Materials Science and Engineering
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Lecture – 10
Quantitative Metallography

Hello friends, we have discussed a microscope and metallography in the previous lectures. So, we now know that how microscopes work and how we can use microscope to get a microstructure ok, and we have also try to understand that what different features are there in a microstructure ok, but whatever we were trying to understand that there are different microstructures or there are grain boundaries different phases unless we do a quantification of that there is no meaning to only doing or looking at a microstructure.

Just a qualitative understanding is not going to give us any value which we can use to find out the properties of the material ok, as an engineer you can understand that I need data or values to, to do my design process or if I want to do any change in the properties ok. So, I need some kind of data for that ok, so just looking at the microstructure in the microscope seeing grains, grain boundary different phases is not going to help me ok.

So, to get rid of this problem there is a kind of a whole field which talks about quantification of a microstructure ok, and this is called quantitative metallography ok. And there are large numbers of parameters where people do quantification of course, some we will see for example, about phases about grain size and so on. Then there is another field where people do some powder metallurgy kind of work where they do characterization of the powders, what is the size average size, what is the size distribution or what is the shape of, of the powder particle and so on ok.

So, of course, that this is a very wide field we will concentrate mostly on the properties because we are dealing with bulk materials here ok so, only the properties where bulk properties are going to be manipulated by these micro structural features, and how I can do a good quantification of that ok. So, we will take a two examples here ok, that how I can do with this quantification and of course, if you want to go or you would want to do a any other quantification as and when you require it during your professional life, you have to go through literature ok.

So, this is just to introduce you to the idea of this quantification that it is possible and we can use this quantification later on you will see that we can relate all these quantification to properties also ok. So, if I want to see the importance of this idea of quantification the properties depend.

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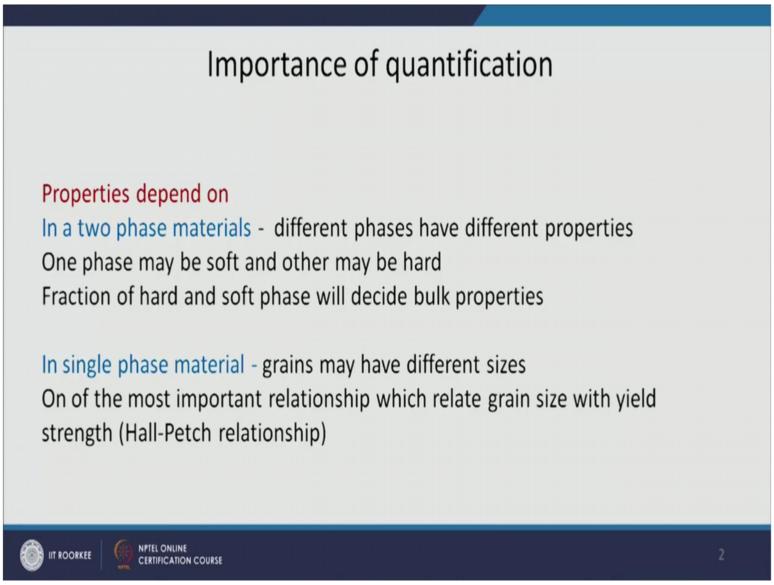

Let us say if you take two phase material, a different phases have different properties maybe one phase will be a softer phase. It can you can easily deform it another phase which is next to it may be a harder phase it is difficult to deform it and these two phases are in are together they are they are they there is an aggregate of these phases ok.

So, when I am doing any property measurement you can understand that because one is soft one is hard ok, the bulk property will be dependent upon suppose there is more of soft phase ok. So, my bulk property will be guided by this soft phase and you your properties for example, let us say strength, the strength will be lower ok. If I have more of hard phase you can again I want to find out the strength you will see that the strength is now more ok. So, depending upon how much content is there for the soft phase, how much is hard phase, you will see that the bulk properties are kind of an average property of these soft and hard phases ok.

So, fraction of this hard or soft phase is very important to know in a given material, if we take a single phase material also the their phases are not there two different phases, but still there are other features which we have discussed earlier also that there may be grain boundary ok, now the grain boundary decides the size of the grain ok.

So, if the grain boundaries are closer to each other the grain size will of course, will be smaller or, of a small size a grain boundaries are far apart you will have a bigger grain ok. So, grain size will be more and there is a very important property which depends upon this size of the grain or grain size and this is called hall pitch relationship.

Later on when we will study the strengthening mechanism ok, you will understand that how important is this relationship actually this relates the grain size with the yield strength of the material ok, from strength of materials course. You must be knowing that yield strength of material is very important in designing, need to design a structure such that, my service load should not exceed the yield strength of the material ok. Or my serviced with the stresses under the service condition should not reach the yield strength of the material it should be well below the yield strength.

So, knowing yield strength is very important, and if I by any means I can increase the yield strength that will also be very important for designing any material I can reduce the size of the component, I can reduce the weight of the overall structure ok, by having a smaller cross sectional area of the material because yield strength is high ok. So, these two are just an example, and I just want to introduce you to the idea of this quantification by these two quantifications of these two features ok.

So, if I want to find out the phase fraction of two different phases, in a material for example, I can I have some material.

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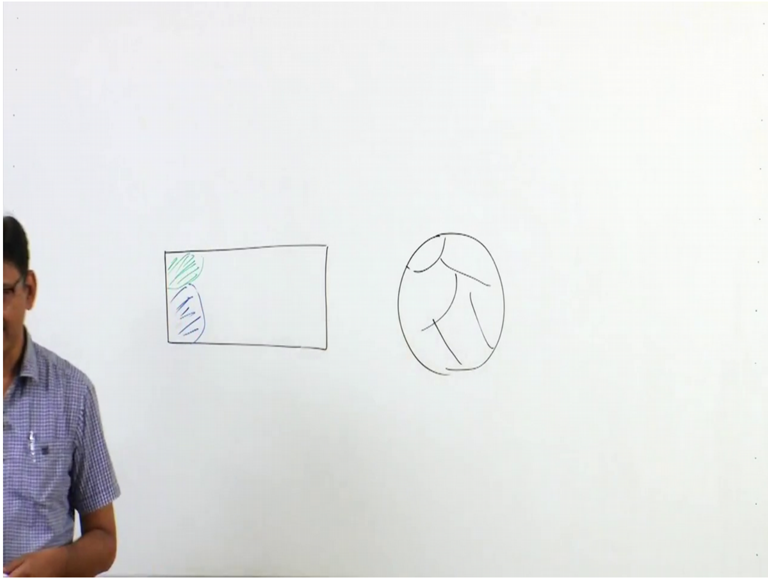

Like this and on that you will have a certain phase here which I am showing by green maybe certain other phase which I am show showing by blue here and so on ok. So, I want to know that what is the fraction of each of these phase in the whole microstructure ok, so what I will do to do that I will place a grid on the microstructure ok. So, the grid is there like a, a vertical lines and horizontal lines ok.

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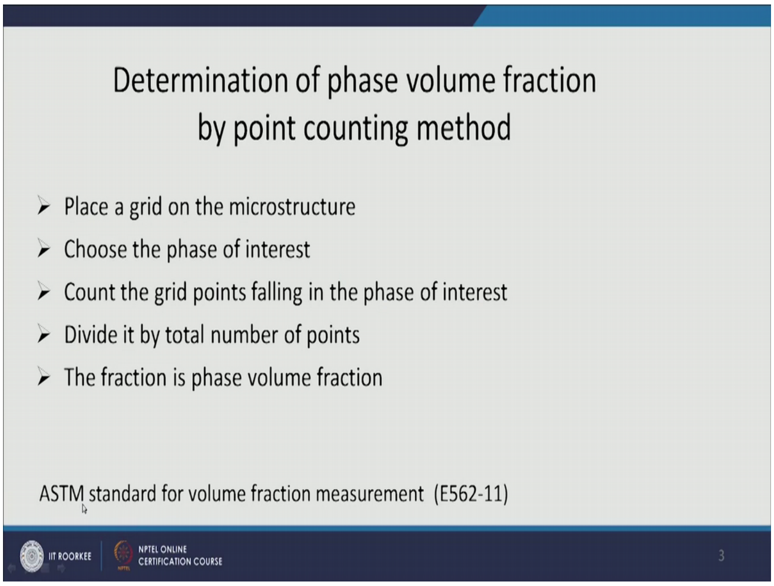

I will choose the phase in which I am interested for which I want to find out that how much is the fraction of that particular phase. Then I will count the grid points falling in the phase of interest, that how many grid points are lying in that particular phase, and I then I will divide it by the total number of points ok.

And that will give me the phase fraction of or volume fraction of that particular phase ok, these all points I will just show you in the next slide, before going there I will just want to tell you that there is a there are standards to do this quantification ok, there is a called a ASTM standard American society of a testing, materials ok.

There are standards for that and this particular standard where we measure volume fraction is given by this particular one E562 hyphen 1 1, 11 ok. So, there are standards available for that how you should do this kind of quantification ok. So, I will let me just explain you with a, with a nice microstructure so this is a microstructure here you can.

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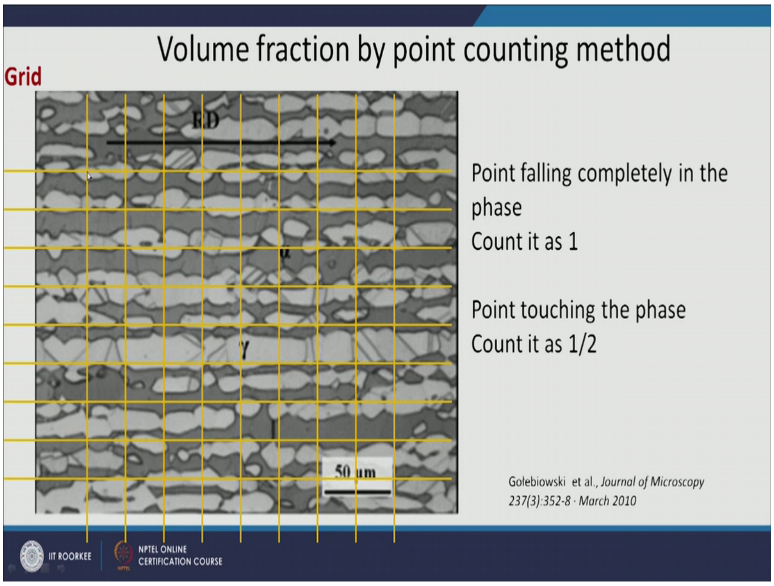

See that microstructure from microscopy and metallography now we know that one phase how why one phase look dark, one phase look bright ok. So, you can see that one of the phase is dark another phase is bright. So, dark one is the alpha phase and bright one is the gamma phase alpha is ferrite; gamma is austenite in a steel the microstructure is taken from this particular paper journal paper ok.

So, now suppose my face of interest here is austenite the bright one I will place a grid over this particular microstructure ok. So, the grid is just helping me to find out where the cross section intersection of these two lines is there. So, that is a point for me, where these two lines are intersecting ok. And I want to count that how many number of points are lying in the bright phase which is austenite here ok. So, as you can see this first point is lying in this phase second one is also lying in this one, but third one is not lying in the bright phase it is lying in the dark phase which is also a which is ferrite and so on.

So, let me just point out here the points which are falling here this one will also come; obviously, now I will do this for the whole grid ok. So, maybe let us say I have points like 1, 2, 3, 4, 5, 6, 7, 8, 9, in this in the row 1, 2, 3, 4, 5, 6, 7, 8, 9, in the in the column. So, it will be total number of points will be 81 ok, and then I will count the number of points which are falling in the bright phase for example, this one this these are at the intersection that you can count as a half wherever the point is lying fully in that phase that can be counted as one.

So, you can do all this counting ok, so let us say you your count comes let us say 50 50 points are lying in the this bright phase which is austenite and total number of points are 81. So, 50 divided by 81 will give you the fraction of austenite phase in this particular microstructure ok. So, by doing this a simple counting method or counting of points which are falling in a particular phase, we have found out the volume fraction of the this particular phase in the microstructure.

Now what is the basis of saying that the points which are falling in a particular phase and counting them finding out the fraction is also going to give me the volume fraction of the a particular phase ok. So, that rational is that is basically a statistical analysis which says that if a point is placed at random within a volume.

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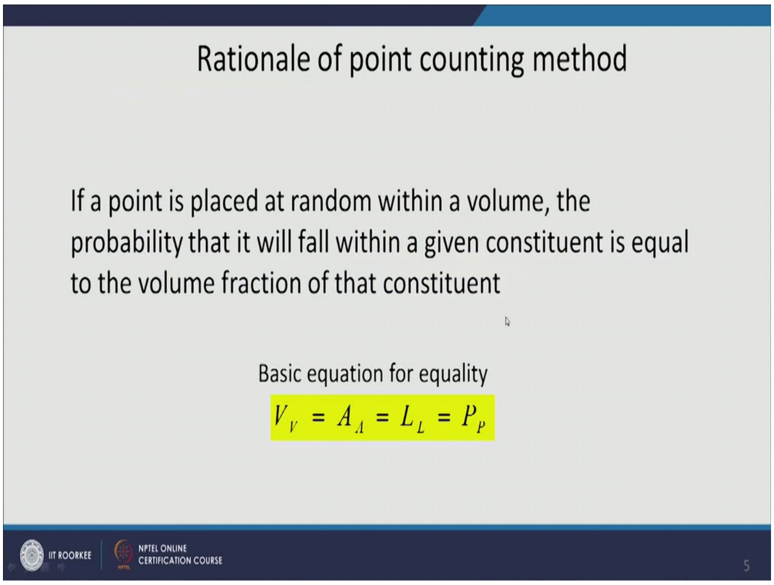

The probability that it will fall within a given constituent is equal to the volume fraction of that constituent ok. So, if when a particular phase is more than the probability of a point falling in that phase is going to be more ok. So, that is the basis for this and which gives a equality between whether, I want to find out fraction using point method, or I can do the same thing by measuring the line segment which are falling in that particular phase and divide dividing it by the total line length ok. If I want to find out from that or if I want to find out from area that half what is the area of a particular phase in the given total area ok.

If I want to do with any of this method ultimately I will get the same thing if I want to find out in terms of volume ok, now in a bulk material solid material I cannot go in the material and find out what will be the volume of a particular phase ok. So, I have to rely on either a fractional area or fractional line length, but both this will be a very tedious process to find out by planimetry method maybe of finding out the what is the area or what is the line segment falling in a particular phase ok. So, the easiest one, and when you have the easiest one the, the mistakes which you can commit will come down drastically ok.

So, if you have the easiest method then you will also commit less mistakes ok. So, the easiest one is where you can do the same thing by counting the points which are falling in a particular phase and dividing it by the total number points ok. So, whatever fraction you will get in terms of point that will also be the fraction in terms of volume ok.

So, by a simple method like that you can find out that what is the fraction of different phases in the material? and depending upon that in fact, your properties will be dependent on the on the fraction the second very important feature in a microstructure is grain size already we have seen what do we mean by grain ok. So, the size of a grain earlier a popular method used to be what they used to called as so ASTM grain size number ok.

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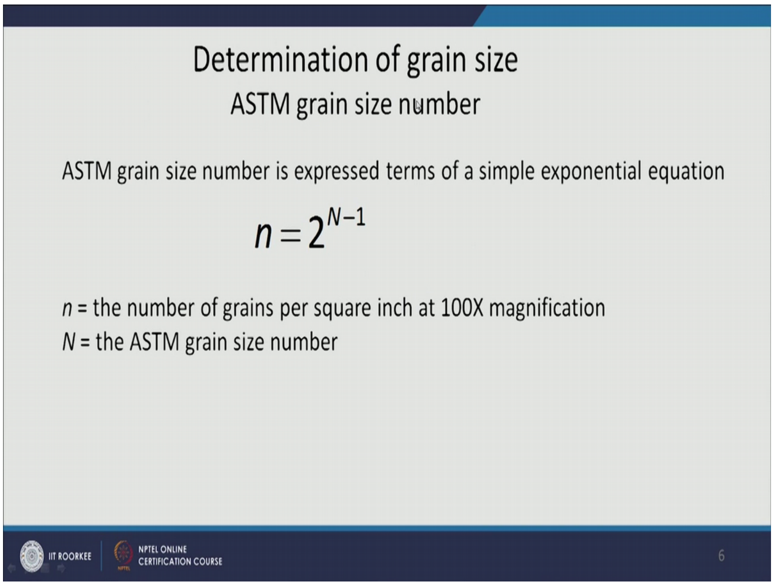

And that is actually a simple exponential equation given by an equation like this; a small n is equal to 2 to the power N minus 1, where a small n is the number of grains per square inch at 100 x magnification. So, in the microscope you set the microscope such that you are getting a 100 x magnification and in that 100 x magnification then you take a, a circle of a some, some area ok.

So, whatever is the number you are getting per square inch that is the n here ok. So, if I put n here equal to 2 to power n minus 1, the capital N will give you the ASTM grain size number ok. So, simple calculation like that will give you a ASTM grain size number and because this is the exponential equation ok. So, if ASTM grain size number the big N is 1.

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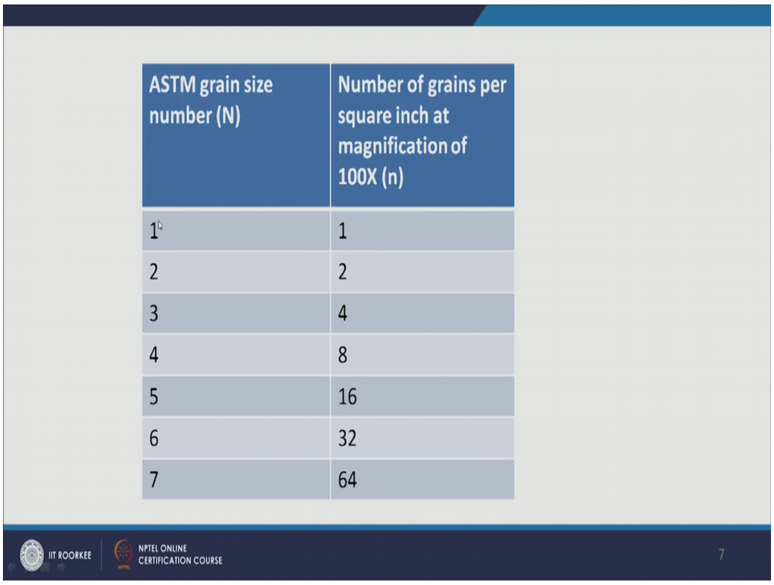

ASTM grain size number (N)	Number of grains per square inch at magnification of 100X (n)
1	1
2	2
3	4
4	8
5	16
6	32
7	64

Then the number of grains per square inch at magnification of 100 x, which is a small n will be one if it is two then it is 2 of course, but if it is 3 then it will be four if grain size number ASTM grain size number is 4; that means, the number of grains in a square inch area will be 8.

If the ASTM grain size number is 5, then the number of grains in a, a per square inch it will be 16 and so on. So, you can see though we are increasing linearly here in ASTM grain size number, the number of grains per square inch on the right hand side is increasing exponentially ok. So, by this you can give that in a square inch area how many number of grains are there, you can also make a judgment from this that if, but there are more grains are coming in the in a square inch ok; that means, the grain size will be small the grains are find ok.

More grains are able to come in a circle of you can have a circle like this, find out the area of this circle, and count how many grains are coming in this particular circle say if more are coming; that means, the grain is fine and the it has a smaller grain size.

So, ASTM number if it is more the grain size is small, it will be grains, grains are finer please remember that, the higher the ASTM number it is the finer the grains then there are other methods more popular now earlier it used to be this ASTM grain size number and this is called linear intercept method ok.

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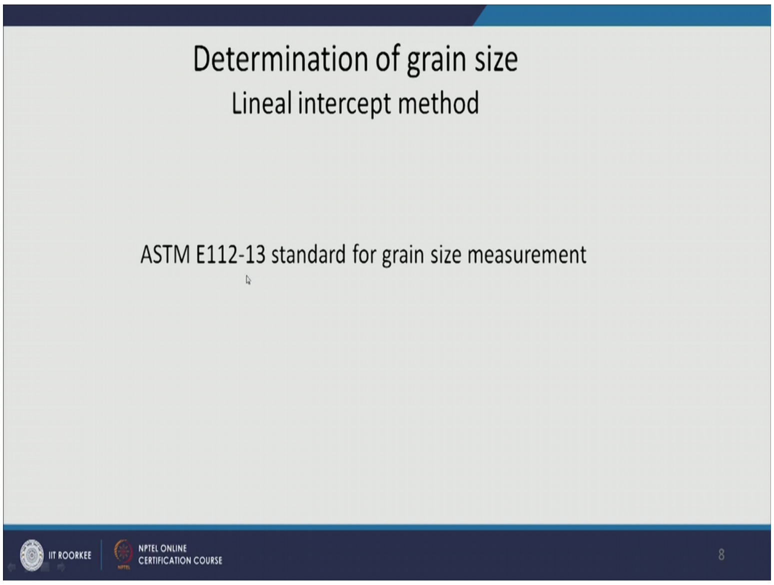

And again there is a number for that E 112 hyphen 13 to measure the grain size ok, for grain size measure paint and how it is done before coming to that just I want to tell you that, what is the ideal shape of a grain.

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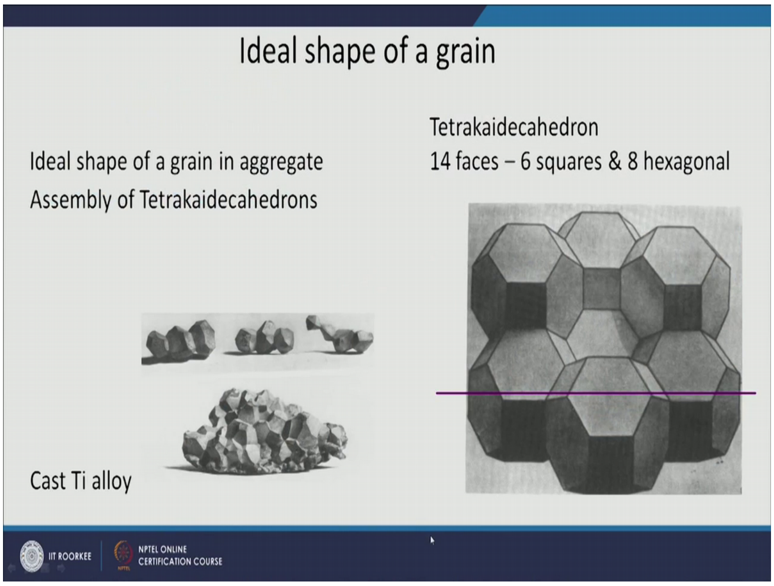

Ideal shape of a grain is called Tetrakaidecahedron ok, which has 14 phases which contains 6 squares and 8 hexagonal So, you can see one hexagonal here one square here another hexagonal here another square here and so on and some faces will be in the back. So, this is a kind of an ideal shape which you want to have for grains and which can give you a space filling arrangement ok, and some evidence are there for example, again a cast titanium alloy you can see grains are visible here.

And looks very similar to what idealized case we are taking here ok, you can see that there are number of phases here some looks hexagonal and some look square faces, and if you, combine them then you can have a space filling arrangement. So, this is the ideal shape of a grain, we do not have to worry about that too much now how to do a grain size measurement by this linear intercept method ok.

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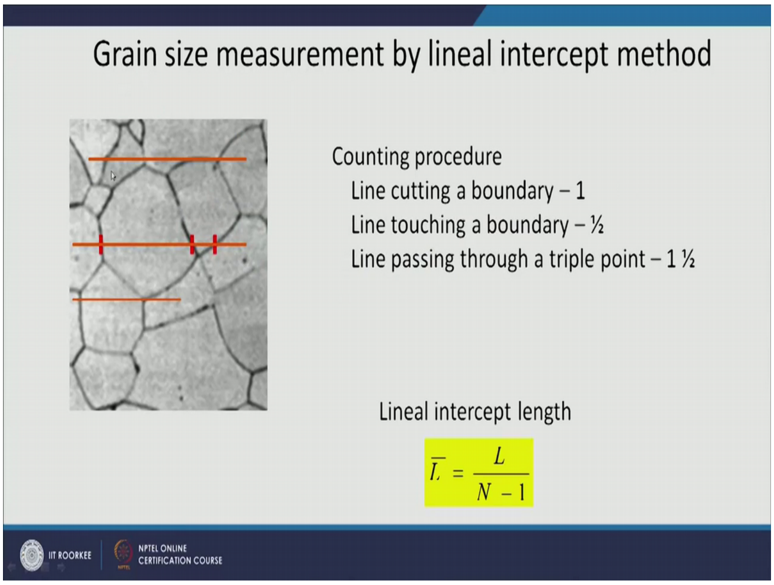

The idea is this, that if you get a microstructure as shown here in the slide you can see that there are grain boundaries and so on ok. Again a very simple method that you start putting some lines on the microstructure ok. For example, this middle line if you take; now we will count the number of intercepts this line is making with the grain boundaries ok.

And the counting procedure will be like this if a line is cutting a boundary then it will be the count 1 ok. If a line is touching a boundary as shown here in the first line here, boundary is touching the line then it will be called as a counter is half. If a line is passing through the triple point, you can see that there are three grain boundaries which are joining at this point. And our line is passing through that then I will be counting it as one and half ok.

So, this is our counting procedure ok, so you will do counts. So, suppose I do account 1 2 3 3 and half here maybe a 4 and half, 5 and half, 6 and half, 7 and half, and 8 and 9. So, there will be 9 intercepts on this three lines and I, I will be before end knowing that what will be the length of this line all this three lines. So, my intern length divided by the total intercept. So, either here I will be putting 9 minus because I am taking three lines here I will be putting three here instead of one and that will give me the average linear intercept length ok.

So, instead of finding a, a number I am directly giving you the grain size in terms of length ok. So, suppose if this microstructure are use it usually in micron size ok, this length will also be in micron size ok. So, if I say that just for arguments sake let us say this line lengths are equal to 50 micron.

So, it will be 50 divided by 9 minus 3 that will be 6. So, 50 divided by 6 will be the inter linear intercept length and that you can say that it is approximately close to the grain size ok, but there is a still a twist in the story, and the twist is that I have to do some kind of correction here and the correction is as you can see the in the on the slide ok, instead of that 14 faces kind of a drain I am assuming the grain shape is a spherical here.

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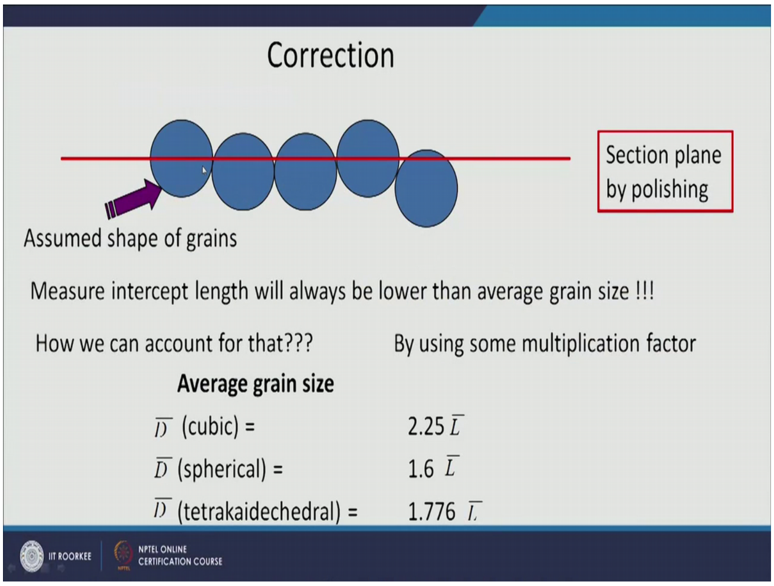

Just for simplicity so suppose these, these are grains all this spherical as you can see on the slide ok, and when you are doing a polishing then you are not knowing beforehand that which plane you are going to cut these grains in what will be the plane. So, suppose you have this grains which are arranged in all kinds of shapes all kinds of a, a different planes and this red line is depicting the section of the plane which you have created by a polishing ok.

So, you can see that it is cutting this granite different lengths or a different locations ok. So, in some cases it is cutting exactly through the center of the grain in some cases it is cutting towards some there is an offset or a some distance away from the center of the grain ok. For example, in this case in this grain you can see very clearly this is the center and I am cutting it here.

Now, when I am looking from the top, so this is the section I have created and now I am looking from the top to see the microstructure ok. You will see that in this grain I am only measuring the grain size up to this particular dimension this is what has been cut whereas, in this case I will be measuring the true grain size because I am cutting through the center ok. So, wherever I am cutting away from the center I am actually measuring the size, which is a smaller than the actual size ok. So, after cutting basically you will see a grain size like this after the cutting from the top ok.

So, when I am measuring the smaller size means the; it is whatever I am I am measuring by taking a section a two dimensional section in a three dimensional body ok. I am measuring it at a, a smaller size than the actual size ok; that means, I have to do some kind of correction to do that correction there are some multiplication factors are given here ok. So, if you consider as I told you the ideal shape of the grain is this polyhedral of 14 phases ok, then I have to multiply it by 1.776 ok, the other two shapes are not there it is just a, a statistical analysis for cubic and a spherical.

So, if you assume that these shapes are cubic the grain shape is cubical then you have to multiply by 2.25. If you assume it to be spherical then it is 1.6, but it is more close to this shape. So, we will not we will take this particular correction factor as 1.776 into L bar that will give you the average grain size ok. So, whatever you have done the measurement in the previous slide as I told you ok, L bar whatever average linear intercept length you have got that has to be multiplied by 1.776 to get the average grain size ok.

So, by doing all this a quantitative metallography ok, we have only taken two example as I told you in the beginning, we have found out the grain size by a linear intercept length which is the most common way of doing measurement nowadays ok. And we also use a point counting method to find out the phase fraction and these two are a very important measurement in terms of bulk metallic properties. So, but there can be other quantifications also this is just to introduce you to the concept of this and there are ASTM standards available for that.

So, you can go through that also to find out that what is the actual correct procedure to do the measurement, just I can take one more example here specially in industry that will be of interest to us usually in the industry you will see a process called rolling ok. So, basically a big block of material will be there it will go through two big rolls and then you reduce the cross section area of the block ok.

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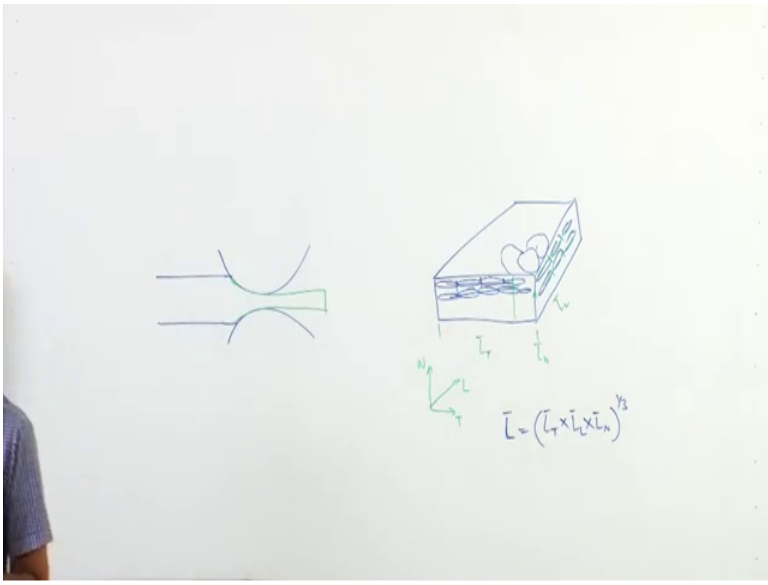

So, basically if you start there may be thicker material like this then there will be two rolls here like this and the material will go through that so that I will draw it like this ok. So, you have reduced the thickness of the material, but in this process what happens is you get a grain size that I will try to show you in three dimensions ok.

So, the grain size becomes like this which we call as pancake shape ok, something like this and in this direction it gets elongated like this and on the top if you see the grains will be some shape like this from the top it will look as a kind of a that, you will see it as that there may be a spherical ok, but if you see on these two sides you will see that they are elongated ok.

So, in this kind of a microstructure the measurement like this will not give you the correct grain size ok. So, what you can do is you can do a this again linear intercept size in this direction, which I am going to call as L T this is my transverse direction this is my longitudinal direction and this is my normal direction ok. So, I can do this linear intercept measurement in by plotting lines like this and counting the intercepts.

Similarly, I can plot different line and find out the intercepts ok. So, in this direction I will be having intercept length L bar ok, and in the normal direction by plotting a line like this and counting the intercepts ok. I will be having L n ok, and the average linear intercept length then will be multiplication of all of these and taking the cube root of this ok. So, this is one of the specific case of doing a measurement in a different type of microstructure.

So, if you have a microstructure which is in the volume is of same type of aspect ratio in this direction in this direction in the normal direction then you can directly use the technique which I showed you in the slide, but suppose you have a different type of microstructure which is a rolled microstructure, which gets elongated during rolling the grains elongated gate during rolling ok.

So, in that case you have some measurement like this also. So, in that ASTM standard you will get all this information for different situation, how you will do the grain size measurement ok.

So, with that I will like to thank you.