Mechanical Behaviour of Materials
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Lecture - 26
Introduction to Plastic deformation - V

Hello, I am Professor S Sankaran in the Department of Metallurgical and Materials Engineering.

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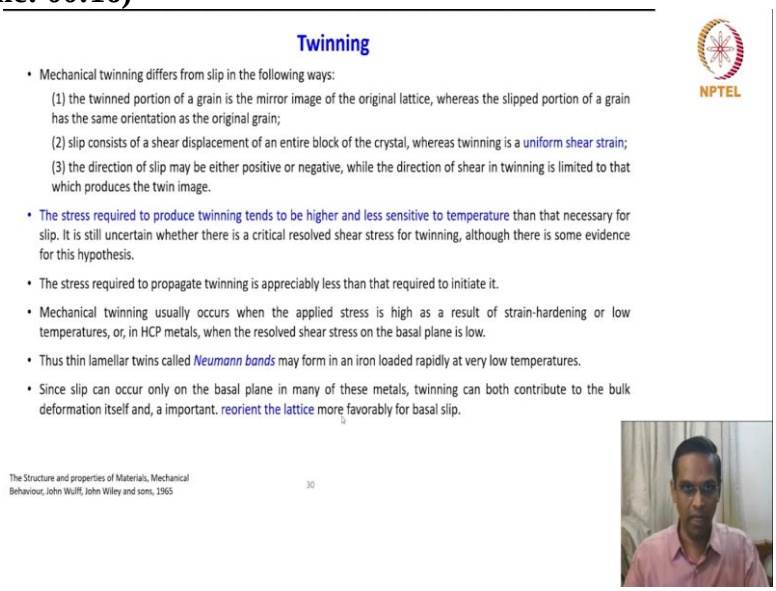

Hello everyone, let us continue our discussion on twinning, in the last class we started off with the type of twins it forms and then its origin and we started describing its characteristics. We would like to continue that and we are talking about mechanical twinning. So, mechanical twinning differs from slip in the following ways. The twinned portion of a grain is a mirror image of the original lattice, whereas the slipped portion of a grain as the same orientation as the original grain.

This was quite evident from the pictures we have displayed in the last lecture. And slip consists of a shear displacement of an entire block of the crystal whereas; the twinning is a uniform shear strain. So, this is one primary difference between a slip and twinning for us twinning to take place there is a uniform shear strain is accommodated that means, a cooperative you know displacement of atom has to take place.

This is very important it is not like few dislocations will glide and you backup systems it is significantly different from a slippage. The direction of the slip may be either positive or

negative, while the direction of shear in twinning is limited to that which produces a twin image yes this is the another characteristics. The stress required to produce twinning tends to be higher and less sensitive to temperature than the necessary for the slip.

This is another important aspect by which twinning is characterised the stress required to produce a twinning is high, this is very important point you have to remember. It is still uncertain whether there is a critical resolved shear stress for twinning although there is some evidence for this hypothesis. So, you will have to now just look at how we started off with slip we started off with a slip saying that the primary requirement for the slip to take places τ_{CRSS} has to have a critical value that is a characteristic value.

And beyond if it the applied stress exceeds that then the slip starts happening. So, similarly, if you are considering this as a deformation mechanism similar situation should arise here. But that is not the case because we are not sure yet this experimental evidence is not conformed this is happening. So, it is hypothesised that is why it is hypothesised. The stress required to propagate twinning is appreciably less than that required to initiate, once the twinning I mean twin blocks are created.

Probably it is easy to move them and that stress requirement is much less than the stress required to initiate twinning. We will we will look into these aspects much more closely now. Mechanical twinning usually occurs when the applied stress is high as a result of strain hardening or low temperatures or in HCP metals when the resolved shear stress of the basal plane is low. So, this sentence carries lot of information what is that it conveys.

Mechanical twinning usually occurs when the applied stress is high as a result of strain hardening or low temperature that means, we looked at some of the strain work hardening ability or strain hardening ability when it goes to the very high stage in the strain hardening for example, we looked at shear stress shear strain curve for an FCC crystal where the highest stress you know, where the material experiences during the stage 3. So, that kind of a situation when the better whether it is a BCC or FCC bands such kind of situation arises.

Or alternatively it can be a low temperature. In the normal you know cubic systems we are considering or it has to be in HCP metal. So, why we are preferring HCP metals because HCP metals are characterised by very less number of slip systems as compared to the cubic

systems, this is also another condition. So, that is why you know mechanical twinning has you know, it occurs very in a restricted manner that is a point I want to emphasise here.

Thus thin lamellar twins called Neumonn bands may form in iron loaded rapidly at very low temperatures. So, in a cubic systems it is very rare. So, unless the load is rapid enough and also the very very low temperatures, this kind of twinning is possibility I mean there is a possibility of forming and typically they are characterised as Neumonn bands in a iron, crystal and so on.

Since slip can occur only on the basal plane in many of these metals, twinning can both contribute to the bulk deformation itself and a important reorient crystal lattice more favourably for basal slip. What is this sentence say, you see we have to remember one point here we are talking about deformation mechanisms and we are talking about slip in a cubic crystal and twin in the cubic crystal.

So, when the deformation proceeds in this cubic crystal still the primary fraction of the deformation will proceed with the slippage only, only a small fraction will be of twinning that you all remember but on the other hand a situations where a crystal system is a HCP are the crystal systems were do not have easy access to the slip systems are very low temperatures then the twinning becomes a bulk deformation mechanisms.

There is a huge difference we have to understand this we have to really remember this. In a normal cubic materials, where the slip systems are available, twinning is only a fraction of the deformed structure, but it becomes a bulk deformation mechanisms are predominant mechanisms only in a restricted conditions are where the HCP metals and so on. So, this is very important and other point is the only the basal plane in a HCP systems reorient the lattice which is favourable for this twinning. That also we will see now.

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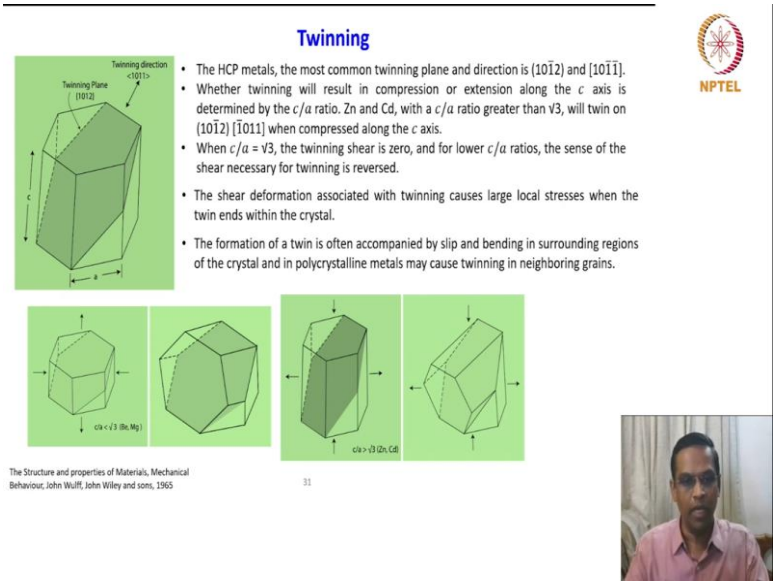

So, this is one illustration of HCP unit cell where you see that the lattice parameters are not a and c and this is a (10$\bar{1}$2) twin plane and this is [10$\bar{1}\bar{1}$] of family of twinning direction. So, these are the most common twinning plane and direction in HCP metals. And but you have different situation here in HCP metal it is very interesting whether twinning will result in compression or extension along the c axis is determined by the c/a ratio.

Very very important twinning is going to result in a compression or extension along the c axis whether it get compressed or elongated. There are two situations that depend upon the c/a ratio. For example, zinc and cadmium with the c/a > $\sqrt{3}$ will twin on (10$\bar{1}$2) plane and [$\bar{1}$011] direction when compressed along the c axis where is that reference.

So, this image shows that the HCP metals such as zinc and cadmium which is having c/a > $\sqrt{3}$, when it is compressed then this is the slip system. So, that means the c/a > $\sqrt{3}$ then it will elongate the c axis will elongate that is what it is mean. When c/a =$\sqrt{3}$ that twinning shear is 0 and lower c/a ratios the sense of the shear necessary for twinning is reversed.

So, what does it mean? So, this is what these pictures shows that effect what is that when the c/a<$\sqrt{3}$ for example, in beryllium and magnesium so it is try to extend along this or it get compressed along this c axis. The shear deformation associated with twinning causes large local stresses when the twin ends within the crystal. This is again very important because it is a restrictive deformation it leaves behind large local stresses. Especially when the twin ends within the crystal.

The formation of a twin is often accompanied by a slip and bending in the surrounding regions of the crystal and in polycrystalline metals may cost twinning in the neighbouring grains as well. So, you can induce twinning in the neighbouring grains as well. So, this is one of the manifestations of this twinning process.

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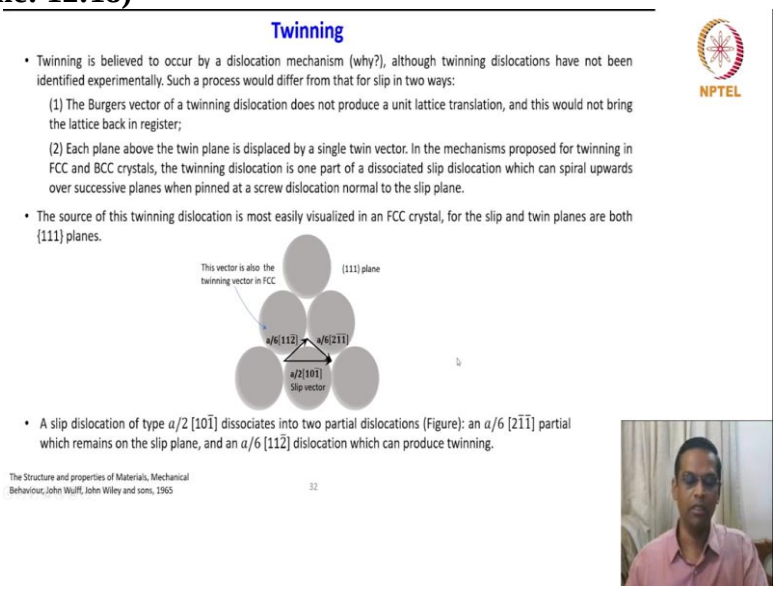

So, twinning is believed to occur by a dislocation mechanism although twinning dislocations have not been identified experimentally, we have to ask the question here. Why do we believe that it has to occur by a dislocation mechanism if you recall when we just looked at a perfect single crystal, we also looked at the theoretical you know strength of a perfect crystal. And if you assume that twinning also takes place without a dislocation or without any assistance of the dislocation.

Then you have to imagine that how many atoms displacement have to happen in a cooperative manner then you imagine that the theoretical strength would be extremely high extremely high as compared to I mean similar to slip we have just seen and then we said that only with the help of dislocation motion these critical results shear stress use less in reality as compared to theoretical calculation.

So, similarly if you think of a twinning takes place without assistance a dislocation activity, then this theoretical strength would be extremely high. So, that is one reason why we believe that twinning also takes place using a dislocation mechanism. So, this is also a hypothesis,

but we are here to identify clearly what kind of dislocation assist this process. Let us assume such processes are differing from that for slip in two ways.

We are saying that it is happening through this location, but what are the primary differences of twinning with compared to a slip process. The Burgers vector of a twinning dislocation does not produce a unit lattice translation very very important. And this would not bring the lattice back in register. So, that means you recall edge dislocation which is moving inside the crystal when it exit the crystal it creates a step and that is exactly a unit lattice translation.

And if it goes in a reverse normally it will restore the crystal, but in this case just not going in the case each plane about the twin plane is displaced by a single twin vector like a slip vector here we call it a twin vector in the mechanisms proposed for twinning in FCC and BCC crystal the twinning dislocation is one part of a dissociated slip dislocation which can spiral upwards over successive planes when pinned at a screw dislocation normal to the slip plane.

So now, what we are trying to understand here is we are saying that we are hypothesising that the twinning takes place via dislocation mechanisms. So, how it can happen, what people are believing it is that a perfect dislocation will dissociate into two partials. And then one of the partial that is a part of the dissociated slip dislocation that can spiral upwards, so that has to be a screw compound then only can go up over successive planes when pinned at a screw dislocation normal to the slip plane.

So, the other dislocation will lie in a slip plane I mean the other partial dislocation will lay the one part will screw will move up to facilitate this twinning. That is what the current understanding goes. The source of this twinning dislocation is most easily visualised in a FCC crystal for the slip under twin planes are both on {111} planes. So, this is one advantage we have to visualise this hypothesis we can choose FCC crystal system itself because, in FCC crystal systems both slip and twin takes place in {111} family of planes that is important.

So, we know what is {111} family of planes and this is the schematic nicely shows and you can see this slip dislocation of type a/2 $[10\bar{1}]$ dissociates into two partial dislocation as shown here a/6$[11\bar{2}]$ and a/6$[2\bar{1}\bar{1}]$. And this particular a/6$[2\bar{1}\bar{1}]$ partial which remains on the slip plane and a/6$[11\bar{2}]$ dissociation which can produce twinning. So, this particular type of a

partial dislocation which is of screw type will facilitate the twin formation. So, this is a twinning vector in FCC. So, this is one way of looking at to the hypothesis, this location mediated twinning.

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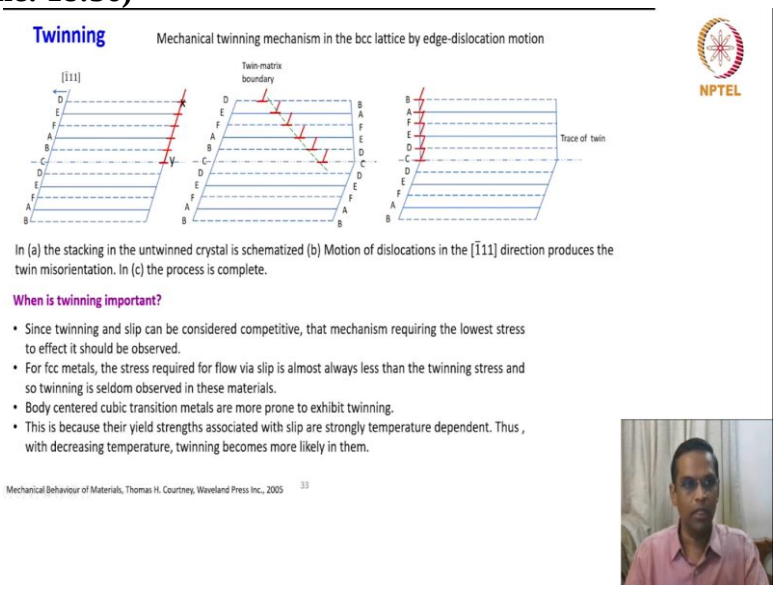

We will look at one more illustration regarding this mechanical twinning mechanism in an BCC lattice by an edge dislocation motion, this hypothesis can be understood by another illustration here, what is that you are seeing it is these are all a stacking and untwined crystal is shown in this schematic and this is [$\bar{1}$11] direction and then this is the a trace of 112 in a BCC in BCC, you have this trace 112 for twinning.

So, what is shown here is a dislocation a edge dislocation of similar sign they are all lined up here and then they all move in a cooperative manner you have to understand this point see in a twinning it is not like a slip one or two a burger vectors are one or two edge dislocation factor but all this at edge dislocation has to move in a cooperative manner to accommodate the uniform displacement. So, if it moves like this in this direction in this plane.

Then it will create this kind of twin. So, this is a twin ratio here and you see that these dislocations try to move in this way and then it can create a like this. So, this is one way of visualising how the dislocation is aiding in formation of the twin, but there is no experimental evidence so far, but this helps a little bit when is twinning important since twinning and slip can be considered competitive that mechanism requiring the lowest stress to effect, it should be observed.

So, see when is twinning important is the question itself relevant only in the case of you know cubic materials, but in HCP by default we can say that it is the twinning will be the bulk definition mechanisms. But given the situation whichever the mechanisms will carry the lowest stress to affect any of whether slip or pin that will be observed. For FCC metals, the stress required for a flow via slip is almost always less than the twinning stress and so the twinning is seldom observing this material.

So, this is quite obvious because in FCC materials we have already seen that it is the τ_{CRSS} is there I know it is less on the (111) plane. In body centred cubic transition metals are more prone to exhibit twinning. So, this is another characteristic a body centred cubic transition metals there more to twinning. And this is because they are yield strengths associated with the slip or strongly temperature dependent.

Very important and fundamental aspects we are touching now, why BCC metals are I mean exhibit yield strength which is highly dependent on temperature, this is one of the reason that is with the decreasing temperature twinning becomes more likely in them. So, in this BCC materials yielding can easily sorry yielding can proceed with twinning; we will talk about this temperature dependent of yield strength. As we proceed with the deformation and mechanical testing so on, we will concentrate on this aspect much more detail, but this we are just introducing this concept here itself.

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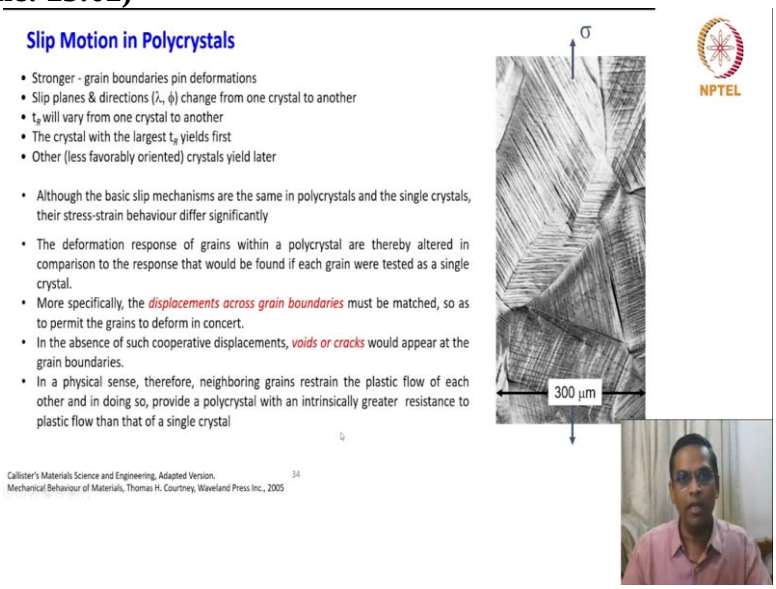

Slip motion in polycrystals so, now we looked at the basic mechanisms of plastic deformation called the slip and twinning in single crystals and then we looked at all the all possible I mean

the details. Now, we move on to polycrystals and the word itself says that the polycrystal will have a lot more constraints because they have grain boundaries they are going to strongly pin the deformations that is one idea.

The second important point is to slip planes and direction which are characterised by the parameters λ and Φ which is very different from one crystal to the other. So, the τ_R this is a typo here this is τ_R will vary from one crystal to other that is typical results just will vary from one present here, the crystal with the largest τ_R, let us τ_R not τ_R yields first. Other crystals which are less favourably oriented yield later.

So, now we look at this micrograph it is very nice illustration here a polycrystalline material is being subjected to uniaxial tension that is what it does symbolised here and this is a scale 300μm and what you see here is clearly the grain boundaries this is a perfect triangle grain and then you see the grain boundary, you can see the white here and all other grain boundaries you can see there is elliptical grains here.

And if you look at little more closely inside the grains, you can see that the high dense slip lines are uniformly there, primary slip lines and then secondary slip lines, these are all a signatures of the crystals undergoing multiple slips. In fact, you can see here all this secondary and primary, secondary and primary, secondary and primary slips or multiple slips. So, that is very clear.

So, now we will just try to understand this on what circumstances these things happen and what each and what happens to the characteristic deformation behaviour of each grain in the presence of its surroundings. Although the basic slip mechanisms are the same in poly crystal and single crystals, they are stress strain behaviour differs significantly. But important idea the deformation response of the grains within the polycrystals are thereby altered in comparison to the response that would be found if each grain were tested as a single crystal.

So, this is quite obvious like suppose if you imagine that you pull out this each grain and then consider them as a single crystal and then tried to deform they would behave very differently as compared to what is actually behaving during deformation in the presence of its surroundings, that is what it means, more specifically that displacements across the grain boundaries must be matched, so as to permit the grains to deform in concert.

So, what does it mean suppose here I mean, if you look at this micrograph this grain is subjected to a tensile force and then slip planes are approximately you know happening in a 45° it is not exactly 45 but just imagine, but here if you look at this grain, they are not showing the slip planes similar to the other grains. So, there slip planes are oriented much different angles.

But some of the deformation has to proceed because then only the material shape change will happen with somewhere it has to be accommodated. So, for that the displacement across the grain boundaries must be matched. So, the displacement across this to be matched, but it is not going to happen so, easily that is a constraint. So, that is the first and strong constraint that what it is.

That is very first point is grain boundaries will pin the deformation strongly. That is because of this displacement across grain boundaries are quite difficult to match. In the absence of such cooperative displacements, voids or cracks would appear under grain boundaries. So, this is quite obvious. Suppose, if the deformation proceeds without the cooperation of all this boundaries.

Then voids and cracks will form you can here itself we can see that the boundary which appears here is you know, very different that is I am feeling there is a huge step here. So, there is a restriction each boundary will restrict because of its orientation. And if it is not accommodating the strain, it will end up in the cracks and voids. In a physical sense therefore, neighbouring grains restrain the plastic flow of each other and in doing.

So, provide a polycrystal with an intrinsically greater resistance to plastic flow than that of a single crystal very important point. So, in a poly crystal, you have intrinsically greater resistance to plastic flow provided by the neighbouring grains. So that is the point we have to remember.