Mechanical Behaviour of Materials - 1
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Lecture – 24
Steps in Dislocations

Welcome back students. So, today we will talk about another interesting aspect related to dislocation motion. So, we now know that plastic deformation in a material takes place by generation and motion of dislocations because we showed at the very beginning that if we were to assume that the whole plane shear that would require a much larger stress and the stress observed is orders of magnitude smaller.

And hence it was theorized that there must be something like dislocations, which were later proved to be indeed true. Now, what we will show is that even our understanding that the whole row of atoms will move at a time is incorrect and what happens is that these dislocations move in steps and the steps become larger and larger and encompasses the overall length of the dislocation.

And in fact, that is also how it is able to accommodate a dislocation, which is not a straight line because ideally, we were showing the theoretical ideal dislocation would be straight line, but a real dislocation is always a mixed dislocation, which has curvature and all. So, that kind of concept does not hold for such kind of mixed dislocation or curve dislocation, and it will be possible only if we have steps taking causing the movement of the dislocations. So, let us begin.

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So, let us say that we have a plane like this, and it can have dislocation on the bottom side, it is not coming out straight line. So, let me draw it again, it is like this, or it is like this and if you are applying a shear stress on the plane which is like this, then this dislocation would like to move in this direction and this dislocation would like to move in this direction. So, our initial understanding would have said that this whole dislocation would move from here to over here like this or this one would move from here to over here.

However, now what we are saying is that is not the case, what will happen would be something more like this. So, if we have this negative dislocation and it must move it will move more in steps like this, so it will have a step formation, in fact it can be a much smaller step than this. Similarly, if we are talking about the positive Burgers vector dislocation, it is moving like this, it will form steps.

So, this is the step that is getting formed and in fact after some time it will look not like one step but it may have very varied shape. So, what we are saying is that these kinds of steps may form which expands, so this one moves in these directions at a very high speed and therefore the whole thing can move. But even then, it is not that it must go all the way to the end. In this case, these steps are moving.

These steps that have formed will move over here and this one will move in this direction and over a long length of time you may see something like this. And here these steps are called kinks. So, here what we have is one kink that has formed, here is another kink that has formed, and the kinks move away from each other which result in the overall translation of the dislocation.

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So, the important points that we gather like this process of the dislocation glide takes place in steps and these steps are called kinks. These kinks then move across laterally which result in average displacement of dislocations. So, overall, what we understand is that kinks lead to the glide of dislocations, which lead to the overall deformation or in other words earlier we thought that this deformation is taking place by the sharing of the whole plane.

Then we said no it is the glide of the dislocation and now we are saying that again glide is taking place by the help of kinks, small steps in the dislocations. And here is again another video which will help you understand the glide and if you look at it closely you would realize that indeed there must be steps getting formed because it does not look like the whole dislocation is moving at one step.

And this is again given by Josh Kacher group, this particular dislocation video which is actually obtained from in-situ TEM. **(Video Starts: 07:32) (Video Ends: 07:50)**.

So, clearly what you see in the video is that it is not that the dislocation moves just one place ahead as a whole piece and its movement clearly look like there are certain regions which are moving first and other regions follow and how is this happening it is happening because of the kinks.

So, the kinks form and it very quickly at very large speed they move across and cause the overall displacement of the dislocation and that is why we get that feel that some regions move first and then the rest of the regions follow.

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So, here is a schematic which to show more clearly how kink in a dislocation would look like and this will also help you identify what are the characters meaning edge character or screw character of these dislocations, the steps that are forming over there. So, since this is an edge dislocation, so it is like this over here and let me use a different colour so that it is visible now.

Since this is edge dislocation, so we know that the Burgers vector must be like this which has to be perpendicular to the line vector. And now this step that has formed at least here that we have shown at the very atomistic level it must be at 90 degrees to this which would mean that this section M has to be parallel to Burgers vector. The L is our original dislocation line. So, for this the line vector is same as that for the original distribution which would be perpendicular to b.

And now here N is the new place where the part of the dislocation has moved and therefore it would also have same line dislocation as that of the L Section, L and L must be parallel and then we have not written explicitly here let us call this section O, this section would be same as M. So, overall if you look at the L, M and N, so clearly for L we know that Burgers vector is perpendicular to line vector.

Burgers vector for M section is actually parallel to line vector and for the N section Burgers vector is again perpendicular to line vector. We should keep in mind that for a given dislocation, Burgers vector does not change. So, for L, M and N for all these the Burgers vector remains constant, and this would imply that this has an edge character while M has a screw character and N has again edge character.

So, this small step that we see over here is also involving screw character. So originally, we started with the edge dislocation, but the step that is forming over here has a screw character to it and this is how it looks like and this whole thing will move apart, the M section and the O section, so let me call this here O, so M and O will move apart and then the overall dislocation would have some displacement.

And like I said after some certain amount of time, it may look a lot more jig jagged than a simple step over here and that is where you can; at a macro level it may look like it has a more curvature to it. So, let us say this is one plane. So, this particular plane, the dislocation after some time of movement may look something like this. Now, this kink that we have shown at the atomic level it could be 90 degrees.

But it will also get rounded at a larger length scale and why does it get rounded because this roundedness decreases the energy. So, if we were to look at let us say extra half plane, so there is an extra plane over here and there are layers of atoms here, here, then here and here. So, there is a dislocation here and it is forming a step like this. Now, this is step.

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Now, we will try to draw the profile of the dislocation from the top view where we are able to see the other planes of the atoms. So, these are the dark lines are the ones where the energy would be lower so the dislocation line would like to lie in these. So, the dislocation would like to be a little rounded, but that too will depend on the energy profile of that the Peierls-Nabarro.

So, for example even the Peierls-Nabarro valley is shallow but then the dislocation would have more rounded character. So, if you were to look at this as I said these are the energy valleys. So, these are the energy minimas and let us compare when Peierls-Nabarro valley was much sharper or they had larger energy difference between eigenvalue So, let me draw another.

So, we are looking from the top and the dark lines are where the energy minima lies and like I said this time the energy is much starker. So, let us say it looks like this. So, when it is like this in that case the dislocations would have less curvature, it still wants to have curvature, but then the curvature would not be possible to the same extent, and it will have less curvature to it.

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So overall dislocation reduces energy by eliminating sharp corners. This even in that case the energy the roundedness or how much it is able to get roundedness that will depend upon the energy barrier, Peierls-Nabarro energy valley. So, two important things we learned here about the kinks. The kinks are formed, and they are the steps, they cause the formation of the steps which lead to the movement of the dislocation and what you see here are actually what is will be called a double kink.

So, this is the first kink, and this is the second kink, so where it brings it back to the original dislocation. Then next point is that the kinks would like to get rid of the sharp corners and it is done to reduce the energy. However, the roundedness would depend upon the Peierls-Nabarro energy valley. So, when the energy valley is narrow, then the dislocation would tend to become more rounded.

When the Peierls-Nabarro energy valley is very sharp, meaning it has very large difference between peak and valley, then it will not have as much roundedness, and it will quickly switch as you can see from one minima to other minima and it will have less region or less length in the higher energy region as you would expect. So, this is the step formation for the glide.

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Now, we have also talked about climb and similar kind of steps we will find is also present in climbs and it is called jogs. Here when we were talking about the climb, we saw that actually the vacancies can actually move into the dislocation core, and you will see a small step. So, by very origin climb involves step wise formation and therefore it can be individual vacancy or cluster vacancies which lead to the climb of atoms rather than whole row of atom moving up or down.

Cluster of vacancies lead to climb in steps rather than whole of row of atom and from the climb itself we know that it can be both positive and negative. So, when the dislocations are absorbed or when they sink into the dislocation that it leads to climb up and when the dislocation acts as the source for vacancies that are coming out and the dislocation is climbing down.

And in both cases, there will be nucleation of the step which we are calling as now jogs. Both positive and negative climb proceed by nucleation of unit step and what is the name of this unit step? The name of this unit step is jog. So, in totality we can say it is the jogs which are the source and sink for vacancies and it is a source when it is giving out meaning it is climb down and when it is sink meaning it is climb up for vacancies.

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So, first let me try to draw this, then I will show you a schematic. So, let us say this is the extra half plane. So, what I have tried to draw here is that there is an extra half plane and since we are talking about the climb, so this is the dislocation and this is the glide plane, the original glide plane. Let us say there is a vacancy which I will draw as cube for simplification. So, let us say a vacancy moves in over here, therefore there will be a step formation and it will become like this.

So, this would be called a jog. This will also be a jog and the overall dislocation line you can see has climbed up and if there is a cluster of it, then let say we have more than one vacancy trying to move in, then this whole thing would look like. So, now I will draw the dislocation line in a different colour. So, you can clearly see that this is now the new dislocation line and the size of the step has increased and this would be called one jog.

This would be called another jog, and both are moving as more and more vacancies or cluster of vacancies could keep moving in. Then these jobs keep moving away from each other and the overall average height of the dislocation line has increased. So, overall, it will become higher and higher.

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If we were to look at it from a different perspective, then this is how it would look like. So, I have drawn extra half plane and let us say we have other planes are like this So, these are our full plan, and I will redraw it in another colour and these are the jogs, and this is how it would look like. So, this is the original dislocation line which has moved up a little bit and then again there may be more jogs over here and this will keep moving and eventually you may get a lot more complicated shape.

So, for example in the end what it may look like would be something like this. So, on the top side we have the extra plane and on the bottom side we have the missing plane. So, this is inside a crystal and everything about this is the extra half plane. So, what do we see here is that these are jogs, and these are moving like this as more and more vacancy clusters keep getting absorbed or this part if you look with respect to the original, this is climb down. So, this is a source for vacancy.

So, the vacancies are coming out from here. So, at some places the vacancies are getting absorbed, some places the vacancies are getting released where it acts as a source. And like we said that this is activated by diffusion mechanism of the vacancies and therefore it is a thermal process. So, it will be more supported at higher temperature this kind of movement of dislocation line and therefore climb kind of process is all usually observed at higher temperature. So, this is your climbing dislocation and in this particular case.

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So, now let us talk with respect to what will be the character of the dislocation that steps, different components of the steps. So, let us look at this one. So, here we have edge dislocation, this is extra plane, this is extra plane and therefore the Burgers vector has to be like this. This is the original line vector, so this Burger vector is perpendicular to L. Now, for the case of M it is perpendicular to L, but also it is perpendicular, it is inside this plane therefore it is also perpendicular to Burgers vector b.

So, the M is again line vector as is also still perpendicular to the Burgers vector b and on the other hand is same as L. So, it is again the line vectors perpendicular to b. And then we have O which is similar to M. So, overall, here we can write L, M, N where **L** for the L we have Burgers vector parallel to line vector, for the M we still have Burgers vector parallel to line vector only that the line vector itself is now perpendicular to the original line vector, so I will call it u 2 and N is again same as the original.

So, in this case what we see is that we are getting all of them as edge dislocation and say O would be same as O. So, this is how the steps from in the dislocation by forming kinks when it is gliding the same plane or forming jogs which will be steps when the distortion wants to move out of the plane and like climb, jog would also be supported at higher temperature because it is thermal phenomena. So, with that we have good understanding about dislocation motion climb.

First, we located a glide which is the usual slip, then we looked at cross-slip, then we looked at climb. Then we also looked at the steps that are formed for the glide and the jog and what we realized is that it is not the whole dislocation line moving at a time, but it is a step, step form and then the steps move out which leads to the overall average displacement of the dislocations. So, we have learned a lot about the motion of the dislocations. So, we will end this chapter with this understanding. Thank you.