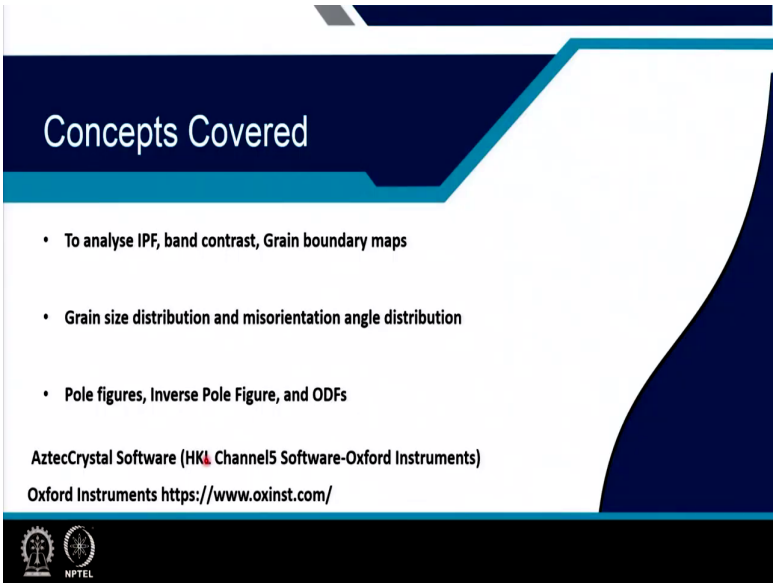

So, initially we were using HKL Channel5 Software of Oxford Instrument, but this one has more enhanced feature. So, I will be showing you these AztecCrystal software. So, we will analyze today the inverse pole figure map using this software like, we did it earlier in the class for another software. And, then we will do the band contrast mapping, which is similar to the you know pattern quality map or image quality map is exactly the same like that and then we will go with the grain boundary map.

So, we will observe the grain boundary and the geometrically necessary boundaries in the microstructure. Then, we will see how we can obtain the grain size distribution and followed by misorientation angle distribution, then we will go to the texture analysis and we will do pole figure inverse pole figure and orientation distribution function.

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So, this video is basically for educational purposes of this for the student. So, that they know various kinds of software which are usually used to do you know EBSD analysis and also some software's which are used to do for X-ray texture analysis. So, today is AZtecCrystal this is version 2.1, this is made by oxford instrument it is available in their website.

So, this say for example, we have this kind of an window in the in our computer right in our computer monitor and this is kind of you know, the icons that come when you load AZtec software's. So, basically AZtecCrystal is the analysis software if we click or double click on this software, you will see that this kind of an window starts to appear, and this is just opening of the software.

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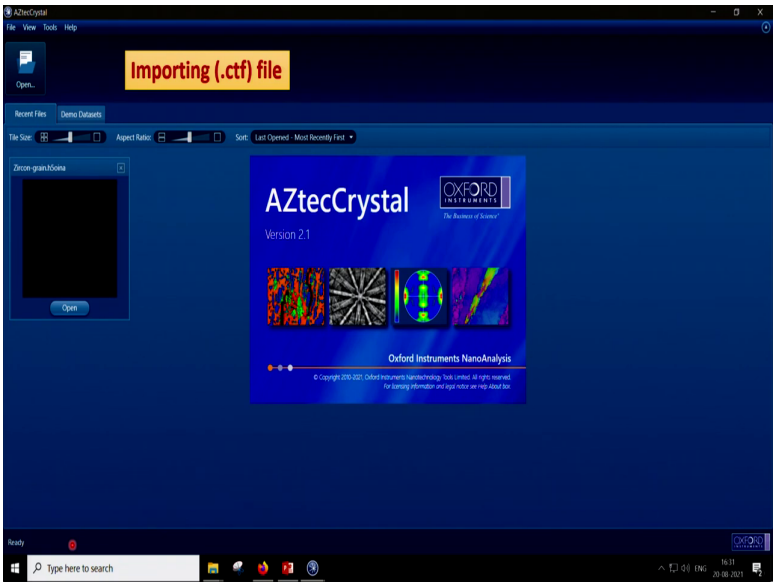

And, so once the AZtecCrystal software is open it will look something like this. So, it has a blue interface and it will have this small pop up window, which shows that various kinds of things that can be done using this AZtecCrystal software you can see that one can do microstructure, one can observe kikuchi pattern, one can observe pole figure and one can see various features of the microstructure in detail. So, the first in this slide I will show that the importing of dot ctf file.

So, why dot ctf file see, when we do an EBSD measurement in a oxford instrument detector in a scanning electron microscope. So, we obtain the hardware and the software integrated with the oxford instrument is AZtec. And, then this software will give you the EBSD measurements in terms of four different files, in which dot ctf is the file which is basically you know opened up in this AZtec crystal software to do all the different analysis.

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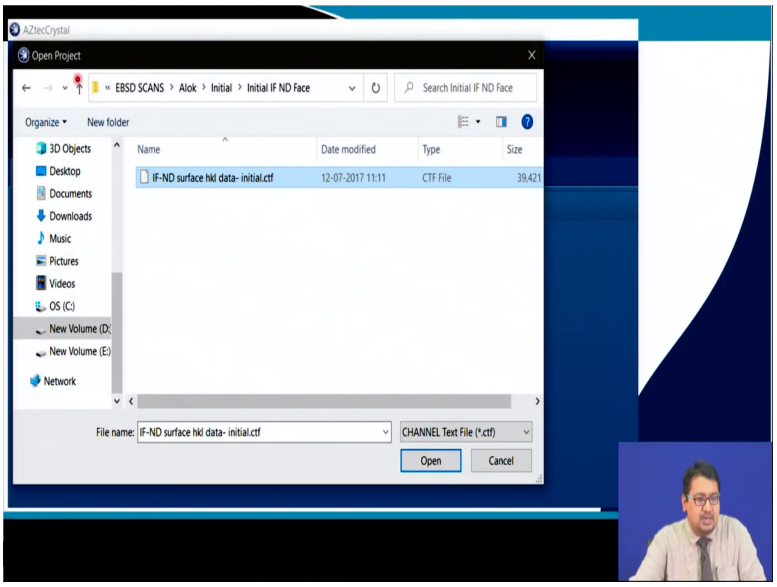

So, we will go to this open and then we will have this kind of an window definitely. And, we will browse through the you know a software say for example, in this case we are using IF-ND surface hkl data initial software dot ctf.

So, we will go here and try to click there could be various kinds of files that could be displayed here and then we will go to dot ctf star dot ctf and then we will select this and do an open. So, once this yes so, I have put a red you know mark or the border here to show that we have to change this you know file type here.

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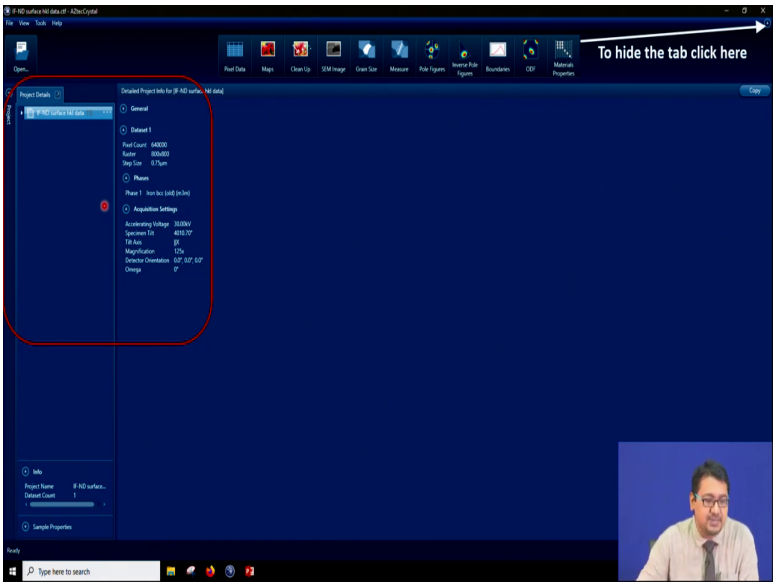

So, once we open this software we will get a window which is something like that and this window contains you know various functions like you see. And then we will as we have opened this IF-ND surface hkl data, which is basically it means that it is of interstitial free steel, which is ferretic steel.

And, we are looking at the surface which is basically perpendicular to ND. And, this is the data which has been taken from the hkl channel5, which is basically the Aztec; that means, from the oxford instruments EBSD detector. So, if we look you know little closer, if we do we are not able to see because the font size of this you know software is very small usually all the software has small fonts right.

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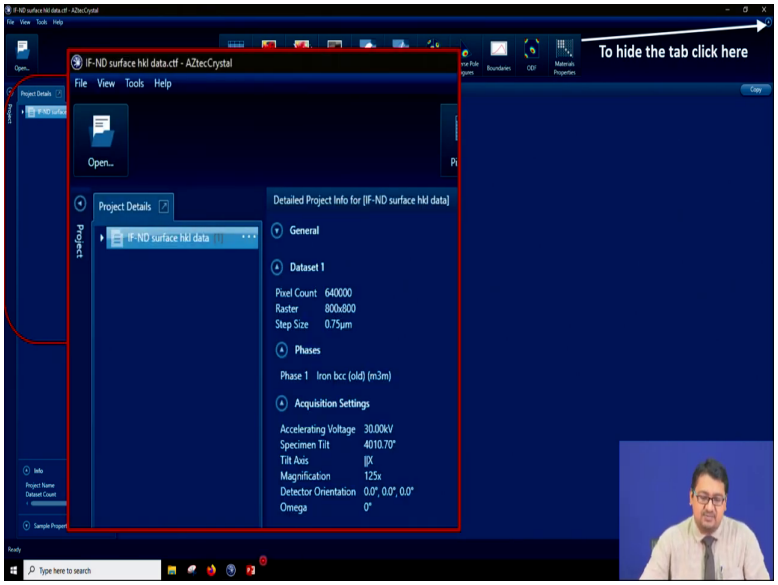

So, let us you know magnify it. And, if we magnify it if we can see, that when we are opening this kind of a file, then we get a information about those files like you see, pixel count that is 640000 pixel counts in the software.

That means, that the EBSD scan contain you know 640000 peaks, which is which means that the electron beam has fallen over you know and rastered over the sampled area 640000 times. And, each time it has taken up a kikuchi pattern right. So, the raster size is 800 into 800 that is in micrometer square the step size is 0.75.

So, we can back calculate the number of pixel count using this information also. The phase that we have taken is iron which is bcc and has a you know m 3 m structure. So, the

acquisition setting can also be observed here, because the information is embedded in the dot ctf file. So, the acceleration voltage was 30 kilo volts the specimen tilt was you see 70 degree the tilt axis is x parallel to x magnification is 125 x detector orientation and omega etcetera everything is given here right.

So, the information of the sample is given here. Now, we can also see the different types of functions in the top part of this you know software and one can even you know click here. There is a very small you know functional button here to kick here to hide this particular tab, sometimes when we need a larger area to for the display of a certain you know property or certain map etcetera.

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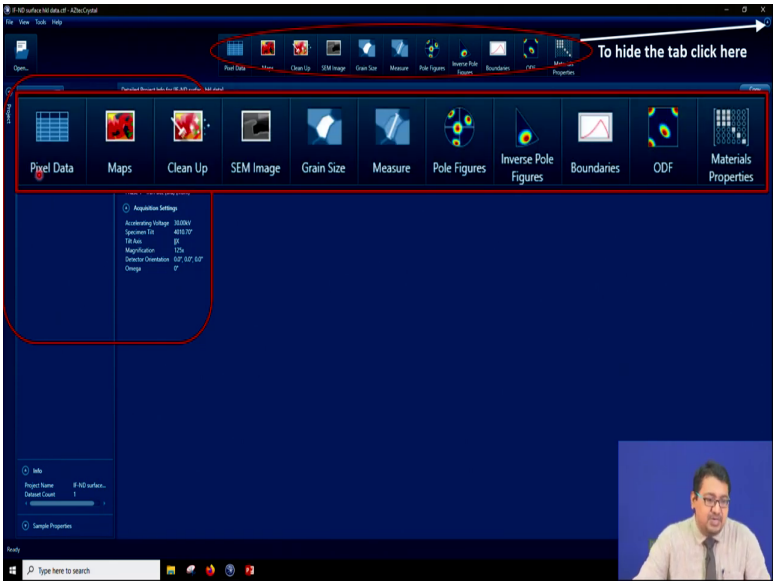

So, we have you see here the pixel data, we will talk about it what is pixel data. But, for a brief information this pixel data is basically the data obtained from each and every you know, when the electron beam for falls on it. So, if each time it falls each pixels it produces each time a kikuchi pattern is produces.

The data pertaining to it is the intensity of certain Euler angles etcetera will be shown in this picture data, then the second one is maps. Maps means, we can obtain if you click here we can obtain inverse pole figure map, band contrast map, or you can say image quality or pattern quality map, or we can obtain the grain boundary map and various kinds of maps could be obtained as required, for research and you know engineering or technological development purposes.

Cleanup; cleanup is another thing like whenever we take up a measurement in an EBSD, few of the data points will come very nicely, few will come with a lower you know confidence and few will come with much may not come at all. So, one can simulate those data point using various techniques in all the software's that I will be showing this kind of cleaning procedure can be carried out.

So, this for the cleaning of the microstructural quantitative microstructural, that is EBSD data in this case also we have the function. Then, we can observe the SEM image and then we can see you know the grain size. So, in that case the grain size distribution the average grain size can be calculated.

We can do various kinds of measurement like you know, if we try to draw a point to point measurement between two positions of the sampled area the EBSD area then one can find out that, what is the point to point misorientation or the misorientation deviation from its origin and there are various kinds of you know information that can be extracted.

The another thing is we can measure the texture. In terms of pole figure, inverse pole figure, orientation distribution function. On the other hand as I said misorientation angle distribution like low angle boundaries high angle boundaries everything could be obtained from this. Various materials properties like isotropic property could also be obtained using this kind of software.

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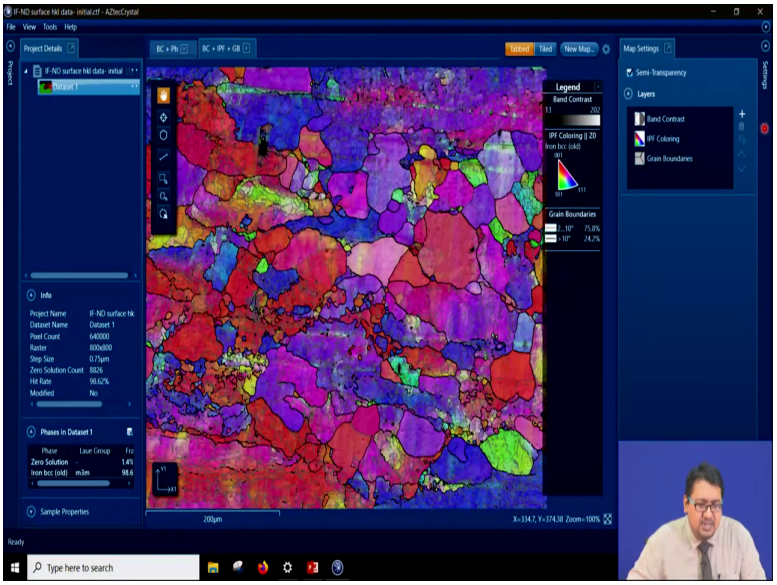

Now, if we look that once we you know import this EBSD measurement data, what happens, that this particular window basically opens up right. This particular window shows a microstructure pertaining to this data set that is interstitial free steel ND surface hkl data. Now, as you know that this is a bcc iron and you can see here in a very small area the color key code.

So, triangular color key code is also there and if we can see this is 001, this is 111, 101. So, the green grains are near to 101 the blue grains are near to 111. And, the red grains are basically near to 001. Now, if we look into this quantitative microstructural information closely, here we have the micron bar. If, we look into this closely what we will see that apart from the inverse pole figure map, it seems to have superimposed with a you know pattern quality or the image quality or the band contrast map.

And, secondly we can also see that, it is super imposed with the grain boundaries. So, if we look on the right side of the screen, this you can see it is written layers. And, there it is written band contrast IPF coloring grain boundaries. So, in this map we have all the 3 out of them ok.

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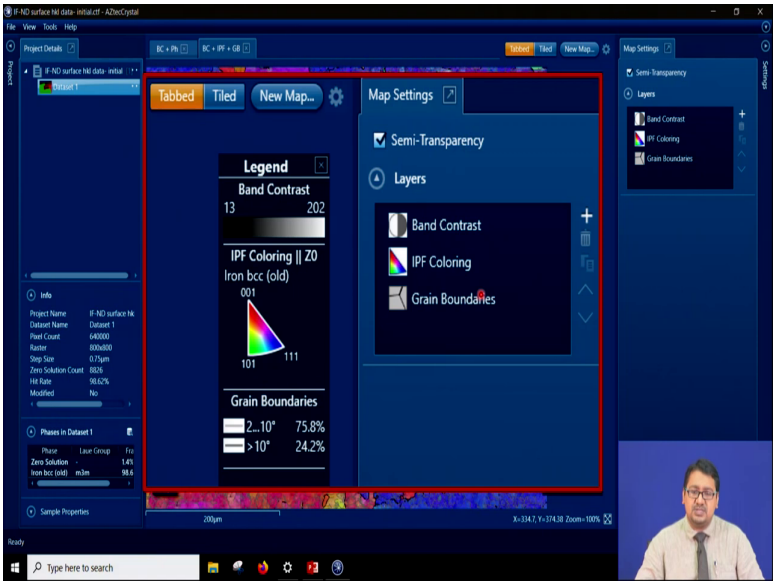

So, what we can do? If, we look into this closely I have just you know magnified this thing. So, that you can able to see it you can see that here is the IPF color code. So, inverse pole figure color code and we can see red one is 001, the green is 101, and the blue is 111.

And, you can even see, now, clearly that there are two kinds of boundaries shown in that microstructure in the earlier slides, that is one grain boundary, which is 2 to 10 degrees is shown in grey and another grain boundary, which is greater than 10 degree is shown in black right or darker grey. So, apart from we can see band contrast IPF coloring and grain boundaries, apart from we can see this we may choose what to see and what not to see.

For example, we can choose to see only IPF coloring without the band contrast or the grain boundaries, or we can choose we to observe band contrast map that is image quality or pattern quality map and not the IPF or the grain boundaries. Even, we can decide that, which grain boundary misorientation pertains to what. How we want to observe it.

For example, here we have seen 2 to 10 and greater than 10, but we can also see 2 to 5, 5 to 15 and 15 to you know maximum angle of grain boundary as usually, we observe in most of the scientific studies.

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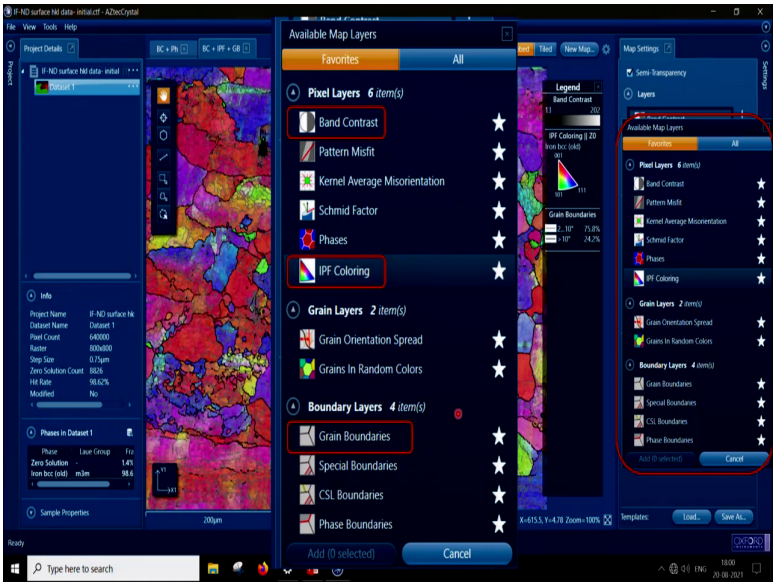

Now, if we go ahead, yes if we go ahead, we can see that there is a drop box here. So, if you click on this plus sign or click inside, you will see that there is a small drop box open. And, I have magnified this drop backs, drop box here, if you look into it and there I have clicked on the favorite.

And, before that if we click on all we will see a large amount of information of regarding, what kind of microstructural image or microstructural map that the we desire to obtain. So,

you see we tick on those which are our favorite and we are clicking on the favorite to show them. So, you see this is the magnification from here right.

So, you can see band contrast map which is image quality and pattern quality as I am say repeating again. Then pattern misfit map can be produced kernel average miss orientation can be produced, smith factor map could be produced, phases can be observed if there are more than you know two phases, more than one phases.

And, then IPF coloring can be observed and then grain orientation spread grain in random colors can be obtained as we have obtained in the other software. Then grain boundaries, can be obtained special grain boundaries, you can see they have shown in terms of like twins or CSL boundaries can be obtained, phase boundaries interface boundaries can be obtained.

So, if we click on the IPF coloring and, we select it then you can see most of the time we mainly require band contrast IPF coloring, grain boundary map and that is what we were seeing in the earlier slide right.

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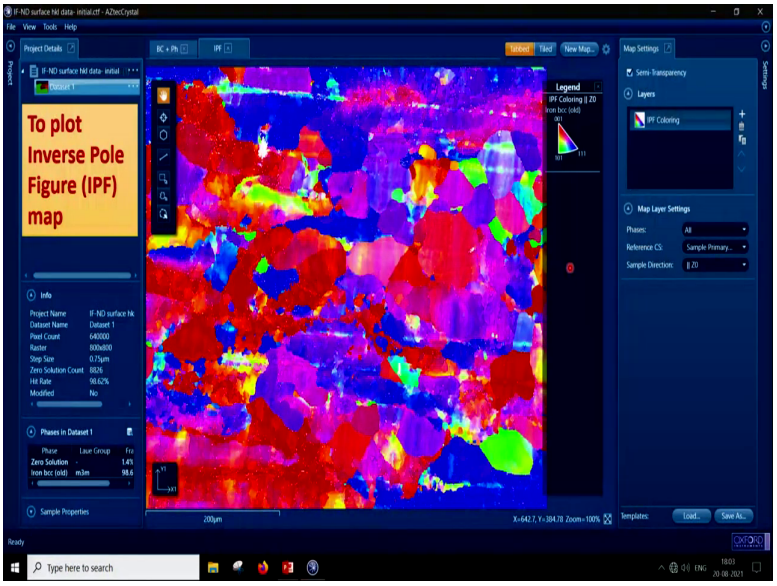

So, if we click on the inverse pole figure map coloring IPF coloring and, we omit the you know grain boundary map and the what you call the band contrast map. So, we can obtain the microstructure like this right. The microstructure, which is basically the inverse pole figure map we can obtain it like that. On the other hand we can as I said we can put the grain boundaries to make this IPF map a little bit more clearer.

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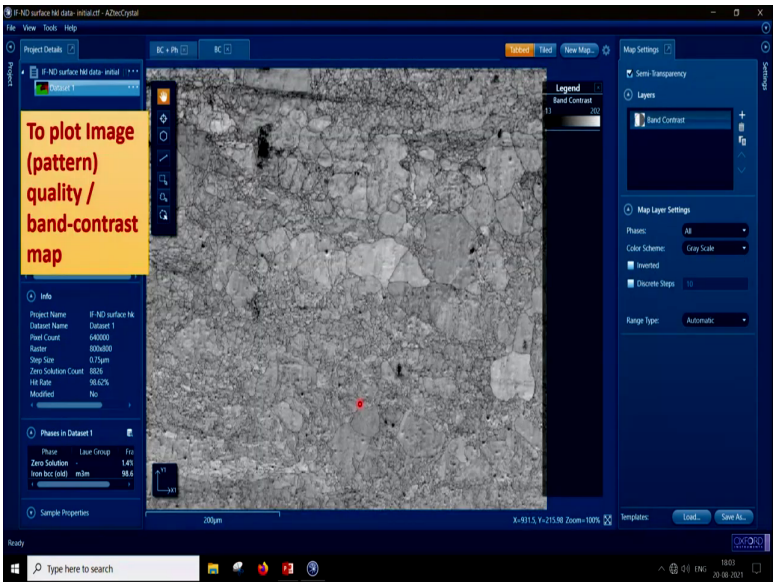

On the other hand if we click on the band contrast, then we can get the band contrast image quality or the pattern quality image right.

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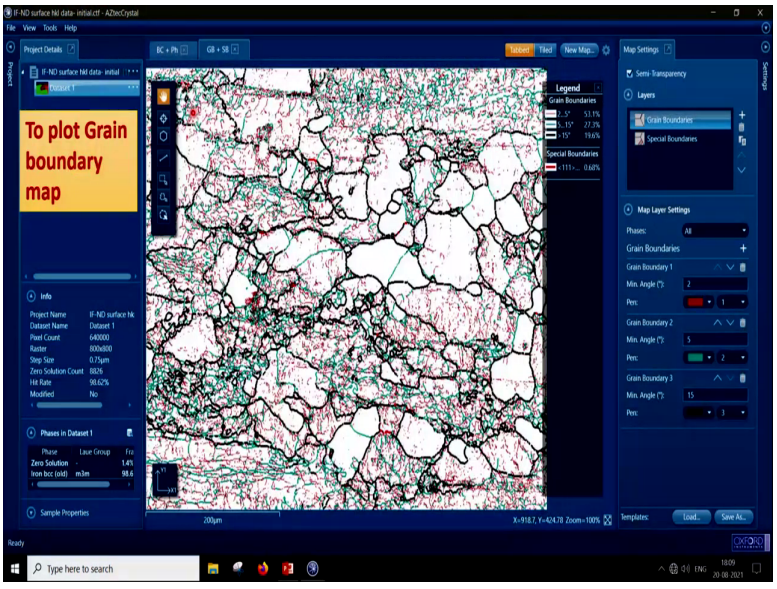

If, we click on the you know only the grain boundaries. And, if we look here and if you look if we select that ok, grain boundary 1, it is red in color it is minimum angle is 2 degrees grain boundary 2 it has you know green in color and minimum grain boundary angle is 5 degree and grain boundary 3, it has a minimum angle of 15 degrees.

So, if we look into this, what we can find out that we can select this and load the grain boundary map right. And, the grain boundary map will look something like this. It will show the black lines as the grain boundaries with misorientation angle greater than 15 degrees. It will show the green lines, here it is bottle green and we can see that the misorientation between 5 to 15 degree could be observed here, the red ones, which are lower than 5 degree, but from 2 to 5 degrees are also shown.

So, we can observe the microstructure in terms of grain boundary map in this way. And, we can also extract the information of about the fraction of grain boundaries from this microstructure, or we can do it in a different manner when we will be doing the misorientation angle measurements right.

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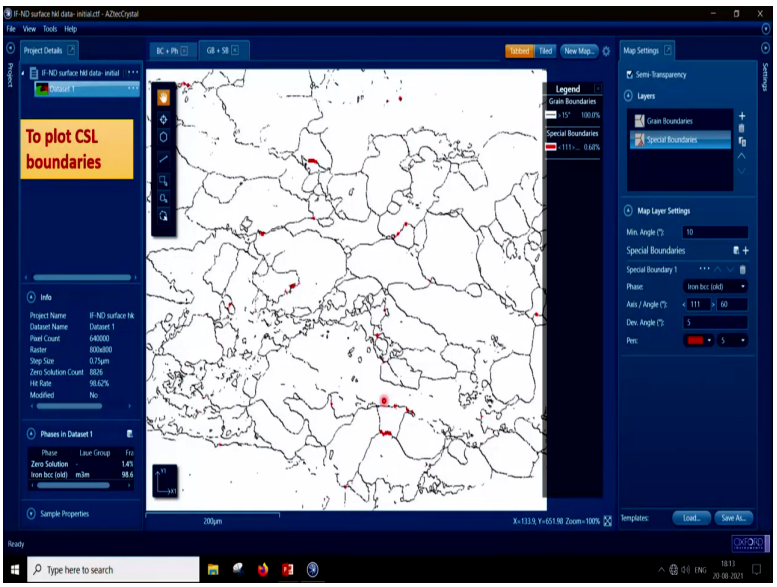

Now, if we on the other hand instead of grain boundary, if we select special boundaries. And, though our microstructure the one which was chosen for this example does not have much of special boundaries or CSL boundaries or you know excess angle pairs.

So, what happened that we are choosing a special boundary, we are saying that ok; this is a ferrotic structured material bcc structure material. So, iron bcc. So, usually there are you know because of the (Refer Time: 18:58) of sacks relationship there could be sigma 3 boundaries, which is having an axis angle pair of 111 at 60 degrees. And, therefore, you see we can put 111 axis and angle 60 degree and we also have used a little bit of deviation say for example, 5 degree of deviation, if there is any deviation following the Brandon's criteria.

So, we have used the red pen and there are very few of these kinds of boundaries present in this microstructure; shown in this red colored small small boundaries. So, what we are observing here is that we can obtain boundaries, we can obtain CSL boundaries we can obtain certain boundaries of certain axis angle value, and everything can be done using this new software AZtec.

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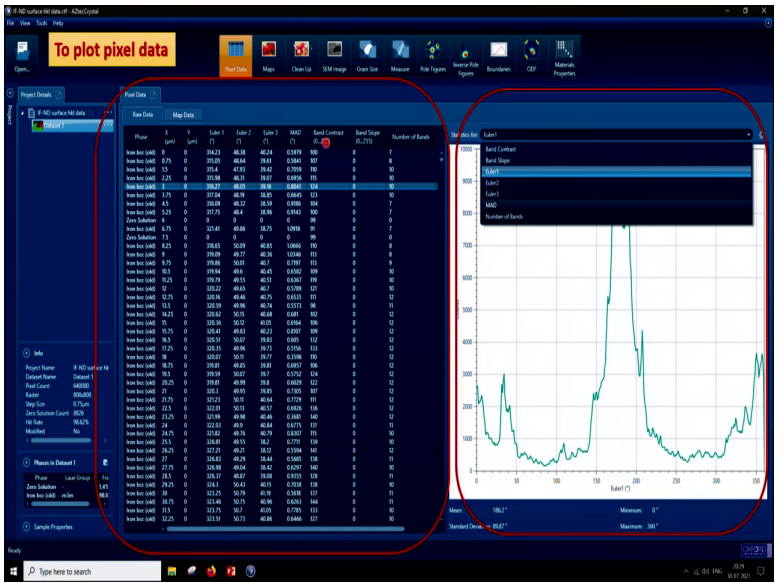

So, in order to plot and observe the pixel data, if it is needed for our analysis; we can click here and which gives us the information of the pixel data. So, it will give us the example that point to point pixel data right.

So, the first point where the incident electron beam has fallen and from where the kikuchi pattern was taken. So, this one and the second one after a step size of 0.75 and then after a step size of 0.75, again that is 1.5 and then 2.25 and 3. And, if we keep on doing like this we can get the information of all the you know scan points that have been used to take this full EBSD information.

Now, this is the you know the figure which shows, that if we select upon a single point, then if we select upon you know what is its band contrast or if what is its band slope or what is the Euler angle? So, here we have clicked on the Euler angle, Euler angle means phi 1, here we have clicked then Euler angle 2 which is phi is also there Euler angle 3 is also there.

So, one can click and one can find out the intensity point or the you know phi 1 value for that Euler angle right. For example, here it is shown this y axis is the count, x axis is the phi 1. And, we can see that the intensity peak is more or less around 1 75 degree of phi 1, at a count of say something around 800 which is you know it is superimposed with this function, but we can see that there is a peak.

So, if we look into this particular you know table much closely and because it is very small now to observe and if we look into this one also closely that we will do in the next slides.

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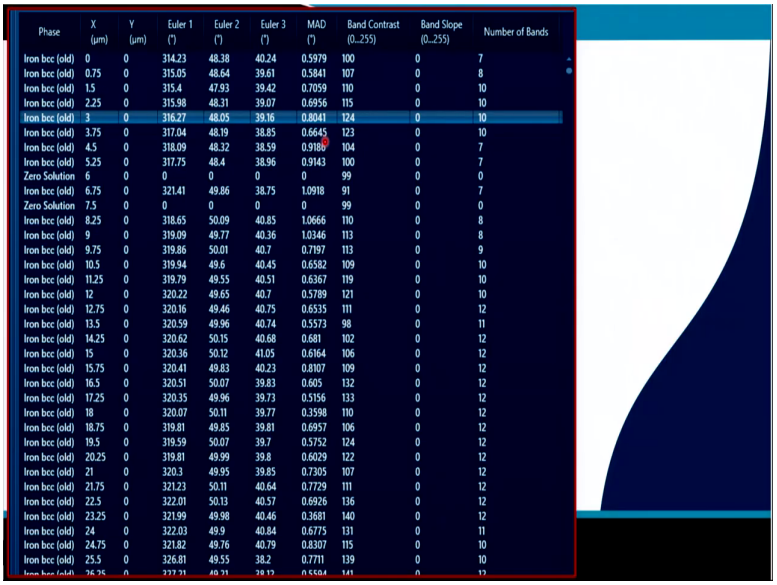

Phase	X (µm)	Y (µm)	Euler 1 (°)	Euler 2 (°)	Euler 3 (°)	MAD (°)	Band Contrast (0...255)	Band Slope (0...255)	Number of Bands
Iron bcc (old)	0	0	314.23	48.38	40.24	0.5979	100	0	7
Iron bcc (old)	0.75	0	315.05	48.64	39.61	0.5841	107	0	8
Iron bcc (old)	1.5	0	315.4	47.93	39.42	0.7059	110	0	10
Iron bcc (old)	2.25	0	315.98	48.31	39.07	0.6956	115	0	10
Iron bcc (old)	3	0	316.27	48.05	39.16	0.8041	124	0	10
Iron bcc (old)	3.75	0	317.04	48.19	38.85	0.6645	123	0	10
Iron bcc (old)	4.5	0	318.09	48.32	38.59	0.9189	104	0	7
Iron bcc (old)	5.25	0	317.75	48.4	38.96	0.9143	100	0	7
Zero Solution	6	0	0	0	0	0	99	0	0
Iron bcc (old)	6.75	0	321.41	49.86	38.75	1.0918	91	0	7
Zero Solution	7.5	0	0	0	0	0	99	0	0
Iron bcc (old)	8.25	0	318.65	50.09	40.85	1.0666	110	0	8
Iron bcc (old)	9	0	319.09	49.77	40.36	1.0346	113	0	8
Iron bcc (old)	9.75	0	319.86	50.01	40.7	0.7197	113	0	9
Iron bcc (old)	10.5	0	319.94	49.6	40.45	0.6582	109	0	10
Iron bcc (old)	11.25	0	319.79	49.55	40.51	0.6367	119	0	10
Iron bcc (old)	12	0	320.22	49.65	40.7	0.5789	121	0	10
Iron bcc (old)	12.75	0	320.16	49.46	40.75	0.6535	111	0	12
Iron bcc (old)	13.5	0	320.59	49.96	40.74	0.5573	98	0	11
Iron bcc (old)	14.25	0	320.62	50.15	40.68	0.681	102	0	12
Iron bcc (old)	15	0	320.36	50.12	41.05	0.6164	106	0	12
Iron bcc (old)	15.75	0	320.41	49.83	40.23	0.8107	109	0	12
Iron bcc (old)	16.5	0	320.51	50.07	39.83	0.605	132	0	12
Iron bcc (old)	17.25	0	320.35	49.96	39.73	0.5156	133	0	12
Iron bcc (old)	18	0	320.07	50.11	39.77	0.3598	110	0	12
Iron bcc (old)	18.75	0	319.81	49.85	39.81	0.6957	106	0	12
Iron bcc (old)	19.5	0	319.59	50.07	39.7	0.5752	124	0	12
Iron bcc (old)	20.25	0	319.81	49.99	39.8	0.6029	122	0	12
Iron bcc (old)	21	0	320.3	49.95	39.85	0.7305	107	0	12
Iron bcc (old)	21.75	0	321.23	50.11	40.64	0.7729	111	0	12
Iron bcc (old)	22.5	0	322.01	50.13	40.57	0.6926	136	0	12
Iron bcc (old)	23.25	0	321.99	49.98	40.46	0.3681	140	0	12
Iron bcc (old)	24	0	322.03	49.9	40.84	0.6775	131	0	11
Iron bcc (old)	24.75	0	321.82	49.76	40.79	0.8307	115	0	10
Iron bcc (old)	25.5	0	326.81	49.55	38.2	0.7711	139	0	10

So, let us see this closely, what are the values there? So, if we look into the first scan or if you look into the third scan 1 2 3 4 5th scan, that is the scan at x equal to 3 and then you can see that Y is 0 now; that means, the scan is taking place something like this 1 2 3 4 5 6. And, then it will go long and then it will come down and then y will become 0.75 and then same thing will go on to scan the whole EBSD.

So, for a certain to this case we can find the value of Euler angle 1, which is 316, the Euler angle 2 which is 48.05, the Euler angle 3 which is 39.16, we can get the misorientation angle distribution pertaining to this position, we can get the band contrast, we can get the band slope which is 0 number of bands, which are which could be detected 10 right. We can get all the information pertaining to this particular pixel point.

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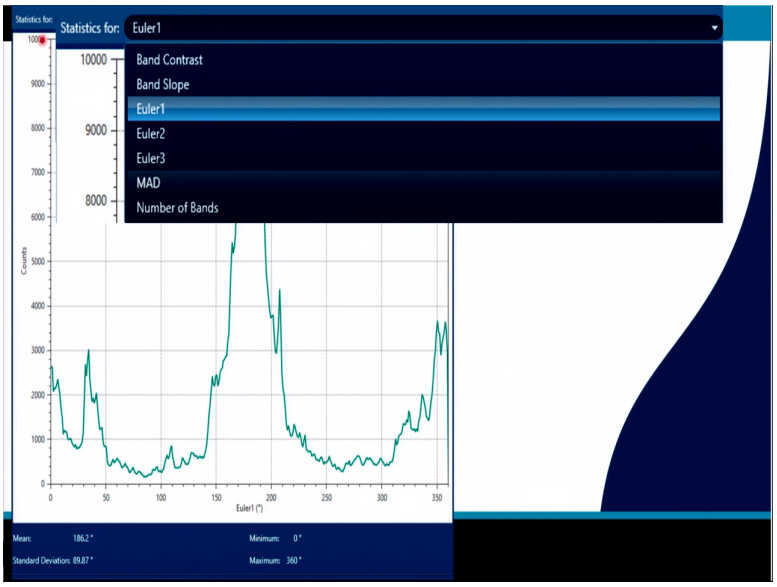

Now, like that for all the pixel points. We can as I said we can get the information in terms of a graph is if needed in terms of you know band contrast, band slope Euler angle 1 phi 1, Euler 2 phi, Euler angle 3 phi, 3 sorry phi 2 and MAD, number of bands everything can be observed in terms of you know as a table or a graph.

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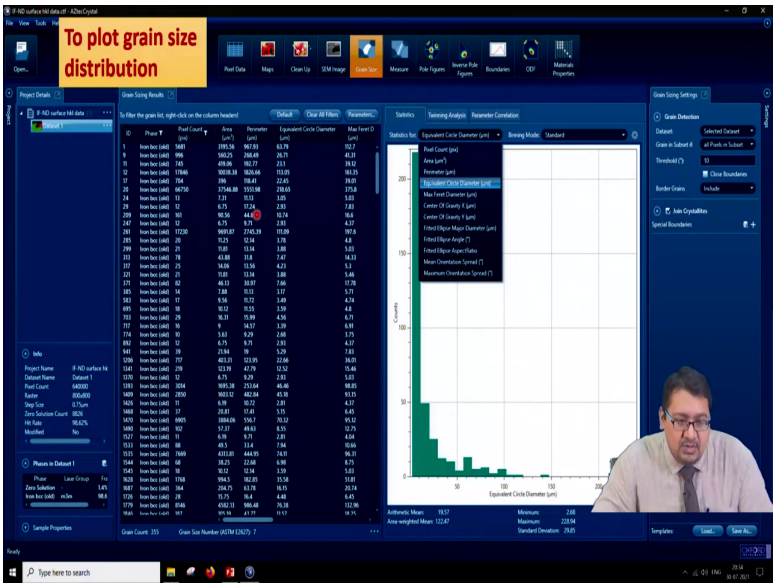

So, how to plot the grain size distribution? In order to plot the grain size distribution, we have to go to this function, which is grain size. So, we have to click on it and if we click on it

automatically like a standard projection, we will get the information about the grain size in terms of a graph, in terms of a graph right and in terms of a table.

And, if we look closely this picture is so, small. So, we what I will you know magnify it and show it to you. So, let us look into the table first right. So, and we will also look into what is this right, because we I can see it, but for you I will make it little magnified.

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So, if we look into the table, when we click on the grain size and if we look into the table, the thing that we can observe is what kind of information it is giving. It is giving the information of the pixel count. So, it is giving that so, many pixel counts have the area of 3195 a perimeter diameter of 967, an equivalent circle diameter of certain max feret diameter of certain.

So, we can get information about the grain size distribution in terms of you know area square or perimeter or you can get it with respect to equivalent circle diameter, which I prefer max feret diameter and there will be more information. If we take this side and there will be more information about different kinds of ways of measuring grain size and its distribution right.

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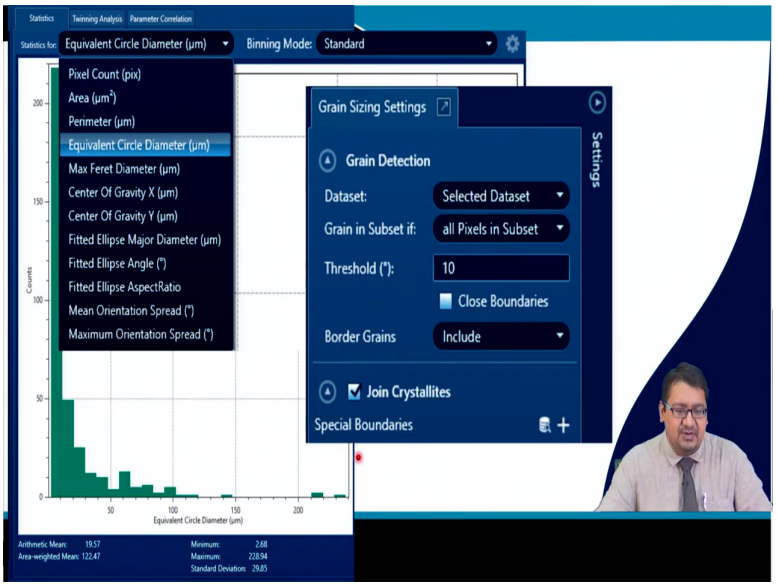

So, here we will be showing in the graph which will be in standard it is coming is the you know this kind of a graph, where the equivalent circle diameter is usually plotted. And y axis is the number of count and the x axis is equivalent circle diameter right.

So, we if we click here, then we get various options pixel count, area, perimeter, equivalent circle diameter, Max Feret Diameter, Center of Gravity X, Center of Gravity Y, many things can be observed. Even the mean orientation spread, maximum orientation spread, you know fitted ellipse aspect ratio. So, apart from grain size we can get a lot of information. But, if we look into the grain size we will you know most of the time I usually prefer clicking on equivalent circle diameter.

And, get the information of equivalent circle diameter in terms of count; count means number fraction. Now, on the other hand you can see that the exact right hand small box that I had you know marked in the whole software, what you call it screen. We can see the data set we have selected is full data all pixel in the subset.

And, the threshold is 10 and border grains are included we can exclude the border grain, we I have taken on the join the crystallites we can untick it. And see that, what happens we can see add or you know remove the special boundaries in order to get the grain size distribution. In case of this thing when we get the number fraction grain size distribution the binning mode is basically standard right.

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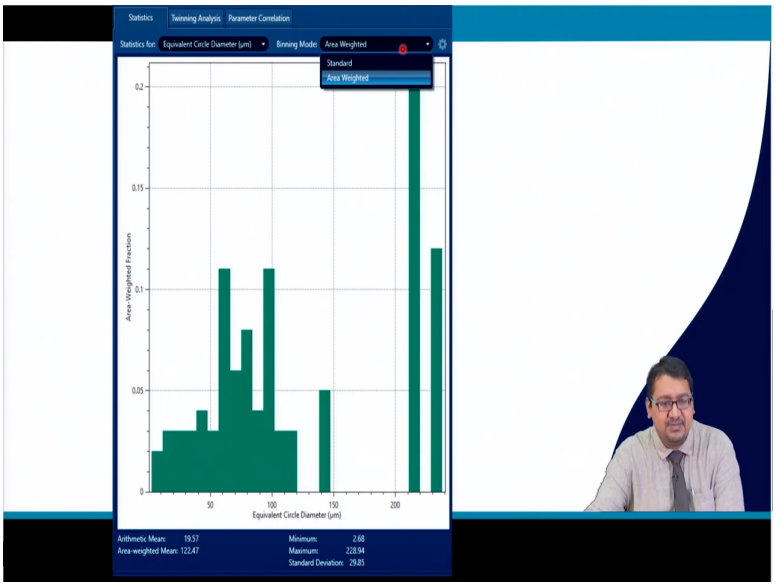

And, if we click here we can change the binning mode from standard to area weighted. So, standard means number fraction and you know we can change it to area weighted and some and we can get for the equivalent circle diameter area weighted grain size distribution. And, sometimes I all I prefer area weighted grain size distribution.

And, in the y axis and while in the x axis it is always equivalent circle diameter. Why area weighted you know grain size fraction I prefer is because you see that, when any poly crystalline material is taken, there could be larger grains medium sized grain and smaller size grains. And, there could be larger amount of smaller size grains maybe or larger amount of you know and less amount of larger size grains.

But, when we do a number fraction measurement the larger fraction of smaller size grain size is always taken into more consideration, than the larger grain which are present in the microstructure, few larger grains which are present in the microstructure. But, these larger grains in the microstructure affects the property mechanical, physical, chemical property of the microstructure, much more than those smaller or very smaller grain size all together.

So, considering the area fraction of the larger grains in the microstructure in area weighted case, gives a better estimation of an average grain size which you know relates in a more seamless way with the properties of the microstructure ok.

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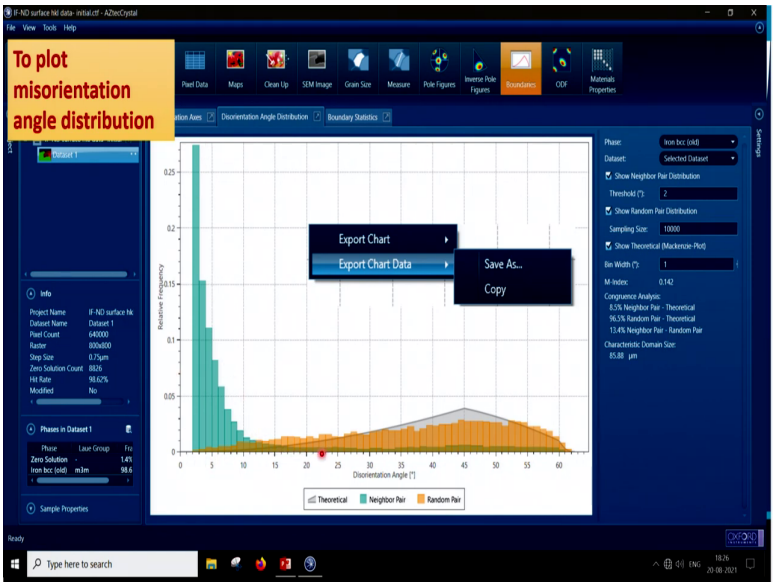

Now, in order to plot misorientation angle distribution, what we do? We have to go and click here, the function is known as boundaries here. And, in this case if we see that we get this kind of a plot, the green color plot that I have shown here is if we click directly on it.

We can you know have a lot of information here, have a lot of function here, which we can you know tick or un tick to get for example, you see we have ticked here. So, this shows neighbor pair distribution. And, what do you mean by neighbor pair distribution? It means that it is giving the misorientation angle distribution between two pairing pixels.

That means, that is it is a you know correlated misorientation angle distribution; that means, this is the actual misorientation angle distribution of that microstructure. So, the misorientation between two adjacent pixels are always given and; that means, it is specially correlated with orientation angle distribution. Now, if we want to get if we tick here we will observe that it will also give us you know random pair distribution, what does it mean by random pair distribution?

That means, if I take a pixel and the misorientation angle difference or the you know in case of AZtec software they do not call it misorientation angle distribution, rather they call it a disorientation angle distribution. So, do not confuse it with misorientation or it is called disorientation it is just a name and it does not matter.

One can say it misorientation because it is a mismatch between the orientation or one can say it disorientation, because it is difference between the orientation. Whatever it is fine I think. Now to show random pair distribution it means, that it is showing you know for each and every pixel the misorientation of all the other pixels present in is basically observed.

So, it can be it is basically uncorrelated you know misorientation angle distribution for that particular texture. And, the yellow colored you know graph basically is showing this you know random pair distribution or uncorrelated you know misorientation distribution for that particular texture.

On the other hand if we tick here, then it shows the theoretical grain size distribution for the random texture. Now; that means, it is showing the Mackenzie plot. So, the Mackenzie plot is shown in terms of a plot here something like this and one can correlate the difference between the uncorrelated one the yellow one, the correlated one which is the actual misorientation distribution with respect to the Mackenzie plots.

And, one can untick it to just see the actual misorientation distribution. One can export this chart or one can export this data to the, you know excel or use origin software to plot these curves themselves, if they want or to do any kind of calculations further.

One can do this for the other you know plots too like grain size or kernel average misorientation or whatever one needs to do not only the plots can be you know exported, but also the plot data chart data can be exported. So, that to use it for research purposes or any requirement industrial requirement purposes etcetera.

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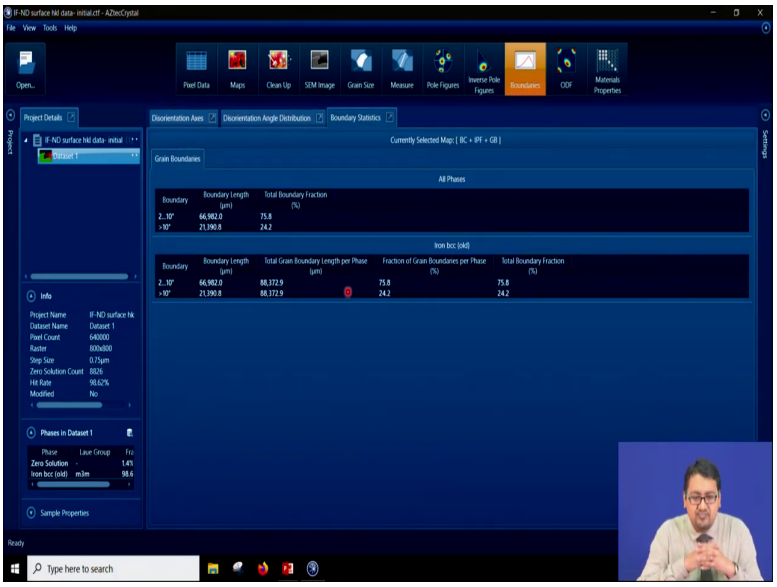

So, let us go ahead here you see that, if we click here at the disorientation angle distribution. Then we were observing the plot and then one can as I said rightly and export the data, and this you can do it for the other things also grain size and the texture and the pole everything, you can do this one can also click here and get the grain boundary statistics. Here you see that, when we are clicking here we are getting the grain boundary statistics in terms of 2 to 10 degree and greater than 10 degree.

And, one can see that in this case the 2 to 10 degree boundaries are actually 66982 micrometer something like that. And, then greater than 10 percent is 21390 micrometer length of this boundary. This indicates that total boundary fraction low angle boundary is 75.8 percentage and high angle boundary of 24.2. But, you see that in this case what we have taken? We have taken that 2 to 10 degree is low angle boundary or geometrical boundaries and greater than that is grain boundaries.

Now, we can tweak this and we can we can change it to 2 to 5, 5 to 15, 15 to maximum as I prefer in my case and I do it for my research. But, one can also you must also know, that the high angle grain boundaries are basically those grain boundaries, which have the highest energy. What happens is that, when the misorientation between this bound between a certain boundary increases, its energy also keeps on increases.

But, after a certain angle and it could be 10 degree, 12 degree, 13 or 15 degrees depending upon different material, the energy of the boundary becomes maximum and it becomes you

know constant. Further increase in the misorientation angle does not increase the grain boundary energy.

And that point where the grain boundary energy becomes constant is basically known as the grain boundary of the material. In universally usually an angle misorientation angle greater than 15 degree is considered to be a high angle grain boundary or a real grain boundary. Lower than that is usually considered as a low angle boundary or one can say that these are geometrically necessary boundaries.

But depending upon different material it could be different as I said and therefore, based upon once material in research one can choose, that what boundary he or she would like to use 2 to 10 as low angle boundary greater than 10 as high angle boundary, or 2 to 5 and 5 to 13 for example, as low angle boundaries and greater than 13 as high angle boundary, its a choice of the person based upon its experience and based upon its you know understanding of the research, and based upon the results that he has got may led to such a decision that yes.

For example, in case of aluminium, I have seen that the high angle grain boundary starts at 12 degrees. So, this may happen.

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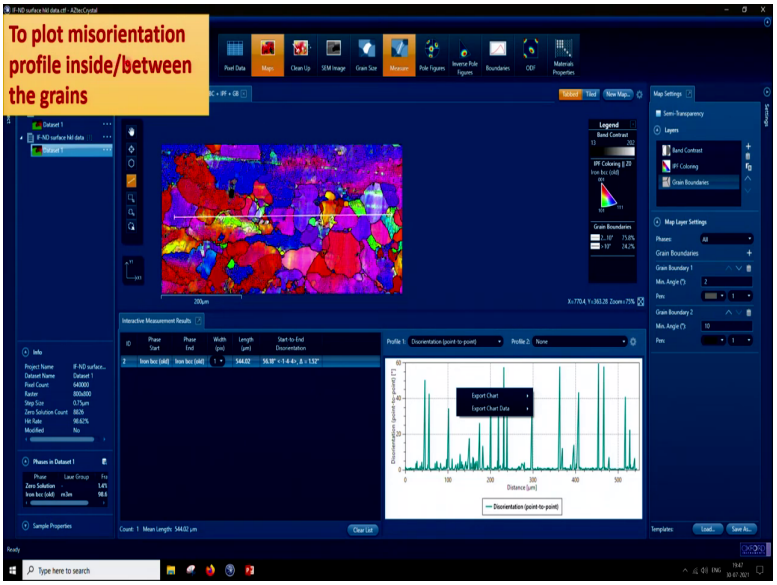

So, if you look further one can also plot misorientation profile inside and in between grains right. So, it one can do a misorientation profile, say for example, if we click in the map it will open this kind of a map, which contains both you know IPF band contrast and grain

boundaries all together. And, then if I click in the measure here and then one can get an opportunity to a window something like that and if we click here and we can get an opportunity to draw a line.

And, if we draw a line here a window like this opens and, this window gives us an opportunity to draw the misorientation of this line. In terms of point to point misorientation or origin to the point miss orientation. So, here we are showing, that if we draw a line like this, what is the point to point misorientation between and as I said, that in this case it is written disorientation point to point and what if we.

So, we can see that how the point to point disorientation is varying. As, I have said that we can export this data and even if we click here we can get origin to point misorientation.

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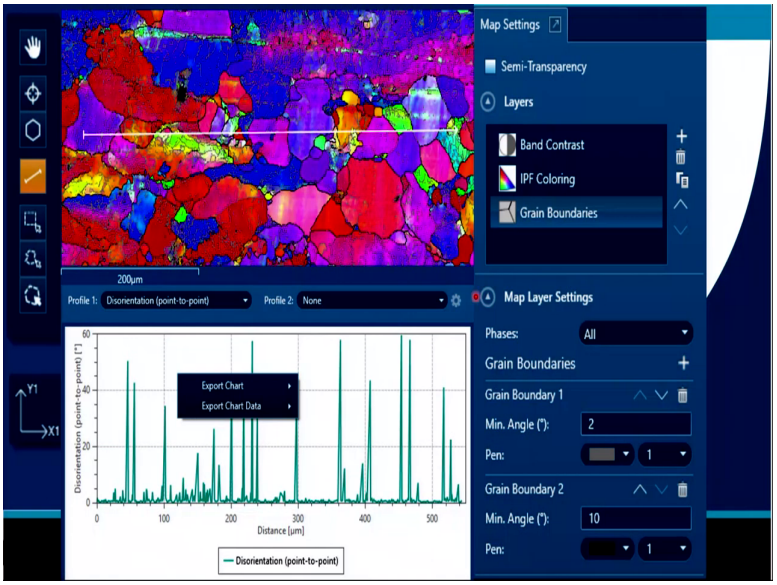

So, I have magnified this as you can see here is the function where we will click and then we will draw a line, and if we draw a line then we can get this kind of a curve. And, in this curve we can see the disorientation between you know from this position to this position and you can see that there is an increase in the disorientation in certain cases and in certain cases it is less than 15 degrees.

Which indicate that ok this is one grain with some amount of g and b is present and then these are high angle. So, this is a position where the grain boundary is there like that the

whole microstructure can be stressed right. So, this is the way we find out you know point to point misorientation or we can find out origin to any point misorientation.

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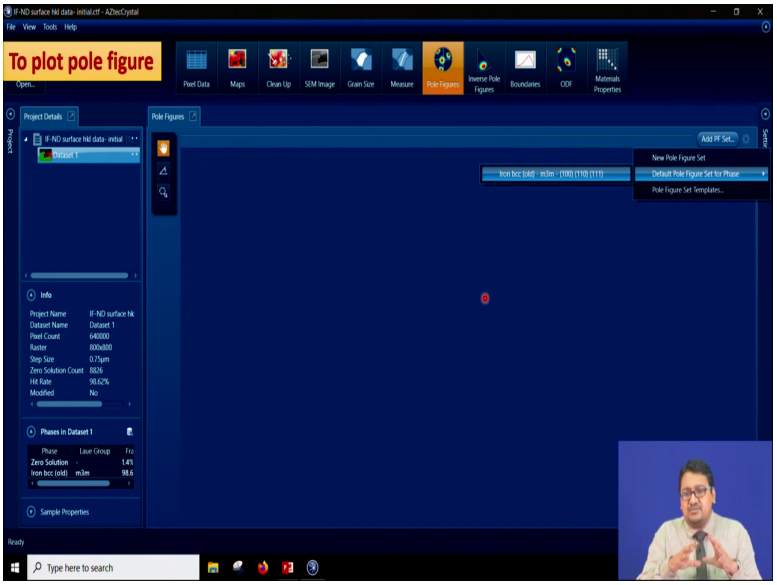

Finally, we can also look into the texture of this microstructure. So, in case of our in our case it is you know iron bcc. So, if we try to plot the pole figures from the above function, we can just you know click here on the pole figure and if we click here a window like this will open in which it is written pole figure. And, then if we look here and it will say that ok add a set of pole figure. So, if we click this it will give three option; one new pole figure set it will give you default pole figure set for the phase and the pole figure set templates.

Now, definitely I do not have any pole figure set templates now, if we put a new pole figure set, then you will get an option that which pole figure you want to plot. So, definitely it is b c c so, I would like to plot 100, 110 and 111 pole figure.

But, on the other hand if you click on default pole figure set for this phase what will happen? That it will directly show that iron bcc and it has an m3m structure, so, it will plot 100, 110, 111 automatically. So, rather I will you know write it down I will just select this option and I will click here. And, once I will click here with a little bit of processing the software will slowly show you the pole figures.

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So, pole figure will have X1 Y1 as a certain direction. When we are putting the soft sample in the EBSD, we should put it in such a way that the R D and the T D is known where we are putting either we are putting it along X1 or we are putting it along Y1 R D.

So, based upon that we will be knowing that how our sample is put and the software is will be detecting X 1 and Y 1. So, we can rotate or not rotate the software as needed right. So, we will get this kind of 3 pole figure this is 100 pole figure, this is 110 pole figure 111 pole figure. And, we will we can also get if we click here we can also get a various options right.

And, when we look into these options here, we will see that here if you look, you will see that it is a equal area projection. And, when this is an equal area projection, then we will have to click here right. And, if we click here, if we click here we will convert it into you know stereographic projection.

Because, you see in case of in our case when we deal with crystallography and texture and stereographic projection, we do not deal with equal area projection. Equal area projection is basically dealt when we deal with geographical you know structure of a globe.

For example, the it has to be equal area when we plot an area of India and area of US right or area of Germany or area of Sri Lanka. So, in that case not equi angular projection is used, but, equal area projection is used. But, in case of crystallography and texture stereographic projection that is equal angular projection is used.

After you convert this into equal area to you know stereographic projection. One can convert export this pole figure set. And, we can export it to the you know say for example, directly to the power point, we can do a copy or we can do an export setting and you can see that, what are the different export functions, which are present. Now, here if we look we have a window, where the pole figure 1 is given iron bcc type of phase type it is a plane and indices 100.

That means, plane means it is taking the pole figure of the plane normal ok. And, then pole figure 2 which is 110. So, we have indicated 110 right in pole figure 3 it is 111. So, it is indicated 111.

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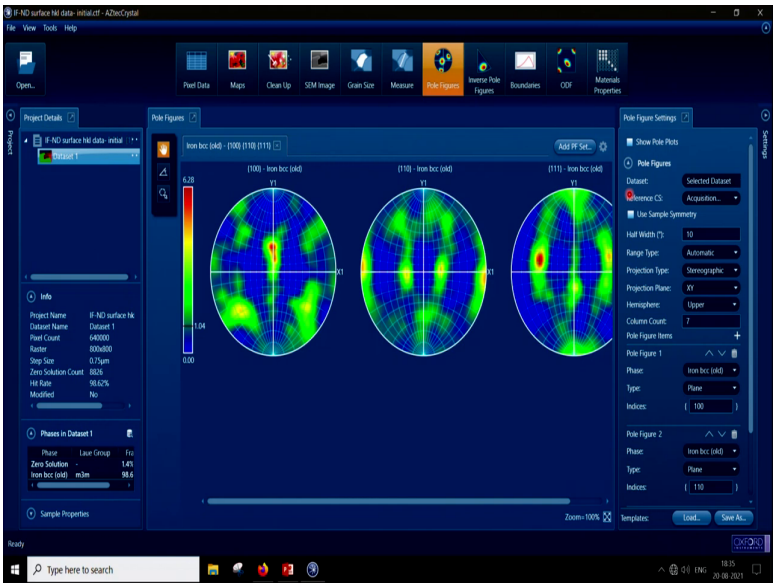

If, we go ahead as you see this time I have magnified it a little and made it little bigger, because earlier it was little difficult to see by the eye. And, now you can observe that the projection type has converted into stereographic when you will get the slides, you can compare the projection when it was equal area.

And, now, when it is stereographic; that means, equi angular. And, you will see that how the wolf net which is superimposed, in this in these pole figures you know changes when we are saying equal area and when we are saying stereographic equal angular.

So, now, we have various things here like, we can change like projection plane, hemisphere, column count. And, once we start dealing with this kind of software and see what is needed

we will slowly slowly definitely recognize that, which function will change what information right.

So, I am not going into details of that, now, but you can see that we can plot, the pole figure as an hole and we can use it with for our research and for knowing what is going on in the microstructure. To study microstructure and texture evolution for a certain material, maybe it is single phase in this case or maybe multiple phases sometimes.

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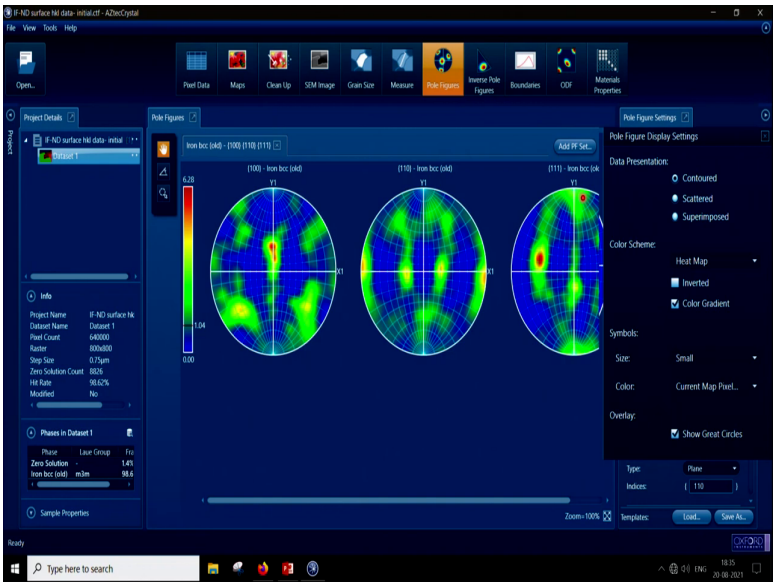

So, one more thing that if we click here we can get more information about how we are plotting the pole figure. So, we can plot the pole figure in scatter as we have plotted here or we can click on the contour and we can plot the contours of the pole figure.

And, we can also you know see that, what kind of color scheme we like we can make an heat map, we can give a color gradient, we can draw an inverted color scheme. Moreover we can also observe that how to change the size of the symbols.

So, you can choose small or big or normal and there are you know current pixel color and everything could be adjusted for as we need in order to plot this pole figures. And, same is there for the inverse pole figure and the orientation distribution function ok.

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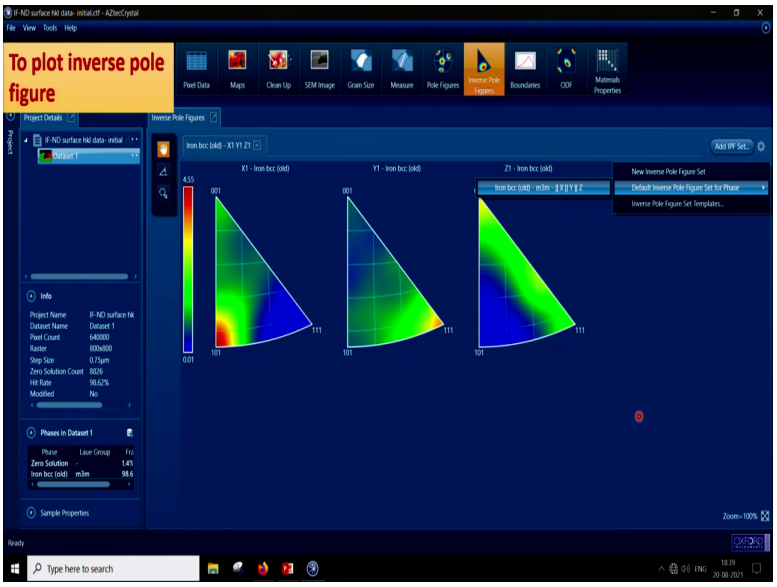

Then, now we go ahead and plot the inverse pole figure. So, if we click on the inverse pole figure the inverse pole figure window will open up and when it will open up it will have this so, we have to click here. And, there will be you know this kind of an small you know window that will open. And, this window it will be see new inverse pole figure set.

So, you can put that I want to do pole fig inverse pole figure for the X 1 axis or I want to do inverse pole figure for the Y 1 or Z 1 or all 3 of them. Rather I will click on default pole figure sorry default inverse pole figure set for the phase, and then it is written here iron bcc old m3m and parallel to X, parallel to Y, parallel to Z. So, I will click here. And, once I will click here I will be seeing that slowly it will you know calculate and plot the inverse pole figure.

So, you can see that this is the pole figure the inverse pole figure with 001, 101, 111 at the edges. And, one can see that X 1 say for example, X 1 is R D. R D has a very strong intensity along 101. So, it is red in color. And, how I know it? Because, I have this key which says that the intensity is very low when it is blue and when intensity of or the maximum of random distribution m R D is high when the color is red which is 4.55.

In this way one can see that, where the Y 1 axis lies it lies near to 111 and where the Z 1 axis lies and we can see that Z 1 is present strongly in 001, but it is also present throughout this 001 to 111 axis right.

So, we get the information of the texture using the pole figure using the ODF. And, we can also play with this you know color key code to change the variation of the color or from which pixel sorry which intensity which MRD to what MRD we need to plot it as required in our case. So, we have seen the inverse pole figure plot.

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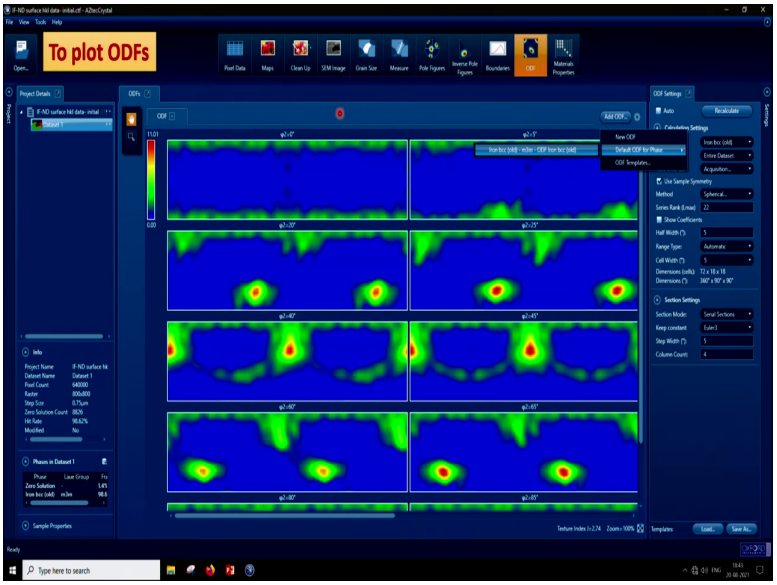

Finally, if we click here we can get the orientation distribution function to plot the orientation distribution function ODF and we will get in default we will get something like this.

So, if we look closely and we will see that what we are actually looking into. We are looking into ODFs with phi 2 equal to 0 sections, because it will come in default as phi 2 sections. And, we are saying phi 2 equal to 05 degree and then 20 25, 40 45 like that. Now, we can see that the window because it has so, many of the phi 2 sections, the window is not able to show all the phi 2 sections.

And, if we go if we take this cursor here, then the other phi 2 other phi 2 sections which are hiding below on the right side may come up. So, what we do that there is some functions here. And, we can see, what are these? You see it is written iron bcc, it is written entire data set it is written acqusition.

And, the method of calculating this orientation distribution function is spherical harmonic method, and the number of times the series rank function has run is 22 and then the half with this 5 degree, the range type is automatic; the cell width is 5 degree and then later the section

settings. And, this setting is little more important for us in this case like, if we want to plot you know phi 1 phi, phi 2 this is bcc iron.

And, we know that what should be the range of phi 1 phi phi 2. Based upon you know it has a 4 fold symmetry. So, you it should have phi 2 divided by 4 and then it has a mirror symmetry which makes phi 2 0 to 90, it has a you know mirror symmetry another mirror symmetry so, phi is basically 0 to 180 degree without any mirror symmetry.

So, phi becomes 0 to 90 degree again here and then phi 1 depends upon the sample symmetry deformation symmetry. So, it could be you know triclinic symmetry or it could be or sorry orthotropic symmetry or it could be axial symmetry. So, phi 1 let us say that it has a triclinic symmetry we do not know that, how this material has deformed. So, we will use phi 1 from 0 to 360 degrees. On the other hand we see that phi basically as I said is 0 to 90 degrees. And, phi 2 of course, it will be from 0 to 90 degree. So, the software has considered that.

But, now, which sections of phi 2 we need to observe. In case of bcc material we basically need to observe mostly 2 section phi 2 equal to 0 and phi 2 equal to 45 degree sections. So, let us say that we are not going to observe all this section which is present here, maybe we will observe only few. So, let us say that we will use a step width of not 5 rather we will use a step width of 15.

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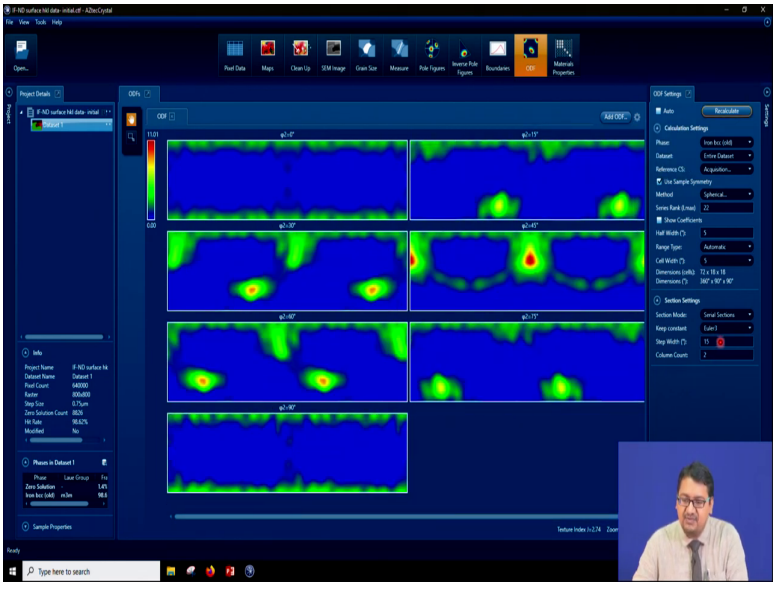

Now; that means, it will give us ODF sections of phi 2 equal to 0, then 15 degrees. And, you see then 30 degrees and 45 and 60, 75 and 90 degree, for phi 1 0 to 360 phi 0 to 90. And, we instead of having 4 columns 1 2 3 and outside this screen 4 column. Let us have 2 columns. So, that we can see the whole ODF, we have then we have changed this column to 2. And, then we can see the whole picture of the ODFs.

So, in this way the earlier hkl channel5 software and now AZtecCrystal software can you know show the texture plot, pole figure, inverse pole figure, orientation distribution function. One can use various you know functions here to change the intensity of the plot in terms of it can you can make it scattered, you can make it contour type you can do a spherical harmonic, you know function calculation to iterate the texture intensity using this kind of software.

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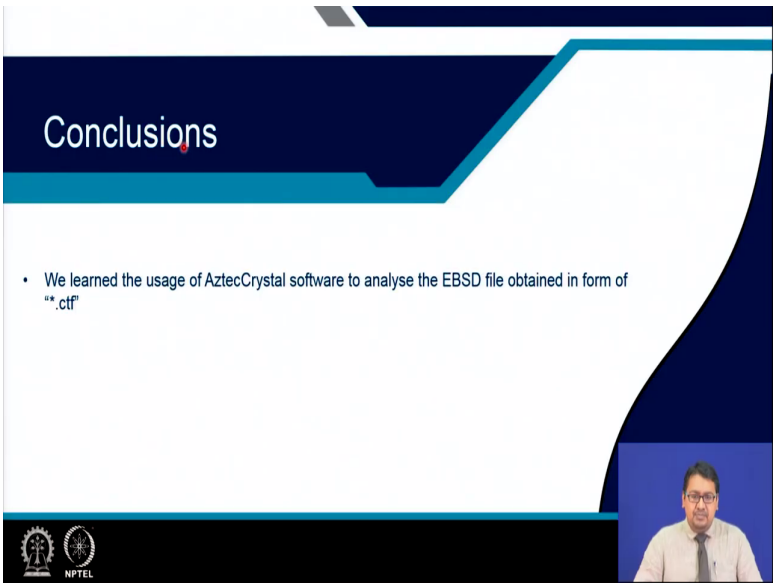

So, in today's class what we learned? We learned the uses of a AztecCrystal software which is made by oxford instruments. You can go to their website oxford dot com and can see that. And, sometimes they give a demo version for the students to use it and to get familiarized with it and the institutes can buy that from oxford instrument. And, this is a very nice analysis software to analyze EBSD data from the dot "ctf" file.

Thank you very much.