Introduction to Materials Science and Engineering
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Lecture – 122
Grain size hardening

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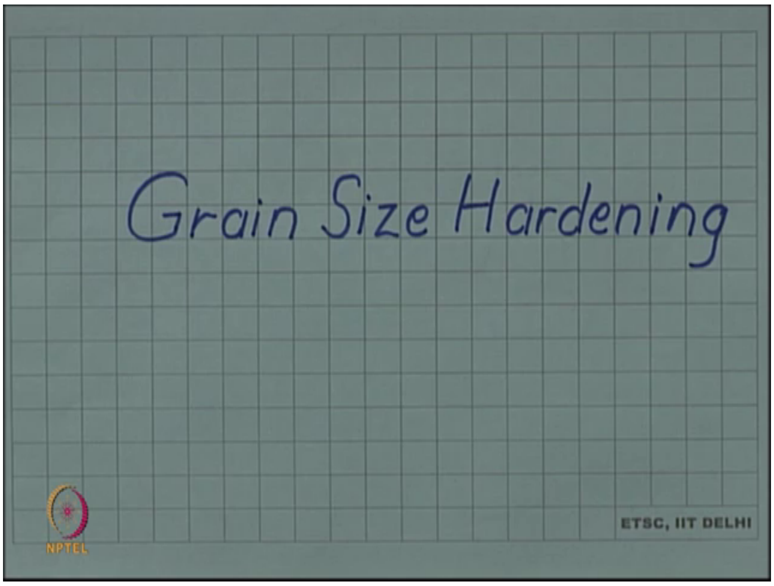

As an another example of a strengthening mechanism, let us now talk about Grain Size Hardening.

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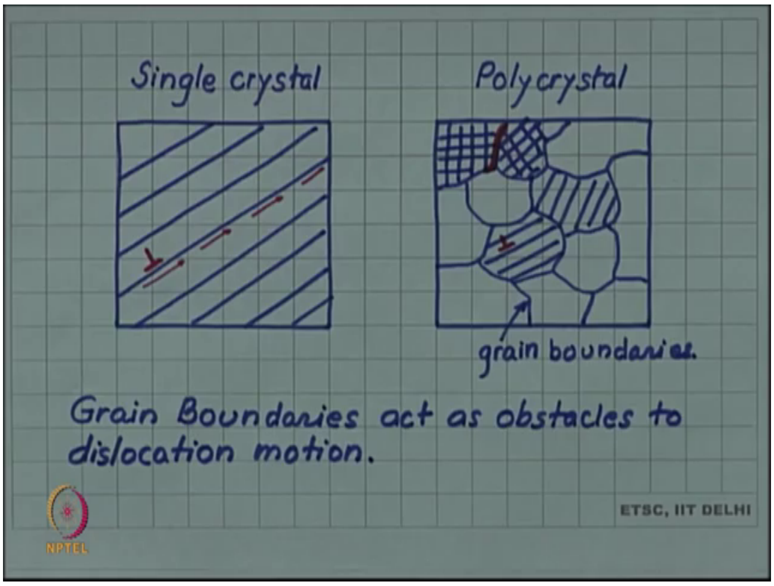

Let us recall, what we mean by grain size? If we have a single crystal, then all the unit cells in the entire sample are all oriented in the same way. So, we have only one real crystal. When we talk about crystal or when we think about crystal, a single crystal which we are thinking about.

But the real crystalline material are mostly polycrystalline that is the orientation of the unit cell changes from region to region. So, if we have if we have unit cells like this; here we have talked about this; when we in the defects chapter when we were discussing about grain boundary. So, the orientation of the unit cell changes. This change in orientation creates what is called a grain boundary because there is a region, there is a disturbed region between two grains which is called the grain boundary.

So, here I have indicated by these lines the grain boundaries and the regions are different grains. Now, if we if we now; let us try to a draw a particular plane, let us call the slip plane. So, in a single crystal, the slip plane will be all parallel and will go from surface to surface of the crystal. In this single crystal, if there is a dislocation on the slip plane, remember we use this symbol to indicate a edge dislocation.

So, suppose there is an edge dislocation and it is gliding on the slip plane, so, then it can keep gliding on this plane till it comes out at the surface where it will create a Burgers vector step. But if you look at the same situation in poly crystal, then if I draw particular set of slip plane, the slip plane continuity is broken at the grain boundary because the orientation of the planes in the other grain is different from this.

So, a slip plane will not continue into another grain. So, if I now have a have a dislocation line here which is moving, it has to necessarily stop at the grain boundary. So, for deformation to continue, another dislocation has to be activated in the other grain which may not be so, favourably oriented. So, thus the entire motion of the dislocation is obstructed by the grain boundaries and it is becomes more difficult to continue the deformation through the dislocation motion. So, grain boundaries; grain boundaries act as obstacles; obstacle to dislocation motion.

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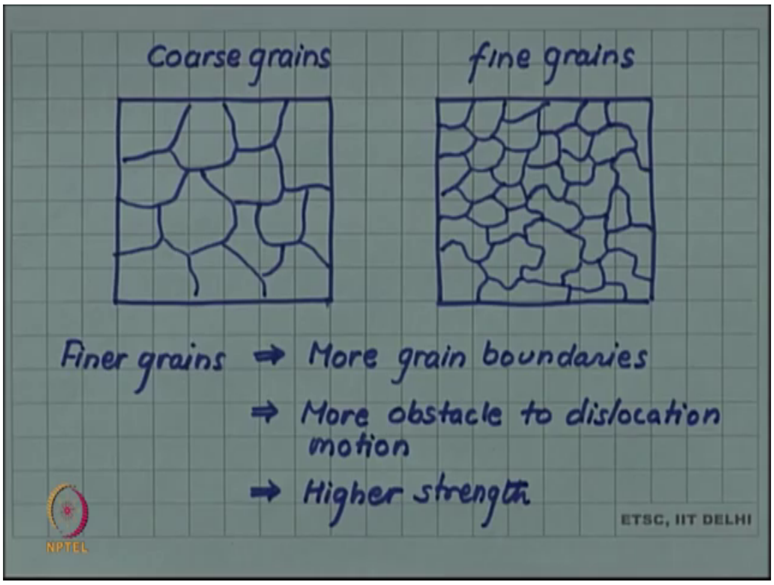

Now, if you accept that; then it is very easy to see. Now, I have shown you two examples here. So, in one case, you can see that the grain size sort of average grain size, we will soon define that what we mean by that is larger here in the first example than in the second one. So, we will call this coarse grain whereas, we will call this a fine grain material because here the average grain size is a smaller. So, you can see if grain boundaries are obstacle to the dislocation motion, dislocations will have more frequent interference in the finer grains because there are more grain boundaries than in the coarser grain.

So, finer grains more grain boundaries. So, more obstacle to dislocation motion which means higher stress is required to cause plastic deformation, so, higher strength.

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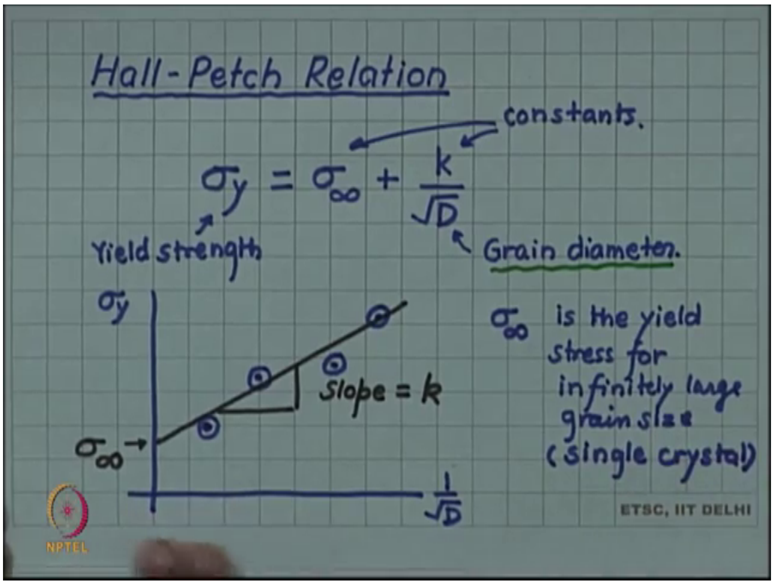

This has been quantified by a famous relation known as Hall-Petch Relation after the discoverer. So, they empirically found that the yield stress of a material can be written as.

Let me let me write the sigma infinity. By actually doing experiments they found that yield stress can be related to the grain size. So, this is grain size or a grain diameter and this is yield strength, sigma infinity and k are constants and the way these constants can be found or way this relationship can be established is to try to prepare a specimens, this is what Hall and Petch did, try to prepare specimens of different grain size and plot 1 by square root of D as x axis and sigma y as y axis. So, if we make a plot of this for different grain size, so, if this relationship is true, you should expect a straight line.

So, to the experimental data, if you fit the best fit a straight line, then the intercept; you can see from here, if 1 by root D is 0, then this will be the intercept and that will be sigma infinity and the slope will give you the constant k, here your data points. You can give a physical interpretation of sigma infinity; you can see that sigma infinity is yield stress at 1 by root D 0, which means sigma infinity is the yield stress when D is infinity. So, sigma infinity can be understood as infinity is a yield stress for infinitely large grain size. So, infinitely large grain size maybe you can assume it to be a single crystal because there are no grain boundaries. So, sigma infinity can be thought of as some sort of yield stress average yield stress of a single crystal.

But one point here is still not obvious that what do we mean by grain diameter? What is meant by grain diameter which we are plotting along the x axis?

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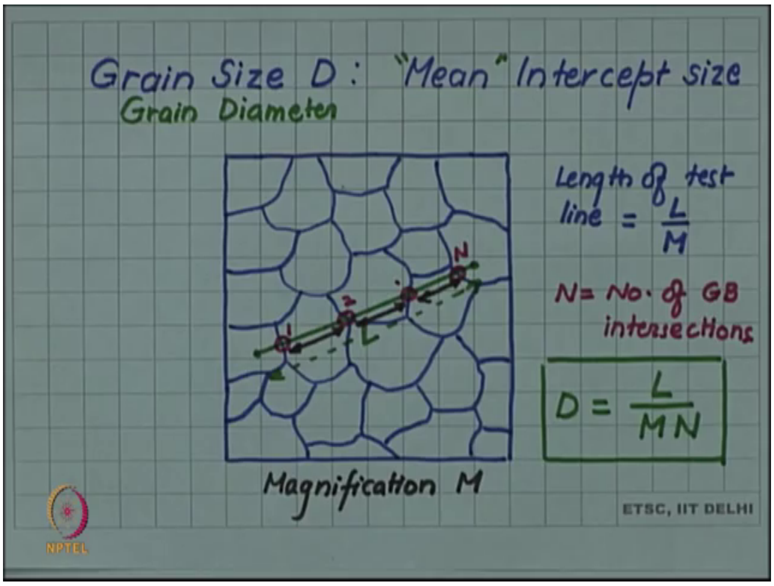

So, let me try to make it little bit quantitative. So, the way the grain size or grain diameter is measured, one way it is measured is what is called linear intercept method or intercept size mean intercept size. What you do is to take a micrograph like this which is showing the grains and grain boundary and then draw a line on this of a given length, will let L be the length of the line and then you count the number of grain boundary intersections. So, let us say 1 2 N grain boundary are intersecting and let the magnification of this image be M because this is a microstructure, grain sizes are usually small; not visible by naked eye, you have to use microscope. So, you have to see at some magnification. So, let us say that the magnification is M.

So, this means the real length of this line; the real length of this line is L by M on the specimen. So, length of test line is equal to L by M and since there are N grain boundary intersections, we can see that there are N intercepts on this line, we are calling this as our intercepts and this will be different for different grains and as I choose my line in different orientation also these will vary.

So, if there are N intercepts, number of grain boundary intersections; then we define the grain diameter D as simply the length of the test line which is L by M divided by the number of these intersections. Of course, you will have to take various test lines and take the mean of it and that is why the phrase Mean Intercept grain size is used for this purpose. So, this kind of grain size is what we are talking about when we want to use Hall- Petch relation.