Mechanical Behavior of Materials-1
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Lecture - 29
Image Forces

So welcome back, we have looked at dislocation motion, dislocation interaction. And in this lecture we will look at or we will understand a concept called as image forces. So what it means is that when a dislocation is very near the surface that tend to anneal out meaning they tend to move out of the crystal surface and disappear or basically go away so that dislocation density will reduce.

What this implies is that very near the surface some thickness which we will be able to calculate, you will have no dislocation. The other implication is that, if your dimension of the material is very small, let us say we take a whisker rod, which is two times the thickness then it is almost completely free of dislocations. And what do we understand when there is no dislocation that the strength would be very high.

Because there is no dislocation to cause the deformation. No movement of dislocation which will allow deformation process or slip of the crystals. Therefore, it will be very useful to understand what this image force is and up to what depth this will act. So let us move on.

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So like I said very near the surface, so let us say you have a bulk material like this and there is a dislocation somewhere over here, which has a slip plane like this. Then because there is you can say relaxation near the surface, what happens is that there are some forces acting on the dislocation, which tend to move this out. And how do we find that forces?

It so happens that this can be the force acting on it, can be calculated by assuming that there is another dislocation at almost same distance outside this material, but with a different Burger vector. So you can see there will be attractive force acting on this. So there is a force, theoretical force on this dislocation and there is a real force acting on this real dislocation.

So we can calculate the force acting on this dislocation and find out how much force is acting. So let us say this is the distance d, then the other dislocation must also be placed at a distance d outside the surface and the interaction between these two dislocations would govern how much force is acting on this dislocation. Here since, okay so let me put it in words what we are doing.

An imaginary dislocation is placed outside the surface at a distance equal to that of the real dislocation. So here the distance what is d, so this distance is also d. And the Burger vector, Burgers vector would have same magnitude but opposite sign. What this implies is that an attractive force is acting on this dislocation.

So this phenomena where the dislocations experience a attractive force or a force pulling them out is experienced only by dislocations near the surface not for dislocation inside bulk. Once we look at it in closer detail, it will explain why it is so, why only the dislocations near the surface experience this, but not the dislocation inside the bulk.

And this is true for edge and screw dislocation as well. So now, we will calculate how much force is acting on this. So for that we have already seen that there is a dislocation and we know the relation what will be the force acting on it.

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$$\boldsymbol{F_X = \frac{-Gb^2}{4\pi d}}$$

So coming to this equation, coming to this condition we can write F x for the edge dislocation it is attractive force, you can go back to the equation and you will see we will have a relation which will be like this. So y is equal to 0, only x is distance here which is equal to 2d into 4d square divided by 16 d 4 which becomes -Gb square by 4 pi 1 minus nu d.

This is for edge and if you were to calculate it for screw dislocation then obviously, this 1 minus nu term would not be there and this will turn out to be -Gb square 4 pi d. So for edge dislocation this much force is acting on the dislocation over here which is trying to pull it out, which is trying to make the distribution move towards the surface and for a screw dislocation this is the dislocation force that is, this is the force that is acting on the dislocation.

Now the question is, is this force sufficient to move the dislocations? Just because there is a force can we say that yes this force will be sufficient to make this dislocation move out of the surface. So the answer is no we will have to first compare it. It must be greater than some minimum value which is the lattice resistance. So only if F x is greater than lattice resistance, that dislocation will move.

So one can theoretically calculate that lattice resistance or one can also look at the depth and back calculate what is the lattice resistance. So in effect, this also can be used as an effective method for finding what is the lattice resistance against motion of the dislocations.

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And once this force is greater than this lattice resistance dislocation will move spontaneously. So if you were to draw, let us say I am drawing a rod or a whisker and some thickness t is found to be free of dislocation, meaning this region, so this dislocation this much region is free of dislocation. And how did it become free of the region, free of the dislocation?

Because here the F x acting on the dislocation, the F x acting on the dislocation was higher than the lattice resistance. So the dislocations moved out and they are able to and hence this system becomes free of the dislocation in this region. But inside this there is still force on it and this is where I said that we can explain why bulk of the dislocation does not move, only the those at the surface.

Here also the force will be acting, but if you look at this equation, it is inversely proportional to d, meaning the force acting on the dislocations in this region is smaller. So they are smaller than that critical value or that lattice resistance value and hence the dislocation is not able to move. And as soon as it reaches some region over here this force becomes equal to the lattice resistance.

And when it is on this side of this dashed line, then the forces are more force acting on the dislocation is more than the lattice resistance and hence it is able to move up. And thus we only see outer layer of such system to be free of dislocations.

And if you happen to have a whisker, which is just two times of this thickness, so now, if I make a whisker which is in diameter equal to 2t then it implies that it is almost free of dislocations, whiskers. So this also explains why whiskers have very high strength. We know theoretically that whiskers have very high strength, close to the theoretical value. And this explains why whiskers have very high strength, explains the very high strength of whiskers.

Now we will understand or try to get a feel of the numbers by looking at one example.
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So let us say we have a rod or a wire which is which has diameter has, is 100 nanometer. So this diameter D is equal to 100 nanometer and let us say that for this material it is also given that the modulus, shear modulus is equal to 200 Giga Pascal and the Burgers vector is equal to 4 Angstroms and nu is equal to 0.5. And let us say that the lattice resistance or the minimum force per unit length required for dislocations to move is 1.02 Newton per meter.

Then the question is find out the thickness of shell of this wire which is free of whiskers. So you have to find out t where t is this distance. So this is given, this copper rod or actually the material happens to be copper as you can see from the values. And rod or wire of 100 nanometer thickness is given to you. And it is also known that what is the latest resistance which is 1.02 Newton per meter.

Now with this value you have to find out up to what thickness it will be dislocation free. So as you can, as we have mentioned earlier the closer it is to the surface higher is the force and the more in depth you go the smaller becomes the force acting on the dislocation. So at some point the force acting on a dislocation would be equal to 1.02 nanometer and that would be the point along this line.

Below this the force acting would be smaller and if you go to the right or closer to the surface the force acting on a dislocation would be higher than this. And that is why all of dislocations disappear beyond this. Therefore, we have to find t by equating the force equal to 1.02 nanometer.

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$$\frac{F_X}{L} = \frac{-Gb^2}{4\pi(1-\nu)t} = 1.02$$

So F x by L we already know is given by Gb square, this is the force acting on the dislocation 4 pi 1 minus nu d. And this is equal to 1.02 Newton per meter. And here d is actually t. So from here this value we will be able to get the thickness, which will be 200 into 10 to the power 9 into 4 square into 10 to the power -20 which is for the Burgers vector and 4 pi into 0.5 1 minus nu and 1.02.

So what we will get is equal to 5 nanometer if you solve it. Therefore, a thickness up to 5 nanometer would remain dislocation free. And if you happen to have a whisker, it is almost free of dislocations. Why I am saying almost free is because what we have assumed so far is that the glide plane is oriented normal to the surface.

And therefore, what is the minimum whatever is the minimum force required it is equal to here equal to the force acting on the dislocation and hence it can move. But what if some dislocation are oriented such that the glide plane is like this. In which case this dislocation would be able to move from a much lower depth. So probably somewhere over here. That also we can calculate.

So only up to this depth the dislocation would be able to move out. Because the lattice resistance would also be different over here and the dislocations below this would still be there. So there would still be some region where there is a dislocation. And that would also be true for a whisker of 10 nanometer.

But as you keep reducing the diameter of the whisker, then the probability of getting any number of dislocation becomes smaller and smaller. But then it comes to the length of few atoms and therefore, it fabrication of such whiskers and any proper testing of such whiskers would also become problematic.

So I hope that you are able to understand the concept of image forces that act on dislocations and because of which some, up to some depth of the material, this material remains dislocation free. And this also explains the very high strength that we observe in whiskers. So we will end this chapter with this. Thank you.