Mechanical Behaviour of Materials
Prof. S. Sankaran
Department of Metallurgical and Materials Engineering
Indian Institute of Technology - Madras

Lecture - 16
Introduction to Dislocations IV

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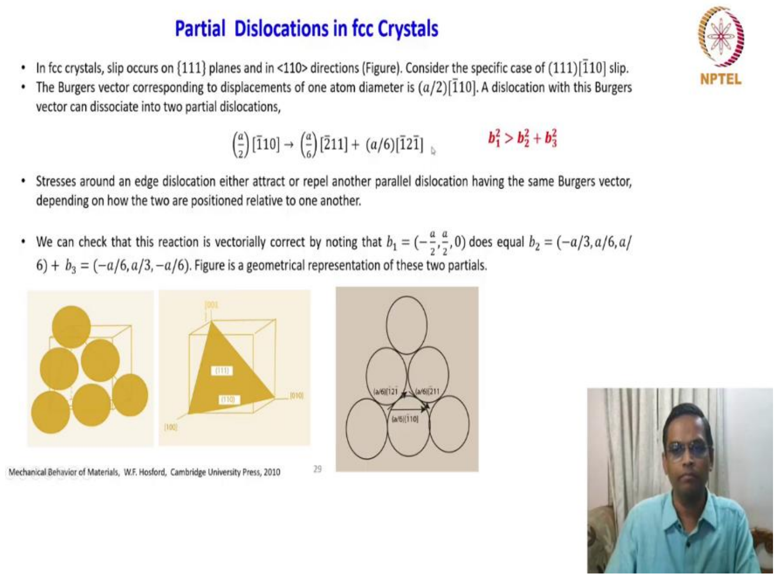

Hello, I am Professor S. Sankaran in the Department of Metallurgical and Materials Engineering. So, now, we will move to the dislocation dissociation that is partial dislocation. Especially FCC crystal, why FCC crystal? Because in other crystal forms these partial dislocations are not that stable, it is not that able to form or something like that. In FCC crystals it forms it remains stable. So, please understand.

So, most of the textbook talks about FCC partial dislocations is not that it is not forming in BCC some other coastal towns they may not be stable. In the FCC Crystal is slip occurs on {111} planes and in <110> directions consider the; specific case of the slick system (111) $[\bar{1}10]$ direction. So, this is the schematic of the (111) plane and this is the direction <110> direction and what is shown here is this, but this Burgers vector here and we will come to that little later. The Burgers vector corresponding to the displacement of one atom diameter is (a/2)$[\bar{1}10]$.

So, this is (a/2) there is a typo here this is a/6. So, it should be (a/2)$[\bar{1}10]$. That is a correction and dislocation with this Burgers vector can dissociate into two partial dissociations. So, (a/2)[$\bar{1}10$] can dissociate into (a/6)[$\bar{2}11$] + (a/6)[$\bar{1}2\bar{1}$]. So, there should be a plus sign here that is also a typo is it is corrected stresses around an edge dislocation either attract or repel another parallel dislocation having the same Burgers vector depending upon how the two are positioned relative to other.

This also we will see. There are some you may have consideration on energy, the orientation also will matter sometimes, we will see that why? So, we can check this reaction pictorially correct by noting that b_1 has the coordinates like this does equal b_2 the coordinates and b_3 and that is what is shown here the dissociation and whether this dissociation can happen or not, is purely decided by the Frank's rule this is a Frank's rule. So, we have just discussed about the Frank rule in a few minutes back, I was mentioning this idea.

So, you can just simply verify this that whether this is indeed true, you can just substitute this coordinate into this formula and then see whether it really the case if this is not that if it is not following this and this reaction will not happen.

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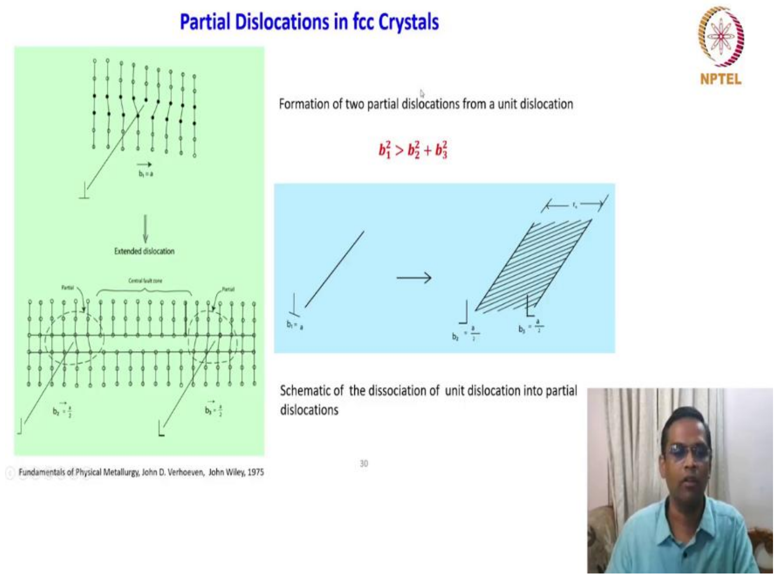

So, this is another nice schematic which shows that how the unit dislocation dissociating to partial dislocation, the purpose of me bringing this schematic to you is it gives a very good visual appeal. How the partial dislocations are kept in that lattice in a deformed, I mean the dislocated lattice usually, you know, people just show the Burger's vector dissociation reaction and then we done with it and very rarely.

We come across this kind of a pictorial representation which is in my opinion very important to get the grasp of what partial dislocation means. So, here extra of plane and then you know that this is a unit dislocation. But the unit dislocation which is a how it splits into two, but still it is how the lattice will look like a distorted lattice will look like. So, that is very important to not so, because of you know a small moment in our displacement in the lattice position how it gets distorted locally and then how this is influencing the rest of the atoms neighbours.

So, that is very important and that decides the arrow does the fault zone this is a side view. So, this gives a very nice idea. So, the unit dislocation decomposes into two partial dislocations. So, what is that a/2 a/2 but then these two dislocations, how it influences the inter atomic distance in a finite area. So, that area is called central fault zone. We will see that in another minute a fault region stacking fault and so on. So, this is very useful for that kind of discussion.

So, the full dislocation is represented like this half dislocation for your convenience we can put it like this L shape and this is another reverse L shape the Burger vector also is this half half. So, this is the same way of representing this but this is much more elaborate way of representing this and this hatch region gives a area of fault region. So, this is partial dislocation of course, this also happens because only after very friendly we can the Frank rule can be verified and then that will predict that whether this kind of reaction is feasible or not.

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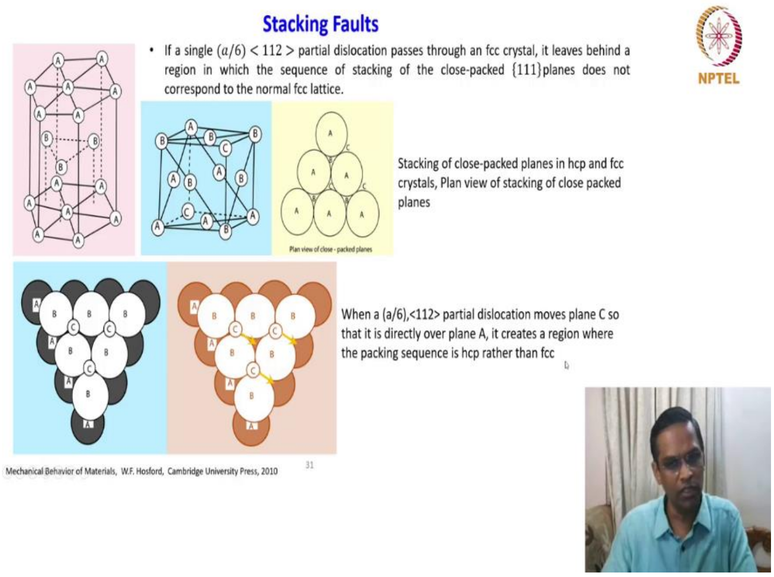

So, coming close to that kind of an idea that is another important aspect of these dislocations called stacking faults. So, if a single (a/6)<112> partial this dislocation passes through an FCC crystal, it leaves behind a region in which a sequence of stacking of the close-packed {111} planes does not correspond to the normal FCC lattice. This is exactly as shown here right suppose if you just assume that this is a partial dislocation of a/6 we are not showing that but this kind of a disturbance it will create.

So, it will not follow a normal ABC, ABC sequence and an FCC. So, this is a FCC unit cell you have A layer and then you have a B layer and then you have a C layer. So, you have three layers ABC, ABC. This is a hexagonal closed pack unit cell which has the packing of A layer, B layer, A layer, B layer and so on. So, in a (111) plane view is normally shown like this, so, A layer and then you have inverted triangle void is B layer again a normal triangle void is C layer.

So, this is a stacking view and so, what how this; what is written here, suppose, if you have this kind of a partial try to move from here to here. So, this is what it is. This is the same partial a/6 partial dislocation moves a plane C. so, this void to this void. So, what is this C void? C void is a equilateral regular triangle void and from that to it tried to moves to that inverted triangle void position and I am just giving the description of the void just to indicate the position of the atom.

So, if it tries to move from this position to this position, then also it creates a packing sequence change that is, it creates the region where the packing sequences hcp rather than FCC. So, this is another problem.

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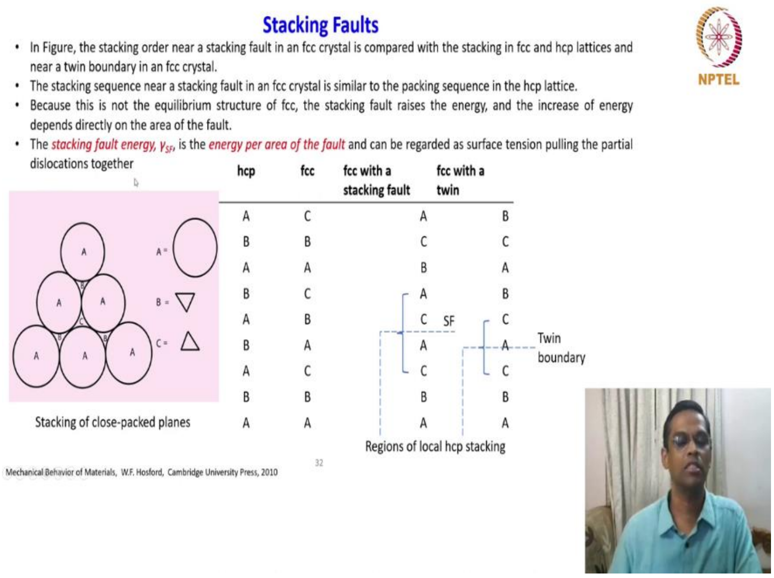

So, if you look at the stacking order near a stacking fault an fcc crystal is compared with the stacking in fcc and hcp lattices and near a twin boundary in an fcc crystal. So, this is the AB AB sequence in hcp unit cell, or hcp lattice. This is ABC, ABC in FCC ladders. Suppose, if there is a fault suppose what we have just moved in the previous slide the C is moved then it creates that layer.

So, this is ABC and then it becomes AC. So, this is a region of a stacking fault. The similar way. So, it becomes AC, AC, AC, AC. So, here similarly, you can also form a twin if it moves like this A B C and then AC. So, here it becomes twin we will see when we look at the mechanics of things also we will refer this. The atom displacement is very very small, but homogeneous that you have to remember that how the twin if you can see that you know the; atom displacement or fraction of inter atomic spacing.

But it has to happen in a homogeneous manner for large number of items has to cooperate and formed this boundary. You will see that when we discuss a twinning but here it is considered here we are concentrating on the stacking point. The stacking sequence near a stacking fault in an fcc crystal is similar to the packing sequence in hcp lattice that is known because this is not the equilibrium vector of fcc the stacking called raises energy.

So, this we already know see, here we are still talking about a dislocation only, but here it changes the sequence of the stacking it becomes a fault obviously, that will raise the energy of the system and the increase of energy depends directly on the area of the fault. So, since this is as I just showed you in the previous slides, it takes quite a bit of a region faulty region you know it pushes all the inter atomic spacing in the nearby region to some extent it completely disturbs.

So, it is considered like a region. So, the energy is also measured per area the dislocation energy is measured by unit length, but stacking fault it happens over a region or area. So, the gear energy per meter square area. So, that is the only difference between considering individual dislocation and versus the stacking fault. The stacking fault energy γ_{SF} stacking fault is the energy per area of the fault and can be regarded as the surface tension pulling the partial dislocations to the, so, this is another nice way of connecting things.

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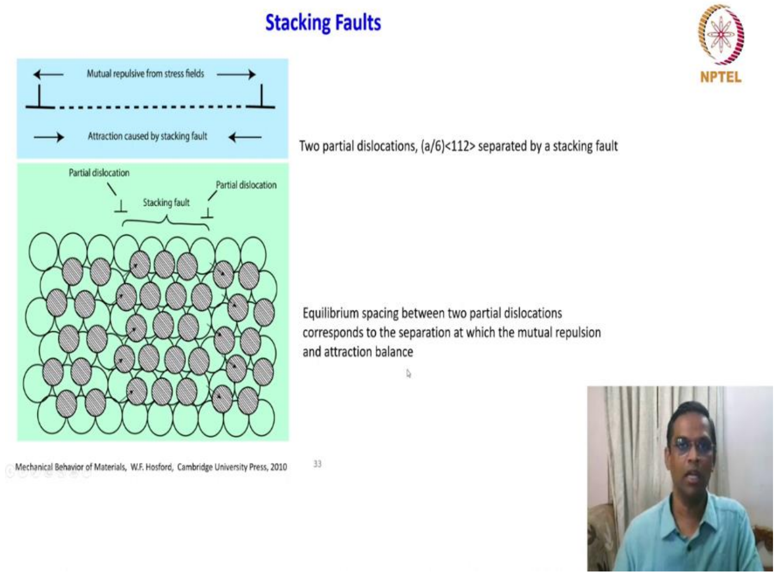

So, now that we are familiar with what kind of stress fields around edge dislocations and how it is going to affect us. So, we can easily recognize. So, this is two edge dislocations of the same sign for mutual repulsive force from the each stress field and this is an attraction caused by stacking fault. Suppose, if you have this kind of a configuration two partial dislocation (a/6)<112> separated by a second part.

So, this is a similar figure what I just showed before but it is much closer look compared to the other one. So, two partial dislocations come from both sides and you can see that this moment from inverted triangle void person to the triangle void position. So, in between region will be not a perfect FCC it will be a region of a faulty region. So, this is this region is called stacking fault region and the energy associated with this region is called stacking fault energy.

Equilibrium spacing between the two partial dislocations corresponds to the separation at which the mutual repulsion and attraction balance. So, this is something about how these stacking faults are stable so, you know that you know if the repulsive and attractive forces are imbalanced, then they are trying to be some stability so, that is all it means.

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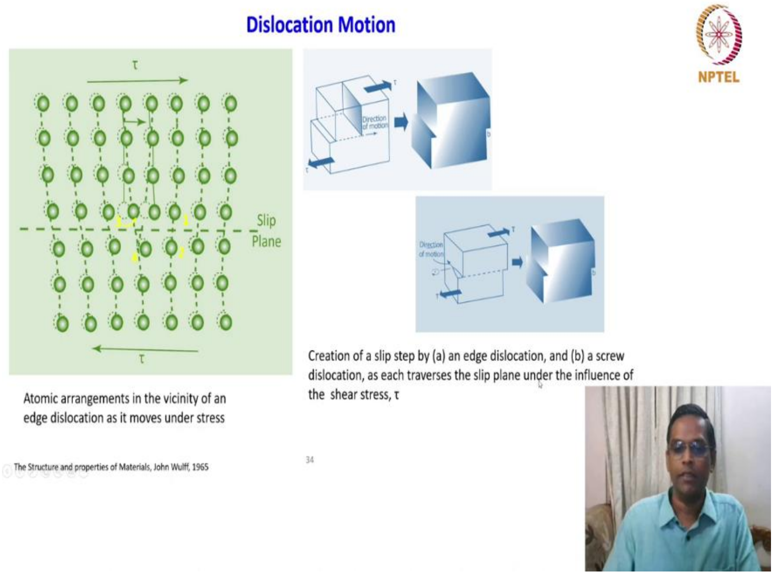

Now, we will slowly move get into the dislocation motion. So, far we have seen the type of dislocations and dislocation energy, dislocation strain fields and the strain detailed description of strain fields and its consequences on the second phase particles or second foreign atom or solid solution or even with the other dislocations how it is going to react and now, we will slowly get into the dislocation mechanics and then the first step is we should describe what is the dislocation motion happens. How does this location motion take place?

So, here is the nice example here this is a lattice 2D lattice with the edge dislocation and the shear stress is applied on this both directions here and here and what you are seeing here is have a close look at this and the atoms are coming are since because of the shear stress the atoms are trying to move away from this equilibrium position which is given by the dotted circle around each of the atoms and this is a slip plane and we have marked the atom 1 2 3 4 in yellow.

See, we are now trying to give some atomistic accountability of how dislocation moves. Please remember that this is we are still talking about elastic deformation because the full speed and energy is described by elasticity theory only so far. So, suppose if you look at the atom 1 and its reaction, because of this shear stress what it will do the shear stress will try to move away from its position because of the shear stress is moving this direction.

But at the same time the atom number 2 and 4 will try to move opposite direction get in to closer to equilibrium position that means, there should be some energy balance. What is the balance here, the energy elastic strain energy which is stored in this atom or when it tried to move that energy is balanced by this external stress and the same energy will be equal if the same elastic stored energy which is trying to move from this position is balanced by this same elastic stored energy to restore this 2 and 4 in its equilibrium position?

Then that dislocation will I mean this atom will try to move I mean this is with respect to just motion of atom 1 with respect to 2 and 4 because it both in opposite directions that means the elastic stored energy responsible for holding that atom 1 in that position and 2 and 4 in that position should be restored or balanced by the application of shear stress. So, that is the idea I mean the otherwise the work to be done by that external shear stress is to give this energy balance.

Then the atom will move from that position and the external stress is good enough to move this to the extreme right then this crystal will slip. So, this is one way of looking at it how the dislocation moves. The other important point we have to remember in mind when the dislocation moves there are two things, the edge dislocation again screw dislocation that are when the dislocation moves.

It moves parallel to the edge dislocation moves parallel to the motion of the display, I mean the dislocation moves along with the dislocation line the direction of the dislocation line. On the other hand, it moves perpendicular to that dislocation line. So, this is what is so this is a screw dislocation.

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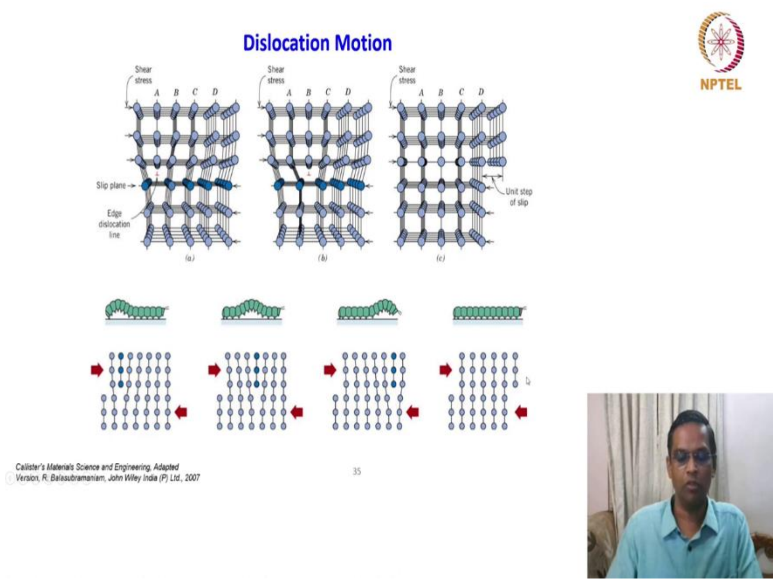

And these are the book schematic shows how the motion of the edge dislocation takes place in a lattice. So, you see that the extra half plane is getting shifted from a position A to position B to position beyond the impact and it creates a unit step of slip. So, this is something like similar to the how the caterpillar moves. So, this schematic clearly brings that analogy how the caterpillar moves. So, again if you look at the stress field also it will go like this, if you remember some of the stress field it is a nice motion like that.

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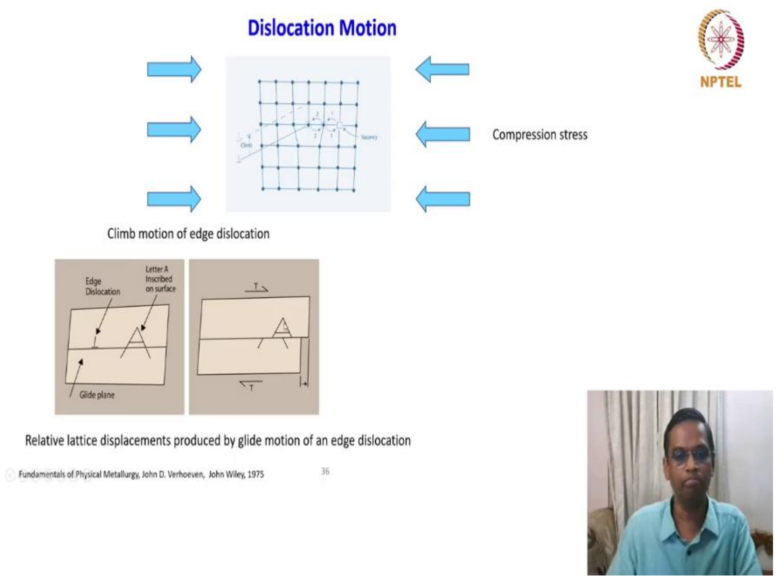

And if you look at the other aspect of the motion, suppose if the vacancies are involved in the dislocation motion, then the extra half plane will become shorter. How it become shorter suppose the vacancies are getting attracted by this compressive tensile force or the vacancy moves here then the atoms will go here then this will become shorter the extra half plane will become shorter.

So, that is normally in this situation the compression strain from this both ends will aid this, this kind of a mechanism that is what is shown here. So, you should also remember that if this kind of vacancy motion is there, in that little bit high temperature, we later we will see a line of a complete string of vacancies has to form in the dislocation line for the entire half plane to move up. So, huge dislocation vacancies have to migrate to move the extra half plane up that is another way of looking at the climb motion.

This schematic very interesting schematic shows and a kind of you know it gives an idea what really happens if the dislocation edge dislocation moves in a lattice and what is the consequence. What is the consequence here, the edge dislocation comes and the A letter is there here and it cuts through that and on the glide plane and it makes the shift so, the shift measurement will be equal to one Burgers vector.

So, what does it mean is the relative lattice displacement produced by the glide motion of dislocation leaves a new neighbour of each environment you may restore the lattice configuration, but each atom will have its new neighbours. That is my idea.

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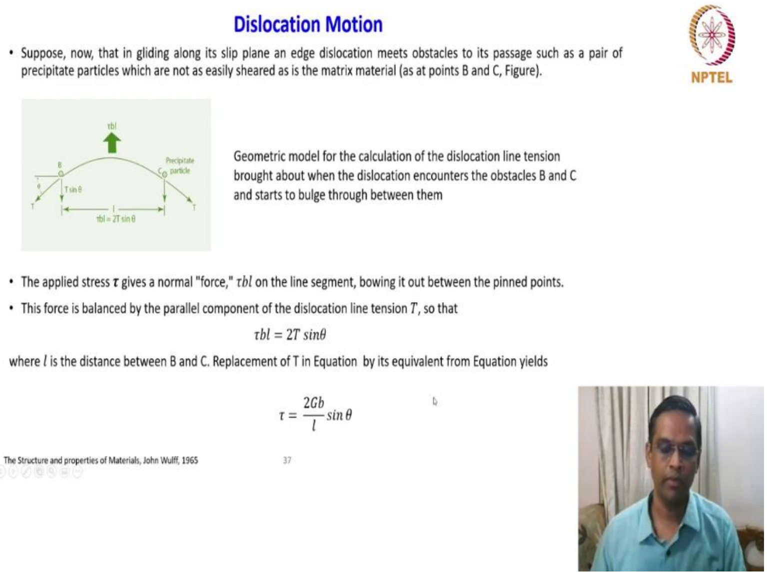

Another very important slide this is we will spend some time. Suppose, now, that in gliding along its slip plane an edge dislocation meets obstacles to its passage such as a pair of precipitate particles which are not as easily sheared as is the matrix material B and C there are two hard particle which is not sharable it is an obstacle for the dislocation motion. So, this is a dislocation line which encounters these two particles and it tries to bow the bowing takes place and what else is happening?

So, if you look at this the geometrical model for the calculation of dislocation line tension, so, this line tension where it is not new to us. We have to seen it line energy we correlated this surface energy to you know surface tension to surface energy and line energy to light tension we have already discussed. So, the dislocation line tension brought about when the dislocation encounters the obstacle B and C and start to bulge through the between them.

The applied shear stress tau gives a normal force what is normal force τbl, l is the distance between the two obstacles B and C and τb you know this is a force we are very familiar with the τb on the line segment. Bowing it out between the pinned points this force is balanced by the parallel component of the dislocation line tension what is the parallel component of the dislocation line tension.

So, this is a T parallel component is $T\sin\Theta$. So, this is T this is $T\sin\Theta$. So, we have two so, it is $2T\sin\Theta$ so, $\tau bl = 2T\sin\Theta$ simple force balance. So, where l is the distance between B and C and the replacement of T in equation by its equivalent from its equation similar terms what we have already seen $\tau = (2Gb/l)\sin\Theta$. This is the shear stress that the dislocation encounters when it meets the two obstacles and non-sharable particles. So, this is very important idea as I said this expression will be will be very useful when we go to the strengthening mechanism aspects.

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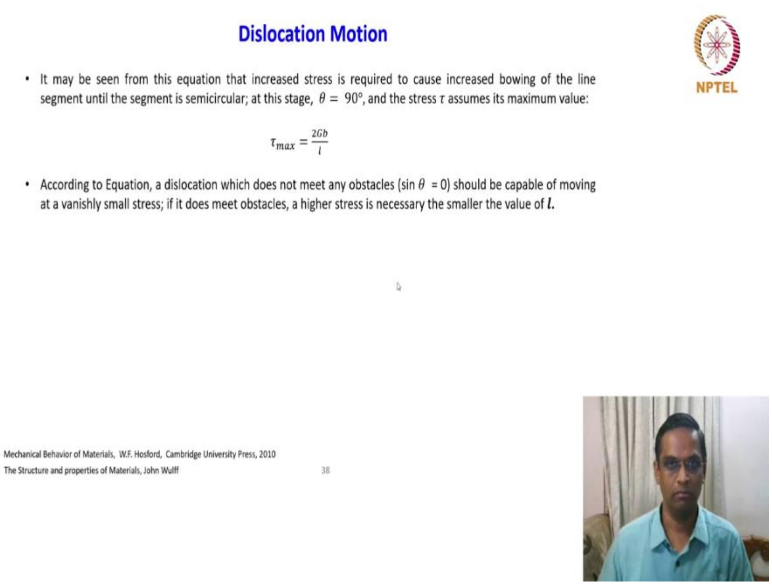

So, it may be seen from this equation that increased stress is required to cause increased bowing of the line segment until the segment is semi-circular at this stage ϴ = 90 and the stress tau assumes its maximum value τ_{max}=2Gb/l. This is obvious ϴ=90 you can just plug in this value and see peddlers. According to this equation, a dislocation, which does not meet any obstacle sin ϴ = 0 should be capable of moving at a vanishly small stress.

If it does meet obstacles a higher stress is necessary the smaller the value of l. So, this is also very important statement. So, how the obstacle size and the distance between them influences the stress required for the dislocation to bow or counter this obstacle clearly explains.

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Dislocation Motion

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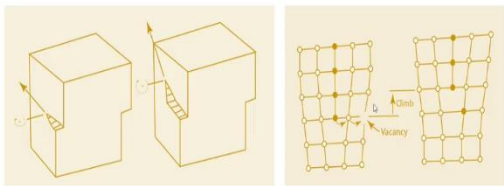

(a) Cross-slip of a screw dislocation, and (b) Climb of an edge dislocation

The Structure and properties of Materials, John Wulff, 1965

Finally, I would like to show one small images about dislocation motion. So, this is a screw dislocation, which is supposed to move here in the straight line, but then it is going into other some other plane it cross slips it need not screw dislocation always glide I mean it need not glide in a same plane but if you go to the next plane by cross slip mechanism and this edge dislocation vacancy movement we have seen which will try to climb motion.

So, similar I mean there are a lot of mechanisms or I would say that mechanics of dislocations are also useful to explain the crystalline materials deformation behaviour. So, we will see a lot more examples of dislocation motion and then I will say mechanics in much more detail in the next class. We will stop here and see you later. Thank you.