Mechanical Behaviour of Materials

Prof. S. Sankaran
Department of Metallurgical and Materials Engineering
Indian Institute of Technology - Madras

Lecture - 18
Introduction to Dislocations - VI

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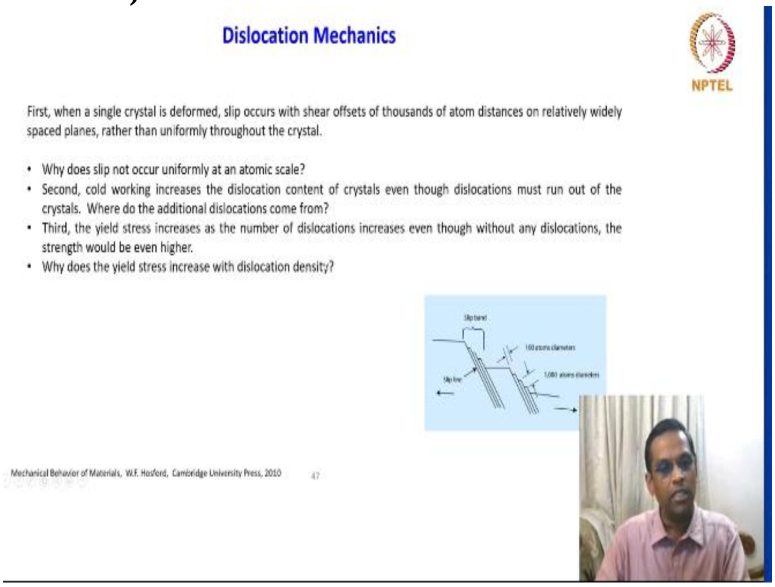

Hello, I am Professor S. Sankaran in the Department of Metallurgical and Materials Engineering. So, now, we move on to another important aspect of dislocations what are the aspects we are going to see now, first when a single crystal is deformed slip occurs shear offsets of 1000s of atom distances on relatively widely spaced planes, rather than uniformly throughout the crystal. You see, when I started this chapter, I was just mentioning that we are looking at this dislocation and description because the primarily theory of elasticity deals with most of the calculation of energy and the stress field equations.

So, that is why I wanted to bring it in the beginning itself but now, we are concentrate on mechanics. Now, that we have some idea about the dislocation and its nature and other details of stress and energy, so on. I want to just complete some introduction on the dislocation motion and mechanics, but then when you talk about mechanics then it involves other aspects which we have not looked at for example, when we talk about dislocation motion in a crystal system, then we will talk about deformation, which we are yet to see.

But then what I want you to just understand this is suppose if you are getting some idea itself as a background and this will be easy to know it will help to understand the plastic deformation or plasticity discussion which we are going to do it in subsequent classes. So, some of the new terms will come here for example, work hardening will come, but do not just get you know worried about that but we will bring it explanation then and there wherever it is required.

So, I just want to give this information before we get into describing this dislocation mechanics. So, we are now here talking about a single crystal deformation and which occurs through slip a mechanism called slip with the shear offsets. So, this is how most of the textbook describes the slip. So, these are the crystal slip steps small, small steps and this is called the slip line and this is the shear stress direction.

And some approximate numbers are given how many atoms will be involved in a step or a bunch of steps 100 atoms diameter 1000 atoms diameter and these steps together they are called slip band. So, we will get into the details when we start discussing the plastic deformation, but then here we are discussing we are bringing the context because we are looking at the dislocation. Why does slip not occur uniformly at an atomic scale?

So, this is one question suppose, why are we looking at dislocation mechanics there need to be some valid reason. So, this is one of the reasons why does slip not occur uniformly at an atomic scale. So, here the slip bands are localized there is a gap between this slip band and other slip band and why there is a heterogeneity here that is what the question is though this is not exhibiting the atomic scale image, but the if you just imagine that all these number of atoms are shown here, it will not show that uniform different slip.

There will be some gap here and there is a gap here and then this kind of step happens with some intervals, why does it happen? Secondly, the cold working increases the dislocation content of crystals, even though dislocations must run out of the crystals. Where do the additional dislocations come from? So, this is one point you have to understand first what does that cold work means you deform at low temperatures much below I mean recrystallization temperature and so on.

I mean for example, room temperature deformation that kind of deformation increases the density of dislocation and you have to understand one important point why this crystals undergo the deformation especially a plastic deformation at room temperature, though that defect density increases, but most of the defects run out of the crystals from the velocity by which the dislocation moves pretty fast, we will discuss that when we come to the deformation behaviour.

So, most of the defects will get generated will run out of the crystal system that is what it is shown written here. Then, if you assume that most of the crystals I mean get rid of this dislocations during cold deformation that how the dislocation density that increased. So, where do the additional dislocation come from these are the other questions. Third, yield stress increases as the number of dislocation increases, even though without any dislocations, the strength would be even higher.

So, this is something you have the clue now, because in the beginning of the dislocation chapter we looked at the strength of the bond calculation theoretical value of the bond strength. So, even without dislocation the strength must be very higher, but the yield stress increases as the number of dislocation increases, so, there is a difference. So, why increase in dislocation density helps or influence the yield stress is the question mark. And why does the yield stress increase with the dislocation density?

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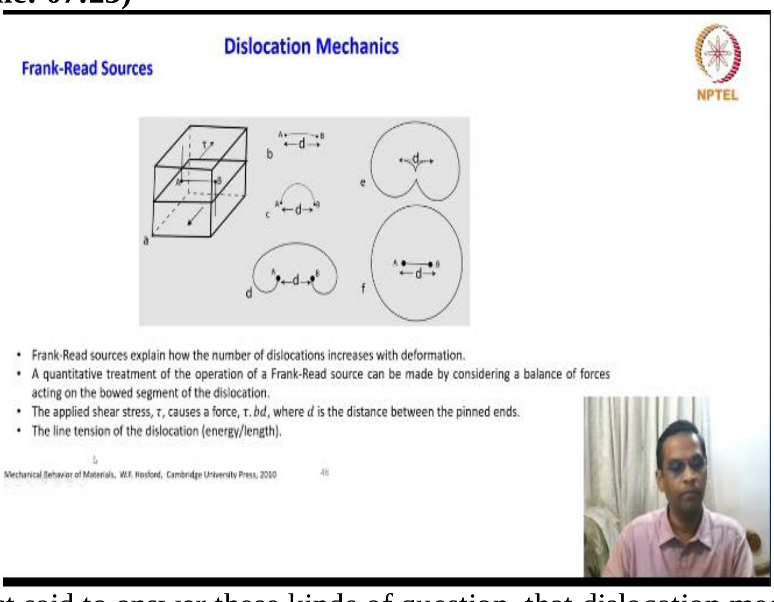

This is what I just said to answer these kinds of question, that dislocation mechanics is looked at more critical. So, one of the important or primary mechanisms by which the dislocation multiplies into the crystal system is popularly known as frank read sources. So, what is this frank Read source? Look at the schematic here this is a perfect crystal you are looking at the slip plane in the middle of this crystal and the dislocation line A, B.

And the shear stress is applied in this direction the first off and these bottoms off these two are pulled in opposite direction then what will happen to this A, B that is a question. So, what happens in the first stage, so, you are seeing this dislocation line which is getting bow a little bit as the stress slowly start increasing this looks like bow the distance between these two points is d and as the stress continues to increases this bowing becomes more significant and the radius becomes more and more.

And then what happens the extension of this dislocation bowing becomes extreme at this situation as the shear stress increases and finally, what happens is this two ends this enlarged loop try to come together and they bring to this kind of a contact and then it becomes an another fresh dislocation line leaving a huge loop around it. So, yesterday we have seen the dislocation encounters an obstacle and this is how it evolves.

It is like line tension, we have looked at that energy force balance and then we formulated an expression to calculate this so similar mechanism. So, if it you just imagine this mechanism continuously operating that means, what happens this kind of mechanisms will leave a loop after loop as the deformation proceeds or the crystal is experiencing the shear stress continuously this kind of dislocations source will generate a lot more dislocation inside the crystal.

In spite of a lot of dislocations I have run out of the crystal lattice during the cold deformation that is how we have to understand that. The frank read source explained how the number of dislocations increases with the deformation. A quantitative treatment of the operation of frank read source can be made by considering the balance of forces acting on the bowed segment of the dislocation, this is all that. The applied shear stress τ causes a force τ.bd and where d is the distance between the pinned ends dislocation, the line tension of the dislocation energy per length that we know.

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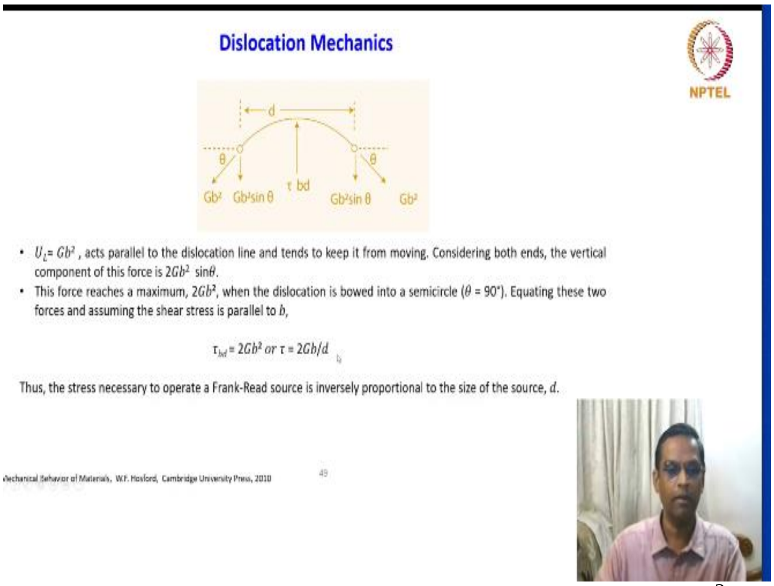

This we have already seen it is a repetition here so, the line in T is Gb^2 and if you consider this theta part then it will become $Gb^2\sin\Theta$ and this is the τbd the no line tension here. So, $U_L = Gb^2$ acts parallel to the dislocation line and tends to keep it from moving. So, considering both ends the vertical component of this force is $2Gb^2\sin\Theta$ so, this is vertical part.

The force reaches maximum $2Gb^2$ when the dislocation is bowed into a semicircle that is Θ= 90°. Equating these two forces and assuming the shear stress is parallel to b then we get this

$$\tau_{bd} = 2Gb^2 \; or \; \tau = 2Gb/d$$

it is the same equation we already have derived in the last class. So, what does it give what is the physical meaning of that the stress necessary to operate frank read sources inversely proportional to the size of the source d so, the shear stress is inversely proportional to d.

So, if the d is small that means, the two obstacles are placed very closely then accordingly your shear stress will be very high so, that is what it means.

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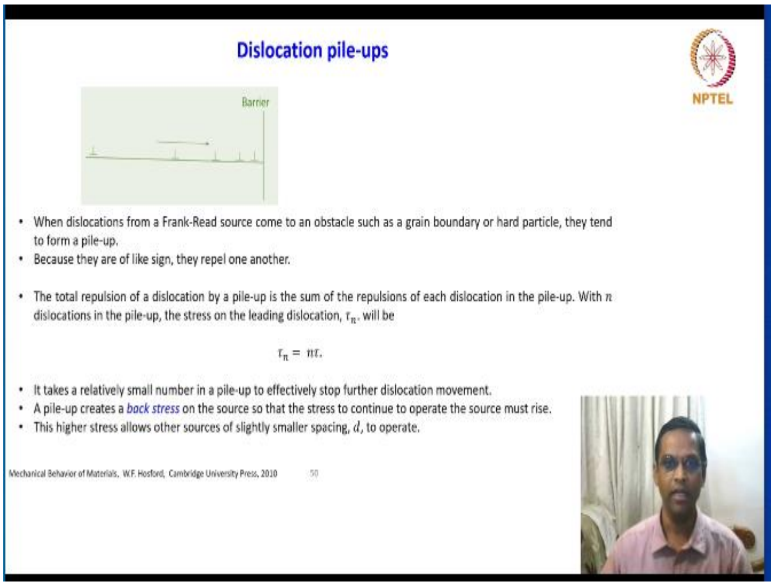

So, the next important aspect of this dislocation mechanics is dislocation pile ups. So, this again we will use this term quite frequently in the deformation behaviour of polystyrene materials as well as so, that is a obstacle for dislocation motion and then whatever the dislocation which gets generated inside crystal get you know get piled up against this barrier, this kind of situation.

When dislocations from a Frank-Read source come to an obstacle such as a grain boundary or hard particle, they tend to form pile up. Because they are of like sign they repel one another so eventually what happens, that is our interest. The total repulsion of the dislocation by pile up is the sum of the repulsions of each in the dislocation in the pile with the n dislocation, the pile of the stress on the leading dislocation τ_n will be $\tau_n = n\tau$ so, huge n force if you add up all of them.

It takes a relatively small number in a pile up to effectively stop further dislocation movement. A pile up creates a back stress on the source so that the stress to continue to operate the source must rise. So, this is very important idea the back stress. The back stress also has a huge role to play in explaining some of the dislocation mediated plasticity, we will be using this term quite often, especially in the work hardening theory.

So, the pile up it creates a back stress on the source so that the stress to continue to operate the source must rise. So, this again as I mentioned, this parameter will be useful while we are looking at the work hardening period. This is higher stress allows other source of slightly smaller spacing d to operate obviously, so, just previously we have seen the d becomes small you need a higher stress so, when the higher stress comes then even when closely spaced particle also will generate frank read source of dislocation that is an idea.

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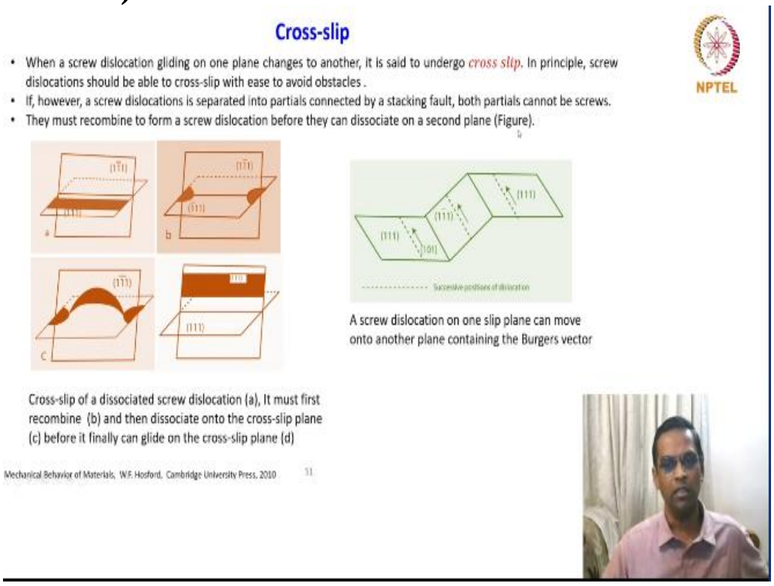

Cross slip this is another mechanism by which the dislocation moves. And if you look at this schematic, this is nicely shown here there is a (111) plane where the dislocation line is there and Burgers vector is there the direction of motion is there and there is another plane which is not of the same level but with some angle. So, the screw dislocation can move and very easily can just glide on this angular plane and then move on to the next higher level plane like that.

So, that is the description of successive positions of dislocation especially a screw dislocation what are the implications will see one by one. So, when a screw dislocation gliding on one plane changes to another, it is said to undergo cross slip. In principle screw dislocation should be able to cross slip with ease to avoid obstacles. We are now talking about screw dislocation not edge dislocations the previous slide we showed that pile up we showed the schematic only for edge dislocations.

So, the screw dislocation will easily avoid the obstacle and like edge dislocation so that is one information you can keep. So, what are these schematics? This is a cross slip of a dissociated screw dislocation suppose that dissociated screw dislocations as shown here and these two planes are intersecting planes of similar nature but then how these dissociated dislocations will try to move in this kind of circumstances is the question. So, if they are dissociated screw dislocation, they will not just like that cross slip but it must to recombine.

So, it must recombine this way it has to recombine and form a single unit dislocation then dissociate into cross slip plane like this cross slip and then finally again dissociate before it finally can glide onto the cross slip. So, again recombine cross slip dissociate and then glide. So, this is again a partial dislocation on a different level now so, it is almost looking like two partials which we started here. So, this dynamics is again that energy criterion.

So, this is just one example how screw dislocations move. A screw dislocation is separated into partials connected by a stacking fault this we have seen already here two partial dislocations. They are connected by the region of faulty reason it is called stacking fault both partials cannot be screws. They must recombine to form a screw dislocation before they can dissociate on a second plane so, this is what we have illustrated here.

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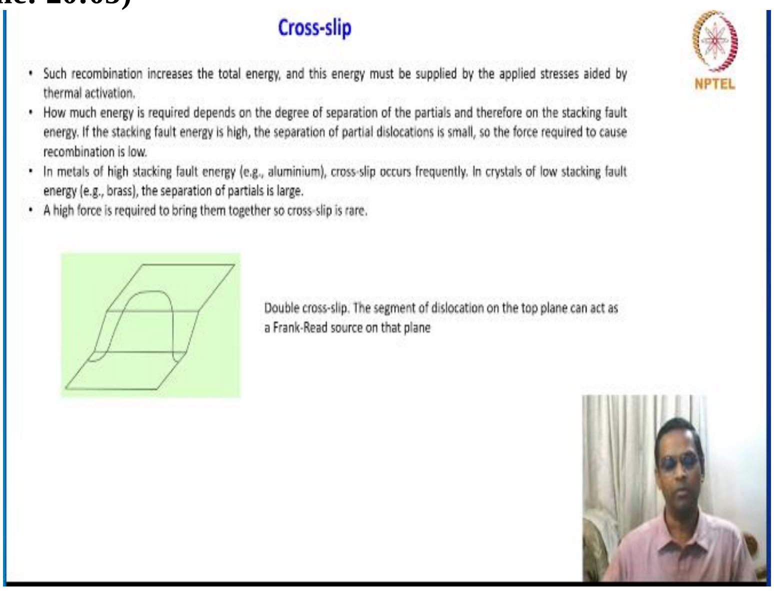

So, this is an another schematic of double cross slip the segment of dislocation on the top plane can act as a frank read source on that plane. So, this is another example of a cross slip but it is double cross slip such recombination increases total energy and this energy must be supplied by the applied stresses aided by thermal activation. So, this point what we are talking not pertaining to this this is something I know the previous description recombining now, these two partials it increases the total energy.

So, how much energy is required depends on the degree of separation of the partials and therefore, on the stacking fault energy this also we have seen. The separation between the partials decides the amount of stacking fault energy. If the stacking fault energy is high the separation of the partial dislocation is small. So, the force required to cause recombination is low. So, yesterday we started with the partial dislocation then I raised 1 question the title I showed was partial dislocation in FCC crystal system.

Then I raised the question why not in a BCC crystal system then I mentioned it is not that partials are not their BCC but they have very unstable configuration even exist and recombine they exhibit very unstable configuration. So, this is one idea so, very high stacking fault energy material, but in terms of aluminium they do not show partials because what happens if the energy is very high the force required to cause recombination is very, very low.

So, even a such a system previous no partial dislocation will stay stable this idea we have to remember later we will use this based on this criteria and when we connect the stacking fault energy with the deformation behaviour and classification you will see that we will classify materials based on this you know, dislocation morphology or mechanics, so, called wavy slip material or you know I would say planar slip material and so, we will see all of them so, they are all connected terms so just like that.

In metals of high stacking fault energy example aluminium cross slip occurs frequently. In metals of low stacking fault energy like a brass the separation of partial is large. So, this is one classical example aluminium and brass so, the aluminium will have the stacking fault energy in the order of 200 milli joules per meter^2 whereas brass will not close to single digit 8 to 10 milli joules per meter^2. So, the recombination requires huge I mean energy so, that is why these partials remain stable.

A high force is required to bring them together so, cross slip is rare, the cross slip is rare in materials with the low stacking fault energy that is why they are called planar slip they exhibit planar slip the slip occurs only in the plane that means, that dislocation activity or glide motion confined to individual plane not the cross slip. In other way we can say that in a very simple term, the three dimensional mobility of dislocation is highly restricted. So, this is also another way of looking at it.

So, when the three dimensional mobility of dislocation is facilitated, then the dislocation will climb through cross slip very easily and you will see all sorts of dislocation morphology, long extended dislocation like angles and cells and so on. So, we will see one way you can we come to a description of the deformation of procedure. So, I think I will stop here, we will and the next topic I want to discuss is dislocation intersections, just few examples of dislocation intersections where it will contribute to several microstructural you know, I would say stability and also it controls a lot of mechanisms, phase transformation mechanisms and so on. We will see it in the next class. Thank you.