Defects in Materials

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Lecture – 22
Forces Between Dislocation

Welcome you all to the course on Defects in Materials. In the last class, we have looked at an elegant methodology with which we can find out the direction in which the force is going to act on the dislocation, and what will be the magnitude of the force both aspects we have look that it. Now, let us look at the case where if many dislocations are present, around each dislocation there could be some internal stresses, which are they represent different directions in which the forces can operate on them. Let us try to derive an expression for the forces between the dislocations this can be done first we will do in a qualitative way to understand it, and then we try to go in a, do derive an quantitative expression.

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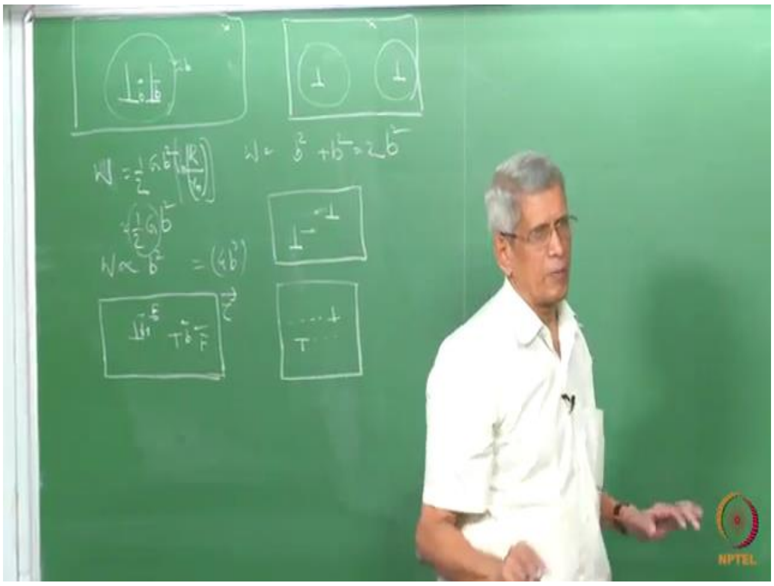

Let us assume the case that we have a one dislocation, it could be an edge or the screw dislocation it does not matter which are burgers vector b. And then another dislocation is there which is very close to it with the burgers vector b. What will be the effect of this dislocation on this stress field in a sample here? What is the possibility in which we can consider it is there we assume that these are so close by if we try to do here burgers circuit around this dislocation these two together, what will be the burgers vector of these this location, this together will turn out to be 2 b correct.

So, the expression for the self-energy of a dislocation W we have written half G b square logarithm of R by R 0 where R 0 is the core radius assuming these to be since the logarithmic then we can neglect it. This will be equal to this is for a h dislocation, this is for a screw dislocation. So, essentially G is a material constant, so essentially depends upon w is proportional to b squared it become correct. So, if you look at the b squared that is self-energy here it will be 4 b squared in this case it will turn out to be correct.

Let us take the same case where these two dislocations, one dislocation is here another dislocation is here, the same slip plane, but it is very far away. Then if you take and find out a stress field around a particular point, we have to find out a stress due to this as well as due to this. Then the self-energy due to both of them will be one will be b square the other one will be b square. So, the total energy due to this dislocation W will be equal to twice b square that means, that as that dislocations are far apart the total energy is getting reduced. That means, that if we have two dislocations, which are very close they will try to repel each other, so that they move far apart to reduce their overall energy. Is it clear?

Student: Yes sir.

This is essentially what is going to happen. This we can qualitatively we can understand it.

Let us take another case where that is a one dislocation. Another dislocation which is there, these are burgers vector b is in this direction positive, here the burgers vector b is in this direction that is this is something like an edge dislocation, if you consider in one the burgers vector is extra plane is in this another extra plane is in this direction. In fact, if you use the expression of force equation, which we have written earlier that if we apply a stress in this direction in one of this dislocation, the force will be acting in this direction, in this one the force will be acting in the opposite direction. That means, the this dislocation will move in this direction, this dislocation will move in the direction when they come and meet together the extra planes will become one on top of the other the dislocation will vanish. That means, that these dislocations are going to attract each other qualitatively we can understand that.

The third case which we can consider is these dislocations are not the same slip plane, one dislocation in this plane another dislocation in this plane is going to be there. What will happen when these dislocations are present like this or one moves in this direction another moves in this directions. The other case which we can consider it is that one dislocation like this, another dislocation is like this, but this is in one slip plane, this is in another slip plane. What is the sort of forces which will happen? Looking at, it is difficult to tell correct. We have to do some quantitative expression to find out what will be the stresses, forces which will be acting between the dislocation, this is precisely what we will be trying to look at it.

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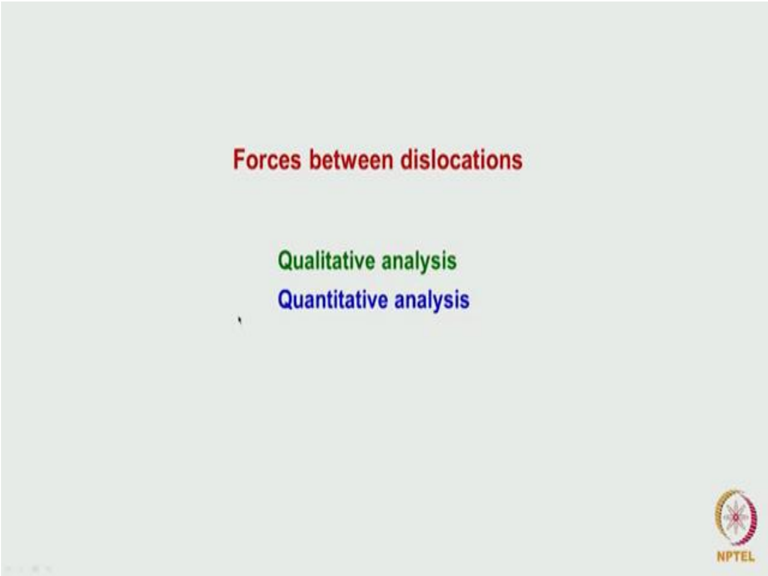

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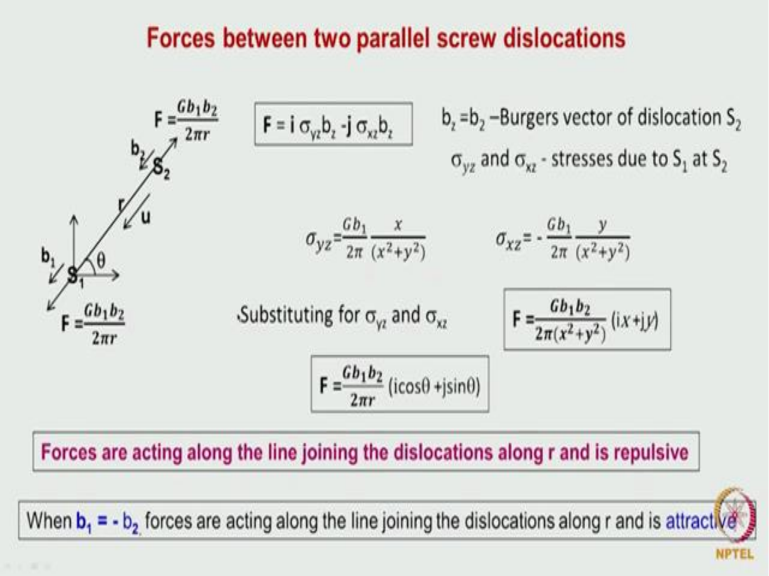

What we have considered here is the case of a two screw dislocations S 1 is one dislocation, S 2 is an another dislocation which is in a slip plane in which it is moving. S 2 is in an another slip plane, and the line direction of the dislocation for both of them is in the z-direction positive is z-direction is this direction, this is x and this is y. Just to differentiate between these two dislocations, I had put that burgers vector of this dislocation is b 1 and burgers this location of this dislocation is b 2. Most of the perfect dislocations, which will be the burger vectors could be the same value.

And in the last class we have derived an expression for what is the direction in which the force is going to apply, for generalized expression for if we apply an external stress, what will be the force. In this one the philosophy what we have to look at it is it that if there is assume that that is a dislocation which is there in this S 1.

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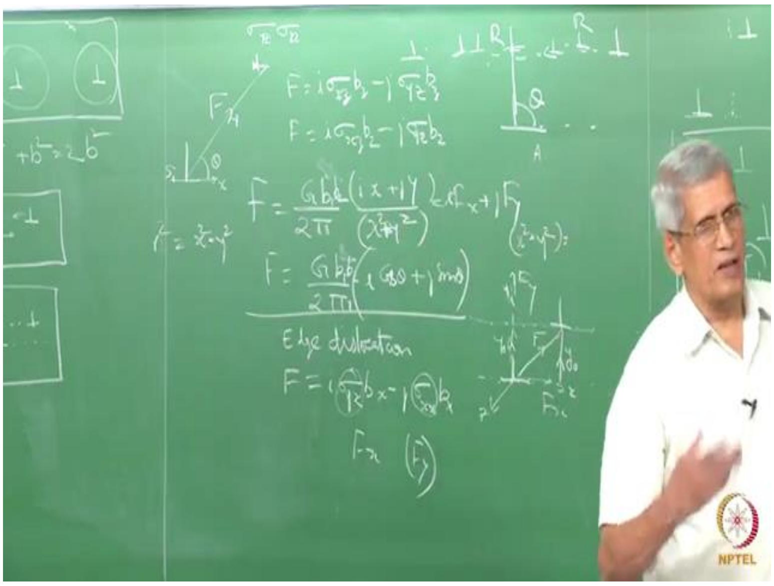

So, essentially if a dislocation is present at this position at a particular position here, this dislocation will be generating some stresses. Those stresses are sigma y z, sigma x z these are all the only stresses which are going to come. And we know the burgers vector of the dislocation, we can find out the strain field, we can find out what is going to be the energy corresponding to that point and the rate of change of energy will give you the force which is acting. So, that will be the force between acting between a dislocation present and the second this is the distance r between the dislocations that is essentially what is being shown here.

So, sigma y is z and sigma x is z are essentially nothing but the stress which the first dislocation is going to act here. And in this expression F is equal to x z into b z minus j into sigma y z into b z this is nothing but the burgers vector of the second dislocation. Now, we substitute for sigma x is z and sigma y is z the expressions which are derived. Then this force equation will turn out to be x squared plus y squared, this is how it will turn out to be. So, with respect to i, if we take it that corresponds to a force that this is equal to f x plus i into f x plus j into f y we can write it. Is it not?

The same expression there is with a Cartesian coordinate system, which we have used. We can use a coordinate system where with respect to this x-direction angle theta and this is r. r is nothing, but r squared equals x squared plus y square. If we substitute for this, this expression will turn out to be this is the sort of an expression which will be getting it, and that is what is given here. Or this should be strictly speaking the way we have different it should be b 1 and b 2, b 1 is the burgers vector of the dislocation, if b 1 equal to b 2 that will become b square. This expression gives what is the force which is acting along the line.

And here b 1 and b 2 are a magnitude of the dislocations which we are taking it. If at the same type of a dislocation b 1 and b 2 are in the same direction, b 1 and b 2 if take product is going to be a f is going to be a positive that means, the force between the dislocation is repulsive and it has a radial symmetry. So, any direction if you take it for a screw dislocation, if there is dislocations are lying parallel to each other, one dislocation like this another dislocation like this parallel to each other. It does not matter where it is with respect to distance or the same force, which is going to act. And the direction in which the force is going to act is along this line joining, the line perpendicular to two dislocations line that is the direction in which the force will be acting. Suppose, we assume that one has got a burgers vector which is positive and another there is got a burgers vector which is negative, then the force is going to be attractive one because of its negative. This is much easier to understand.

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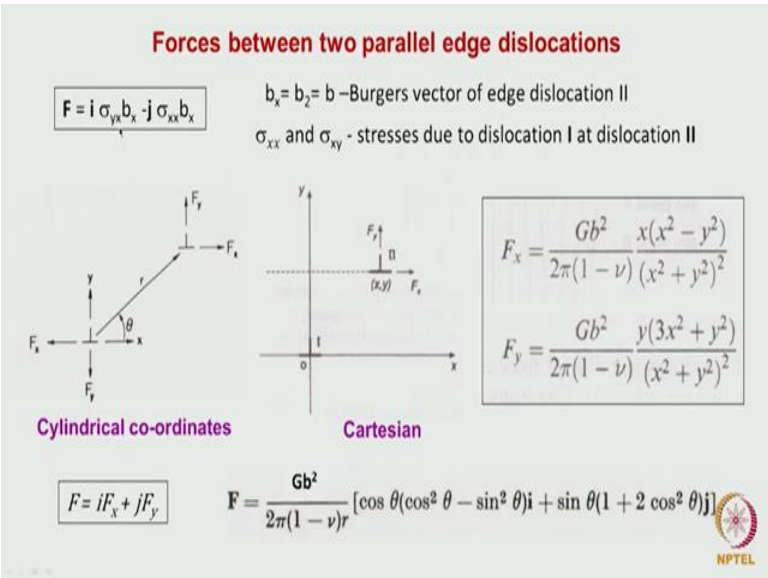

Now, let us look at the case between forces between two parallel edge dislocations. What will happen in the case of an edge dislocation? In the case of an edge dislocation, the force which is going to act this expression we have derived already. This for an edge dislocation F equals, this is what the force which is going to be. Now, b x will be nothing but you for the second dislocation you give a burgers vector b 2, assume it to be then it will be b 2. And if the first one has got b 1 then we have to substitute for sigma y x and sigma x x the expression which we have derived for a stress field around edge dislocation. If you do that this is a sort of an expression, which will be getting it for f x this is the expression, and this is the expression which will be getting it for f y.

If you use cylindrical coordinate system then what is going to happen is that that f will be and if the burgers vectors are less same magnitude b 1 equals b 2, then it will be G b square where these are all the terms here. So, this the one term which is that i this part corresponds to the f x, and this one will correspond to the f y that means to the force which is going to act between the dislocations. That is what we have done is though we have considered in this case also one dislocation which is moving in this plane; with respect to this, we have define the coordinate system this is the is z, x and y. And this is the slip plane of the other dislocation; other dislocation is at some height you can take it to be y 0 above which that slip plane is going to be there that dislocation is moving

Here we have to consider a few cases. Suppose, this entire experiment, which we are doing it is assumed that it is at room temperature. When we do an experimental to room temperature, the dislocations most of the time only glide on the slip plane that means, that when the dislocations glide on the slip plane, we have to consider the force between the dislocations in the x-direction only has to be considered. At high temperatures, when the dislocation can climb at that time only we have to take the climb forcing into consideration.

Now, let us take this case of room temperature. In this particular case, we have to take only this force F x only has to be considered F y we do not have to consider for the present. This is the expression for F x correct; and y we assume it to be some distance what is y, y is some distance with respect to that is along the slip plane what is the height at which this dislocation is being present. So, in this particular case, when we take x squared plus y squared, all these terms have to be taken with respect to y remaining constant only the x is changing; that means, that suppose this dislocation is stationary we assume that this dislocation is moving in this plane correct. If it moves in that plane what is the sort of force which will be acting between the dislocations.

The force which will be acting will have a component that general force will be in this direction one with an component in this and the another in the component in this direction. We are looking at you only they are component which is there in that glide plane is what we are considering it. And for these calculations, to make it easier, these distances x and y itself can be written in terms of the burgers vector as a unit that is essentially what is being done and shown here.

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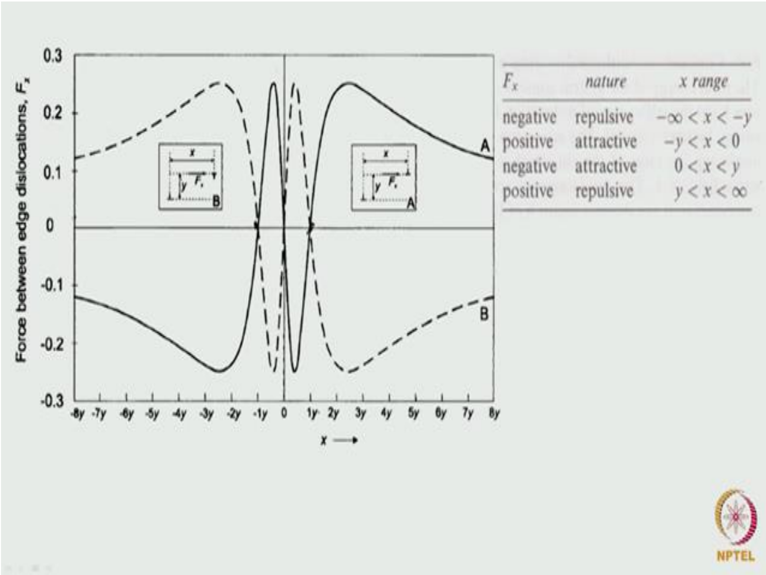

Here that is one are this can be written in terms of another way in which y is a constant that is these is I had taken it be y 0 that figure it is given as y. So, if this is constant, x can be written in terms of y 0 that is only for the purpose of making the calculations simpler. And in this you take F by these factors to be the one which we are trying to plot them we come because dimensionless parameter. Now, if we try to look at it, what is becoming very interesting in this case is that as the dislocations are coming close to each other, the repulsive force increases that is you assume that one dislocation is here, another dislocation is here. This dislocation comes close to this dislocation moving in the slip plane then the force is repulsive force is increasing, because both the dislocations have got the same sense of burgers vector that is both of either positive or negative.

And then at some particular distance you find that the force starts decreases, then it becomes 0 at some particular distance, then it becomes from repulsive to attractive, again it changes direction that is after dislocation you assume that it moves from here and reaches this point. Just going on top of it various positions, we can assume this dislocation as more, but each of the position will be see. As it comes close up to a particular point it becomes repulsive then from here to here it becomes attractive then from here to here it becomes repulsive then again become attractive that is the way it is going.

So, if you look at this expression itself, it becomes very clear. In this expression that for the expression for F x, if x becomes equal to y then it becomes F x becomes 0 that is value in between what is essentially going from the repulsive forces will start decreasing. Reaches a maximum start decreasing reaches 0, then you can see that the similar thing it should happen on the other side and for value of x greater than y, x squared minus y squared if we see this is going to be always a positive quantity that is where the repulsive is going to be there. Then the other case when x squared x and y are positive, but y is greater than x then it will become negative. So, it becomes attractive that is why this force term when we look at it we have this sort of a force which is acting on the dislocation.

So, there are regions as the dislocations are moving in the slip plane, repulsion, then repulsion decreases and it becomes 0 then it becomes attractive, then it changes. What will be the consequence of this? These sort of a motion especially let us look with respect to that expression here. When theta becomes 0 that is theta becomes 90 degree that is one on top of that is when this dislocation comes here on it, this angle theta becomes with respect to this theta becomes 90 degree. Then what it becomes, it becomes 0.

Student: (Refer Time: 21:38).

Professor: For z 0 correct that means, that when the dislocation is moving from here to here like this, if it tries to remain on top of it the force which is going to be there in the x direction is going to be 0. That is a low energy configuration as far as the stresses are forces acting between the dislocations that is what it will try to prefer.

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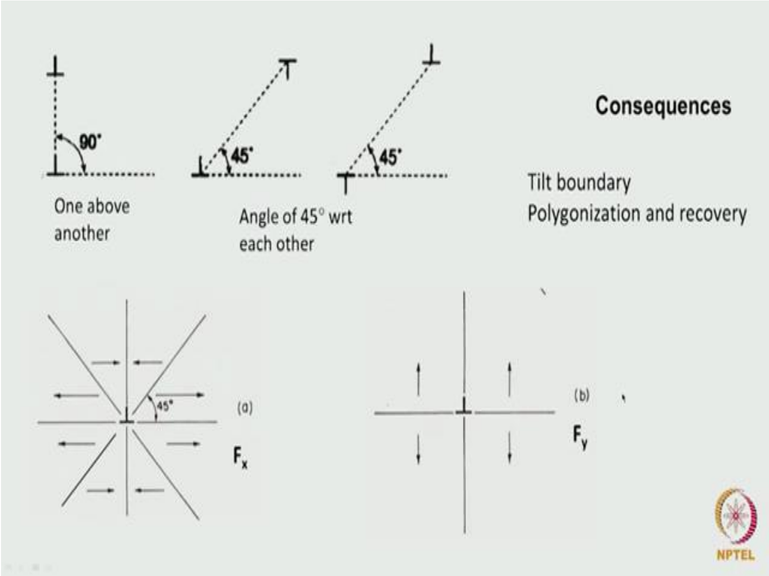

Suppose the two dislocations have different burgers vectors - one is a positive and another is a negative, then what will happen is that these force directions will.

Student: Change.

Change that is what essentially is being shown in the other curve A and B correspond to that.

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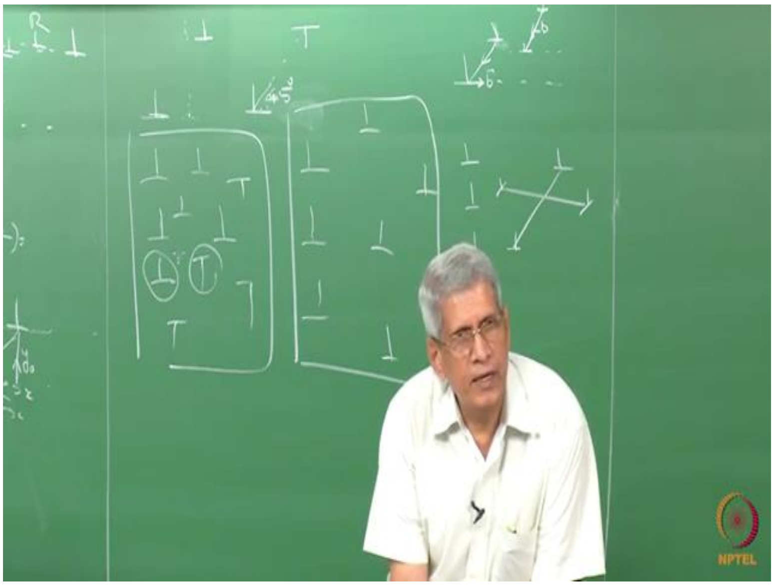

So, the effect of it is that suppose we have one dislocation, and the another dislocation which is of the same sign, which there when assume that both are moving when they are moving if they move. And at some position this is a position in which this dislocation reach it has reached in these configurations, it has a minimum energy. It will try to maintain that because force in the x-direction becomes 0. Suppose that is dislocation in this a dislocation is in the same slip plane is there, this will attract each other and cancel.

The other case is that instead of it this dislocation is going to be here, now what it is going to happen is there, when this dislocations are going to be making an angle of 45 degree this is going to be a minimum energy configuration for the F x. So, they will try to remain in a in that configuration it can be there. What is essentially is going to happen is that the dislocations get attracted positive edge dislocation and negative they will be attracting each other, so they will try to come together. At some position, let say minimum the force is going minimum that is a configuration is minimum.

Now, if the dislocation has to move, both of them have to move together that they will not be able to move independently. When we start with the dislocations are randomly distributed or generator at small that is when the density of dislocations is very small and the dislocations are very far away, the interaction between the dislocation is not going to be very effective. But after dislocation density increases then we find that the dislocations move there are positions where the dislocations can come together. Now, it has become like they have become a couple dislocation.

Now, the stress which will be required is to make this couple itself to move. This sort of situation when it happens when you have a positive dislocation and (Refer Time: 24:50) dislocations on two different lines join together like this, you know what it is called this called as dislocation dipoles, and this dipoles has to move together. What is a dipole, dipole is nothing but yes dislocation with the same sense vector, but burgers vectors different. And if they are on the slip plane, now they cannot come and join together at room temperature, but the minimum energy configuration is in this position. So, it has to move like this. This is over dislocation dipole will form during deformation, this is considering at room temperature.

Now, let us consider the high temperature case, what will happen at a high temperature. At high temperature, you have to consider this force F y which is going to act, because F y is the force which is acting between the dislocations that component because any direction the net force is going to be always between these dislocations in this direction. But this we are splitting it up into a component which is F y and a component which is F x; at room temperature F x is the only component which is important because not that its location. If it has to climb the vacancies have to be generated, and the vacancies have to be move by are the vacancy should refuse it to climb up or down.

So, when the temperatures where the vacancy movement becomes important then what will happen if you have lot of dislocations which are present in the material and that dislocations are randomly distributed like this, and the some dislocations maybe like this. So, this dislocation and this dislocation two different planes let us consider this case between this one and this particular one. Because of the force glide force, which is going to be there these two come at a particular position that is the minimum energy configuration, which it will reach. Then the climb force can make the dislocation emitting vacancies are absorbing vacancies to climb up and then these two can come together and cancel each other correct. So, this is what it will happen between dislocations with the positive and negative burgers vectors.

Let us take the case, what is the situation in which this sort of phenomena can occur, this sort of a process can occur is suppose I have a sample, which I have deformed at room temperature cold work sample. And as you know the cold work sample the hardness is very high. Now, I wanted to reduce the hardness for which I take it temperature close to 0.5 tm annihilate it, then these dislocations will start moving and rearranging themselves. So, in that processes all the positive and negative the dislocation because the number need not be that same the density of the dislocations with positive burgers vectors and negative burgers victor need not be the same, but they will be moving and canceling each other.

Then if they annihilated and annihilate by this process and they are removed, but what about these dislocations with only edge character which are going to be present that is the dislocations with not edge, edge or screw, but with the same burgers vector direction they are going to be present. We assume that only this sort of dislocation will be present like this, randomly distributed now because the other dislocations positive and negative in this case have annihilated. Now, in this particular case, how will this dislocation interact? The force is going to be essentially a repulsive force correct. So, this repulsive force if we try to look into this expression, this gives what is going to be the force between the dislocations. When they are above each other this term the x term is going to be 0. This will reach a value of a minimum value, repulsive.

But, then what will happen is that here that force in f direction that is going that component is going to be 0, when they are above each other. Now, these dislocations will try to arrange themselves into one on top of the other, this we call it as a polygonization phenomena, you might have studied this is what a polygonization is that is dislocations move and arrange themselves on top of it essentially this creates what we call it as a small angle boundary.

So, if the dislocations are randomly distributed, the forces between the dislocation is going to be high. If they arranged in this sort of a configuration, the forces between the dislocations is reduce considerably, this is a more stable configuration, this is how during recovery process lot of small angle boundaries are generated in the material. And then dislocations with positive and negative burgers vectors, they climb up that process also will take place. In addition to it, as we have seen they are attracted to each other also, both these processes will lead to the annihilation of dislocations with the positive and negative sense. Often that either for screw are for h dislocation that is the forces between dislocations which are of either edge character or screw character, but they are parallel to each other.

That is another case which we can consider is suppose it is the same dislocation this is how this dislocation is there. And there is going to be another dislocation which is being present somewhere else here. We assume that there is a dislocation which is there, this is a burgers vector in this is in this direction, here burgers vector in this direction line direction remains the same for more both them, but one is in this slip plane another is in another slip plane right correct. There is this dislocation has got a burgers vector in this direction, this dislocation dislocate burgers vectors this location. So burgers vectors are perpendicular to each other the line directions are the same, but these two dislocations there is neither attraction nor repulsive forces will a come between them.

If you look at this expression this is for an edge dislocation correct. And if the dislocation that the origin turns out to be yes screw dislocation, this stress does not general this stress internal stress not this stress it will generate. So, because of that the force between the dislocations just you say just 0, it does not matter. Whereas, dislocations whether it is screw or edge dislocations, the same type of dislocation that is what we talked about so far each with respect to if these are all are edge dislocations, but one with a positive burgers vector and another with a negative burgers vector. This is how they will try to annihilate each other, the same thing will happen first screw dislocations as well.

So, these the expressions give us a quantitative way of finding out what is the sort of forces which will be acting between two types of a dislocations. In fact, here we have considered only dislocations, which are parallel to each other. It can so happen that we can have a one dislocation is lying like this, there is an another dislocation which in this way also dislocation could be there, they could be edge or there could be a screw character. There are various ways in which the dislocations will be lying with respect to one other than in real materials, when they are being deformed.

Using these expressions, we have only just looked at between parallel edge dislocations of parallel screw dislocations, but with the parallel dislocation with the one edge component for one that burgers vector is in one direction a line directions are parallel, but for an another h dislocation the burgers vector of both of them are perpendicular to each other. There are so many cases, which we can consider all these things have to be considered in real systems to find out the sort of forces, which will be acting between them. And these are all the forces which are going to decide what sort of micro structure which will evolve in the materials when the process of recovery takes place or when we do an annealing of a material that will also tell how the hardness is going to change or how the strength is going to change correct. So, this information is very much necessary.

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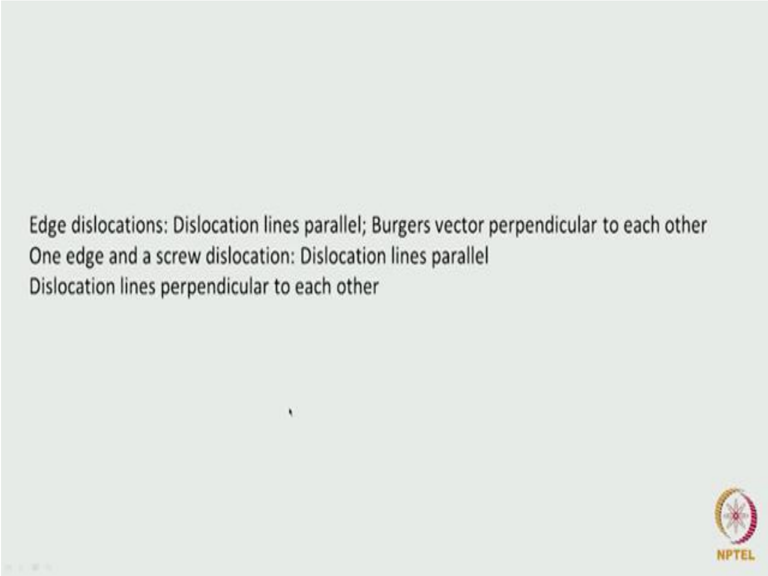

Essentially what we have looked at it is that forces between dislocations we have considered qualitatively as well as how to quantify these forces. What is the effect of these force on real examples of when we do recovery of that is deformed samples when we try to anneal them. What is the way in which the dislocations annihilate each other, and how different cells or small angle boundaries they are forming in the material that is what we have looked at it.

In the next class, what we will try to consider it in that we so far concerned about the high temperature, but about the high temperature process, we mentioned that the dislocation climbs up and then annihilate what the force. But we did not talk about what will be there effect of the consequence of climb on a concentration of vacancies in the material, what will be the effect of this vacancies on forces which it will generate. These aspects, we will look at the next class. We will stop here now.