Project of Materials (Nature and Properties of Materials: III)

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Lecture 28

Dislocating Generation: Frank Read Source

So, welcome again to the new lecture of the course Properties of Materials. So, let us just briefly recap, what we have done in past few lectures.

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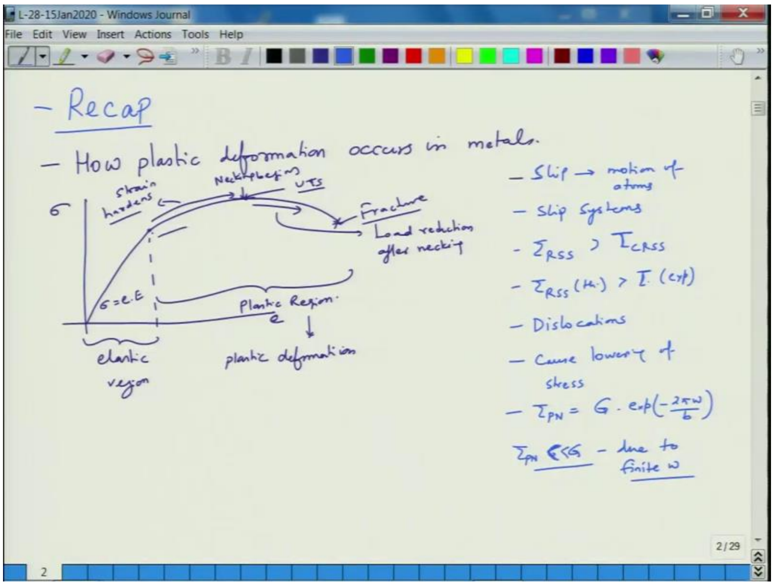

- Recap

- How plastic deformation occurs in metals.

- Slip → motion of atoms
- Slip systems
- $\tau_{RSS} > \tau_{CRSS}$
- τ_{RSS} (th.) > τ (exp)
- Dislocations
- Cause lowering of stress
- $\tau_{PN} = G \cdot \exp\left(-\frac{2\pi w}{b}\right)$

$\tau_{PN} \ll G$ - due to finite w

So, let me just provide you a summary of basically overall discussion that we did. So, basically at this point what we have understood is how plastic deformation occurs in metals. So, metals have this kind of stress strain curve, it is a engineering stress strain curve. So, before they, so this the region which is let us say the, up to this point is the.

So, this is stress, this is strain up to this point is the elastic region where sigma is equal to e into E and this region up to facture is the, you can say is the plastic region and this is the region where deformation, the plastic deformation occurs.

So, we saw that up to this, so this point at which your load is maximum or engineering stress is maximum called as UTS. At this point your necking begins, so up to this point material strain hardens and beyond this point there is a load reduction because of after necking because of excessive reduction in the area at the neck and then you of course have fracture.

Now the plastic deformation as we saw. So, this is the region in which you plastically deform the material. So, the question was first off all what is the stress that is required to cause deformation? So, plastic deformation and how does plastic deformation happens? So, plastic deformation happens by a phenomena called as slip.

Slip is nothing but the motion of atoms. Slip requires slip systems which means you have a bunch of planes and directions on which slip can occur along certain direction which are, which are basically in most cases the closed pack directions and the planes are, planes with highest atomic density which contains these slip directions.

So, based on this what we calculated was resolved shares stress and for deformation to occur this resolved share stress has to be larger than the critical resolve share stress. Now to critical resolve share stress is a material property. So, now we saw that tau RSS theoretical is way larger than tau which experimental value and the reason for this was presence of dislocation in the material.

Because if you do not have dislocation you will have to break lot of bonds for atoms to move across each other. Whereas if you have dislocation, extra one bond per atem for in the vicinity of dislocation and then with the movement of dislocation this stress is lower. So, dislocation cause lowering of stress and this stress is called as Peirells Nabaaro stress, tau PN and this was equal to G into exponential of minus 2 pi W divided by b.

So, metals generally have wider dislocations as compared to ceramics. So, that is why tau PN is much lower than G because of due to finite W. So, if W is b or 2b or 3b or is of magnitude like that, then you have substantial reduction in the stress and Burgers vector is also for metals its shorter, for ceramics its larger for the balance between W and b provides a tau PN which is lower than the theoretical share strain. This is what we saw until now.

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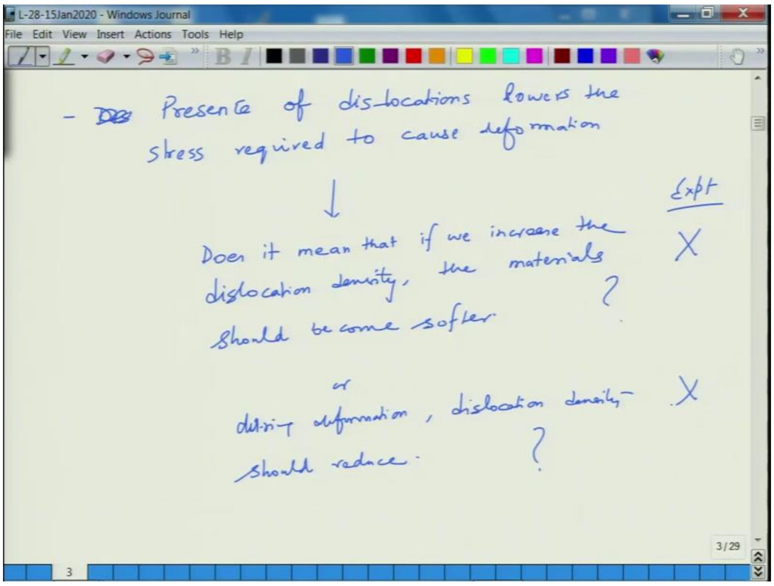

- Presence of dislocations lowers the stress required to cause deformation

↓

Does it mean that if we increase the dislocation density, the materials should become softer ?

or

during deformation, dislocation density should reduce. ?

Expt

X

X

So, now what we are going to see is that, so we have seen that dislocations cause presence of dislocation lowers the, to cause deformation, presence of dislocations lowers the stress required to cause the deformation. What, so does it mean that, so by natural intuition it means that if you increase the dislocation density.

So, does it mean that if we increase the dislocation density the material should become softer or during deformation, since we are saying dislocation moves and it creates a step the dislocation density should go down. Now this happens, so these are the questions and experimentally speaking this is also not true, this is also not true. So, experimental observations are different.

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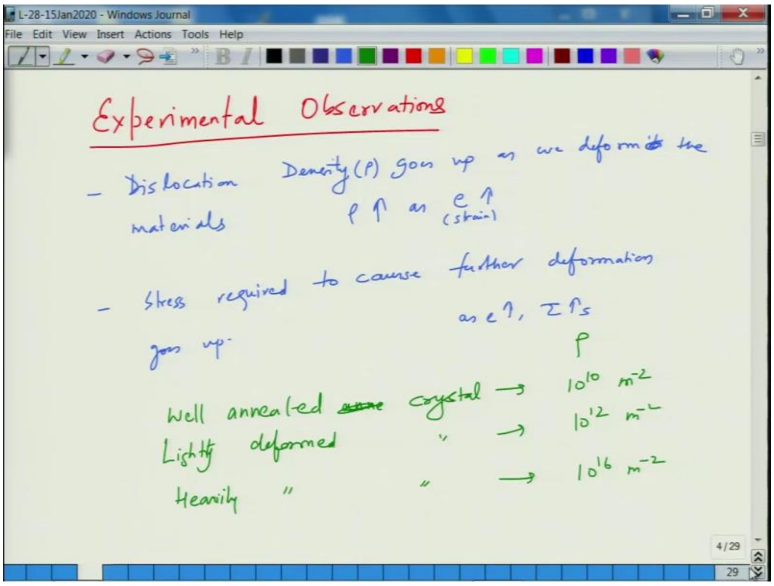

Experimental Observations

- Dislocation Density (ρ) goes up as we deform the materials

$\rho \uparrow$ as $\underset{(strain)}{e} \uparrow$

- Stress required to cause further deformation goes up.

as $e \uparrow$, $\tau \uparrow$s

ρ

Well annealed crystal → 10^{10} m^{-2}

Lightly deformed " → 10^{12} m^{-2}

Heavily " " → 10^{16} m^{-2}

In experimental observation what we see is that, what experimental observation show us is that the dislocation density goes up as we deform as we deform the material and then the stress required to cause for the deformation goes up. So, dislocation density let us say rho, rho increases as let us say e increases which is a strain and as e increases the tau increases.

So, which means what we are saying is that on the contrary what is happing is as we, first one as we deform the dislocation density goes up and as the dislocation density goes up the stress required to cause for the deformation goes up this is contrary to what we have just now said that stress dislocation actually lower the amount of stress that is required to deform a material and if you make the measurements a well annealed crystals, annealed means well heated crystal well.

So, something which has been held at long temperature to thermally collaborate and cool slowly which means it has lower number of defects, well annealed crystal will have a dislocation density of 10 to the power 10. So, rho the units per meter square and if you have a lightly, deformed crystal this showed a dislocation density 10 to a power 12 meter cube per meter square and if you take heavily deformed crystal it shows the dislocation density of 10 to the power 16 per meter square this is contrary to what we have said because we are saying that the dislocation leaves the crystal causes a step as we deform.

Which means the dislocation should reduce in number as we keep deforming the material. So, why is the dislocation density increasing and as we deform the material that is a question and the reason lie in because not only we eliminate the dislocations.

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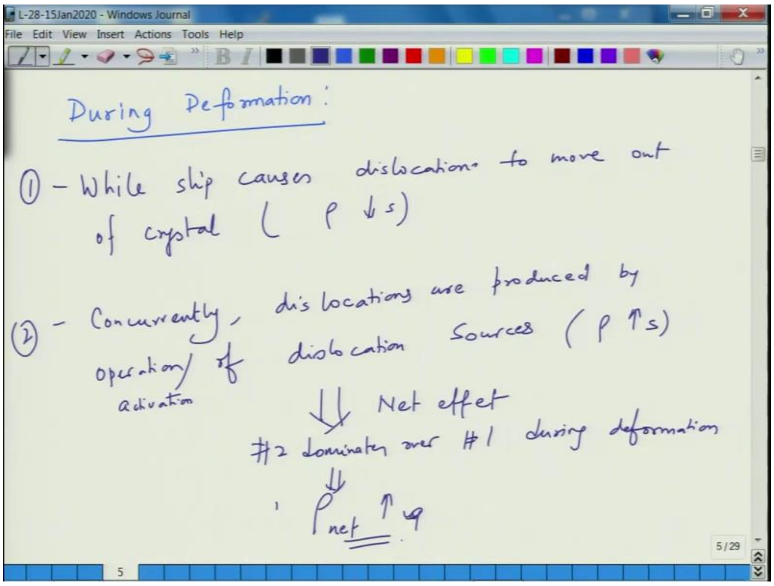

During Deformation:

① - While slip causes dislocations to move out of crystal ($\rho \downarrow$s)

② - Concurrently, dislocations are produced by operation/activation of dislocation Sources ($\rho \uparrow$s)

$\Downarrow$ Net effect

#2 dominates over #1 during deformation

$\Downarrow$

$\underline{\underline{\rho_{net}}} \uparrow$ up

So, during deformation while slip causes dislocation to move out of crystal which means rho should reduce. Concurrently dislocations are produced by operation of or activation slash activation of dislocation sources.

So, there are sources in the material which produce dislocations. So, this tends to increase the dislocation. So, the net effect is, so this is number 1, this is number 2, net effect is number 2 dominates over number 1 during deformation as a result the rho net goes up, so as a result the dislocation density goes up. So, this, what are these dislocations sources now?

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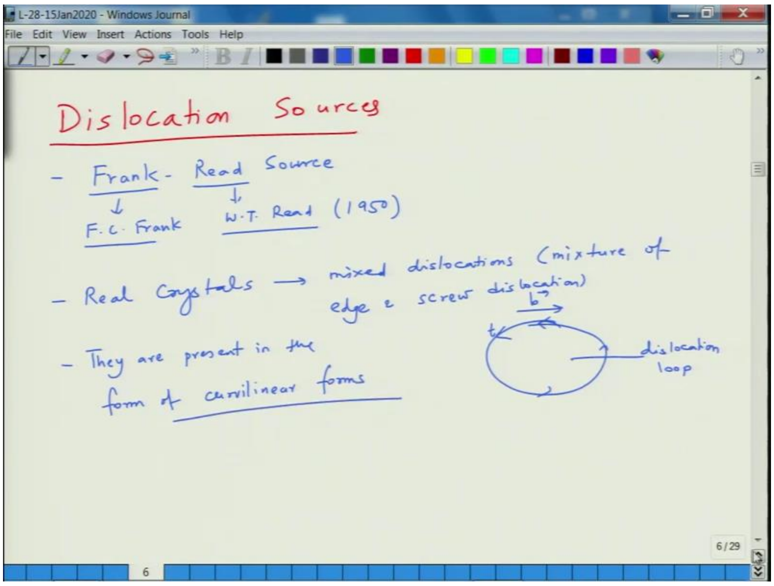


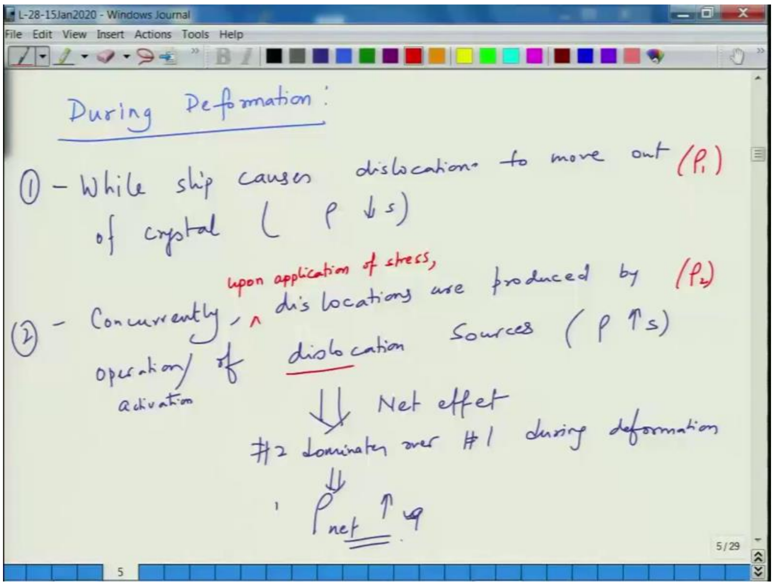
Dislocation Sources

- Frank - Read Source
  $\downarrow$ F. C. Frank, $\downarrow$ W. T. Read (1950)
- Real Crystals $\longrightarrow$ mixed dislocations (mixture of edge & screw dislocation)
- They are present in the form of curvilinear forms

$\vec{b}$

t

dislocation loop



During Deformation:

① - While slip causes dislocations to move out of crystal ($\rho \downarrow$s) (ρ_1)

② - Concurrently, upon application of stress, dislocations are produced by operation/activation of dislocation sources ($\rho \uparrow$s) (ρ_2)

$\Downarrow$ Net effet

#2 dominates over #1 during deformation

$\Downarrow$

$\underline{\underline{\rho_{net}}} \uparrow$s

So, dislocation sources, so we are saying that when we cause the deformation the slip causes dislocations to move out of crystal which means that the dislocation density should go down that is one effect, let us say this is row 1 and this is row 2, concurrently at the same time when you apply stress the.

So, we can write here up on application of stress dislocation are produced by operation some of the dislocation sources which get activated or they operate upon application of stress this leads to increase in dislocation density. The net effect is number 2 dominates over number 1 as a result the net dislocation density goes up.

So, now the question is what are these dislocation sources? That is what we are going to look at now. Now one of the most important sources of dislocation is called Frank Read Source. It's after two people Frank and Read. So, basically Frank is F.C. Frank and Read is W.T. Read. So, these are two persons who postulated the theory of dislocation sources in 1950 in Pittsburgh, in USA in a symposium.

So, what does what this Frank Read sources. So, Frank Read sources let us say you have the real crystals have mixed dislocation they have neither completely edge. So, we can say mixture of edge and screw dislocations. So, just like you know dislocation loop we have something like this. So, this is the T vector, so depending upon the net step that is being created you will have screw and edge components.

So, this is let us say the b and this is t, so depending upon the correlation between b and t we will have edge and screw at various sites. Now, when these are mixed dislocations, they are, they are present in the form of curvilinear forms. So, let us see, let us make a picture of how does it look like.

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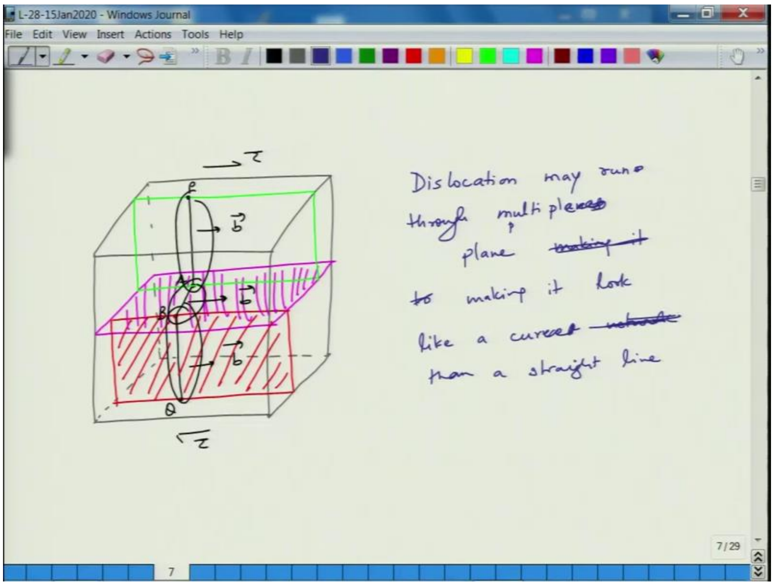

Dislocation may runs through multiple plane ~~making it~~ ~~to~~ making it look like a curved ~~network~~ than a straight line

So, this is let us say a crystal, so let us draw our intermediate plane first, this intermediate plane let us says this, this is a plane on this plane we have a line let us say this is a line and this line goes through. So, this line travels in this plane in this fashion and then we have, so this is the one plane and then we have this another plane is this a magenta plane and then let us say we have another plane which is this one in the back and this flow, it travels on this plane and this direction.

So let us say we have this segment P, A, B and Q and the Burgers vectors points in this direction and this is let us say the share stress that is applied. Now we can see that these are different planes and dislocation faces different situation here, then here, then there and if this planes are inclined then it is going to face different share stresses also on these planes.

So, basically what we are saying is that the dislocation may run through multiple planes. So, I just, multiple planes making it to rendering it, basically making it look like curved network kinda straight line. Making it like a curve than a straight line. So, basically inside a material if you make a global picture, the global picture is going to look like this.

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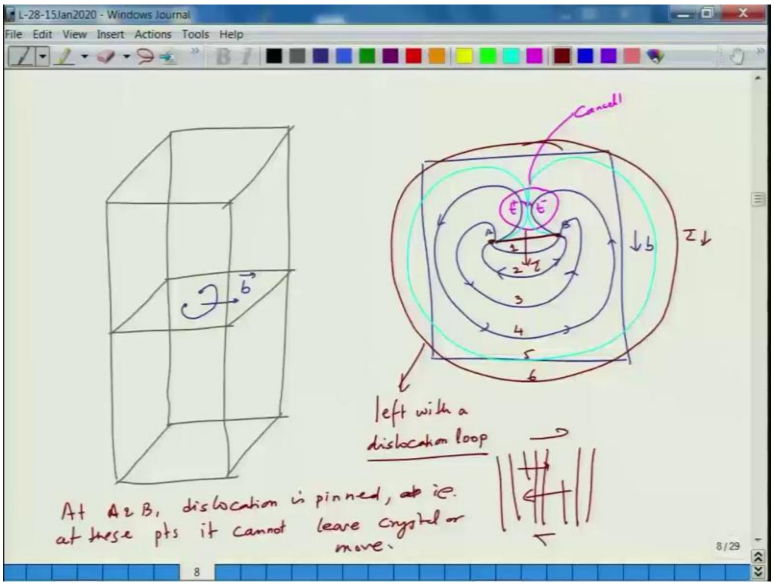
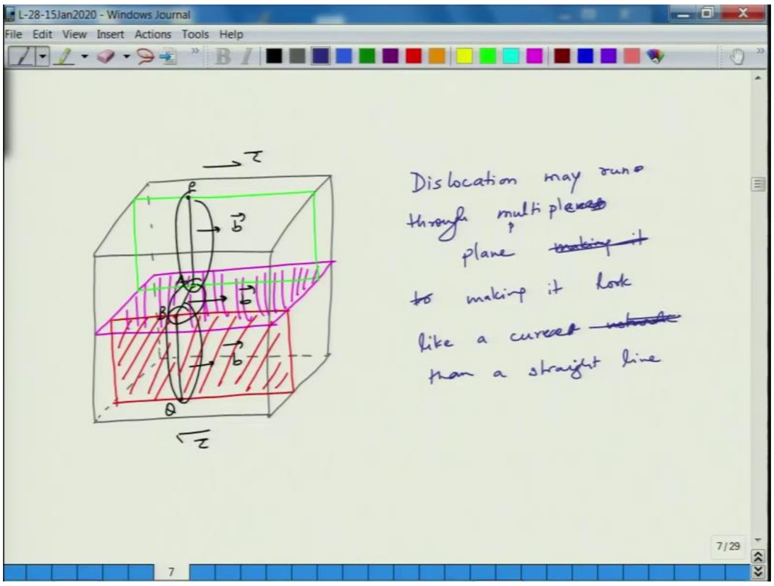


left with a dislocation loop

At A & B, dislocation is pinned, i.e. at these pts it cannot leave crystal or move.



Dislocation may run
through multiple plane ~~making it~~
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than a straight line

So, you have a crystal something like this, so the sake of clarity let us make a crystal which is something like this, in this crystal at certain plane le us say we have a certain plane here in this plane we have a dislocation which is let us say like this, because we can see that dislocation is pinned on this side and this side because it has gone through different planes.

So, it is gone through different planes as a result these are the two ends at which it gets bend. So, when you apply stress along this direction let us say Burgers vector is there then the dislocation tends to, tends to balloon itself let us say and this is the Burgers vector let us say.

So, microscopically speaking the dislocation will look something like this, these are two ends initially dislocation was this let us say this is a and b when you apply stress it becomes like this you apply further stress it becomes like this and you apply higher stress it becomes like this and when you become apply even higher stress it turns like this and then we know from geometry that this is let us say the Burgers vector this is b and in this case this is the t line but t curves itself in this fashion.

So, it changes its character from positive screw to negative screw positive edge to another negative edge depending upon orientation of t with respect to b. So, we will, as when you have these two lines approaching each other, so as it keeps ballooning at some point it will adopt a behaviour like this and what is this, at this point this is B. So, let us say if this is t this is positive t this is negative t.

So, this is t this is t, but this is t positive this is t negative, t positive and t negative, this is t perpendicular to b. So, this is edge kind of dislocation, so both of this will cancel each other, so they will cancel and then leave and what we will left remained with is a, when you further applies stress this will be left with what we called as a left with a dislocation loop.

So, you started from a line this line was pinned at these two ends because the other ends were moving into other planes which could not move. So, sort of it got pinned at a and b when you apply stress in this direction it allows it to balloon in further direction let us say this is tau. So, it adopts this is the first stage, the second stage, third stage, the fourth stage, fifth stage and the sixth stage and as you keep ballooning it.

When the negative ends when the opposite ends of dislocation comes close to each other, they cancel each other. This is like you know you have a dislocation let us say you have a crystal which is like this, in which you have one dislocation and then we have another dislocation and when we apply here stress this guy will move in this direction, this guy will moves in this direction, when they come close to each other, they nullify each other.

So, they have nullified each other at this point, but they have also given rise to bigger loop at this point which is a bigger dislocation. So, as you keep doing it when dislocation is pinned at this two ends. So, basically what we are saying is that at A and B dislocation is pinned which means that is at these points it cannot leave crystal or move. So, this intermediate portion between a and b will move and this will keep ballooning itself as you keep applying the stress and the stress that is required to move this dislocation.

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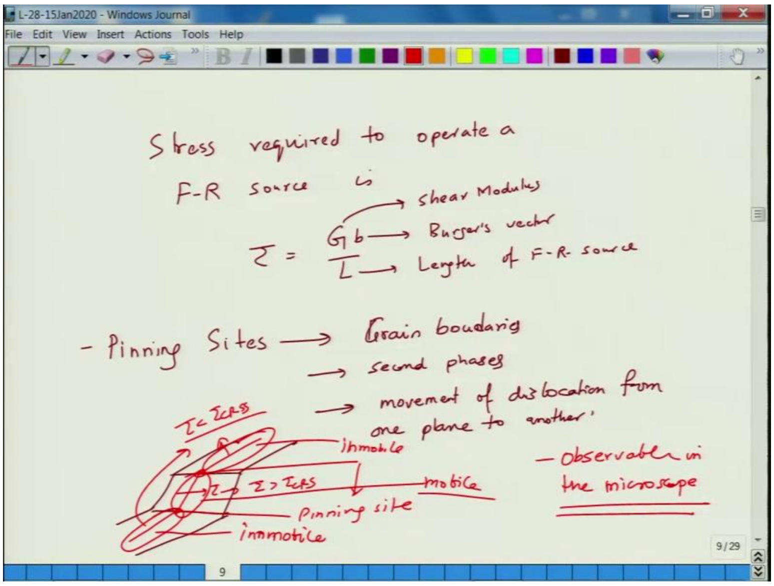

Stress required to operate a F-R source is

$$\tau = \frac{Gb}{L}$$

G → Shear Modulus
b → Burger's vector
L → Length of F-R source

- Pinning Sites → Grain boudaries
→ second phases
→ movement of dislocation from one plane to another.

- observable in the microscope

So, stress, so this is called as basically Frank Read Sources stress required to operate a Frank Read Source is given as tau is given as mu b by L. So, or we can write it as not mu but let us say Gb by L this is shear modulus B is the Burgers vector and L is the length of Frank Read Source.

So, larger the length is lesser the stress that is required to operate a source and b is the Burgers vector. So, basically what we are saying is that if you have more pinning sites in the material which we have because materials are polycrystalline, they contain grain boundaries, they contain impurities. So, basically what we have in material is pinning sites and these pinning sites could be because of grain boundaries second phases and a movement of dislocation from one plane to another.

So, basically it may be mobile in one slip plane but it may not be mobile in other slip plane because of which resolved stress becoming not sufficient. So let us say if you have a situation like this, where you have one plane, you have another plane and you have another plane and you have another plane and you have a dislocation running like this.

So, in this plane tau is more than tau CRSS. But in this plane and in this plane tau is less than tau CRSS. So, basically here it becomes immobile here it becomes immobile, but here it is mobile but since it’s a continues array of items these two length act as. So, these act as a pinning site and this also act as pinning site.

So, basically this is immobile, this is immobile but in between it is mobile. So, what it does is that, it then operates like a Frank Read source. So, essentially this is what it is going to do when you apply share stress when you have pinning sites like grain boundaries, second phases and you know crisscrossing of dislocation across various planes and this is something that you can observe in the microscope.

So, this is observable in the microscope, so we will dwell upon this further what we are saying is that in a material when you deform on one hand we said that when the slip occurs the dislocation goes out which means that dislocation density should have gone down but on the other hand what we observed is that there are other mechanisms like, there are mechanism like Frank Read sources which gives rise to this location.

So, you have two competing effects, on one hand dislocation density goes out decreases because of slip, but on other hand dislocation density goes up because of phenomena like Frank Read source operation which lead to multiplication dislocation also this.

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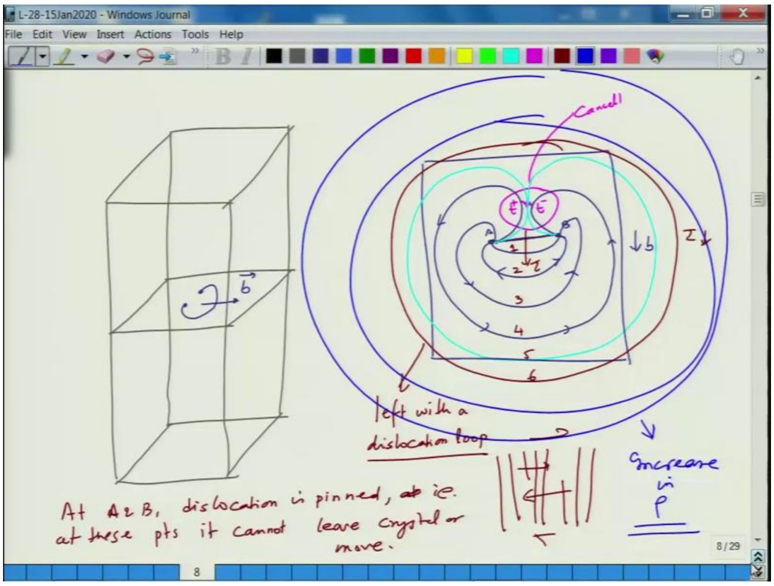

At A & B, dislocation is pinned, ~~at~~ ie. at these pts it cannot leave crystal or move.

This thing as you keep operating it, so it will give rise to multiple rings like. So, you will have one ring you will have next ring you will have another ring, so this will keep creating dislocation loops. So, this leads to basically increase in dislocation density, so these two competing phenomena leading to decrease and increase in the dislocation density. It leads to increase in the dislocation density as you deform and this is because of Frank Read sources creating many dislocation very quickly and this is something, if possible we will see a video in the next class how does this happens in real materials.

So, what we have done is basically we have looked at operation, we have looked at how the dislocations are created in a material through operation of this Frank Read sources. In the next class, what we will do is that, we will lead, we will study that how these understanding of dislocation, annihilation and dislocation creation can be used to our advantage by making to make the material stronger. So, we will do that in the next class, thank you.