Defects in Materials

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Lecture – 21
Force on Dislocation

Welcome you all to this course and Defects in Materials. In the last 2 classes, we have looked at; or studied the stress and strain field around a screw edge and mix dislocations and also the because of the stress and strain field around this dislocation, what is the increase in energy which will occur in that material and which is called as the self energy of the dislocation. Then we looked at this self energy itself is can be considered as equivalent to the line tension that is because dislocation can be considered like a line which is a quite tall. So, that tension how to derive and explain how the line tension can be related if a dislocation is bend, what is the sort of stress which will be required to bend to a particular radius. These are all the aspects which we have looked at it.

In the next few classes, we will look at if we apply an external stress to this dislocation which are essentially creating in normal strains and stresses within that material, what all the type of forces which will be acting on the material? What is the first thing which you should to understand the force on dislocation because we know that what we are generally applying to a material is when we apply a load, we always try to find out what is the stresses which are acting on different surfaces that is the information which we have.

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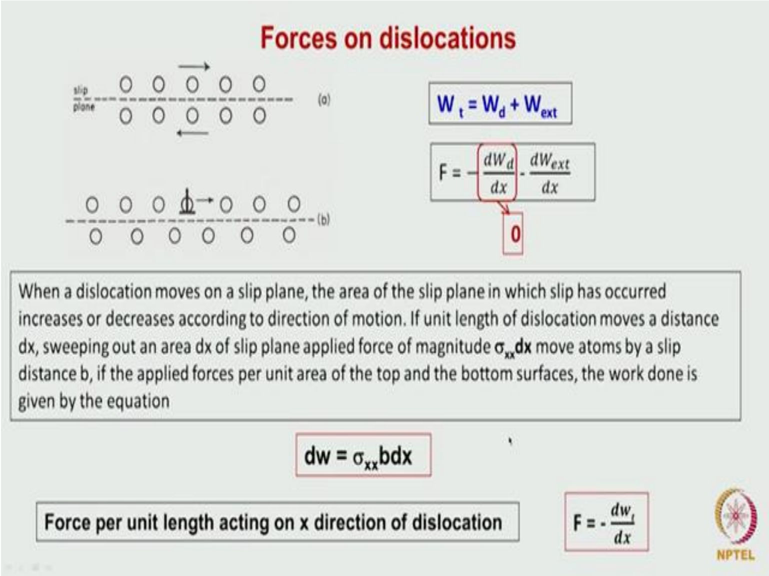

Let us consider this case, where there is no dislocation is being considered, it is on a surface one plane which we call it slip plane over which the one layer of an atom moves on top of it the other. In this particular case when a stress is being applied what are types of forces which we can have? When we apply an external stress, it will be doing somewhat suppose you assume that the case where there is a dislocation is present in the material, what are does this location do? This location we will see that the dislocation moves from one position to another, we are seeing the image of the dislocation which is moving. That means, that when the dislocation moves we can consider that this force is essentially or this stress is doing some work on the material, correct.

So, one when a dislocation is present there is a stress and strain field around dislocation that we can calculate what is a energy that is the self energy of the material.

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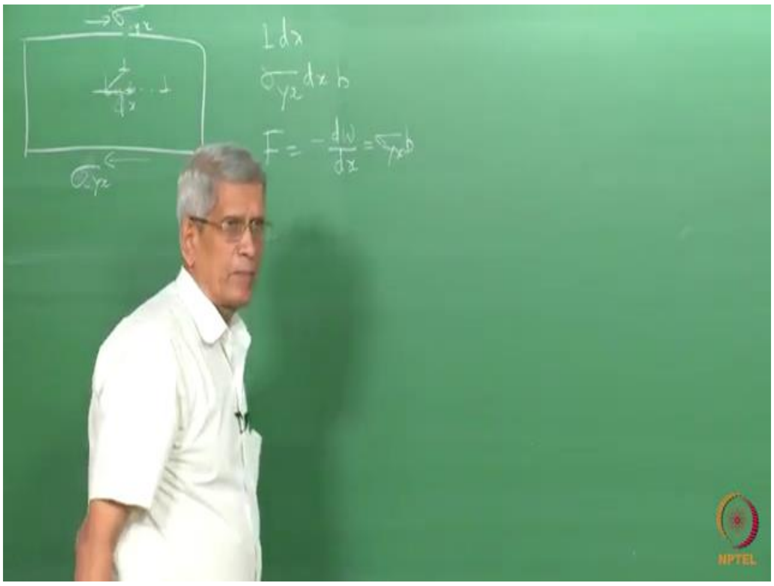

When we apply an external stress, in this direction we are applying where the dislocation moves from here and reach this here. So, what we will see is that as a function of position of the dislocation in that sample the self energy remains the same, it does not vary.

Only think what the external stress does it makes that dislocation move from one region to another region it has moved. It is equivalent to a unit length of a dislocation in we let us consider, example, this length assume that it has moved some distance d x; the dislocation is moved under the action of the stress which is applying. So, what is the area which it has covered, the area it will be into one into d x correct is a unit length this area if you multiply it by this stress that gives the force which is acting on that area, correct this can be written as y x into d x, correct.

Student: This is into (Refer Time: 04:41).

This is the stress which is a force; which is a acting on that area of that because stress multiplied by area gives the force acting on that, but what it has done? Whenever any dislocation moves it displaces every atomic layer by a burgers vector; that means, that if it has moved from here to a position here and this distance is d x, this much layer which was originally was there at composition has been displaced by a burgers vector always corrects the total moment it was like this, each layer has moved means that from here the next position when it has been shifted by the burgers vector. So, that is the displacement.

So, if you put that displacement into account, how we guess what is the work which is being done to move the dislocation, correct?

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So, this is a form of an energy which we get it and the force is nothing but minus d x which it will turn out to be this will be sigma y x into b it will come correct we have looked at the work. So, that is what this expression which it gives is the, what is the total energy. Now in this we can look at it this way suppose we assume that the across the slip lines if you look at this is the slip line around this slip plane the top layer and the bottom layer is being relatively displaced correct what is the displacement which has taken place this location which was there initially here it has moved to this place suppose we assume that under dislocation we have force which is acting on that unit length of the dislocation it has displaced it by this distance d x then this force into displacement becomes the work one will be opposite of the other and we can equate these to d x.

From this immediately we can get that force will be equal to sigma y into x sigma y into at that sigma that shear stress multiplied by burgers vector, but only problem in this way of looking at it this gives a qualitative way of how to find out the force, but which direction the force is acting we do not get any information from this sort of an expression because in this particular case which we had given it here.

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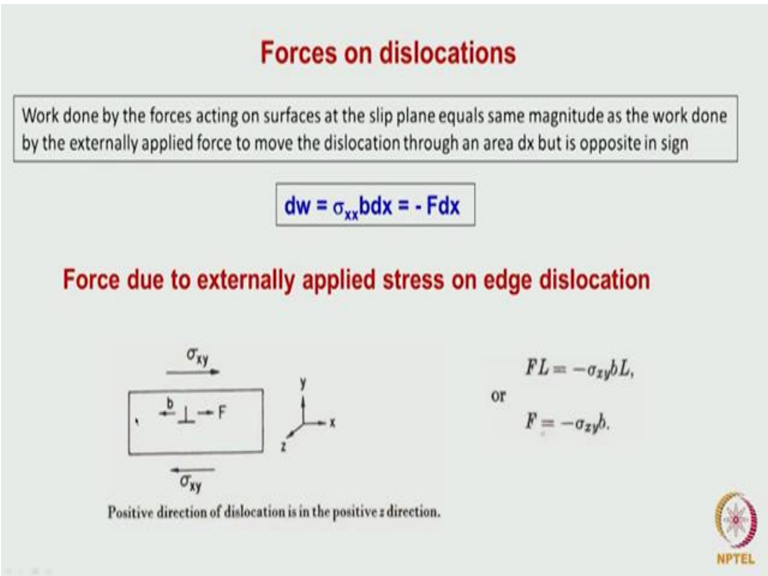

The burgers vector is in the negative direction then sigma x y, we supplied in this direction and with respect to a definition which has been used if we substitute for the value of b here the b is minus because in the negative direction the force turns out to be in the positive direction this way we already we can find out the situation becomes more complicated when we look at a force on a screw dislocation.

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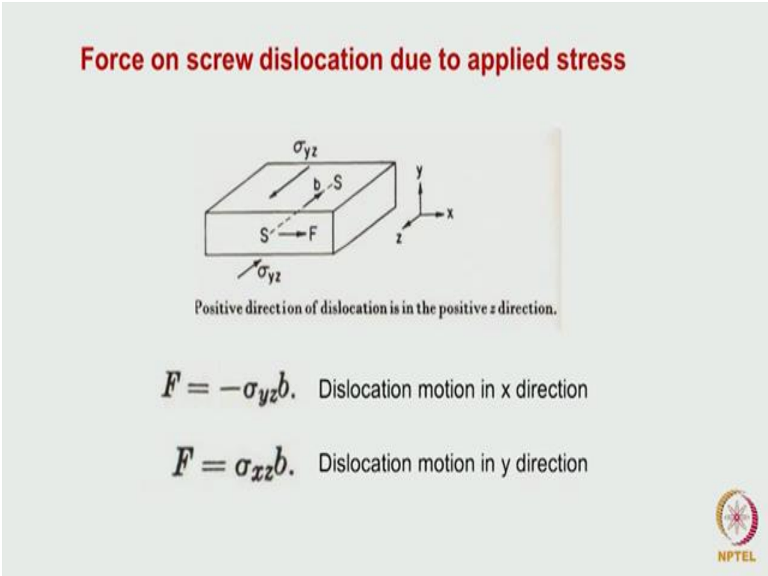

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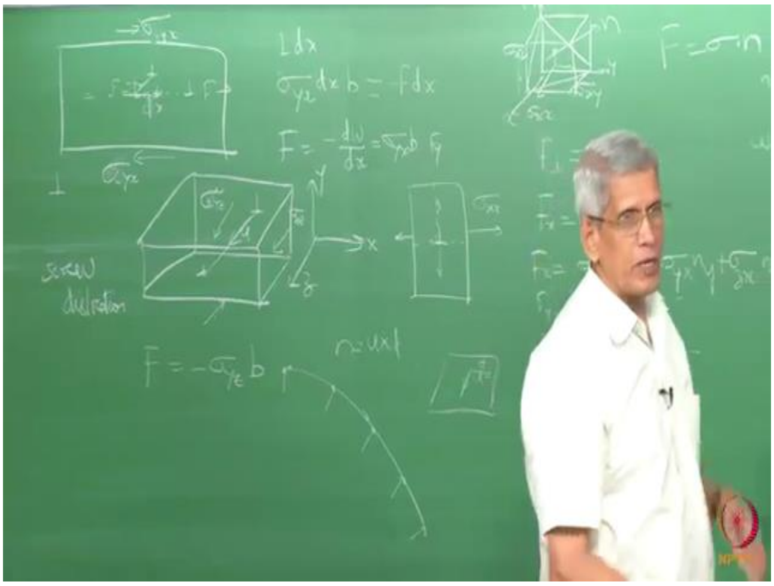

What are the types of forces which can act on a screw dislocation that is if you consider a block some material where you assume that a screw dislocation is they are going block and coming out onto this self because we simple which we use if you use the same symbol for the screw and then into dislocation which should not confuse with it. So, this is what is there in this block, it is a screw dislocation a coordinate system which we are using it is x y and the z is the coordinate positive is the direction this is the direction u of the dislocation which we taking.

The stress can be applied in this direction this will be. So, on the negative side of it we will be applying it in opposite direction then which is the direction in which dislocation moves here actually the expression tells that the force is equal to into b it turns out to be, but in which direction this force is going to act on the dislocation that does not become very clear actually this force will be acting in the x direction similarly if s stress is being applied his that is on the x surface sigma x is z the same thing will happen, but application of the external stress looking at it we are not able to make out what is the direction in which the force is going to be applied that is one of the problem of this way of looking at it and just showing many cases where that it is not that easy.

Let us take suppose your material which contains a screw distribution instead of the screw an edge dislocation is there that same material where an edge dislocation if there instead of a shear stress we apply a tensile stress on these surfaces tensile or a compressive stress then what do we naturally expect to happen to the edge dislocation this dislocation under the action of a tensile or compressive stress is essentially its pulling it apart or compressing it and h dislocation means that having and one extra plane above this slip plane correct above this slip plane we have an extra plane which is going to be there if you apply a stress what will happen tensile stress what will happen then.

Like see this example here we have a; this one I am just showing it this is normally what it is there? I apply a stress tensile stress and try to pull it this will just go in. So, the whole extra layer will move inside. So, if the whole extra layer move inside are when this is there like this to which when I apply a compulsive stress it will be pushing this layer out and out and it will be finally, just coming out of the subset that whole the dislocation will vanish; that means, that the dislocation that of as if under dislocation line the force is acting which is able it is making it move up or down. So, now, the force is acting here the force is acting in that the x direction here the force is acting in that y direction we will call it F y as a component.

the application of a tensile stress or a compressive stress under sample essentially makes the dislocation move up and down this is what we call it as a non conservative motion or a climb process of a dislocation correct, but in this qualitatively applying a logic we are able to try to find out in which direction the dislocation is motion is taking place, but there is an elegant way in which this center thing could be derived.

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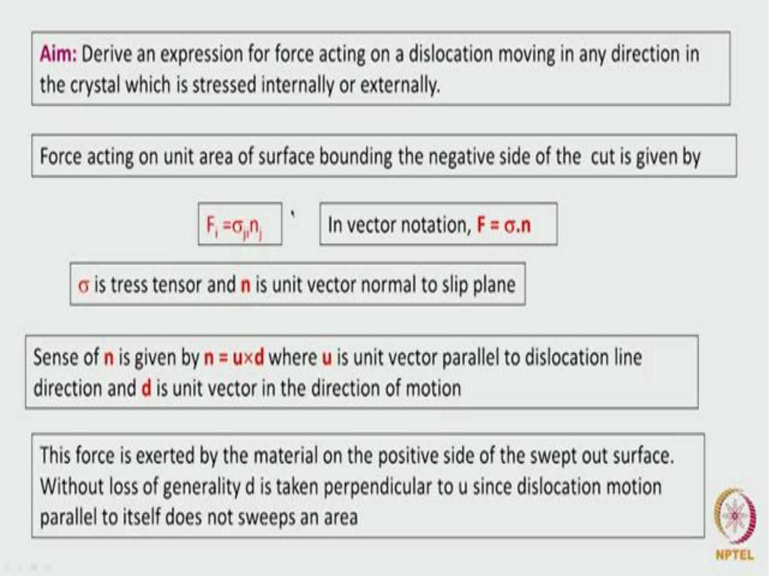

That is what we will look at it, there is we wanted to find out the force which is acting on a dislocation which is moving in any direction in the crystal which is stress internally or externally.

If you remember when we talked about the stress and strains we said that there are 9 components of stress which are there which we defined with respect to a small unit q correct you remember that i think if take a small q.

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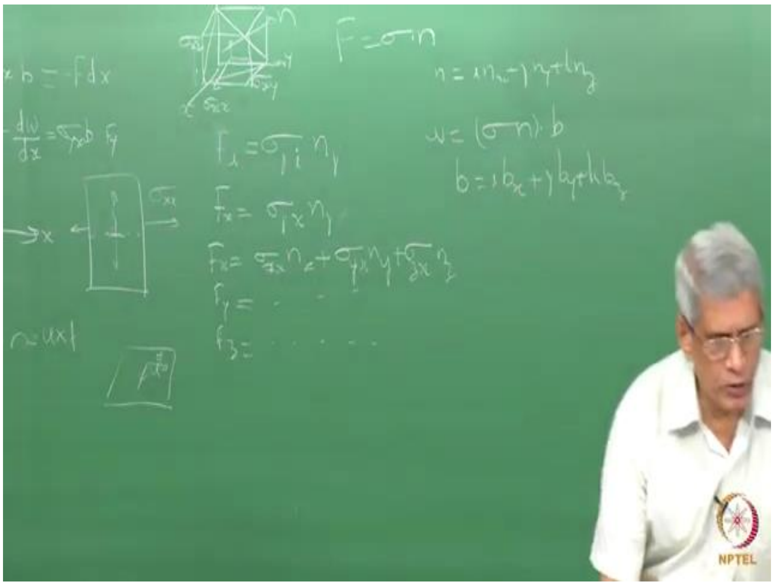

Then this is how we defined x, y, z, with respect to this coordinate system which we have chosen on this face will have sigma xx, in this direction sigma x z, correct, this is how the similarly on all the other faces are there if we have these components which have known what will be the force which is acting on any random plane that expression which we have derived.

Suppose we assume that there is a plane which we consider it as a this plane and the normal to this plane is n and the force which is acting across this plane that is a component F i will be into n j. This is the sort of expression which we have derived row if you remember then this is nothing but writing F x will be equal to j x n j, correct. Similarly we can write an expression with respect to the normal stress which is a with respect to a plane normal we can find out the components of the force acting across this plane in x, y and z direction we have derived that formula i am not going into that detail.

So, this will turn out to be if you expand it will be xx into when is similarly for a F of y F of z we can write similar expressions correct which tells what is the force which is going to act across this now let us assume that take care of the slip plane let us look at that slip plane is defined by the plane normal correct that is assume that n defends the plane normal to the slip plane and then what is the force which is going to act if you know that you assume that we apply a load the external load and the components of the stresses which are going to act on means are given by these terms then we can find out what is going to be the force which is going to act on this by this expression sigma into n this is how we write it, write (Refer Time: 16:36) notation the force which is acting we can write it like this whereas, n will be i into n x plus j into n y plus k into n x n sigma will be essentially these terms which will come into the picture correct the line components which we know.

So, this gives us what is going to be the force which is going to act a across the slip plane now we have to look at how do we define in that if we know as a slip plane if you know the line direction I assume that the line direction it is the direction of the dislocation we define it as u and the if the dislocation moves by a distance the this the there is unit vector in the direction. So, the cross product of it n will be equal to u cross d, we can write it apply normal because in that plane the dislocation line direction and the direction in which the dislocation moves we take it to be a unit vector in that direction then the cross product will tell you the. So, n can be now return us u cross d where u use a unit vector parallel to dislocation line direction and d is a unit vector in the direction of motion of the dislocation.

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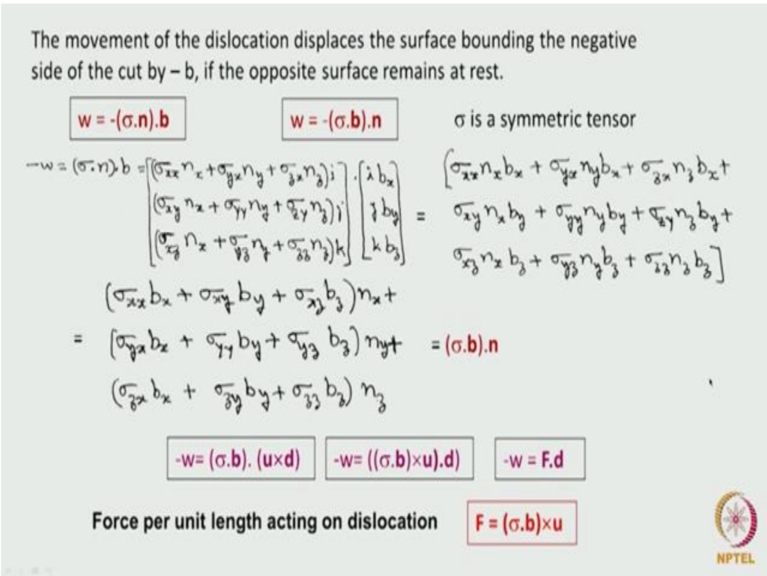

But what we have to look at this now is that when this force is being applied suppose it makes that dislocation move because d is the movement of the that dislocation a unit vector in the direction of motion of the dislocation when at dislocation moves what is going to be the work which is going to be done is this force times the burgers vector dot product if you take it that will tell you the force because you remember that when we initially derived what is going to be the force which is acting on an area that essentially displaces that area by a burgers vector. So, if we take the dot product then what will be sigma n because this is not a you should understand it when I put a dot now term this is not a dot product which we use it for vectors this dot b it will come this is what the work which is going to be done.

If you try to expand this that is this force we have already written that terms then that b can be defined as i into generalized form if you write it i into b x plus j into b y plus k into b z these are all the components of b n; x, y and z direction the coordinate system which we have chosen then when we check this product that is what essentially is being shown in this slide now you can see that this is sigma xx into n x into b x plus sigma y x into n y into b x these are all terms are all scalars corrects its only coefficients now this can be rearranged in a different form n x and b x n x and b y there. So, if I write it in terms of the coefficients which correspond to n x then I will be writing it in this form sigma xx into b x plus sigma x y into b y this way I can write it if I write this way, now this will be equivalent to I think that dot b will be equal to sigma into b dot n this just changes. So, these are only some mathematical operation which we have just done.

So, this is equivalent to what is the work which on the plane that is on the dislocation what is the force which is going to act under dislocation times the distance which it is are moved that is equality and that force is always going to be negative that is what essentially is being given here now we have written n to b equals to u cross d if we substitute in this.

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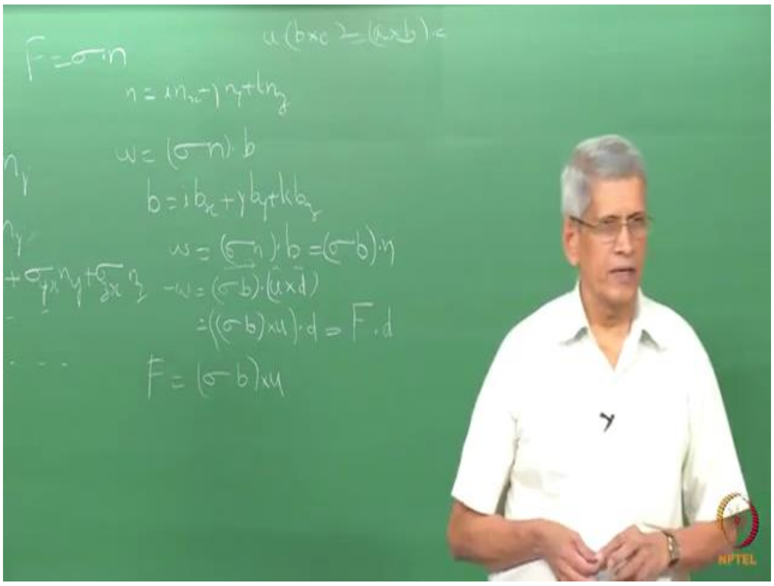

So, now, this is a vector this is a vector correct this is a vector. So, you know this in vector algebra a scalar vector product if you look at it this can be return as that is a dot b cross c can be written as a cross b dot c these are all the same correct box product. So, the same thing which we do it so then this becomes sigma b cross u dot d we can write it is it not. What is this d? A is a moment you a.

Student: (Refer Time: 22:41).

Which; has taken place in the dislocation movement direction unit vector movement. So this can be written as equivalent to F force which is F dot d that is also equivalent to energy. So, this force now becomes equal to d cross u. If you look at this expression it immediately becomes very clear that the force has to be perpendicular to these 2 vectors correct; that means, that if this perpendicular to this vector means that this is u is the line direction that the force acting on the dislocation is always perpendicular to the line direction this is a first point which becomes obvious from this. That means, that suppose we have a dislocation which is curved like this the force will in this direction because this will be the line direction and here the force will be in this direction here the force will be in this direction here the force will be each of this direction you look at this the force has to be perpendicular to that line direction.

What will be the consequence of it this has a lot of consequence because these a very important significant result because this result can explain how the dislocation is going to move and expand one of the simplest case which I will consider.

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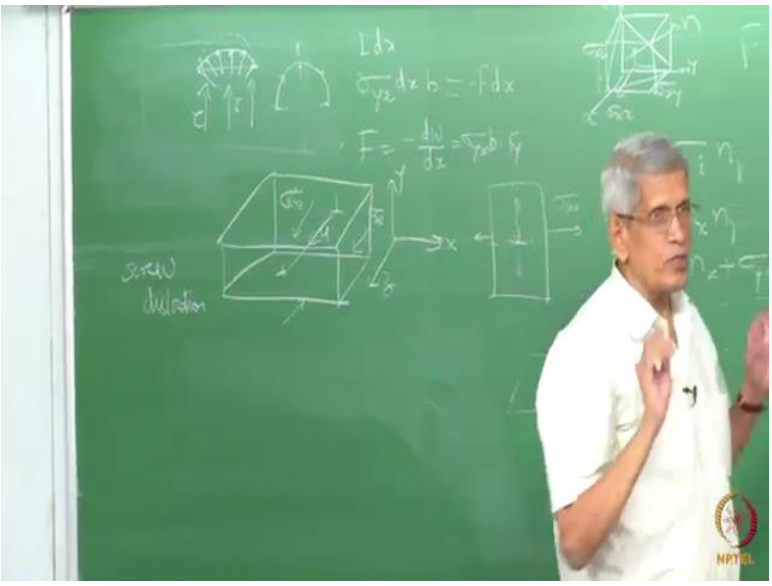

Suppose we assume that dislocation is held are on these 2 points it is being pinned initially the dislocation is like this and some stress is being applied the dislocation bends like this and then the bending becomes more and at some particular stage it becomes like equivalent to that of a semicircle when it reaches that stage in this particular case this is the direction in which the force will be acting right this is the direction when it reaches the case you consider when it becomes a semicircle how will the force act the force will be acting here in this direction on the dislocation, but at this one, it is being pin the force is acting in this direction.

Student: (Refer Time: 25:31).

Perpendicular, so when that happens, the dislocation moves in the direction force which is acting in that direction that dislocation is moving. So now, the dislocation can try to bend around this that is what makes the dislocation form loops your own precipitous this we will come later when we talk about dislocation precipitate interaction, but what I wanted you to understand is that though stress is applied in the same direction this is the direction in which the external stress is being applied, but the force which is acting on the dislocation because of the external stress is always perpendicular to the line direction because of that this dislocation this part may move in this direction this part may move in this direction is the expansion correct. So, this is something which is very significant which one should understand that.

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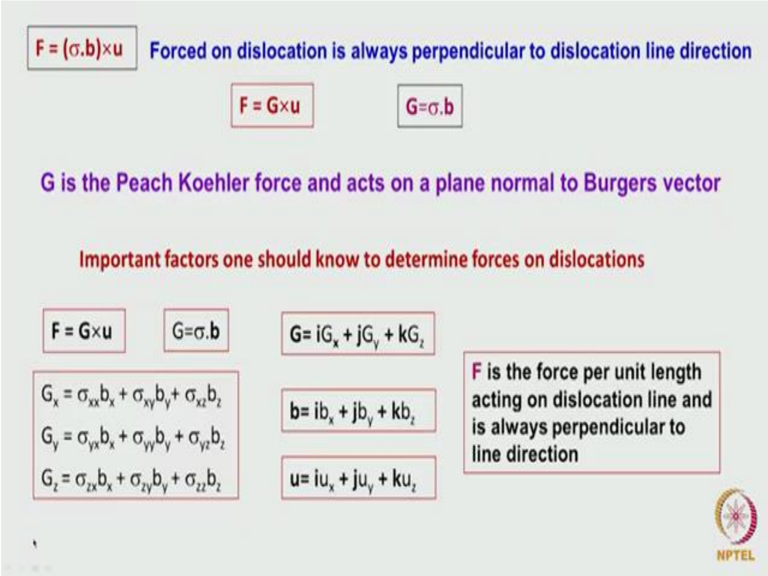

This one sigma that b because here we started with; with respect to a plane normal the force which is acting with respect to a plane normal and now using this mathematics we had come to this one where this is a forces this equivalent to because b is a vector correct. So, the force which is acting across a plane which is perpendicular to the burgers vector this force is called as pitch coiler force is this clear.

So, if this is clear now what are terms which we should know about the forces which are acting on the destination there are its a generalized expression which we have derived if you know the components of the stress which are acting un different directions with respect to crystallographic system which we have chosen we can find out the force which is acting across the burger vector direction and also the force which is acting in the slip plane on the dislocation line we have derived that expression.

So, essentially if you look at it, I will just write it down because I consider that this is one of the most significant tasks because this expression will be required also further to look at various cases.

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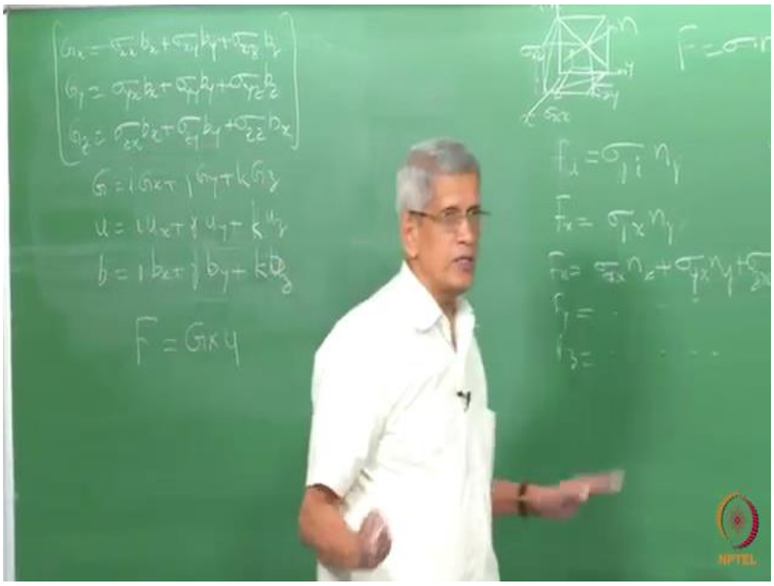

Instead it is going to b x this is one and this is nothing but the g equals i into g x correct plus j into j y plus k into g z then the line direction u we write it as i into u x plus k into u y plus j into u z burgers vector j into b y plus k into b z these are all the things that is this is the way we generally represent that burgers vector and the line direction and the pitch coiler force.

Then if this is there the other significant expression F is equal to g cross u this is how we can find out the force which is acting on our dislocation which has a line direction u and the burgers vector b and this F whatever you consider is always the force acting per unit length of the dislocation that we should always remember.

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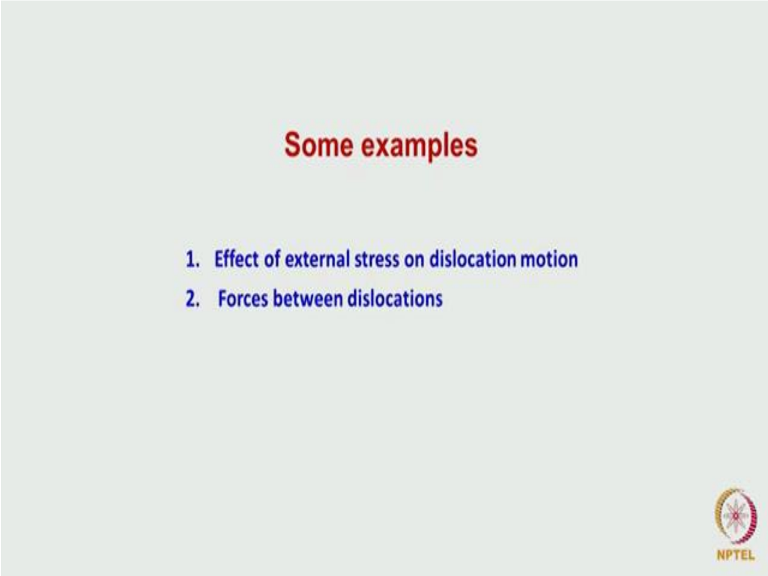

Let us consider some examples one is an effect of external stress on dislocation motion we will consider it on a single dislocation another is suppose dislocations are present within the material what are the types of forces which are going to act between the dislocations when more than one dislocation is present that is first we consider the case when is an effect of an external applied force on a single dislocation.

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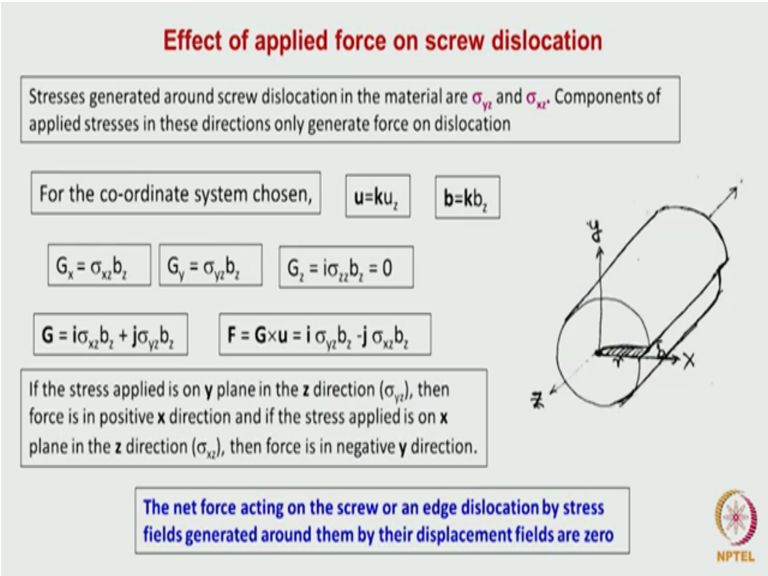

This is almost what we are trying to do is coming back to initially we started with a problem of looking it; what is the direction in which the force will be up and acting on a dislocation you remember that s.

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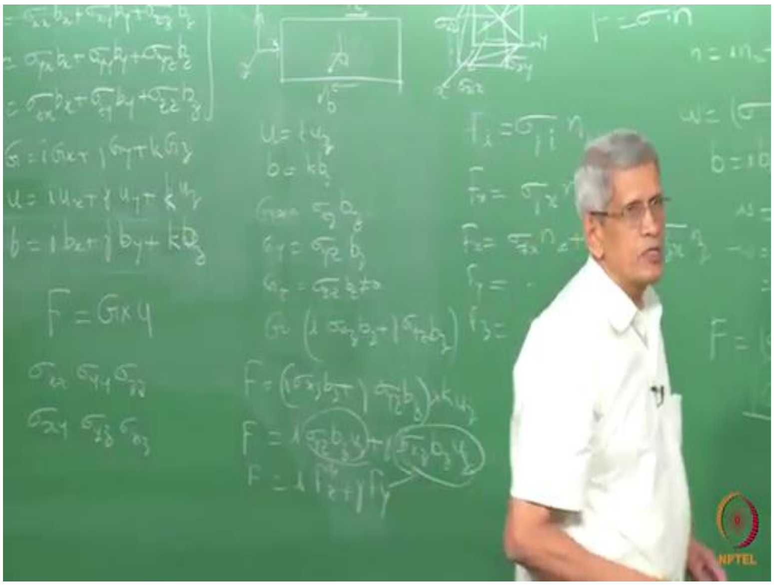

We consider this case assumed that the dislocation in there suppose we choose a coordinate system z y; z x y and what is the direction if this is the applied in this direction what is the direction in which in this particular case b x positive direction is the one we the burgers vector going to be there for an edge dislocation what is the direction in which the force will be acting on this location we wanted to find out.

So, what is the simplest way in which we can do this we can do it for an edge as well as a screw dislocation let us first consider the screw dislocation in the case of a screw dislocation if we consider the internal stresses which are generated are only in sigma y z and sigma x z direction with respect to a coordinates which we have chosen that is for a screw dislocation this is the direction positive direction of a line direction and the burgers vector is also going to be in this direction correct.

So, u will become k into u z correct with respect to a vector notation which have taken the others are going to be 0 because we say generalized direction of vector for you then for the burger vector then it will be coming b will become k into b z, only the z component because that expression which you have derived is for a with respect to a coordinate system the generalized directions for u and a generalized direction for the burgers vector.

Now, any external stress if you try to apply and I find out the components of the external stress which are going to be there then the components which external stress will have is the 9 components will be there sigma xx, sigma yy, sigma zz then sigma xy, sigma yz, sigma xz, all these components are after load which have applied in a particular direction that components will be there along these various directions with respect to coordinate axis with 9 components, but which of the ones will be acting on that the effect each only sigma yz and sigma xz that is where the displacements are. So, only these components of the external stress will have any effect on that is left screw dislocation others will not have any effect on the screw dislocation. Is this clear?

So, we will consider this case that if that is the case, in this expression of g which we have written here, here it has to b z correct then k b z correct no b x and b y all these terms are 0. Now what will this g x turns out to be? G x will turn out to be sigma xz in to b z correct g y will be equal to sigma yz into bz, gz will be equal to sigma zz into b z, but this term will be equal to 0 because sigma zz, all not have any F a. So, only this, now, g becomes i into sigma xz into b z plus j into sigma y z into b z correct. So, what is the direction in which the force is going to operate this is g cross u. So, that will become b z cross u is k into u z correct finally, this expression will turn out to be i cross j will be minus j cross k will be i, correct.

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So, this will be i into sigma y z into b z into u z minus j into sigma x z into b z into u z if u is a vector which we take on to be essentially unit vectors then u z term will be just one correct now we can find out that what does this i means? This can be written as F can be written into i into F x plus j into F y this term equals F x this term becomes that is.

Student: (Refer Time: 36:11).

Plus I will put this is equal are minus. So, these with a minus sign.

Student: (Refer Time: 36:21).

Will be minus sign will become F I, correct. So, this tells what all the forces which are going to act on the dislocation x and y direction the alone which is going to be there, but if you try to look at what is the net force that will be if we integrated to over all the area it will turn out to be 0 on the dislocation, but what this important is that this is just telling us that what will be the effect of the applied force now let us take that internal stresses if you take it what is sigma y z is the stress which we are externally applying it, correct.

So, at any particular point with respect to dislocation we try we are trying to find out what is going to be the external stress which will be acting on it correct with respect to this suppose y z, we applied that is x is in the only y z, if you are trying to apply on this what it tells is that the force is going to act in F x, correct that is in the x direction the force is going to act in a screw dislocation this is equivalent to the case of the screw dislocation which we have considered in the case of a screw dislocation which we considered earlier the stress is being applied y z in this direction and in this direction on the bottom surface y z and that u is in this direction, burgers vector is also in this direction and because it is the coordinate system which we of chosen x y and z now what we are finding is that the force is going to act in that x direction correct when sigma y z stress is being applied on this plane the force is in this direction what is going to happen that is suppose the stress which is being applied is sigma x z sigma x z means that on the x surface in the y z direction we are applying a stress shear stress when that stress is being applied in this way the force which is acting is given by only the second term that is F y.

Now, from this expression it automatically becomes clear that if we apply a stress in a particular direction, what is the direction in which the force will be acting on the dislocation? And that is the direction in which dislocation will move. So, under the action of the external stress if you apply a shear stress like this; this dislocation will move if the stress which is applied is on the y surface in the is a direction now the dislocation will move in this direction or in this direction this becomes very clear from this expression, but other ways the qualitative way in which initially we started with it does not become very clear.

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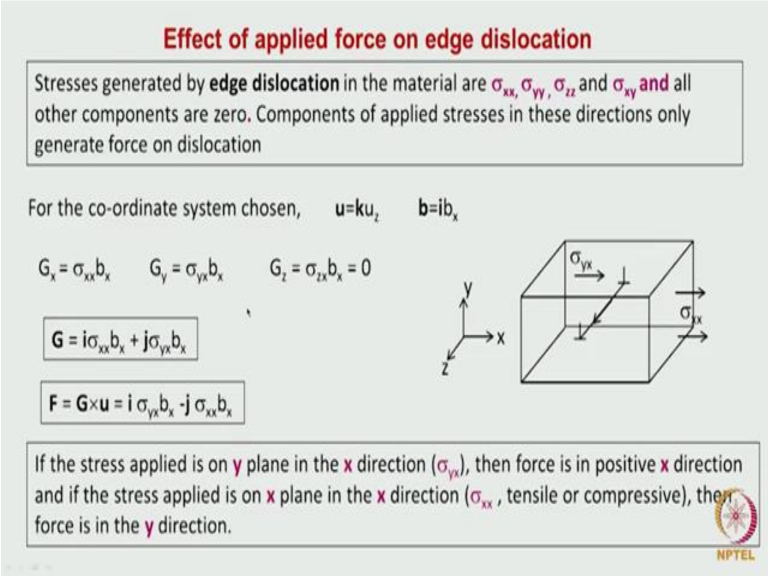

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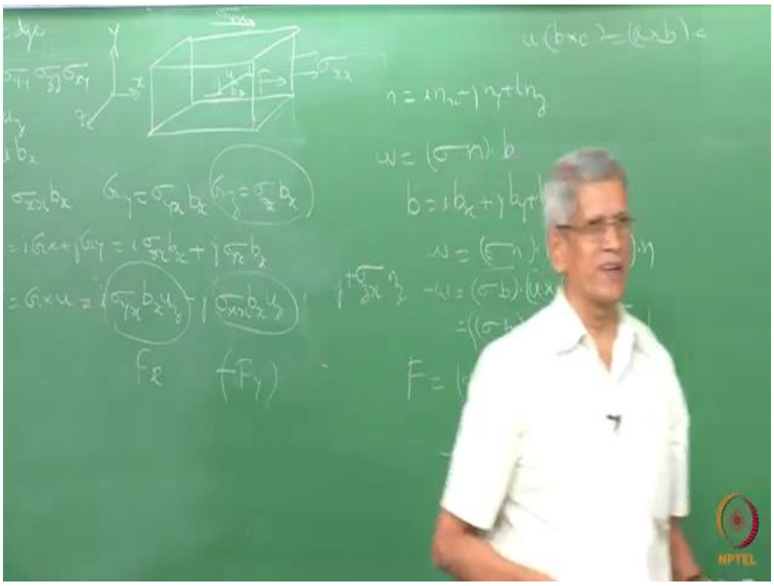

Now, let us consider another, in the case of edge dislocation because so far we have considered for a screw dislocation in the case of a edge dislocation if you consider we assume that we have a this is the coordinate system which we choose x, y and z this is the u and burgers vector will be in this direction if you apply any load it is q, we can find out the components of the stress which are going to be there on applied stress components in various shear as well as that with respect to a coordinate system.

But as far as an edge dislocation is concerned the only stresses which are present internal stresses are sigma xx, sigma yy, sigma zz and sigma xy, all other components are 0. So, only these components can act under then what is going to be the line direction u will be k into u z because if lambda is a direction what is going to be the burgers vector burgers vector this i into b x, correct. Now let us derive an expression that these are all the stresses which are going to know what is going to be the pitch coiler force if we look at this now we will find that g x will be equal to sigma xx into b x these all other components these components will turn out to be 0, correct, g y will be equal to sigma y x into b x plus b z will be equal to sigma z x into b x, correct, sigma zz will not have any effect on the dislocation. So, this term is going to be 0.

Now, g will be i into g x plus g y b x plus j into sigma y x into b x correct now we can take that what is the force which is going to act on dislocation that force is given by g cross u here again if you take it like cross product i cross k will be j cross k will be i y x into b x into u z minus j into xx into b x into u z; u z is a unit vector. So, now, we can see that this corresponds to F x this term corresponds to minus F i correct; that means, that if we apply stress assume that we are applying a stress which is only in the shear stress in x y direction that is y plane in the x direction that is what this represent this introduces a stress what is the direction in which this is on the positive direction we apply sigma y x burgers vector is in this direction the force will be acting in this direction this becomes obvious from this expression suppose we apply the tensile stress which is on this face that is stress which is normal to this the x surface then the force which is going to act this is F i. So, we can immediately see that the forces in the y direction; that means, that application of a tensile stress which we qualitatively by looking at this demonstration we try to understand it this becomes obvious from this mathematical expression itself.

This makes life much simpler because we can find out what direction stresses will be acting. So, what we have to remember only these expressions and that is all, this is all which we have to remember to calculate the force which is going to act on a dislocation this force is very important unless we know the force we will not be able to tell how the dislocation is going to move in a dislocation especially when the dislocation and mix this location the force will be acting on different directions on the dislocation at every point though the stress is applied in the same direction, but the effect of the stress on the dislocation which acts in the form of a force and it is a virtual force as if a force is trying to push the dislocation that force action is always perpendicular to the line directions is it clear.

So far what we have considered is now essentially to derive an expression for the force which is acting on a dislocation and consider 2 cases where and when external stress applied what is the direction in which the force will be acting on the dislocation. The next case which will be considered is that when there are many dislocations are present, what are the types of forces which are going to act between the dislocations? What sort of forces should be acting force which will be acting depending upon the direction in which the dislocations are present?

These dislocations could be one could be an h 1 could be a screw dislocation their directions could be different this is what exactly which is required to know when we deform a sample. A lot of dislocations are generated how they interact their interaction will lead to whether a repulsive force are the attractive force depending upon that the respond of the material will change these are all that expect for that to understand how the material is going to respond, we should be able to find out the type of forces which act between dislocations.

This will take it in the next lecture.