Texture in Materials
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Module - 01
Introduction to crystallographic orientation or texture
Lecture - 03
Processing – Texture – Anisotropic Properties

Good day to everyone. So, this is a 3rd lecture on the Introduction to crystallographic orientation and texture. So, the lecture is basically based on Processing, Texture and Anisotropic Property, association of processing texture and anisotropic property. So, let us start.

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The concepts that are covered in this lecture are processing texture relationship, are all intrinsic material properties anisotropic, deep drawing of the polycrystalline sheet, texture, and anisotropy improve deep drawing ability, the relationship between magnetization and texture.

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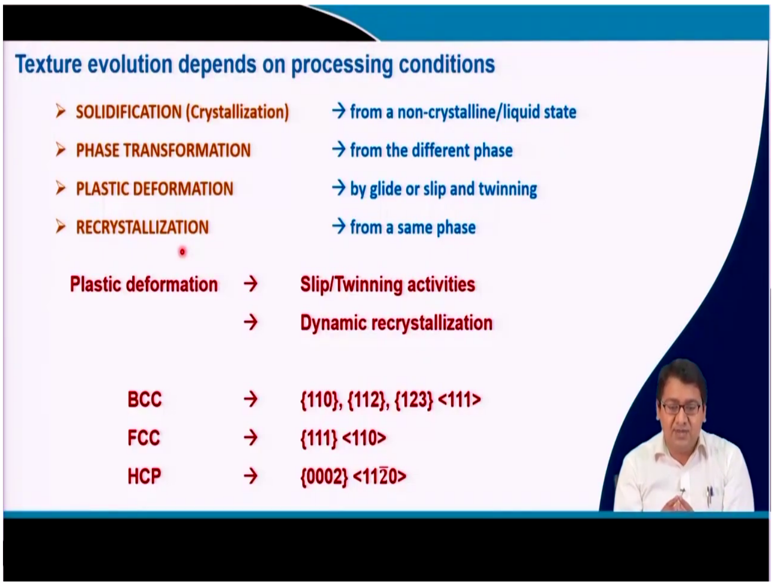

So, as in the previous slides, I have shown that the texture evolution depends on the processing condition. Solidification for example, when the liquid metal or an alloy solidifies that is it crystallizes, poly crystallization takes place from the non-crystallite, non-crystalline state, or the liquid state. So, when solidification takes place, there is always a thermal gradient by which the solidification basically takes place. The grains solidify by crystal growth, like a columnar grain. And therefore, only those columnar grains develop, which can form earlier or which can form faster. Therefore, there is always a preferential texture that is being developed during the solidification process. In order to obtain a solidified polycrystalline material with a weaker texture or a near-random texture; there is a need to engineer the material to obtain that.

The second process is phase transformation; which is the transformation of the polycrystalline material from one phase to another phase. As I said from phase centered cubic to body-centered cubic or vice versa, from body-centered cubic to hexagonal close-packed or vice versa takes place; then also the orientation relationship between the body-centered and the phase centered or the hexagonal close-packed material is maintained by some of the other rules, say, for example, the (Refer Time: 3:49) of sacks law or the Berger's law. And depending upon the previous processing history of this material, the texture is maintained based upon this law; therefore the phase-transformed material will possess some kind of texture. Plastic deformation, on the other hand, occurs by the process of dislocation slip or by twinning.

Now, during plastic deformation, these slip and twinning activities will change the orientation of the polycrystalline material, in some in certain orientations with respect to the deformation direction or the deformation planes. And then during the plastic deformation of this polycrystalline material; there could be a possibility of dynamic recrystallization and dynamic recrystallization may also lead to the formation of certain textures related to dynamically crystallization and we discussed very little about this. The plastic deformation involves information of deformation texture or dynamically recrystallized structure or both. Now, in case body-centered cubic material that is the BCC material, the deformation takes place by pencil glide. That means the deformation occurs in the 110 planes, 112 planes, 123 planes in the 111 direction, and this is known as the pencil glides. And depending upon the temperature and the strain rates, sometimes 112 and 123 planes are active, and sometimes they are active less. So, depending upon the strain rate, the temperature of the deformation, and the amount of strain-induced during the deformation, the body-centered cubic material will develop a certain kind of texture.

On the other hand, a face-centered cubic material that is an FCC, mostly deformed by the formation of dislocation slip in the 111 planes along with the 110 directions; because this is the closest flag direction and the plane. There are four 111 planes and three 110 directions per plane, making it 12 slip systems 111, 110 slip system being present in the FCC crystal. So, during the deformation, this family of slip systems will become active, and thereby relative to the deformation behavior and relating to this dislocation slip behavior, a deformation texture will evolve. The FCC material also has different stacking fault energies of the 111 slip plane. And this stacking fault energy difference depends upon which material it is. For example, aluminum has a high stacking fault energy of 200 million Joules per meter square, copper has a medium stacking fault energy of about 60 milli Joules per meter square and like single crystal, brass has a low stacking fault energy of 20 milli Joules per meter square. And depending upon this stacking fault energy, the fraction of deformation twinning during the deformation apart from slip systems will vary. The fraction of slip system that is occurring in the material will vary and thereby changing or affecting the texture. So, that due to the stacking fault energy also, the deformation texture or the evolution of texture basically varies.

In the case of hexagonal close-packed material and here is an example of pure magnesium, which basically slips along the 002 planes in the 112 bar 0 direction. So, based upon all these slip systems, a certain kind of texture will develop, and if these slip systems are not sufficient for the plastic deformation; then twining will take place and then this leads to the formation of a different texture. And therefore, the texture formation depends upon the strain induced during the plastic deformation, the strain rate of the plastic deformation, the temperature of the plastic deformation.

At the same time, when the material is recrystallized, recrystallization we obtain the recrystallized structure and the recrystallization is basically the material is earlier also in the same phase and after the recrystallization also in the same phrase; only thing is that a temperature has been provided to the material and so, the material basically reduced its stored energy. So, for example, a highly plastically deformed sample is taken, it is put in the furnace, and then it is being heated to a certain temperature for some time say 30 minutes or 1 hour at about the recrystallization temperature allowing it to recrystallize.

So, during this process, the polycrystalline material will slowly reduce its stored energy by dissolving its dislocation to form to do a recovery process; we will talk about this in much detail. But if we do a recovery process by formation of subgrain structure or newly recrystallized grains will nucleate and then may grow a little bit and then recrystallization takes place. And all this process of reducing the stored energy, formation of new grains will lead to the change in the previous texture formed by the deformation plastic deformation process and therefore, texture evolution cannot be avoided by any kind of processing in the material.

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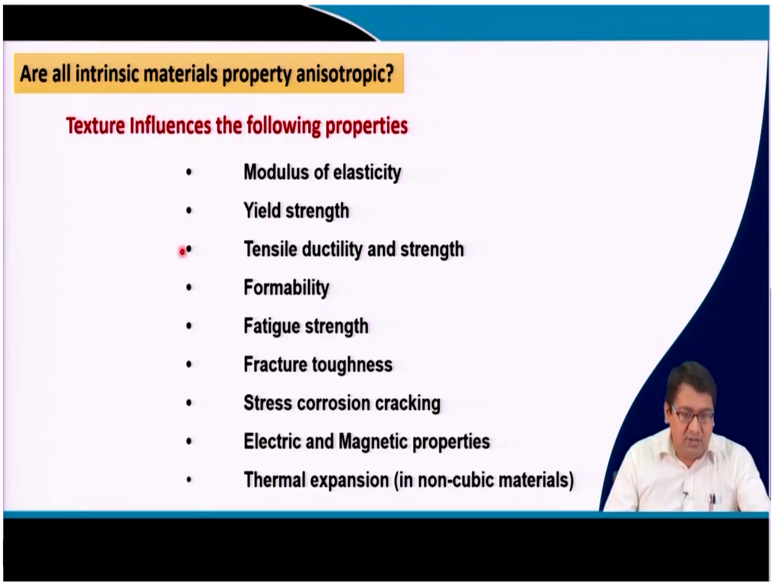

So, when we cannot avoid texture in the material, then the material will remain anisotropic; if not 100 percent anisotropic, some part of it has to be anisotropic. So, it will be always anisotropic and it will influence all the properties; it will influence you to know the modulus of elasticity, yield strength, the ductility, the ultimate tensile strength, the formability of the material including the deep drawing ability, the fatigue strength, the fracture toughness, the stress corrosion cracking resistance, electric and magnetic properties, thermal expansion and it will be mostly in noncubic material, however.

Now, the question arises that ok we understand that yield strength may be different, if we do a tensile test along with textured material, along with the closest pack 110 direction and if we do a tensile test with means along with polycrystalline material with intensities parallel to 100 directions; then there could be a difference in the yield strength. But while the modulus of elasticity, modulus of elasticity is the material property and it should not vary along the direction.

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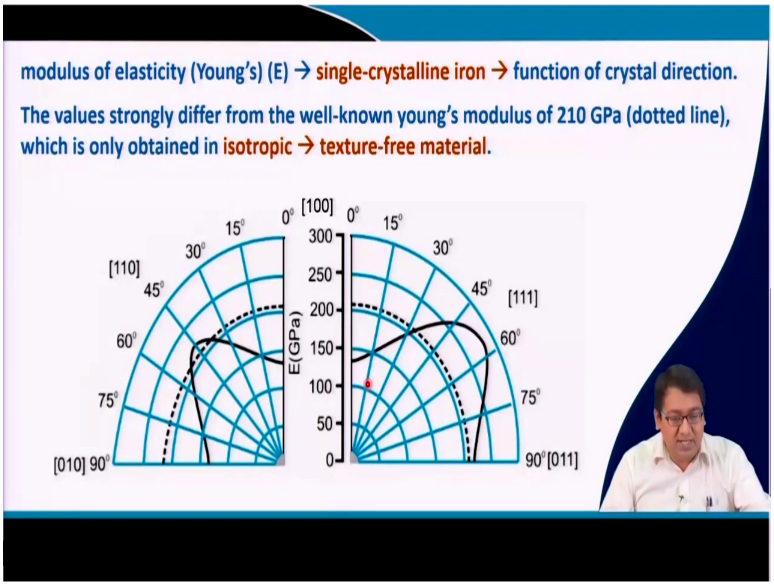

Now, I give you an example of modulus of elasticity or Young's modulus, which is known as capital E for a single crystal iron and I will, and here is the figure showing that. And you can see that the modulus of elasticity was calculated for the 100 direction, for the 010 direction, for the 110 direction; in between them, and then it was calculated for the 1 011 direction, 111 direction, and in between them. And you can see that there is a sufficient variation in the modulus of elasticity as compared to the well-known modulus of elasticity in the case of phyletic iron and which is nearly 210 GPa, which is shown by the dotted lines. Now, this modulus of elasticity of 210 GPa which is known is basically obtained from averaging out of this anisotropic modulus of elasticity, right. And it should be considered that this modulus of elasticity is basically for the isotropic, that is texture free ferritic iron.

Now, the point is, modulus of elasticity basically depends on the bond strength of the material and that this is a ferritic iron. So, this is a body-centered cubic material. And in the body-centered cubic material, the closest pack direction is 111 and the least close pack direction is 100, and the intermediate is 110. And if we look, then the separation of two atoms in the 11 plane, sorry in the 111 direction is less as compared to the separation of atom in 110 and in 100. So, the separation of atoms in 100 is much higher. So, the bond strength of the material is higher along 111, and then it is slightly lower in the case of 110 and then much lower in the case of 100.

And thereby you can see that in the case of BCC material, the 111 direction has the highest modulus of elasticity, whereas the 110 direction has a medium and the 100 directions have the lowest modulus of elasticity present. So, the modulus of elasticity is affected by the texture. So, that it varies because of the anisotropy.

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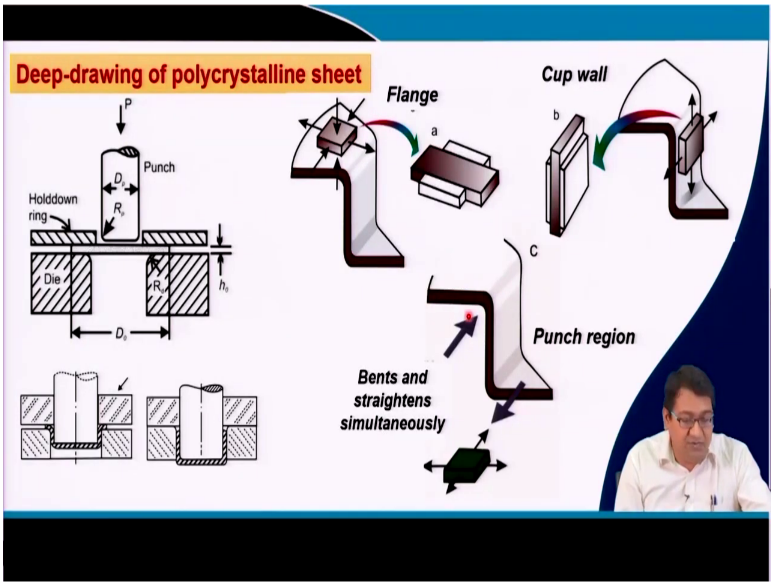

Now, if we look into the industrial perspective, manufacturing of deep drawn sheet, like beverage cans or automobile bodies being deep-drawn in the basic process of deep drawing we can observe from various books and even in mechanical metallurgy heater and you will find that the process is very simple. We have a die here and a hold-down ring and there is a punch and the sheet is kept of a specific size and it is rounded up so that it can be deep drawn and then the die pushes the sheet inside, this die and the hold-down ring basically clamps it, so that it does not slip and wrinkles and then you obtain a deep-drawn cup. But if we look into the detail of this very simple operation of deep drawing, there are various areas of deep drawing; the flange area, the cup wall area.

So, the flange area, the cup wall area and the punch area. And when we are looking into the flange area if you say; the hold-down ring is basically compressing the material like this, whereas the punch is basically pushing the material inside. And when it is pushing the material inside, so it is giving tensile stress along this direction; whereas while the material is being pushed, it is being pushed from a higher circumferential theta r to a lower, because the r is being reduced. So, this circumferential distance r is higher than this circumferential distance because the radius is reduced. So, theta r is reduced as theta r 1 is more than the theta r 2 and then, therefore, it is subjected to the compression stress. And so, in the flange area, the material is subjected to tensile and compression test; whereas in the cup wall , the material is being pushed below. And when it is pushed, further reduction in the circumferential area is not allowed; so the material is now subjected to tensile loading in this direction, whereas the same tensile loading because of the punch is observed in the normal direction. So, in the front flange area, in one direction it is tensile, another direction is the compression.

On the other hand, in the cup wall, both the direction are in tension condition. So, the compression force by the hold-down ring is not that high to create a plastic deformation; it is just to hold down the material, so that it does not wrinkle, so it is not considered that much. Now, the other region that is the punch region is again no tensile region. And the most critical region in the deep drawing process is the cup wall and the flange region. And I will show you how it is. Now, before going to that, there are two more regions that are very critical and this is this region where the bending and the straightening take place. So, these two regions where the material, while it is being deep drawn, is being bent and then straightened and bend and then straightened; unless and until you have a very good from formable metal, formable polycrystalline metal, it is very difficult to have such simultaneous bending and straightening without the material being getting fractured. Therefore, just to let that higher strain hardening exponents are also needed for this deep drawing process.

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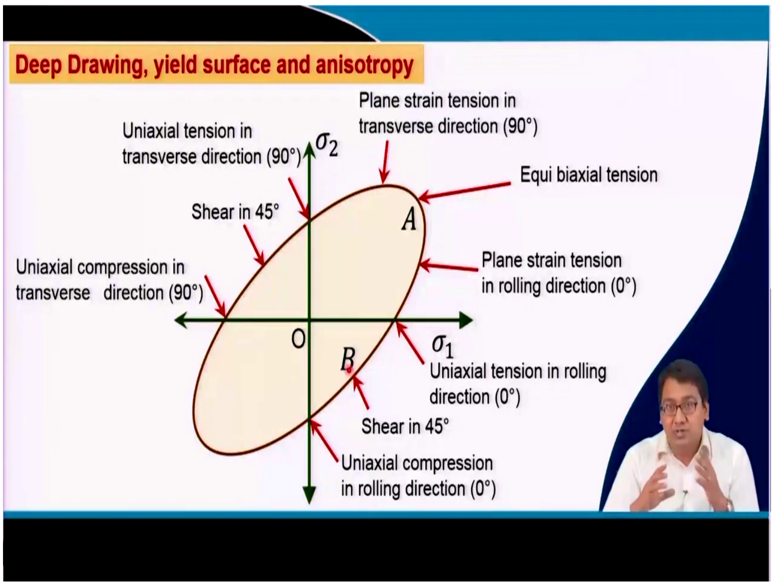

Now, when we consider deep drawing, we should always realize that it is related to yield surface and anisotropy, anisotropy can be utilized to improve the deep-drawing operation. If we look into the yield surface of a material, where the x-axis is the sigma 1 and the y axis is sigma 2. And so, this area is basically the tensile area for the sigma 1 and sigma 2; whereas if we look into this area, this is basically the compression area in both sigma 1 and sigma 2; whereas if we look into this area the fourth quadrant, this is the tensile and the compressive zone; so the tensile for sigma 1 and the compression for the sigma 2. And this area if we look into, then it is tensile for sigma 2 and compressive for sigma 1. So, this is the yield locus and if we say that we are loading along with sigma 1 only; then this is basically uniaxial tension along the rolling direction, considering sigma 1 is along the rolling direction and sigma 2 is along the transverse direction, whereas if there is a sigma 3, then that is the normal direction, perpendicular to it.

While if we do a tensile test along the transverse direction, the stress or the yield point will be somewhere here. On the other hand, if there is tensile deformation. So, tensile which is a plane strain and mostly towards the transverse direction could be here; if it is plane strain tensile mostly towards the rolling direction, it could be somewhere here and exactly at the center it is biaxial tension and which is equi biaxial tension. The same thing if we look into this part or this part, you will see that exactly at the center it will be a perfect shear, which implies basically that along one direction that is sigma 2, it is tensile and along another direction it is compressive. And this is also true here, where along this direction, along the sigma 1 direction it is tensile; whereas along the sigma 2 direction, it is compressive.

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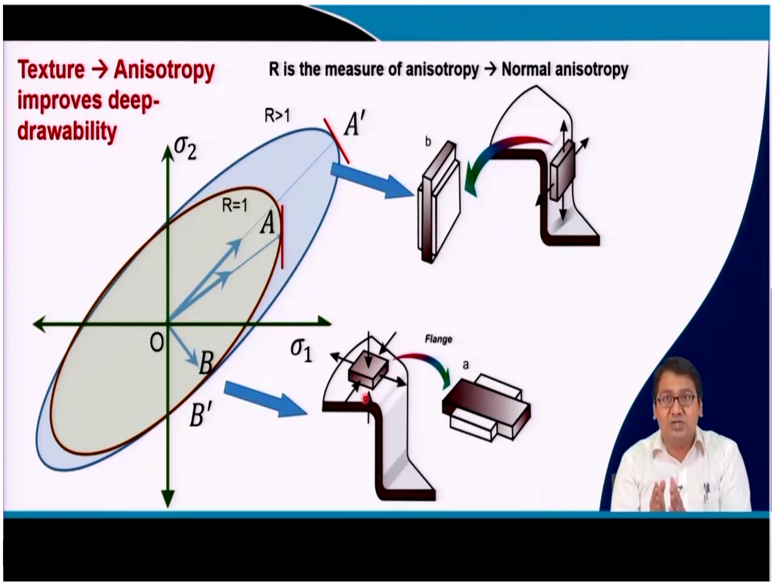

So, that when we look into the deep drawing issue, there are two important positions that we should look at; the one is the flange area, wherein one direction it is tensile, another direction compressive, and in the cup wall, where it is tensile in both the direction. So, that is how is anisotropy actually related to this. So, anisotropy if this is the simple yield locus for a non-anisotropic material and nonanisotropic material means R is the measure basically used for measuring isotropy, and R is basically the normal anisotropy. So, if R is basically 1, it is called the material is fully isotropic and something like this. And then if we are considering the cup wall region that is the tensile region; it is somewhere here right because it is having a tensile more along with the sigma 1 along with the punch and it is a little less along the other side. So, on the other hand, the shear region, where it is tensile in one direction and compression in another direction is given by this position B. Now, the point is that if we introduce texture in this polycrystalline material what happens?

If we introduce texture in this polycrystalline material, the material becomes anisotropic. And as I said that, most material will possess texture in it. So, one can do microstructure and textural engineering to improve the texture or to obtain the most desirable texture, so that to obtain a higher normal anisotropy that is R.

And what does an increase in the R does? It changes the shape of the yield locus and makes it more elongated. And what happens if it gets more elongated? If it gets more elongated, then one can have a loading of sigma 1 and sigma 2 instead of up to A, but to the point A dash.

And thereby you can do or give a larger stress state in the cup region and thereby you can deform the material much larger without having the material necking in the material and fracture in the material at a certain point here whereas, in the B region, now which is B dash and the B and the B dash is almost the same and therefore, without affecting the flange region, which is subjected to tensile and compression that is a shear type situation here.

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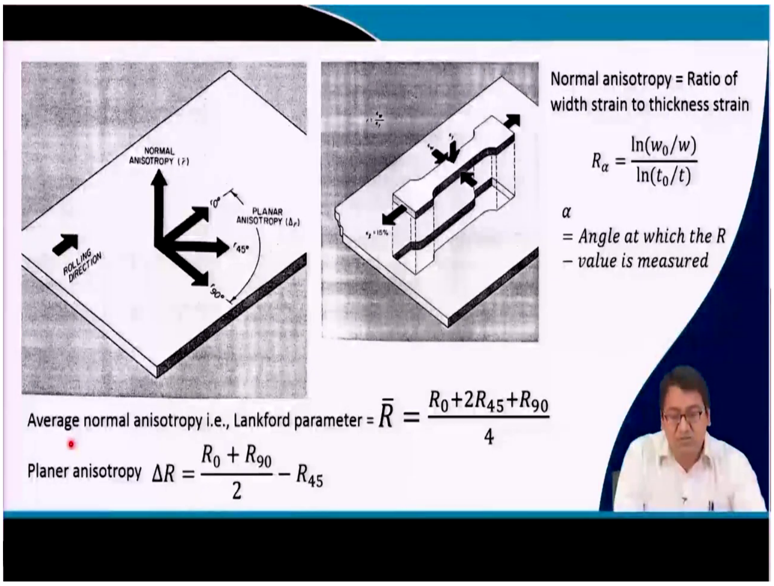

So, now so we see that increasing the R will lead to higher deep drawing ability and let us talk a little bit how a normal anisotropy is calculated and how we basically calculate the R, and how we relate it to deep drawing. normal anisotropy is basically the ratio of the width strain to the thickness strain. If we have a sheet metal like this and we know the rolling direction and therefore, perpendicular to it is the transverse direction and the normal to the rolling plane is the ending; then that R alpha that is R that is tensile is being taken out at a certain direction to the rolling direction, that is an angle alpha, then a tensile test has been done up to say the strain of about 15 percent and then as per the STM standard. And then the log of initial width by final width divided by log of initial thickness by final thickness is being measured. As because the volume is constant sometimes, not the initial thickness is measured and the final thickness is measured; but from the volume constant, the change in the length and the width is used to calculate the change in the thickness and therefore, the R alpha has been calculated for the angle alpha.

Now, in order to find out the average of the normal anisotropic, which is basically called the Lankford parameter R bar, the same R is calculated for the rolling direction along the rolling direction, along 45 degrees to the rolling direction, and along 90 degrees to the rolling direction. And by this formula R bar equal to R 0 plus 2 R 2 times R 45 plus R 90 divided by 4, the R bar is calculated. So, the higher the R bar, the higher the anisotropy and therefore texture, which leads to them having a larger yield locus and thereby higher deep drawing.

On the other hand, there is another important thing which is planar anisotropy and the planar anisotropy that is delta R is basically equal to R 0 plus R 90 divided by 2 minus R 45. And this is very important, because if we have a large difference in the normal anisotropy at different directions; then there will be a good deep-drawing ability, but there will be a formation of ears and faces in it. And therefore, if there is a formation of ears and faces in it; then the deep drawing operation is not a good deep-drawing operation. So, we will have, we have to have a lower value of delta R and which should be near to 0.

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Here are few examples, here are of the aluminium deep-drawn beverage cans and these beverage cans are being produced on large scale to keep the aluminum beverages. So, the most important thing about deep drawing operation is coming up with the formation, in order to produce beverage cans to keep cold drinks and to have a very thin beverage can which could be disposable.

Now, initially, aluminium cans or other cans are being produced by simple operations of deep drawing of course; but the understanding of R bar affecting deep drawing ability was not that much. So, a large deep drawing of cups was not possible and there were always the formation of ear and faces; because delta R was also not maintained and therefore, there was usually a large loss in the in a revenue of the company, who were making this deep drawing cups, because they have to chop off the faces and the ear and make it straight before the supplier. So, there will be there was a lot of wastage and recycling has to be done to which was, which may not be possible all the time. Deeper investigations on this were carried out particularly in aluminum and aluminum has another advantage also, that I will discuss later. The first thing was that initially if multiple textures are present in the rolled aluminum, not only can obtain, one cannot obtain a higher R bar; but on the other hand, the delta R also is cannot be reduced near to 0.

Therefore, not only one cannot have a larger deep drawing, one will not have a larger deep drawing and with a small deep drawing only, it will have a large ear and faces as shown in this figure. However, if microstructural engineering just by a simple plastic deformation process which is rolling, to produce a certain texture component very sharper and in this case, this particular texture component, led to the formation of the rolled sheet which could be deep drawn not only to this extent, but with stages of deep drawing to a larger can with a very thin, but undecked cup portion. And which is very important, which is industrially important; because it not only saved a lot of money, but it also reduced the wastage of aluminum that was used for cuttings.

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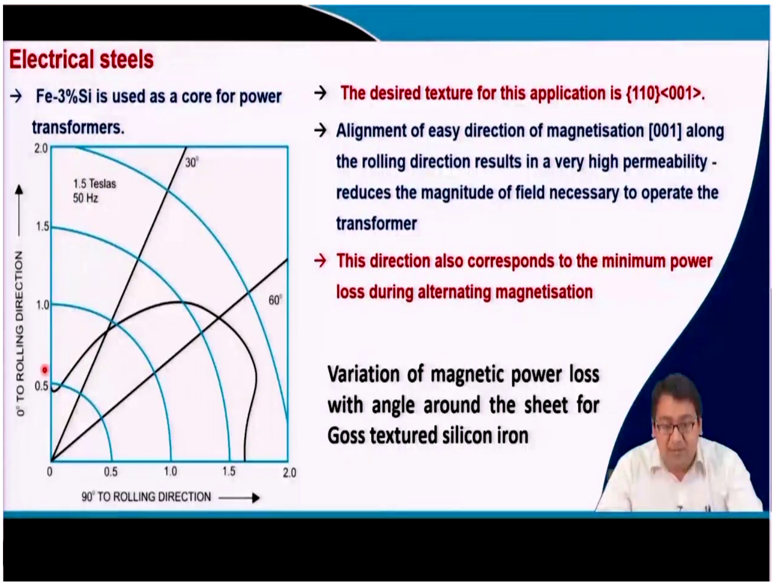

On the other hand, electrical steel. How we can understand that ok mechanical property and even modulus of elasticity is affected by anisotropy and texture, but what about electrical steel? if we look into the magnetic power loss of electric steel, we will find out that magnetic power loss at different angles, crystallographic directions are different.

For example, if we use a rolled steel and that there is an example and the rolled steel is rolling off a steel F e 3 percent SI, near F e 3 percent SI steel is done in such a way so that Goss texture formed and Goss textured is the desired texture. And it has been found out by a considerable amount of research in the late 60s and 70s and they observed that 110 001 type of texture component is most suitable for the formation of transformation transformers in the core of the transformer; because it helps in easy alignment of magnetization and this direction is basically 001. So, 001 direction gives easy alignment of magnetization. So, that it not only does so, but the power loss is also minimum in this Goss orientation. So, the variation of magnetic power loss can be observed; this is parallel to the rolling direction, it is the least and then it increases.

If the angle is increased to 30 degrees and then 60 degrees and then 90 degrees and you can see that, the least magnetic permeability loss is along the 001 direction, which is the Goss texture. So, for electrical steel also Goss texture is being used to obtain better properties.

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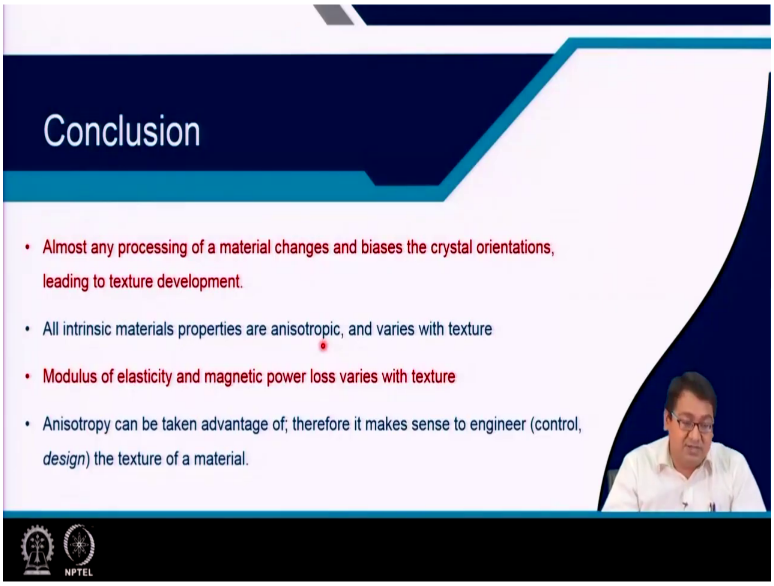

So, to conclude almost any processing of material changes and biases the crystal orientation leading to a texture development; all intrinsic material properties are anisotropic and varies with texture; and it includes modulus of elasticity and the electrical and the magnetic properties. Anisotropy can be taken advantage of and therefore, it makes sense to engineer or control or design the texture of the materials.

Thank you.