Thermo-Mechanical and Thermo-Chemical Processes

Prof. Vivek Pancholi
Department of Metallurgy and Materials Engineering
Indian Institute of Technology-Roorkee

Lecture-06
Microstructure Evolution

Hello friends, we will start with a new lecture today and it is about microstructure evolution. In hot deformation process, the main purpose of our doing this particular process is to change the microstructure or bring new microstructural features and that is done through hot deformation process. So, we want to understand that what microstructure evolution can take place and basically to understand the different type of microstructural features, because these features will keep coming in the remaining lectures.

So, I will introduce those features to you. So, that when we are referring to those features or those techniques to understand the features you will be able to relate with this particular lecture. So, the microstructure features which are important during hot deformation process which we try to do or which we try to change through hot deformation process is basically grain size (refer to below slide).

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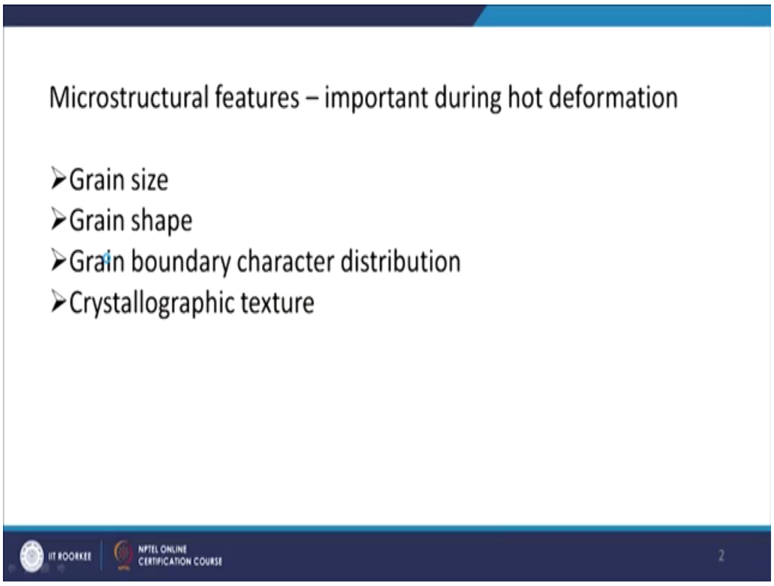

Main purpose is to refine the grain sizes. So, because grain size refinement as you know the Hall-petch relationship so, with refinement in grain size you get more strength. Another is grain shape so, for; with different hot deformation process you get different kind of shapes, it can be equiaxed shape means in all axis or in all the direction the size of the grain is same or it can be as we can say that it can have a elongated grains like this, then grain boundary character distribution.

So, you already know that there is some features called grain boundary in the microstructure in that also there are differences, some are low angle grain boundary, some are high angle grain boundary. So, what is the grain boundary character distribution and of course, crystallographic texture.

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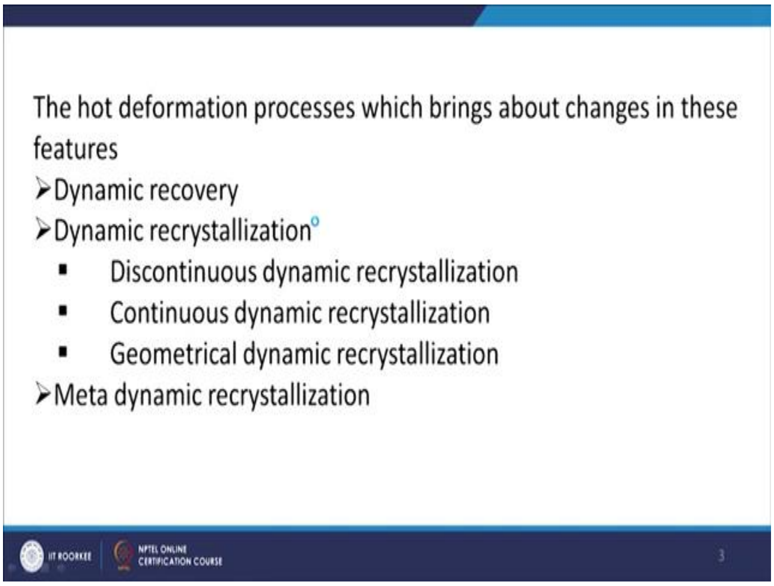

So, the hot deformation process which bring changes in this features as we; I told you about grain size, grain shape, grain boundary character distribution and crystallographic texture. So, the processes which bring this changes in this particular features and which are used in hot deformation process or which are acting during the hot deformation processes are dynamic recovery, dynamic recrystallization.

In dynamic recrystallization also, there are two three different distinct processes have been identified by researchers, these are the continuous dynamic recrystallization, which is also called as classical dynamic recrystallization where you have nucleation and growth. And these we will of course, study or discuss in detail in the coming lectures. Then you have a continuous dynamic recrystallization, recently people have started talking about this a lot.

In fact now, it is it happens that people feel that continuous dynamic recrystallization is the most common and discontinuous is taking place only in few cases and then geometrical dynamic re-crystallization, and another class of recrystallization or dynamic recrystallization, which is called

Meta dynamic recrystallization. So, we will see these recrystallization processes also in detail. Right now, we would like to see what kind of microstructural changes takes place during the deformation process.

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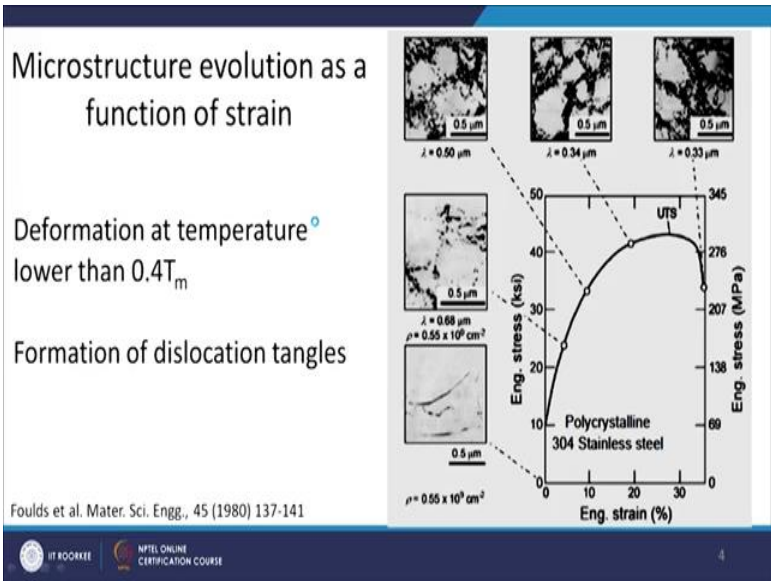

If you see the changes which takes place a very simple way of looking at it is in this particular slide, of course, this kind of deformation we are doing at lower temperature so, you can see that it is a room temperature deformation and the material which is used is 304 stainless steel poly crystalline. And there the researcher have done a very elaborate work on this that they have taken the sample from different stages during the deformation process.

And in these are TEM micrographs (refer to above slide), and they are showing the how the dislocations are arranged. So, please remember that this is not a high temperature deformation; this is a room temperature deformation that means low temperature deformation. So, lot of the processes which happens at high temperature is not going to take place here. But deformation will always be either through dislocation or usually most usual process is through dislocation movement dislocation generation and dislocation movement.

So, this dislocation actually are rearranging in kind of they are tangling with each other they are interacting with each other and they are forming this kind of a small cells. And a very thick you can see very thick boundaries there of these dislocations. So, this is what you will see usually in case of a low temperature deformation that dislocation generation is taking place and then they are tangling and making this kind of cell and these cell walls.

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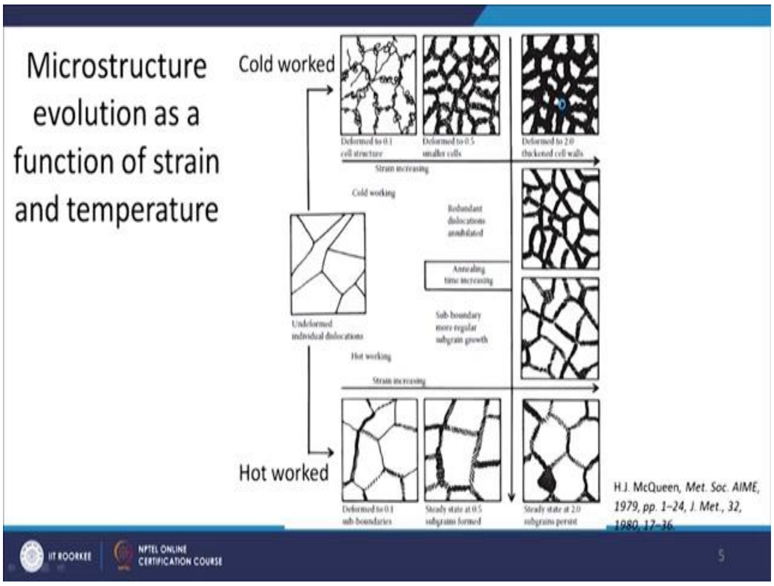

Now, this is a more elaborate kind of picture showing that what kind of microstructure evolution takes place as a function of a strain, these are all a schematic with the strain and temperature. So, the upper ones are shown for cold work material and you can see that the strain is increasing from left to right. Cold worked microstructures are at the top and hot work microstructure at the bottom.

And I would say that a demarcation between cold work and hot work will be lets say, I would say we will take 0.4 of melting point of that material, as the demarcation between hot work and cold work, so, below this we will say a cold work about this we will say hot work there is another segregation here which is also called warm working. So, another addition is there now. So, you have hot working, warm working and cold working.

So, in cold work material, you can see that the dislocations are getting entangled with each other and as you increase the strain. So, the, this cells which are formed initially are becoming smaller and the width of the cell wall is increasing. At even higher a strain the cell walls are becoming even more thicker and the cell size is becoming smaller and smaller. So, you will have very large dislocation density inside the material.

Now, if you compare this with the hot work material here also you can see that of course, dislocation will be there as you are increasing the strain. And now, we are calling them as sub boundaries. So, this thick line actually high angle grain boundaries and smaller thinner lines or these kind of dashed lines are the sub grain boundaries. So, sub boundaries or sub grain boundaries. So, you can see that they are becoming thicker and thicker.

And again the grain is getting subdivided into sub grains and these are all now sub grain boundaries or low angle grain boundaries. With increase in strain, the sub grain are still persisting you can see that the size is not changing much and then also thickness of the walls are not changing much, but there will be some refinement in some localized region, because of the strain and these 2 micro structures are in between the 2 that means the cold work and hot work.

So, you can see that how the temperature is playing role in the last 4 micrographs if you see in this direction my temperature is increasing. And you can see the effect of the temperature as well as the of the strain.

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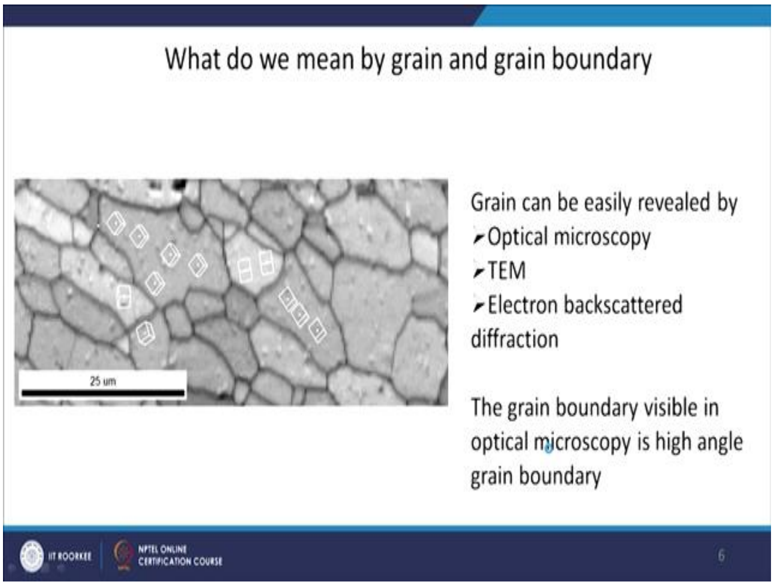

Now, what do we mean by grain and grain boundary, I just want to kind of do a recap for you, if you must have done this in your material science course or if you are from metallurgy in different structural metallurgy course for example, but just to do a recap here, you can see microstructure is shown here (refer to above slide) with some dark boundaries. So, these dark boundaries are basically the high angle grain boundaries.

So, what is a grain, the grain is something is which is surrounded by only the high angle grain boundaries. So, I would say that all these are my high angle grain boundary and if a portion of the microstructure is surrounded by a high angle grain boundary I would call it as grain and what happens in the grain why we separate these; suppose it is aluminium or ferrite alpha ferrite in a steel they have same crystal structure.

So, aluminium is FCC ferrite is BCC. So, within a grain it will have the same crystal structure and in the throughout the microstructure they will have the same crystal structure. So, for example, if you take this as aluminium it will be only face centered cubic then what is the difference between the grain or what is the identity of a grain So, identity of a grain is that if you check the unit cell at different location in this particular grain, you can see that the unit cell is oriented in a same way.

As soon as I cross the grain boundary you can see that now the unit cell is in a different orientation but within that particular grain again this is a grain with angle grain boundary. Again the unit cell orientation is same again if I cross the grain boundary you can see that the orientation of the unit cell as again changed, but within the grain it is still same. So, the grain means that if you want to check the orientation of the unit cell within that it will be same within the grain.

As soon as you cross the grain boundary it has to change and the boundary is the is a defect which kind of accommodate this change in the orientation between the unit cell and the grain boundary. What you see in an optical microscope is what we call as high angle grain boundary. we will see what do we mean by angle grain boundary. And low angle grain boundaries or what we saw in the previous slide schematically they showed sub grain boundaries.

This low angle grain boundary would not be visible in an optical microscope. But for that you can do a TEM transmission electron microscopy or newer technique which is called electron backscatter deflection or EBSD also. So, you can use these techniques to also characterize the sub grain boundary or low angle grain boundary, but optical microscopy will show you mostly the high angle grain boundary and that means only the grain information about the grain not the sub grain.

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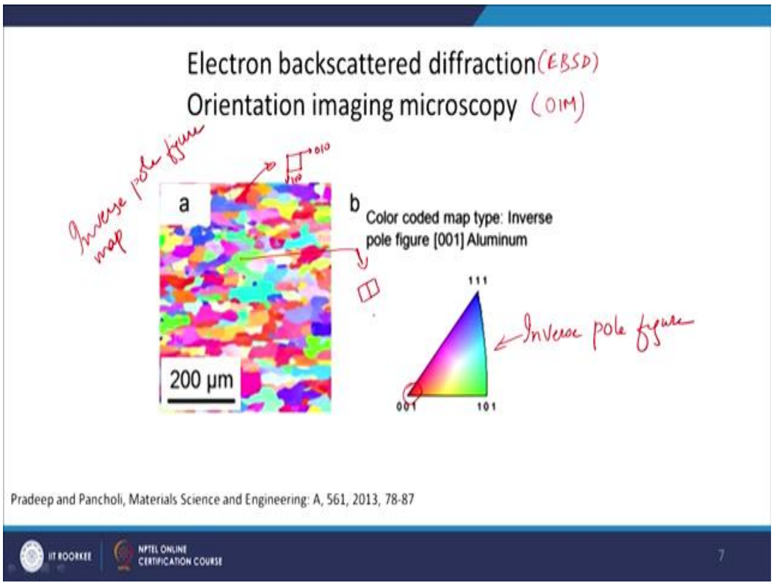

Now as I was telling about you electron backscatter diffraction. A commercial name for this that is for a certain company is also called orientation imaging microscopy. So, in some papers, you will see that the name orientation imaging microscope is used OIM but please remember that it is a name of a product of a certain company whereas EBSD is a generic name. And what it gives you a one of the outputs which it gives is a kind of this nice color map.

Why I am showing is because these again will come at different places during our discussion of microstructure in the coming lectures. So, you will see these (refer to above slide) kinds microstructures a lot. So, for example, in this particular micro structure, I see a very nice color map. And each color actually is representing some information which for which the key is given here this is what you call as Inverse Pole Figure. And this is also that is why it is called Inverse Pole Figure Map.

And what this each color represents is the orientation of the grain as I just told you earlier also that a grain means a unit cell is oriented in a different way. So, you can see that all these different colors is actually representing the orientation of that particular grain and for that the key is here. So if a grain is colored as red, then its 001 axis is coming out of the surface. So for example, let's say take a red color grain from here, let's say this one.

Now, this is a red colored grain. And if I am seeing from the top my unit cell will be like this, because 001 axis is coming out of the surface. So, 001 axis coming out from the surface, so, I would say this will be 100 and this will be 010. If a grain is colored as green, let's say this one here. Then it is a 110 or 011 oriented grain that means the 011 axis is coming out of the surface.

So, if I want to draw that maybe I am drawing it correctly here, something like this or maybe you won't see the edges also here. Let me correct it here like this.

So, 100 is coming out. And this plane is also what you are seeing will be 110 plane. And if it is 111 then it will be blue colored and the 111 axis will come out. So, this kind of map actually shows you this kind of information about orientation and then you can also do other analysis like what will be the texture and all those things, but I just wanted to show you that this kind of information will keep coming during our discussion of hot deformation.

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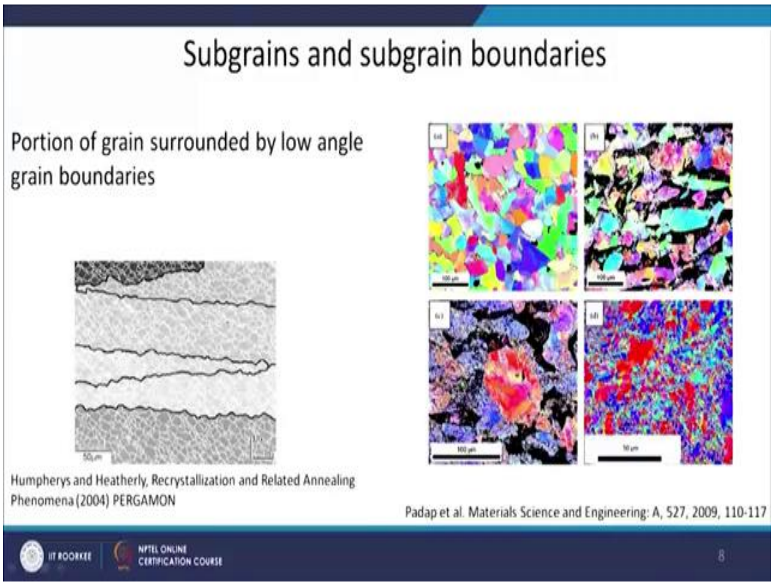

Another as I told you that one is grain, grain boundary then there is another detail to the grain is called sub grains. So, when I would call something as sub grain as you can see sub means it must be something which is in hierarchy lower than the grain. So, a grain I would say is the portion of the microstructure which is surrounded by the high angle grain boundaries and within those high angle grain boundaries as shown in this micrograph very nicely (refer to above slide).

You can see that there are some black lines. And these black lines are high angle grain boundary. And within that there are large numbers of these white color boundaries. And these are all low angle grain boundaries, the portion which is surrounded by this low angle grain boundaries, these are called sub grains. So, a grain is sub divided into sub grains due to deformation process.

Another, as I told you we keep using this kind of map, you can see a microstructure here. So, this is before deformation or maybe a small amount of deformation and then you have more deformation here. So, the grains are now subdivided, and you can see a very large number of these white portions within the grain which is subdividing the grain. So, bigger grain is subdivided into smaller grain using this sub grain boundaries or which is also called as low angle grain boundaries.

So, this kind of division will be there and sub grains will form within the grain and if the boundaries which are surrounding this sub grain will be called a sub grain boundary and the sub grain boundaries are usually basically are low angle grain boundaries. So, this kind of microstructure you will see in very nice microstructure is shown here also (refer to above slide). So, as I told you that there are 2 types of grain boundaries are there. Low angle boundary and high angle grain boundary.

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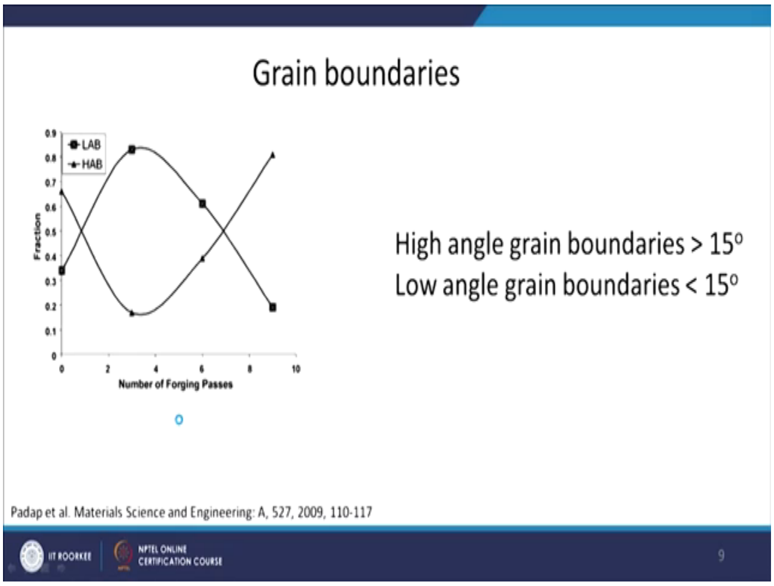

So, the boundaries are typically defined as if the angle between the two grains is more than 15 degree or the misorientation between the two grains is more than 15 degrees then it will be called as high angle grain boundary and if the misorientation between two grain is lower than 15 degree then it will be called low angle grain boundary.

And why we separate grain boundaries on some number like this is if I plot the grain boundary energy; grain boundary energy as a function of theta that is the misorientation then it will have some curve like this (refer to above slide). So, initially it will be a linear change so, as I am increasing the angle theta the energy will increase linearly and after some time it will start getting saturated. So, this saturation point this is typically between this range 15 degree to 20 degree after that it becomes saturate that means the grain boundary energy become independent of the misorientation.

So, this we kind of segregate as low angle and high angle grain boundary and when you do hot deformation these kind of changes keep taking place for example, graph is shown here (above slide) and on the x-axis it is saying number of forging passes so, for our purposes you can just say take it as a strain. So, in x-axis strain is increasing and this is the fraction of low angle grain boundary and high angle grain boundary. So, you can see as a strain is increasing initially the low angle grain boundary fraction is increasing.

So, it is started from in the initial microstructure it was somewhere around .35 and it went up to around .85 after initial strain and of course, if LAGB or low angle grain boundary fraction is increasing then high angle grain boundary fraction has to come down. And as you increase more strain now, you can see that the low angle grain boundary percentage is coming down now it is it is .6 after another amount of strain then it is going even below than the initial microstructure somewhere around .15.

So, the idea is that grain size changes grain boundary character changes during the deformation process, bigger grains subdivided into smaller grains. So lot of changes takes place during the hot deformation process and it makes a microstructural characterization as a very interesting process to understand that how microstructure is evolving through during this hot deformation process.

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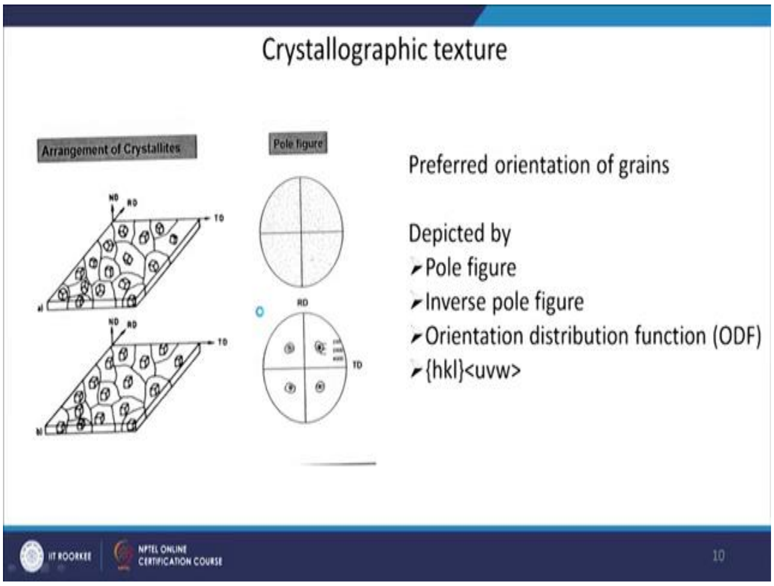

Another very important microstructural change which will take place during the deformation is what we call as crystallographic texture. So, just to give you a quick summary of the crystallographic texture here, we will discuss texture in more detail in the coming lectures also.

As I told you that each grain identity is that what is the orientation of the unit cell, now lets suppose you have a condition, well lets you have 100 grains here (refer to above slide).

And in each grain the orientation is randomly different there is no particular type of orientation is there all the grains are or all the unit are randomly oriented. Then what we can show this kind of orientation information is through one characterization technique for example is like Pole figure, I can use a pole figure to depict the information about the orientation in the grain. So, when all the unit cell are randomly oriented in each grain, then you will have a information where all this each individual point gives you the orientation of one grain.

So, they are all randomly oriented. So, you will see point all over the place in the in this orientation is space, but let's suppose you have a condition now that out of 100 grain let's say 30 grains are oriented in a particular fashion. Then you will see that these points are kind of now crowding at one place. And now I will start calling that maybe the material has texture. And of course, with more grains oriented in a similar fashion, then you will have more intensity of the points clubbing together and I would say that it is a strongly texture or weak texture and so on or random texture.

So, the grains how they are oriented, if more number of grains are oriented in a preferred way, I would call it as crystallographic texture and how we can depict this crystallographic texture is through pole figure, inverse pole figure, another term call orientation distribution function or in terms of hkl, uvw. So, this we will again discuss in more detail and in the remaining lectures.

So, the idea to bring here is that when you do hot deformation process, lot of microstructural changes takes place and microstructure evolution takes place during the deformation and understanding this microstructure evolution actually makes this particular process very interesting that you do deformation and do these microstructural studies. And because these microstructural changes, then bring the changes in the property that what will be the grain size what is grain boundary character distribution then what is the texture, texture is very important in lot of processes, for example, sheet metal forming or electrical steels, so, all these things you have to control through hot formation process. So, with that I will close this particular lecture. Thank you.

Key words- Grain, subgrain, Grain boundary, Subgrain boundary, High angle grain boundary, Low angle grain boundary, Inverse pole figure map.