Texture in Materials
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Module - 10
Texture in FCC, BCC and HCP materials
Lecture - 50
Texture in BCC Polycrystals – II

Good afternoon everyone and we are doing model number 10, which is Texture in face centered cubic, body centered cubic and hexagonal close packed material and this is lecture number 50, where we will be starting we will be continuing texture in body centered cubic poly crystal, this is part 2.

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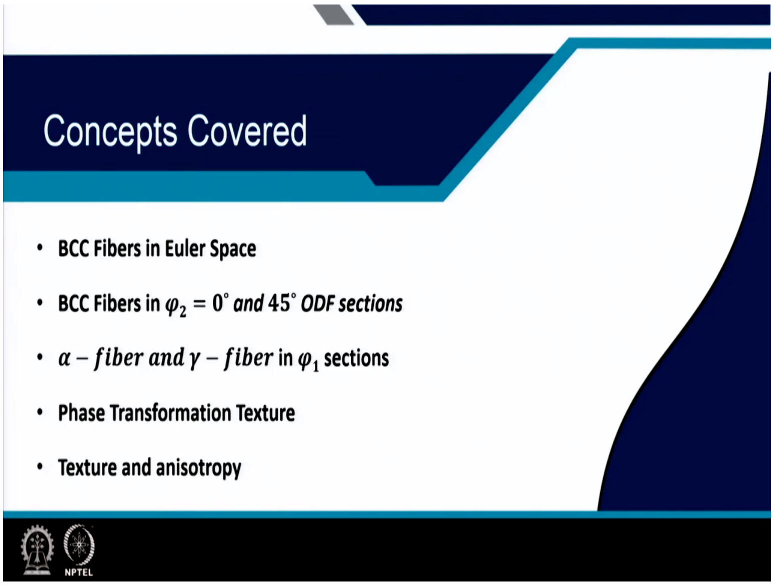

So, the concepts that will be covered here are body centered cubic crystals, fibers in Euler space, texture fibers in Euler space. So, body centered cubic crystal texture fiber in how it looks like in phi 2 equal to 0 and 45 degree ODF section orientation distribution function sections. We will look into detail alpha fiber and gamma fiber and we will see them in phi 1 sections because sometimes it is important to look to into this fibers in this section in order to decipher certain textural properties.

And then we will go and look into phase transformation texture, finally, how texture in BCC are tried to be related with the anisotropy of the material. As we know that BCC material are least anisotropic because of the presence of 48 slip system in it and thereby their structure components do not form you know any of this component do not form with very high intensity rather they form like a fiber. And therefore, the anisotropy in BCC material cannot be very very high.

Of course, there are certain situations where the goss structure is needed like the electrical steels where the anisotropy are tried in terms of increasing the goss texture. So, that the magnetic permeability and the hysteresis loss magnetic permeability is high hysteresis loss is low so that there is a less loss of the energy during any kind of transformer related activity in while for electricity supply.

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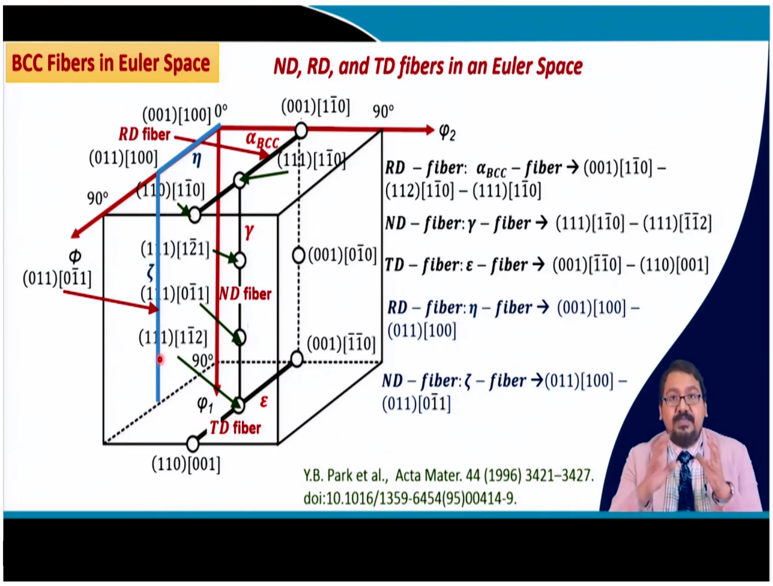

So, let us come to the body centered cubic materials texture fibers in Euler space. So, what are the different texture fibers that we can see? So, this is one of the slide which I have tried to explain previously also, so this is a repetition. So, I will do this a little in a faster mode. So, if we look into this Euler space, what I have done here is that I have drawn an Euler space in such a way that the phi 1 is below, phi 2 is on the right hand side horizontal like this and phi is like this.

This I have drawn it because it is easier for me or and this is taken from this paper Park et al. So, it is easier for us to represent the different fibers while we show the Euler space in this way keeping phi 1 down, phi 2 this side and phi this side. So, if we look here the first fiber that I would like to talk about is the this fiber.

Let me take the laser pointer. So, this fiber and this is basically known as the alpha fiber. This is the alpha fiber for BCC and it is different from the alpha fiber of FCC. So, I have written alpha BCC fiber. So, if we look into this alpha fiber the alpha fiber is going parallel to phi right. So, this alpha fiber is forming after a phi 1 rotation of 0 degree right.

So, phi 1 is 0, phi is 45 degree and then phi 2 is rotated from 0 degree to 90 degree to form this fiber and therefore, as this fiber is parallel to phi which is a rotation along RD if phi 1 is 0 it is known as the RD fiber. It starts from 001 11 bar 0 then it goes to 111 11 bar 0 112 11 bar 0 and ends sorry 112 11 bar 0 and then ends at 111 11 bar 0. It can extend further to 110 11 bar 0 and still remains an RD fiber.

So, basically the alpha fiber is from this position 100 111 bar 0 to 111 11 bar 0. The next important fiber for the BCC material is the gamma fiber. The gamma fiber is this one which is the fiber which is parallel to phi 1. This fiber is known as the ND fiber because phi 1 is the rotation along ND. And this fiber is it starts from you see the 111 11 bar 0 then it goes to 111 12 bar 1 0 12 bar 1 110 01 bar 1 111 11 bar 2 and then it ends here which is 111 11 bar 2.

So, this is the total fiber which is the gamma fiber. Finally, there are other fibers too like the TD fiber as I said and shown in the pole figure and this is the TD fiber and it is known as the eta fiber. And why it is TD fiber? Because it the fiber is parallel to phi, but it has form formed after a rotation of 90 degrees along phi 1. So, it is a TD fiber. So, phi 1 equal to 90 degrees and then phi equal to you see 45 degrees and then this is the position 0011 bar 1 bar 0 which is shown here to 110 001. So, this is the TD fiber there are other fibers that develop in BCC material during the rolling process and this is a eta fiber, this one which starts from 001 100 and ends at 011 100 another. So, this is a RD fiber because it is at phi 1 equal to 0 and it is along phi which is parallel to RD. Then second there is a ND fiber which is parallel to phi oh sorry which is parallel to phi 1. So, it runs from 011 100 and it goes to 011 11 bar 1.

So, here is the fiber which goes from here to here and these fibers are all you know it happens it forms it evolves during the rolling of body centered cubic material mainly ferritic steels. And this fiber if you look if we divide if we show phi to equal to 0 section and phi 2 equal to 45 degree section all these fibers will be visible.

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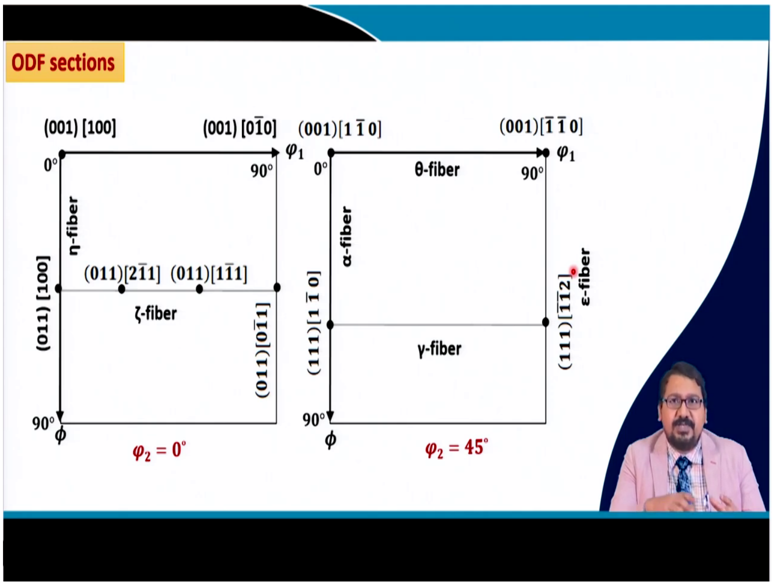

So, we have shown the ODF section of phi 2 equal to 0 and phi 2 equal to 45 degree section with phi 1 0 to 90 degree phi 0 to 90 degree in both the cases. And to let you know that because of the crystal symmetry the phi and the phi 2 is reduced from 0 to 360 degrees to 0 to 90 degree in case of body centered cubic material whereas, because of the rolling symmetry the phi 1 is reduced from 0 to 360 to 0 to 90 degree in this case.

So, as I said if we look into phi to equal to 0 section we can find out that from here to here that is from 0 degree to nearly 45 degrees we can find out exactly 45 degree; however, we can find out the eta fiber which starts from 001 100 and ends at 011 100. Whereas the tau fiber is this one which starts from this you know Miller indices 011 100 to 011 10 2 bar then 011 111 and then it ends at 011 01 bar 1. So, these two fibers can be observed from phi 2 equal to 0 degree section whereas, from in phi 2 equal to 45 degree section one can observe the important fibers which are the alpha fiber right which is 001 11 bar 0 at 0 degrees of phi 1 and phi. And it ends at 111 11 bar 0 which is somewhere around 60 degrees two of phi and at 0 degrees of phi 1.

And then here is the gamma fiber. It runs from here to here which is 111 110 to 111 11 bar 2. So, these are the 4 important fibers that develop during the rolling process of body centered cubic materials and can be observed only by using phi 2 equal to 0 and phi 2 equal to 45 degree section. Therefore, most of the research paper which shows deformation behaviour of body centered cubic material shows only these two Euler's angles phi 2 equal to 0 and phi 2 equal to 45 degree sections.

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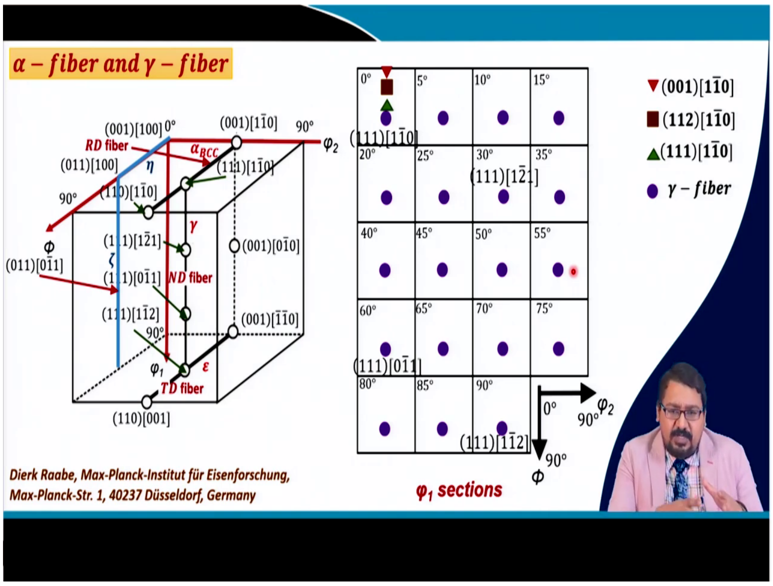

So, as we were looking into this Euler space and sometimes in order to visualize the fibers and to you know explain various mechanism which are related to the formation of fiber researchers. For example, in this case like Dierk Raabe they have shown the phi 1 sections instead of phi 2 section. And here we are trying to show the phi 1 sections for the BCC materials and how the main important fibers that is the alpha fiber and the gamma fiber will look like if we look into this section.

So, this was the Euler space that we were talking about which has the phi 2 here and phi here and phi 1 in vertically down. So, this is the alpha fiber we were talking about and this is the gamma fiber. So, if we are having instead of phi 2 sections if we are having phi 1 section that means, the at each phi degrees if we are cutting the sample in this plane. If you look closely to my cursor to the laser pointer and 5 degrees below to this plane and then again 5 degrees below to this plane.

And like that if we cut them and if you put one by one like we have cut this one at 0 degree we have put here. And then we cut again at 5 degrees and we have put here right and 10 degrees and then finally, at 90 degrees from here and we have put here right. So, when we will observe the phi 1 section we will be able to observe the alpha fiber in phi 1 equal to 0 degree section in which we can see that the inverted red coloured triangle shows the 001 11 bar 0 component.

And below that the brown square shows the 112 11 bar 0 component and then the green coloured triangle shows the 111 11 bar 0 component. And we can see this that when we are looking into the Euler space we can see the same alpha fiber at phi 1 equal to 0 section definitely because the phi 1 is going down, phi 2 a phi at 0 to nearly you know 55 degree section and then at phi 2 equal to 45 degree section. So, the at phi 2 equal to 45 degree at phi 10 and phi 0 we can see that the alpha fiber forms with respect to this three triangular square and green coloured component.

When we look into the gamma fiber, the gamma fiber which is parallel to phi 1; that means, the gamma fiber is an you know RD fiber sorry the gamma fiber is an ND fiber. And as we are looking into the phi 1 section the gamma fiber will seems to form at phi equal to 55 degrees for phi 1 which is increasing from 0 degree to 5 degree, 10 degree, 15 degree and so on up to 90 degree and is shown in terms of a violet coloured circle.

We can see that the gamma fiber basically consist of the fiber with ND which is 111 parallel to this fiber. So, the ND remains 111 from this section this position that is at phi 2 equal to sorry phi 1 equal to 0 to phi 1 equal to 90 degree section. Whereas, the direction that is the RD changes from 11 bar sorry from you see 11 bar 0 to one 1 bar 101 bar 111 bar 2 right. And therefore, the 111 11 bar 0 type component will appear two times in the gamma fiber.

So, it will appear again at 60 degree and we can see that these 111 12 bar 1 and 111 1 bar sorry 11 bar 2 appears at 30 degrees and 90 degrees of the gamma fiber. So, the gamma fiber basically will look like a spot with a large or a small spread depending upon different material and will be observed more properly throughout the whole ODF section if we are looking into the phi 1 section.

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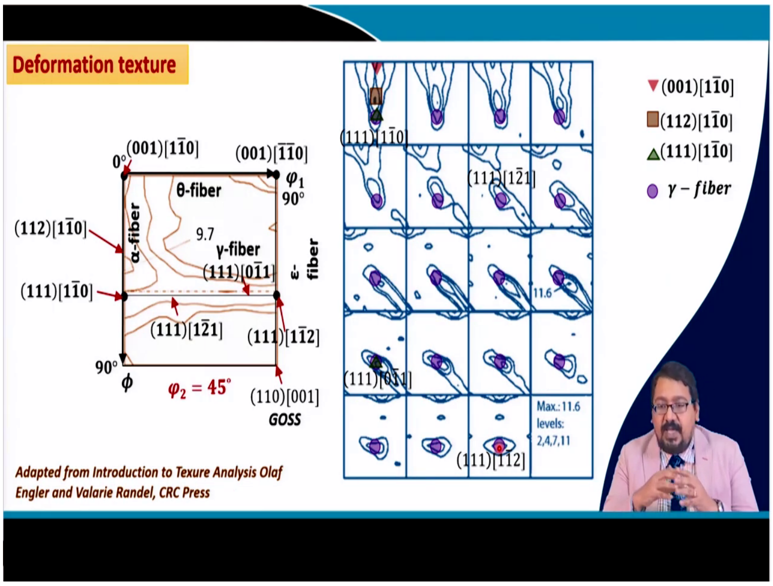

If we look into an example of a certain steel sample which has been rolled and if we look into the phi 1 section of that steel sample and this is a figure phi 1 section 0 to 90 degree of a steel sample adopted from the book of Olaf Engler and Valarie Randel that is introduction to texture analysis. We can see that the alpha fiber and the gamma fiber has formed with quite some other fibrous components. And with a certain amount of spread, when we see into phi 1 equal to 0, 5, 10, 15, 25 like that other sections up to 90 degrees. This particular thing that we can see can be observed if we are looking into phi 2 equal to 45 degree section 2. Now, as you can see that at phi 1 equal to 0 this alpha and the gamma fiber is basically forming at phi 2 equal to 45 degree section in each case. Therefore, we can see this whole information if we look into the 45 degree section in terms of the gamma fiber which forms at phi equal to nearly about 55 degrees.

And phi 2 as I said 45 and goes from 0 to 90 degrees of phi 1 that is 0 to 90 degrees of phi 1 and forms from 111 11 bar 011 2 bar 1 then 01 bar 1 and 11 bar 2 forming the these are the important components of this fiber. And the alpha fiber which is 001 1 bar 11 bar 011 211 bar 0 and 111 11 bar 0. So, this are the way, that the BCC texture components are observed using the ODF section, the phi 2 section in this case and the phi 1 section in this case.

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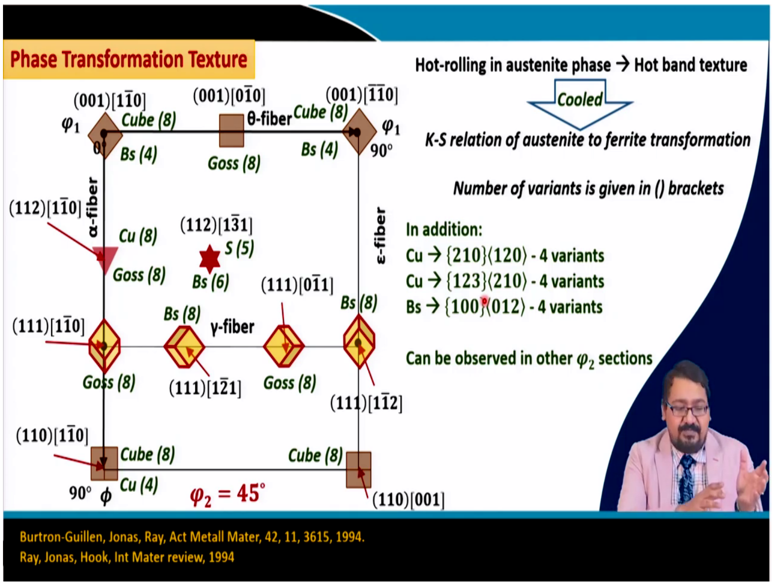

So, this is all about the cold rolled rolling texture that develops in BCC. But, at the same time you see that most of the steels that we have usually are hot rolled and they are hot rolled in a austenitic state. And when they are rolled the after the rolling they are cooled down to form ferrite or dual phase microstructure containing ferrite and martensite or it develops ferrite bainite or ferrite you know pearlite microstructure depending upon the you know the rate of cooling. So, if the rate of cooling is less it develops pearlite.

If it is slightly more then it develops bainite and if it is very high then ferrite martensitic structure starts to develop. And this involves a Kurdjumov Sachs transformation as we discussed in the phase transformation section of this course. Now, during this cooling process hot band texture develops in the ferritic microstructure. So, hot rolling and then cooling leading to formation of a dual phase structure and formation of this structure due to you know Kurdjumov Sachs transformation which may involve twinning or may not involve twinning.

So, there are 24 variants, but there will be a variant selection depending upon the intrinsic you know stress state of the material. And therefore, the initially formed rolled texture which are basically you see the copper component, the brass component, the goss component and the S component you know through Kurdjumov Sachs transformation transforms itself into components of the alpha fiber and the gamma fiber.

And you can see that here is the figure taken from two publications done in 1924. One is by Burtron and Guillen Burtron Guillen Jonas and Ray, Act Metallurgical and Material. Secondly, Rays Jonas and Hooks in International Materials Review both published in 1924.

They have shown that the cube component and the brass component basically can convert into a component which is 001 11 bar 0 whereas, the goss components converts into 001 01 bar 0.

And remember that we are looking into phi 2 equal to 45 degree section here because most of the FCC rolled texture components that converts into BCC texture components and fiber are visible in the phi 2 equal to 45 degree section apart from few which I will tell later after this. So, you see that the copper component which has 8 variants can form 112 11 bar 0.

The S components can develop 112 131 13 bar 1 and it has 5 variants like that you see the cube and the brass the cube the brass can go here. On the other hand the goss component can form 111 11 bar 0 and it can form this component too. On the other hand the brass component can form 111 112 bar in these two positions right. So, there are cube components here the copper components here.

So, these are almost all the components that forms from phase transformation that is when the phase is transformed from gamma austenite which is FCC to alpha ferrite which is BCC using Kurdjumov Sachs transformation. Or it may also happen that certain transformation may occur using Nishiyama Wassermann transformation. Additionally copper forms 210 120 type component which has 4 variants. It also forms 123 210 type component which also has 4 variant and brass which forms 100 012 type component which also has 4 variants.

So, during phase transformation hot band texture sorry during hot rolling in the austenite range hot band texture develops by Kurdjumov Sachs transformation. During cooling of the austenitic from the austenitic phase fluid that is FCC to the alpha ferrite phase fluid which is BCC leading to formation of a texture, which is related, by Kurdjumov Sachs relation or Nishiyama Wassermann relation.

The figure which is a 45 degree ODF section shows that which austenitic texture components forms what BCC texture component and it always follows this phase transformation relationship.

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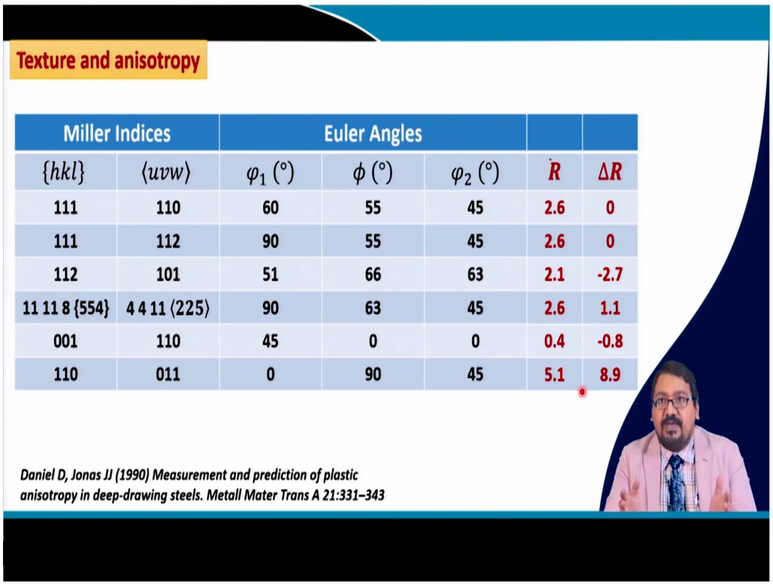

So, on the other hand the texture that developed the sorry the texture that develops during you know rolling as explained few slides before in the previous lecture are follows 111 110 111 112 112 101 and this complies the initial two 111 100 111 12 112 complies the you know gamma fiber. Now, if we look into its position of the Euler space these are exactly these 60, 55 and 45 degree for the 111 110. For the 111 112 it is 90, 55 and 45 degrees.

Now, Daniel and Jonas in 1990 they calculated the R bar and delta R that is the normal anisotropy and planar anisotropy with respect to each of this structure. And they found out that the R bar and the delta R corresponding to 111 110 is 26 0, 111 112 is 26 0, 112 110 is 21 and the delta R is minus 2.7. So, it will be not desirable because it will form an ear and faces while it is being deep drawn.

Now, 554 225 will form R bar equal to 2.6 and 1.1. And so on the other hand you see 001 110 will have a small R bar whereas, completely larger delta R than the R bar itself. On the other hand 1 110 and 0 110 001 will have you know an R bar of 59 whereas, a delta R of 8.9. So, none of these you know texture or combination of this could produce enough larger R bar and if the R bar is increased the delta R increases twice almost in many cases.

So, the anisotropy of this material of BCC material do not reach to a very high extent to have a very high deep drawing ability. But, by developing texture we and compromising on the deep drawing ability we use the body centered cubic material deep drawn sheet in you know automobiles, sheet metal application and all. And there are a lot of research that are going on which are showing slowly and slowly how in these material the R bar can be increased.

And keeping the delta are relatively lower by using two phases of it ferrite and martensite altogether and combination of it by microstructure and texture engineering.

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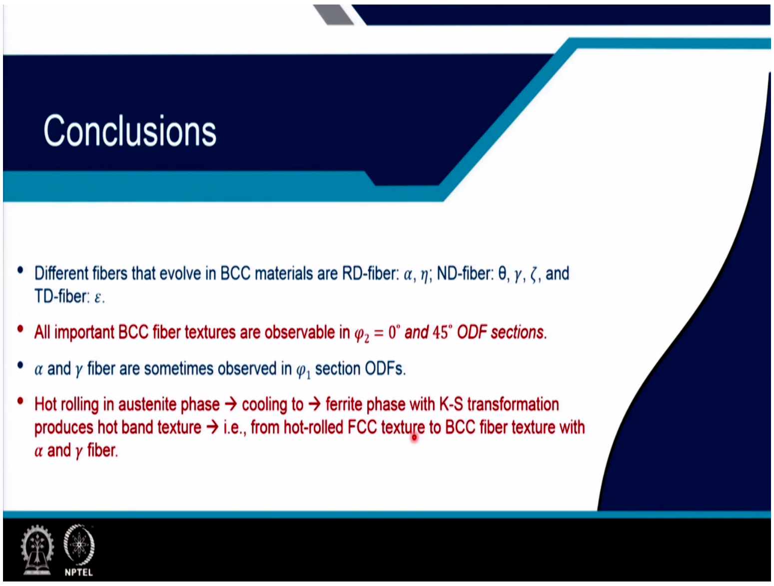

So, in this lecture we found out that different fibers evolving BCC. And these are basically the RD fiber alpha and eta whereas, the ND fiber which is theta gamma and tau and the TD fiber which is the epsilon fiber right. So, TD fiber always forms after a rotation of you know phi 1 by 90 degree which happens along ND right. Therefore, the fiber which is parallel to phi section is not a RD fiber then it becomes an TD fiber. So, all important BCC fiber textures are observable mostly in phi 2 equal to 0 and 45 degree section.

If it is needed phi 1 sections are shown in order to give a detailed explanation of alpha and gamma fiber positions, components of the alpha and the gamma fibers right. Now, alpha and gamma fiber are sometimes observed in phi 1 ODF sections right. So, hot rolling in the austenite phase then cooling it down. So, the ferrite phase forms following the Kurdjumov Sachs transformation produces hot band texture. This is known as hot band texture and that is hot rolled FCC structure to BCC texture forming alpha and gamma fiber is usually observed right.

Thank you very much.