Advanced Ceramics for Strategic Applications

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Lecture - 9
Dislocation

We have been discussing about the imperfect and crystalline solids, last time we were primarily concentrating on the point defects, that is the defect, which is restricted to a particular lattice site. And for example, there may be vacancies, there maybe interstitial or some foreign atoms, substituting the original metallic for metallic ions or oxygen ions and so on; so those are called zero dimensional defects. There are also other variety of defects, either they were one-dimensional, two-dimensional, and at times three-dimensional as well.

So, today's topic is one dimensional defect, and that is called also Dislocations. So, our topic today is dislocation, while point defects we which we have discussed last time, primarily affects the properties of solids or properties of materials such as electrical properties, optical properties and also mass transport properties like diffusion and so on. Dislocations are more important to investigate or to understand the mechanical properties or mechanical behavior of the crystalline solids.

Now, they were primarily discussed or researched on the area sorry area of metals and alloys, where there is a considerable amount of plastic deformation. We will try to understand, what is plastic deformation? However, in ceramics their importance is relatively less, but even then as ceramics being a part of material science, there is always a comparison with other kind of materials. And therefore, it is necessary for even for this ceramics to understand, what is dislocation and how it is important for the mechanical, the formation of crystalline solids?

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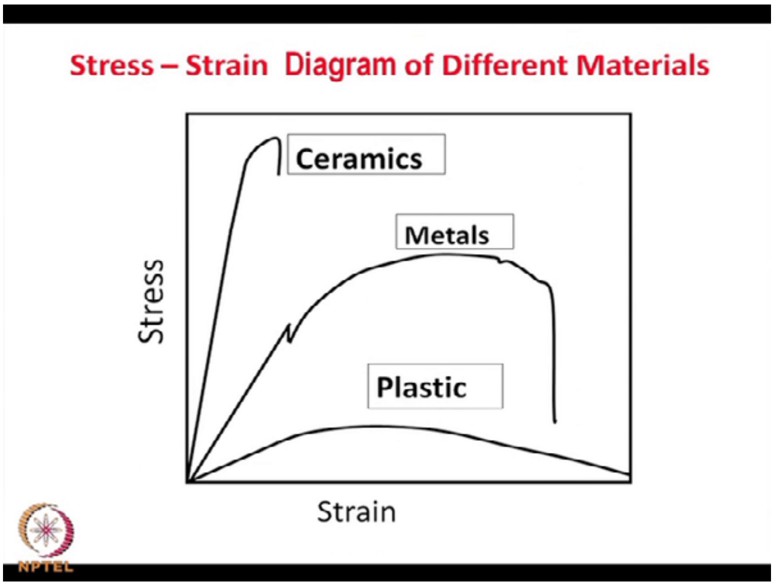

To start with, I like to compare the stress strain diagram, which is one of the very key features of the mechanical behavior for all solids, of three different groups of materials. One is of course ceramics, the other is a metal and the third one is plastic. And they have distinctly different mechanical behavior. To start with plastic, as you can see, what we have brought here is basically strain, and strain means deformation, the extent of the deformation, and then against a mechanical stress.

So, on apply a mechanical stress, any material there is a deformation; and deformation means, there is a change in the atomic dimensions, not the atomic dimension, the inter atomic distance. And of course, it depends on the nature of the bond and nature of the inter atomic forces; so, in plastic being a very soft material, it can be extended at a very low pressure or a low stress, mechanical stress over a long distance.

That means, a very large strain can be produced is small amount of mechanical stress whereas, metals is in between and it needs larger stress to attend the same amount of strain. Whereas ceramics, which is known to be a brittle material, it needs much larger stress, much larger stress even for a small amount of strain. Now, this strain in any material there are two kinds of strain; one is what we call the elastic strain, the straight line portion of the cord is elastic strain, this strain or if you apply the stress up to this point, then there is a reversal that means, it springs back to its original size as soon as the stress is released or stress is removed.

Same case, the same situation happens in case of metal solids, this is up to this point, it is a what you call a elastic behavior. That means, as long as the stress is there, you have a deformation; and if the stress is released or removed, there it comes back its original size or (()).

So, this is what we call a elastic deformation or elastic range and in this, the stress is proportional to strain; stress is proportional directly proportional to strain, and that is the basic rule of or law of Young Hook's law. So, Hook's law applies, when there is a elastic strain and the ratio of the stress to strain is the Young's modulus. So, that is the simple concept of Young's modulus for any material.

And if we are comparing the ceramics material, you can see from this diagram, you need a much larger stress to attend a very small strength and of course, the Hooks' law applies almost up to the end of the curve. So, there is the elastic range is very large whereas, beyond that beyond the elastic range or what we call the in stress, particularly for metals. This the this part of the diagram, either in case of metals or in case of plastic, it is called the plastic deformation, that is the irreversible kind of the deformation.

So, if the stress is beyond this elastic limit, then there is a irreversible deformation or the permanent deformation. And if you remove the stress, that permanent deformation is retained, only a small fraction of the deformation gets released or comes small passing deformation recover and that is the elastic part. So, any deformation or the material consist of two parts, one is elastic deformation and other is a plastic deformation, and the characteristics of ceramics is that, the elastic parts, elastic stress, the elastic component is much larger.

And it needs high stress to generated small strain and therefore, as the stress strain (( )) Young's modulus, Young's modulus of ceramic in general, are much higher much much larger than even for metals. But, the plastic deformation is almost very negligible so it breaks, this downward line is basically, actually breaking lines or breaking points. So, after certain deformation, plastic deformation very small amount of plastic deformation almost negligible plastic deformation, ceramics brakes.

Whereas, metals takes a lot of plastic deformation or permanent deformation before it breaks and if plastic of course, most of the time it takes lot of strain, even at lot of stress and sometimes breaks and sometimes it comes back (( )) in the material. So, our point of concern here, is the plastic deformation range, how this plastic deformation takes place. Because there is a breakedge of bonds and are the bonds length maybe increase and then, it is a permanent increase, it does not come back even if you remove the stress.

So, you understand there is some phenomenon, which is taken place at the structural level, at the atomistic level. So, let us try to understand, what actually happens at the atomistic level, when there is a plastic deformation, where considerable amount of plastic deformation.

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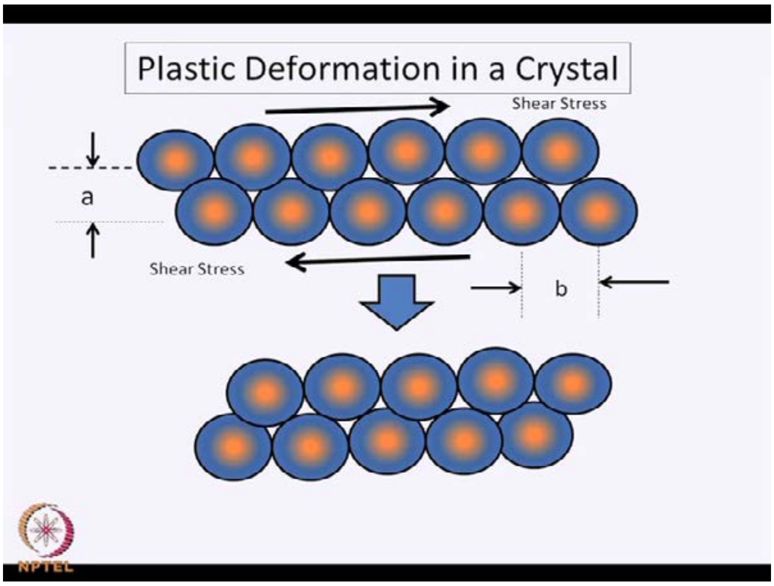

Where before that, let us try to understand, can we make a theoretical calculation of, how much stress, external stress is needed to make a or generate a strain. Strain is nothing but, a moment of atoms, moment of relative moments of the different layers of the atoms. So, the in the atomistic level we can visualize in this manner, if this is two different layers of the atoms, both are in the close packed position, this is first layer and this is the second layer.

So, we apply a shear stress, the lower end we apply a stress in this direction and upper end, on the upper side we are applying the stress on this direction. So, it is a kind of normal stress, it is a shear stress so, we are trying to slight down slight upper layer of the atoms over the lower level of atoms, bottom layer of atoms. And distance here, these are the some kind of interatomic spacing on this side is a and this side is b. So, once it is time to deform your applying stress so this atom will try to move to the next atom and this will go to next atom so on.

So, this is the deform position, this is the arrangement when one interatomic spacing has been def has been moved of the first layer, of the top layer has moved by one interatomic spacings. Now, during this moment one thing has happened, because this is not a since it is a spherical surface, that is the consideration, that is a (( )) assumption. So far, as the atoms are concern the size or the shape of the atoms are concerned so, there is a, there is a hill, over which the atom has to move.

So, initially it is sitting on a trough , here the sitting on a trough and then, when a train to move to the next trough , then it is going through a hell. So, there it has to move up and then come to the next trough so, initially there is a increasing stress, you need more and more stress as you go up the hill, when you coming to the down the hill, then of course, you need less stress.

So, you do not need a uniform stress to make a deformation to deformation in that crystal, our relative moment of the two layers, you do not need always uniform stress, you initially need a increasing stress and then, the stress comes down as it it goes over the hill. So, as the top point is reached the maximum of the stress, is reached and then, you need less amount of stress to remove for further movement. So, as a result you can plot the stress variation of stress as a function of the distance, interatomic spacing.

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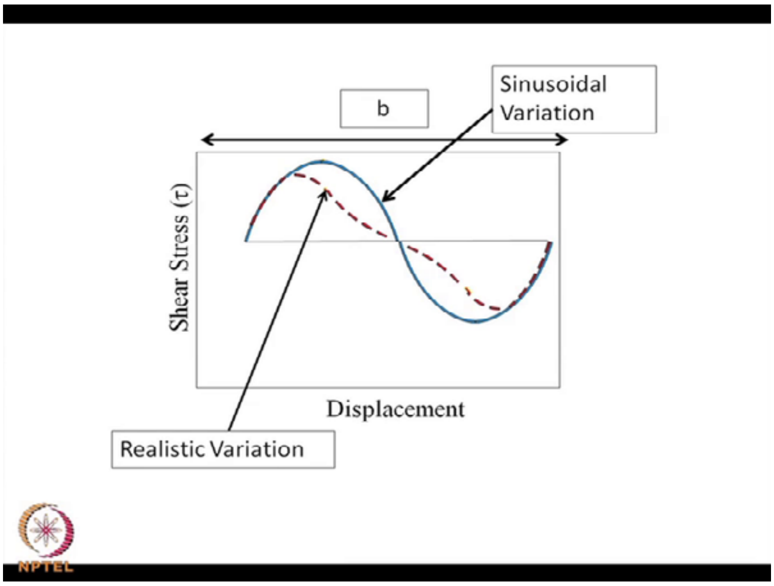

So, that is plotted in the next picture, in the next slide this is basically a sinusoidal cord so, on this side vertical axis is stress and horizontal axis is displacement. So, this is your b, total distance is b interatomic spacing so, we have the maximum stress is needed here, and then it goes down and then again on the other side, you need a lower stress so, it is an negative stress actually.

So, actually you follow this kind of a variably pattern of stress, it is not a uniform stress is needed for the moment. So, it is basically one can assume, one can assume a sinusoidal variation it is and as a function of displacement. So, one can calculate, what is the maximum stress needed for this relativitive displacement impacked, although we can idealize situation is a sinusoidal cord like this.

But in real pattern, real sense, this varies like this, the dotted according to the dotted line but, we (()) for our calculation we assume that, it is as a sinusoidal sinusoidal variation.

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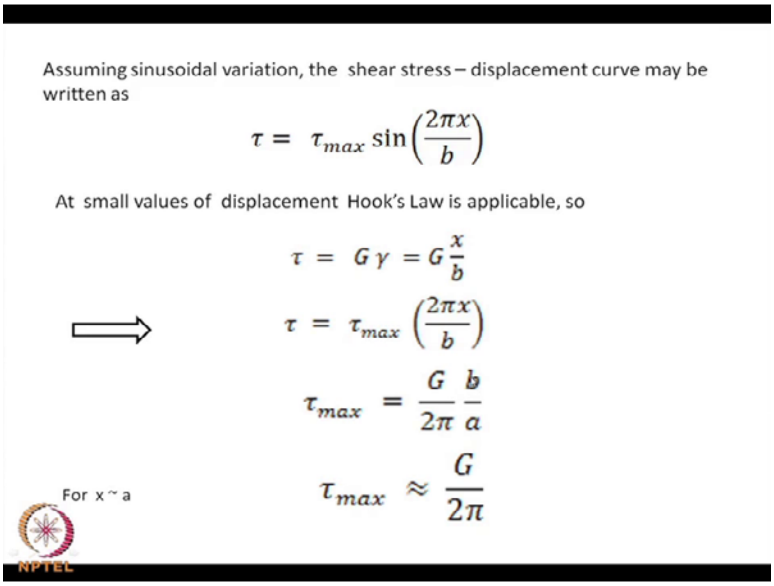

If that the case, one can really find out what is the maximum stress, shear stress needed for this displacement or this deformation. As soon as sinusoidal variation, the shear stress has the displacement called, may be written in this passion tau equal to tau max, that is the maximum stress needed, sine of 2 pi x by b. X is the distance at any point of, at any stedge or the total displacement at any stage. A small values of displacement because, we are talking about very small values hooks law can be applied.

And the stress or one can write tau is equal to G, G is the shear modulus, shear modulus of the material, we are considering and x by b is the strength. So, it is the shear stress into shear strain so, tau is this the stress equal to shear shear shear modulus into the strain. And if u apply that to this equation, then tau becomes tau max 2 pi x once again, it is an approximation.

So, 2 pi x by b and then, from that one can find tau max equal to G by 2 pi b by a, and if x is almost equal to a, then tau max becomes G by 2 pi. So, if know the shear modulus, then we can also find out, what is the maximum shear stress needed for the deformation to take place. And that is a really simple calculation and of course, that is approximate calculation it is not a very accurate calculation, it is a just kind of an order and magnitude calculation.

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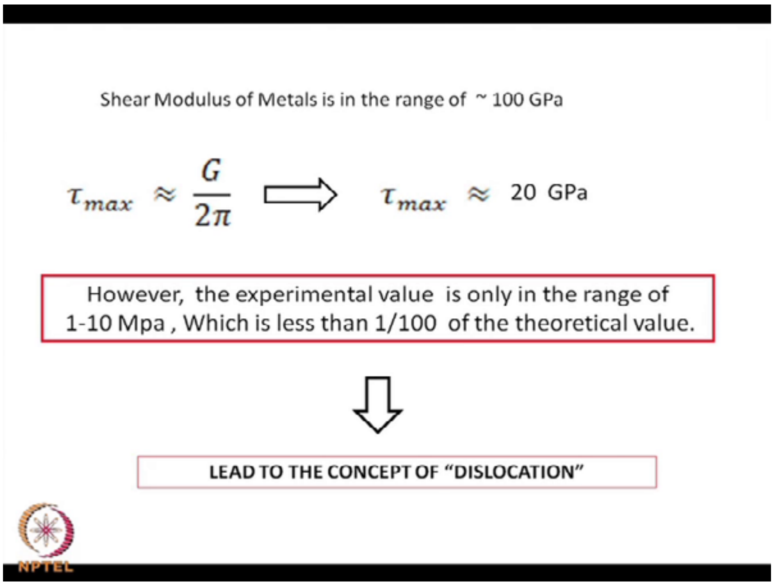

So, shear modulus of metals are in the range of 100 GPa and if u use that value, the tau max is of the order of 20 GPa. It comes to about that value however, the experimental value this is a kind of theoretical value, from the structure point of view, from the atomic structure point of view. However, if you experimental try to find out, what is the value of tau max or what is the shear stress needed for the deformation maximum shear stress needed for deformation, we find it is much much less.

It is about 100 of what is expected of a theoretical value, and that was quite disturbing for the scientist, we have been working on this in this area and then, they come out with what a concept of dislocation. So, if there is a crystal and defects of certain kind then, it can be shown that, we need much lower stress for plastic deformation than what is expected from theoretical calculation.

So, it is if it is a perfect crystal then that value is of course true but, if it is not a perfect crystal, if it is a imperfect crystal and the imperfect sensor of one kind and one what is called the dislocations. So, by introducing the concept of the dislocation, one can realistically find out what is the actual stress required for deform plastic deformation.

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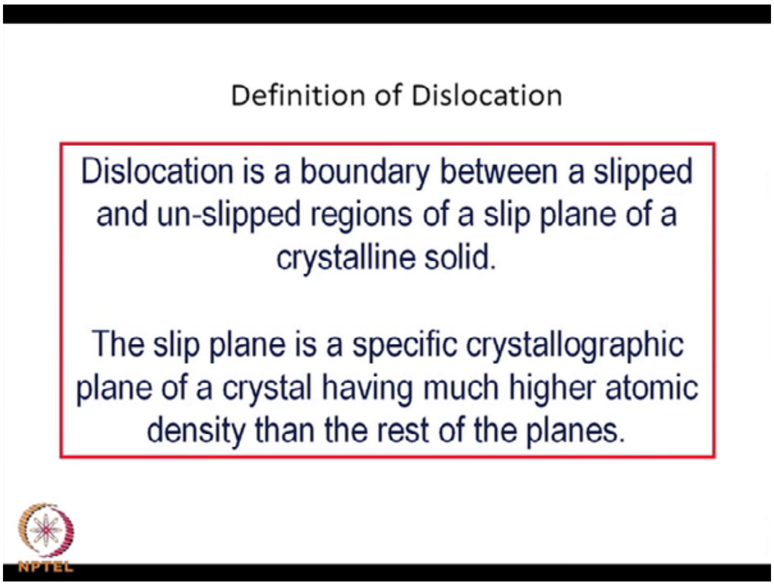

So, in this background that is go back and see, what is exactly a dislocation and why it needs lower stress for deformation. Now, as per deform definition, dislocation is a boundary between a slipped and un-slipped regions of on a on a slip plane, to regions of a slip plane you can say also, slip plane of a crystalline solid. So, a plane is deformed and that is partly is deformed and partly is not deformed, or partly there is a movement of the atoms and on another part there is no movement of the atoms so, that is the boundary.

So, there will be a boundary and the boundary because, it is on plane what you called the slip plane. Because, it is on plane and the boundary becomes a line, is a intersection of two different intersecting planes and that becomes a line, and that is why dislocation is basically a line. A slip plane is a specific crystallographic plane of a crystal, having much higher atomic density than the rest of the planes.

Now, we will at this stedge we will look at, we will look back our concept of crystal structure and atomic arrangement to define what is a slip plane. And we have not discussed much about the crystallography of atomic structures but, at this stedge to understand the dislocation, let us try to look at little bit carefully, what is a crystallographic plane and what is a slip plane.

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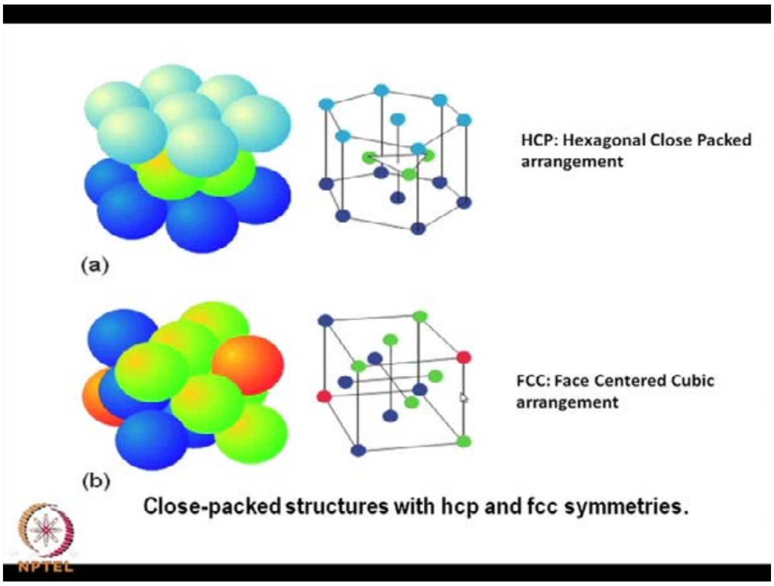

Impacked and coming back to their basics of the crystal structure, atomic arrangement, these are the two structures, which we have discussed earlier. One is so called the HCP structure, hexagonal close packed structure and the FCC structure, face centered cubic structure. Both of them are close packed close packed structure that is the maximum packing what we can achieve with the solids spheres or the sphere atoms of the spherical nature.

This is one can remember that, this is actually what we call the a b a a b a b packing are this is a plane, this is b plane and that is the again a plane. Whereas in FCC, this is a plane, this is b plane, this is c plane and then, again that is a plane. Now if you do if you can notice properly you will find that, the planes we can consider the planes, planes are nothing but an arrangement of atoms on a on a imaginary plane so, these planes are always imaginary and it is the atoms, which are real.

So, atoms the (( )) atoms are arranged we have some points here and we can draw some geometric pattern and from that, we can make some planes. We can imagine there many

many different planes, one can imagine from this diagram for example, we have to imagine a cube here or you have to imagine a hexagon right. And so, hexagon has many different planes some horizontally planes and also some vertical planes so, this a vertical plane, this is another vertical plane and so on where as, this plane is a horizontal plane.

So, this plane contains some number of atoms, in this case one can see 7 atoms around the top plane, 7 atoms black ones are also in the bottom plane and in between, there are 3 atoms, 3 atoms forms a plane. So, there are horizontal planes, there are vertical planes and they one can imagine also incline planes, incline the different angles. For example, here in cubic face center, you have the close packed planes are not actually horizontal planes, horizontal planes are not the close packed planes.

Here for example, the top surface of the cube have only 5 atoms and that not they are not close packed arrangement. Close packed arrangement is a diagonal plane, the green ones is actually the close packed layer. So, it is a diagonal plane and if you refer to this particular diagram cubic diagram cubic arrangement, you will see this diagonal and then this diagonal, if it is connected to this corner so, you have this diagonal plane is actually the close packed plane.

So, there will be another diagonal plane, which is from this the blue ones, the blue ones forms another diagonal planes. So, there are two parallel diagonal planes, which are actually close packed planes, whereas the faces are not close packed. They close packed in the sense, the what is the atomic pattern atomic, how many number of atoms are there for unit area of that particular surface, that is what we called the atomic packing so, in a close packed plane the atomic packing is maximum.

So, more number of atoms are there and there obviously, the distance of separation will be the least. Whereas, in open plane, open structure plane, the number of atoms will be less so, the average distance of separation will be large. So, normally it is the close packed plane, which are the slip planes that means, on edge the atoms can move on that particular plane, one atom can go to the other atom, other atomic site, other lattice site without much difficulty.

Because, it has to trouble less distance to goes to the next equilibrium site so, slip planes defined actually as the closest packing planes and depending on the structure, they may be different. And there be number of a sets of slip planes in a particular crystal structure for example, here in hexagonal structure all the horizontal planes all the horizontal planes are slip planes. An horizontal planes are close packed planes, whereas the particle ones are not the close packed ones, particle are open.

And therefore, if the atom has to go to its next equilibrium site for example, this one it has to go to next equilibrium site vertically it has to move this much. Whereas in the horizontal plane, if the atom is go to the next equilibrium site, which is this one so, the distance of separation in much less. So, it is easier for the atoms to move on the close packed planes than on the opens plane open planes on their, other then close packed planes.

So, that is the importance of slip planes, when you are talking about the movement of the atoms, movement of the atoms for that you need always to know, what is the slip plane and which direction. There is not only the direction not only the plane, but also we have a concept of close packed direction. So, in that around the direction the distance of separation between the (()) atoms at the lowest and so, the distance of the sub distance to be travelled is also less.

So, you need less energy for that movement of movement of the atoms along the close packed direction or on the close packed plane so, that is the concept of the slip plane. So, there are many system of slip plane in many crystals, depending on the crystal structure what we have discussed earlier. We have different sets of close packed plane or which have which may have or close packed directions, we have also discuss that all structures are not close packed, there are open structure are also.

But, they do have slip plane and that is why, whatever the plane has the largest atomic density, that will be called the slip plane. It may not be fully close packed plane but, the even in the open structure the highest atomic density planes can be called as a slip plane. Because, that is the plane on which minimum number of or minimum distance has to be travelled for the movement to take place.

So, that is our concept of slip plane, as you are discussed earlier or even the description, now coming back to the description to dislocation or definition of dislocation, dislocation is a boundary between slipped and un-slipped regions. There will be always slipped and un-slipped regions because, we are talking about deformations and that slip slippings is taking place on the slip plane. So, this is we have discuss the slip plane is a specific crystallographic plane on a crystal of crystal, having much higher atomic density than the rest of the planes.

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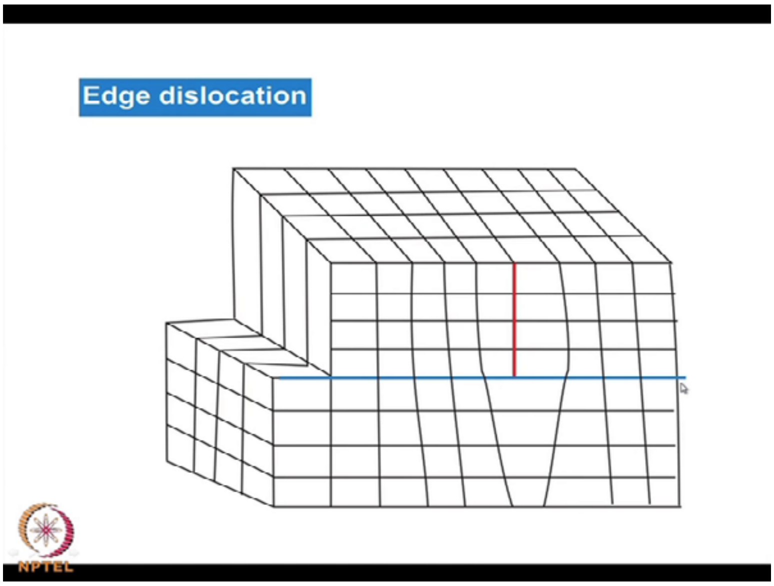

With this background, let us tryout see what is actually a dislocation dislocation when because, it is a related to the deformation of the crystal, it is a plastic also, the plastic deformation. So, it is a permanent deformation, where the dislocations are coming up, for the elastic deformation, where there is no permanent deformation. There is no question of dislocations to be formed or dislocation are not needed this concept of the dislocation is irrelevant there, whereas only for the plastic deformation part, the concept of dislocation is a very, very important. Now let us see, this is a volume of a crystal and these grid lines; these grid lines are actually the planes, the planes of the atoms. So, on those intersection of the grid lines there are atoms, at each intersection there is an atom. So, we have a horizontal plane, a large number of horizontal planes and then, we have also a large number of vertical planes, on which the atoms are residing.

Now, in this let us see that, we are trying to deform this system ideally, what will happen the way we have discussed earlier. Here, we are align or either applying a stress on the top of this crystal, where along a stress in the right direction, the forward direction whereas, in the bottom up along a stress in the backward or the from right to left. So, this is trying to slip in this direction and on the bottom the top up is trying to slip in this direction.

So, that is how we have apply the pressure, normally, if there is no defect in this, what would happen, there will be a cooperative movement or simultaneously along this plane, along this middle plane along this middle plane. All the atoms above this plane will try to move in the right direction and all the atoms in the bottom of the that plane will try to move in the left direction towards left. Now, if we if we see that there is a cooperative movement that completely all of them are moving simultaneously, then we need a very higher stress, that is what the theoretical stress we calculated.

So, if all the atoms on that plane moving simultaneously, then you need much higher stress, instead if you assume a some kind of a different configuration for example like this, you see at this stage intermediate situation, when there is a no (()) has been formed here. All of them are still intact, the atomic positions have not changed here, they remains more or less the same. It might be experiencing some stress but, it has not (( )) whereas, on this side this atom which was here start with, it has moved 1 at interatomic distance.

So, there is a movement of each of these atoms, which was originally on this age, has moved one interatomic distance whereas, on the right side there is still no movement. So, there is a boundary there is a boundary, where the atoms has moved and rest of the atoms are still intact, where it was originally situated. So, referent to the diagram once again, this there is a boundary here, on this side you can see there is little bit of deformation.

This is one plane this is, which has a vertical plane and because of this application of the stress, there has been a movement, there has been shift of the atoms. And this, on the right side there is no shift but, the left side all these atoms have been shifted one interatomic distance. And as a consequence of that, there is one extra plane, which extra plane of atoms which is coming up, which is forming a kind of boundary which is forming a kind of boundary on the left part of that, the atoms have been shifted or the deformation has taken place on the right that that no still there is no deformation.

And so, there is a boundary between the slipped region on left and un-slipped region on the right so, that is what it refers to. So, this is an extra edge of plane edge of atoms, which is called an extra plane right, this has been compressed, the top part have be compressed right, a bottom part has not been compressed. Then, we slight deformations because, there is a elastic deformation but, there is no plastic deformation so far.

If you will not placing this impact to the start with another thing we discuss, to start with, at the very first step, this dislocation would have been here, the extra edge would have been here. One step and as step by step moment is taking place, that extra edge is shifting from the left to the right slowly and more and more deformation is taking place. So, coming back to the diagram, you will see after some time this particular extra edge you will shift to the next point and then, to the next point and then, to the next.

And once that is there and then, it will go out which means, the whole of the top part has been shifted one atomic distance right to the right and the left part one atomic distance left. So far at this, this is a intermediate stage when there is no state has still been formed, that one state has been formed, here no state has still been formed. But, after some time if you continue to apply the stress, this extra edge will slowly move towards that and finally, go out.

So, there will be a state will form and it will come to an equilibrium side that means, the state will also be released, inside there will be no stress. As a result of that stress, a step physical deformation has taken place and a state has been formed. If you still continue to apply the stress, a more number of steps or the state distance will go out, will be will be increasing.

So finally, it may break, the whole of the top part will be slipped from the bottom bottom part and one can say it has been cracked here. So, this part and this part has been separated (()) but, before that there is an intermediate (()), there is a termination region, When there is a partly slipped and partly not slipped, partly deformed and partly not deformed so, this is what basically the concept of dislocation.

So, the dislocation is actually the intersection, intersection of this plane, this extra plane here and the slip plane. The slip plane is a horizontal plane here, the blue line that is the slip plane, on which the atoms are sleeping. On which in the sense, that is the intersection point, where the top atoms are moving and the bottom atoms are residing at their own sight or there is a relative displacement basically.

So, the dislocation is defined as yes boundary, this is the boundary on this diagram is actually the point, the line is on the is towards depth, along the depth depth of this crystal so, the line is away from us. So, that is the boundary that is the boundary the boundary between the extra edge of plane and the slip plane, the horizontal plane. Not the dislocation is not the extra plane, it is the boundary of the extra plane at the junction of the extra plane along with the with the horizontal plane, that is the slip plane.

So, again coming back to the definition, if you can go back to the definition, we say the dislocation is boundary between a slipped and an un-slipped regions of a slip plane of a crystalline solid right. So, the slip plane it is lying on the slip plane and it is a boundary between the slipped portion of that a, this is the slipped portion and right side the un-slipped portion.

So, that is how the dislocation the presence of dislocation has helped actually, presence of dislocation has helped the movement of the atoms, the movement of sliding down or sliding up and down sorry sliding up down, rightwards or leftwards are much easier, at much lower stress. So, this concept it is not a cooperative movement of all the atoms on a slip plane simultaneously but, a step by step movement.

So, one is moving to other and then, it is going to be next side, all of them are not moving cooperative, in a cooperative way, if that has to happen it would have been taken a much larger stress for deformation. So, the movement of this defect, what is called a line defect or dislocation, presence of a dislocation makes our life much easy or makes the material more plastic. It can be deformed at a lower stress, infact that is the advantedge so far as metals are concerned.

Metals that is toughness of the metals is very high because, it needs or it can accommodate lot of plastic deformation, this is a known advantages. If you want to, particularly for fabrication use everything whereas, ceramics that kind of deformation mechanism is not there. And therefore, it is plastic deformation if it is negligible and therefore, until and it is a very high temperature almost ready close to its melting point. So, there occurs there may be some concept of dislocation will be important. But, otherwise the first ceramics the plastic deformation is not there so, there is (()) dislocation movement.

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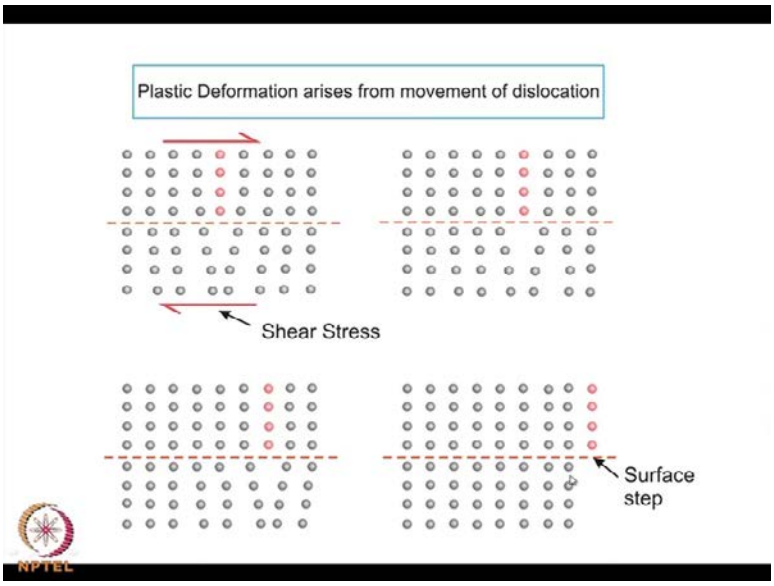

Infact, this is the next step another picture of the same thing, where not a having a isometric view it is only but, it is only a section of the particular plane. And one can see here, this is the dislocation the extra plane the extra plane, you are talking about so, once you have in extra plane over here, this is the dislocation. So, again dislocation here is a point, it is extending, extending perpendicular to the surface of the this (()).

So, these are all dislocations here, this another point what it is shown here is, as the dislocation is moving from left to right, it is you can see it is here it is move one distance one inter atomic distance, it is moved further and finally, it is formed a step. Step of the other side, it is started with the step that has not be shown here unfortunately. It is started on the step on this side or if dislocation is already there in the material, dislocation has not been created.

But dislocation for example, a (()) reason is already there in the inside the structure and if you sub apply stress like this, it will form dislocation, will move away from the interior of the material to the surface. And as soon as it comes to the surface it forms a step so, there is a deformation and that is what it shows, surface (()) formed when dislocation is moving.

So, the dislocation is not a stationary one, dislocation is moving for many it can be moved or it can be mobile for many different circumstances, particularly if you apply stress, it will start moving. If you apply temperature, increase the temperature dislocation may also start moving because, for different little different reason, it is for the term thermodynamic region. Dislocation because, there is a stress field around dislocation because, there is a extra, extra atoms has been accommodated, which was not suppose to be there.

And therefore, there is a internal stress generated, and that stress increases the internal energy of the system. So, if you apply temperature, there is activation energy you are supplying so, the stress like to be released So dislocation starts moving. And as a dislocation go out of this crystal, the stress is released because, at the expense of forming a step, at the expense of state in the sense, actually it is forming a deformation, it is generating a deformation, it resulting into a physical deformation. So, more and more physical deformation is taking place, dislocation density may go may be reduced.

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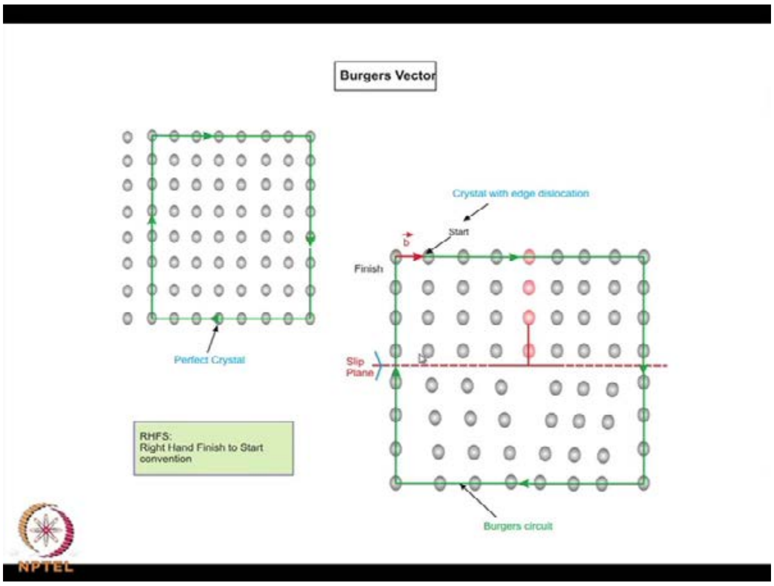

This there is another concept one has to remember what is called the Burgers vector, because there is movement there is a movement so vector is important in the it is in the particular direction. So movement is taking place in a particular detection; so, there is a vector atomic moments are taking place; so, if you have a extra edge of plane here, this is your dislocation. You can see this plane is slightly deformed and finally, away from dislocation, this is the dislocation point or dislocation line.

And around that, there is a lot of stress field because, atoms are stress back push back so, there is a enough energy generated over there. There is a compressive stress here and there is a tensile stress here because, we have a at a larger distance whether here it is a sorted distance than the equilibrium distance. So, you have an extra edge on the extra plane of atoms, on the top surface on one side of the slip plane well, red one is the slip plane.

So, there is extra edge over there and extra plane and here one less extra plane so, the movement of atoms are like this, this atom originally this second atom was originally at the first side and because of the application of stress, is moved to the second side. So, similarly this one was on this side and it has gone there, and the extra is there because this state is still not found. So, once this slowly goes on the right and goes to the surface it founds a step so, there is a extra number of one extra number of planes.

So, Burger's vector is this vector, that is the unit distance the unit distance in the direction of the movement of the dislocation on the slip plane ofcourse. The movement of the, what is the minimum distance of movement and which direction, that is what is the Burger's vector. So, and you can find out Burger's vector on simple way to identify what is Burger's vector, this we start from there where the state has been formed and then, go around dislocations equal number of atomic distance.

If you go 1 2 3 4 5 6 7 and then, you come to 7 on this side or less but, it has to crush this dislocation slip plane, come down the slip plane and then, again go in this direction same number of distances and finally, we will see where it has ended up here. So, you draw what is called the Burger's circuit around the dislocation point or the dislocation line impacted. So, you draw this Burger's vector draw this Burger's circuit taking equal steps in all the four directions and will find there is a gap formed.

And it has if we started with this point and you have ended up with this point and then, this distance becomes your Burger's vector. So, it is the units basically it is unit distance movement on the slip plane and in the direction of the movement of the dislocation because, that is the movement which has caused the formation of the dislocation.

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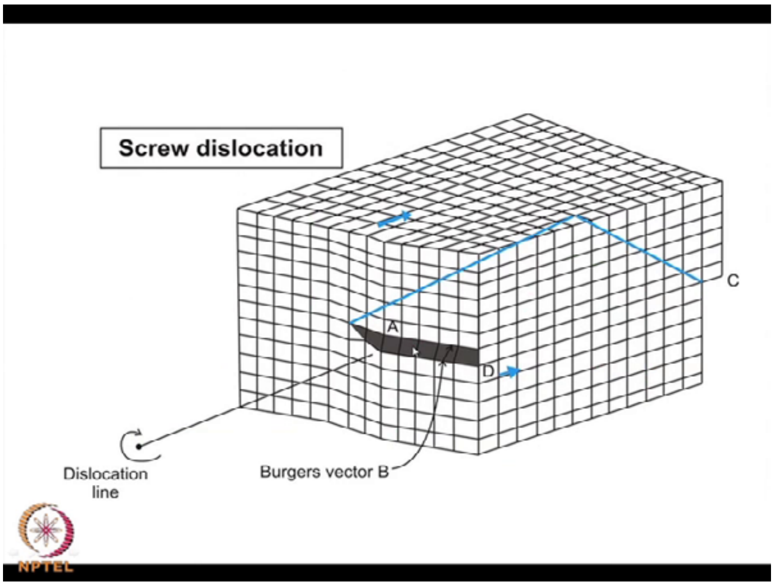

Now, dislocation as per definition, is the boundary of a slipped and un-slipped region and here we have seen they are there is a extra edge extra edge is formed here. Extra plane, which is the dislocation and this particular dislocation, this is one variety of dislocation. There is a second variety of dislocation also, we just discuss that, second variety of dislocation, this is called the first one what we have discussed so far. This called the edge dislocation this is called the edge dislocation, its forms the edge along the along the slip plane on the slip plane.

Whereas, there is a another variety same it also forms a deformation very similar nature but, the mechanism is slightly different. Mechanism is shown here, in this picture you can see these once again the total crystal and this grid lines, they are actual the atomic planes both horizontal planes and the vertical planes. You have also applied a stress from the left to right, this is the direction; that means, the top part is being tried to move in the right direction and the bottom part is being tried to move in the left direction.

But, there is slight difference slight difference between the earlier discussion or earlier diagram in this diagram, in the earlier diagram the top the whole of the top part was being tried to push to the right. Whereas, here the stress has been applied in such a way, that only the front portion is being tried to push in this direction not the total not the total of the crystal. So, the back part here there is no stress.

So, you are applying not an uniform stress across this plane but, you are applying a more intense stress on this portion, on front portion of the crystal whereas, there is no stress on this portion. So, we are trying to distinguish between two regions, one is the stress region here and the back side still not stressed. Under such situation what will happen, once again there will be once again there will be a boundary between slipped and un-slipped portion, this portion has slipped this portion has slipped whereas, this portion has not slipped.

So, the boundary is in a different direction so, the boundary is along the direction of application of the of the mechanical stress or shear stress. Already we have seen the boundary is perpendicular boundary is perpendicular to the direction of the slip or the direction of the application of the slip, the application of the stress. If you look back, this boundary is along is in the distance in the perpendicular distance compare to the direction of the applied stress.

So, the movement is taking place in this direction, from left to right and the dislocation boundary is from the front to the back. So, the dislocation line is perpendicular dislocation line is perpendicular to the application of the stress whereas, in the second case the dislocation line is parallel dislocation line is parallel to the direction of the application stress. So, here you can see applying stress is align in this direction, the boundary is also align the same direction because, the boundaries the un-slipped portion in the back and the front portion is the slip portion.

So, black part here is formation of a step and here, there also a (( )) value corresponding (( )) as already found. So, this part is the slipped portion and un-slipped portion is there and bottom is also un-slipped. So, the distance the boundary becomes in a different direction and this is called screw dislocation, the previous shown, the first one we have discussed called edge dislocation and this is called a screw dislocation.

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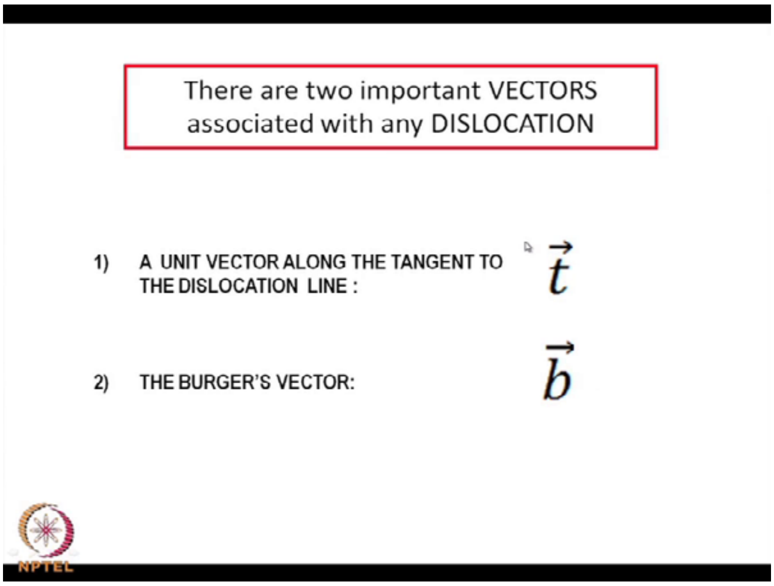

And the basic relationship, well there are two vectors; there are two important vectors associated with any dislocation; one is the unit vector along the tangent to the dislocation line or in the direction of the dislocation line. That means the slip direction, slip direction along the direction; no, it is not the slip direction, it is actually the Burger's vector slip direction. And the result of that slip is a line has been formed and this is the tangent to that line. So, these two vectors are important.

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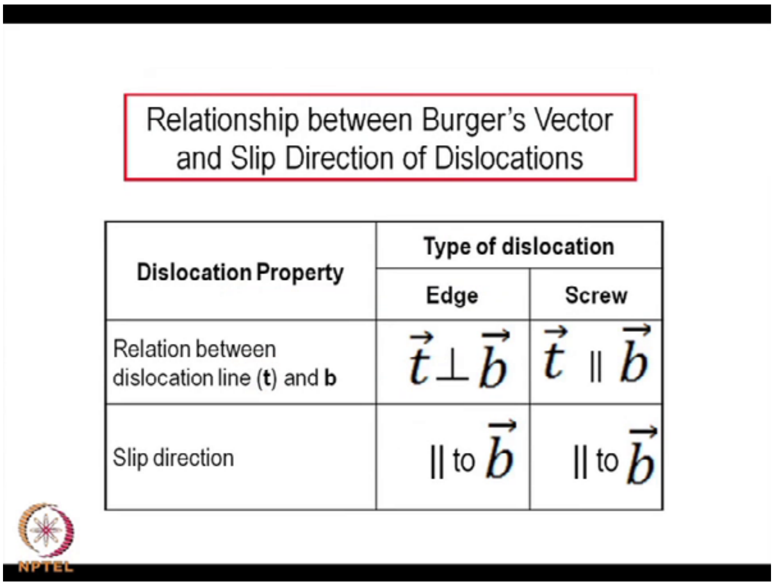

And in case of, I will come back to that the relationship between Burger's vector and slip direction of dislocations are, in case of edge dislocation the tangent vector is perpendicular to the b vector, the Burger's vector. Whereas, in the screw dislocation the tangent vector is parallel to the b vector but the slip direction slip direction always in the direction of the Burger's vector.

Because, the Burger's vector determines the direction of the slip, direction and the magnitude of the slip also, that is basically interatomic distance. So far, the magnitude is concerned, the direction can be at different directions depending on the application of the stress or kind of stress field is generating that.

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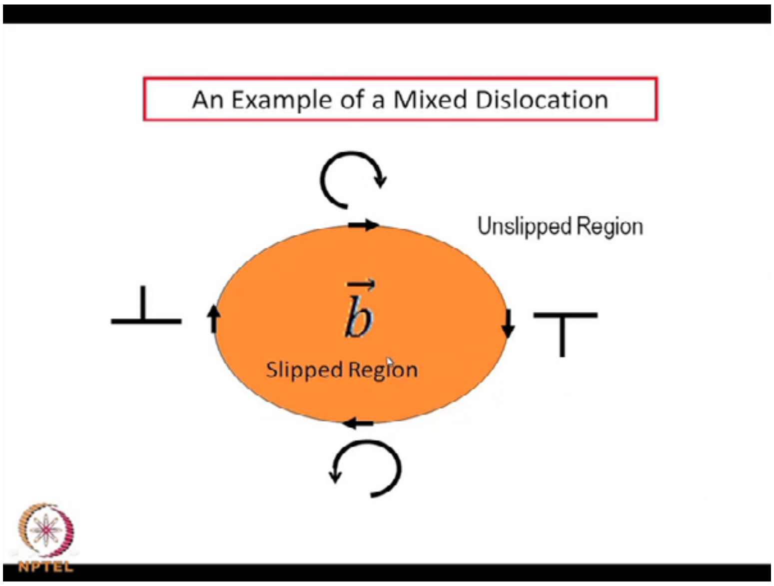

So, these are the two vectors which are important so far as the dislocation is concerned so, there are edge dislocation and then there are screw dislocations. However, these are the ideal cases, these are the ideal situations where, either the Burger's vector is parallel or perpendicular to the tangent vector but, in practice actually they are will be a mixed vector what is known as mixed vector right.

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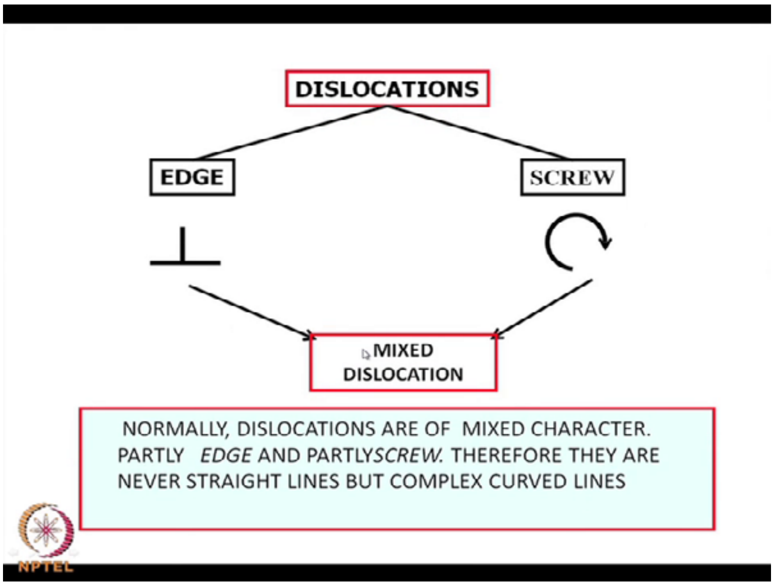

So, these are the two dislocations, nature of this one is edge dislocation it is represented by this symbol two lines joined perpendicularly because, the b vector, the Burger's vector is perpendicular to the t vector, the line vector of the dislocation. Whereas, in the screw dislocation it is parallel and it is represented in the form of a circle, half circle but, incomplete circle. Now, this there is an arrow there, there is an arrow there so, it is also represents a direction, in which direction the screw is moving.

However, we come to back, in most cases they are not ideal situations so, these lines are not either straight lines or whatever we have discussed. So far (()) dislocations are always straight lines, actually in practice, dislocations are not never straight lines, it is completely curved lines. And therefore, these curved lines has some component of edge dislocation is there, rest of the components may be a screw dislocation.

So, when we talk about the dislocation line, it is not always perfect screw dislocation or a perfect edge dislocation, there may be composed of many combination of edge and screw dislocations. And therefore, they becomes very curved lines so, normally dislocations are of mixed character, partly edge and partly screw and therefore, they are never straight lines,, but complex curved lines.

So, one can distinguish dislocation, one can series dislocation under electron microscope under electron microscope because, they are stress fields they generate stress fields around the dislocations, and dislocations that also associated (( )) energy, I am not going to the details of that. But, because of the energy, because of the stress field there, electron beams will be observed there so, we have lesser transparency.

So, as a result you can distinguish between a dislocation line and why dislocation lines are not there. So, dislocation lines are do appear in an electron microscope in the form of complex curves of different discuss lines. So, that is the dislocation, we will see this is a example of a mixed dislocation, instead of a straight line we have a circle or a electrical line. So, this is the middle portion is a slipped region and this is un-slipped region or (( )) depending on where the stress is.

If the b vector is in this direction then, on this you have the slip direction is here, the dislocation line is in this direction and you have so called t joined or t symbol here and this is reverse t in fact, this is reverse t and this is actual t. So, the directions are different because, the tangent to this line is different, the vector t vector is different, b vector is all are in this direction. But t vector may be in this direction or in this direction or in this direction or in this direction or in this direction.

So, for these two b vector is parallel to t vector but in different directions so, this is a clockwise rotation and this is a anticlockwise rotation. So, that is also important how it can be denoted and then, here you have a reverse edge dislocation and a normal edge dislocation. So, these are ultimately this becomes your dislocation line so, this is the boundary and this is the line, what you see may be under electron microscope. So, that is all for this time being and we have some more discussion, may be in next class we will discuss that.

Thank you.