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

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Lecture 29

Dislocating and Strengthening

So, welcome again to the new lecture of the course Properties of Materials. So, let us just prerequisites visit what we did in the last lecture.

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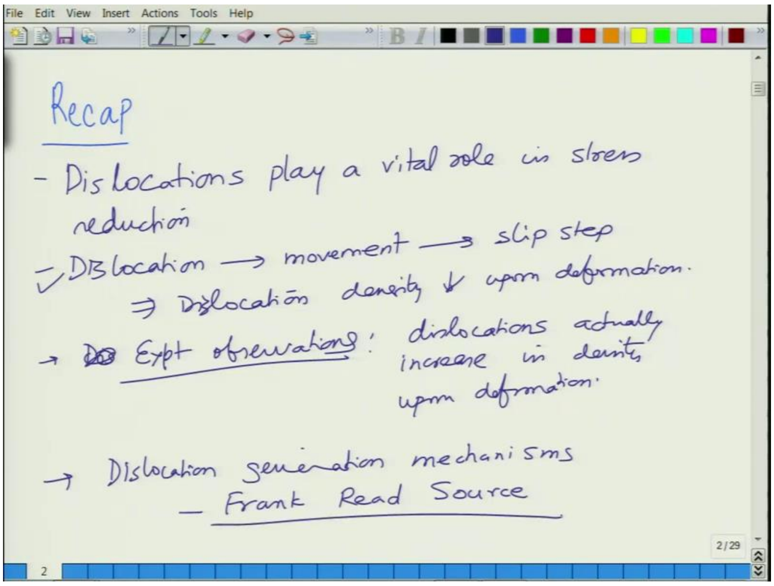

So, in the last lecture also we discussed that dislocations play a vital role in stress reduction and we saw that dislocations moves when stress is applied and they go out of the crystal. So, dislocation movement and then as they go out of the crystal they create a slip step. So, what it means is that, what it means is that the dislocation density should reduce upon deformation this is what should happen. Because if dislocations are getting out of the crystals which means dislocations are getting lesser in number.

However, experimentally what we observed is that dislocations, so basically dislocation density gradually increases as the deformation goes as the deformation proceeds. So, basically on one hand dislocation motion leading to slip. So, that is what we have written here. So, on one hand we have this phenomena which (())(2:10) on the other there is some mechanism which leads to formation of dislocations and formation of dislocation happens.

So, basically there are dislocation generation mechanisms, such as Frank Read source which leads to create which lead to creation of dislocations and this creation of dislocations out ways the, out ways the annulations of dislocation or lowering of dislocation density upon deformation and as a result this dislocation density goes up. Now we also said that dislocation are the ones which lead to lowering of stress. But experimentally what we observed is that as the dislocation density goes up the stress required to move a dislocation also goes up.

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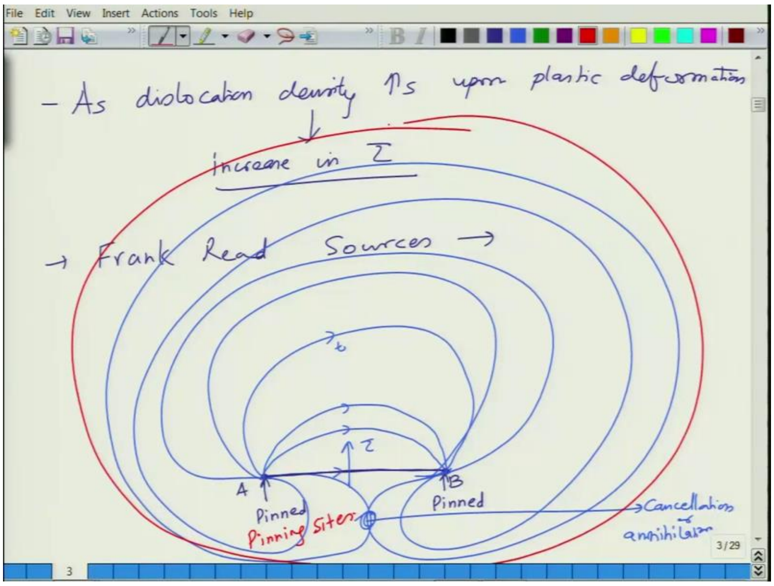

So, basically what we see is that as dislocation density increases upon plastic deformation this also leads to increase in stress that is required to move the dislocation so (())(3:31) plastic deformation. So, basically that is what is strain hardening. So, the reason for that we will see later on but first of all we saw that you have Frank Read sources leading to dislocation generation and what we saw that you know you have dislocation like A B.

So, dislocation line is A B, but A and B are the places where dislocation is pinned. Pinned or it sort of cannot move. So, these are pinning sides, so it could be that beyond A and B the dislocation continuing into other planes which it cannot move or there are things like precipitates or grain boundaries or some other things which are pinning it ground. So, they are holding this line tight, A and B are the pinning sites.

So, basically you call A and B as pinning sites and AB is the dislocation line. So, as you apply the stress tau we saw that this dislocation trends to bulge out slowly, gradually in this fashion and this is mind you the dislocation line T.

So, this is T vector and it just keep increasing like this slowly goes out before it becomes in this fashion and these two components then cancel each other because of they are of opposite signs cancelation or you can say annihilation, leaving a dislocation loop around. So, basically what it looks like is essentially you will have a situation in which that is what we saw in last class. So, let me just show you a brief.

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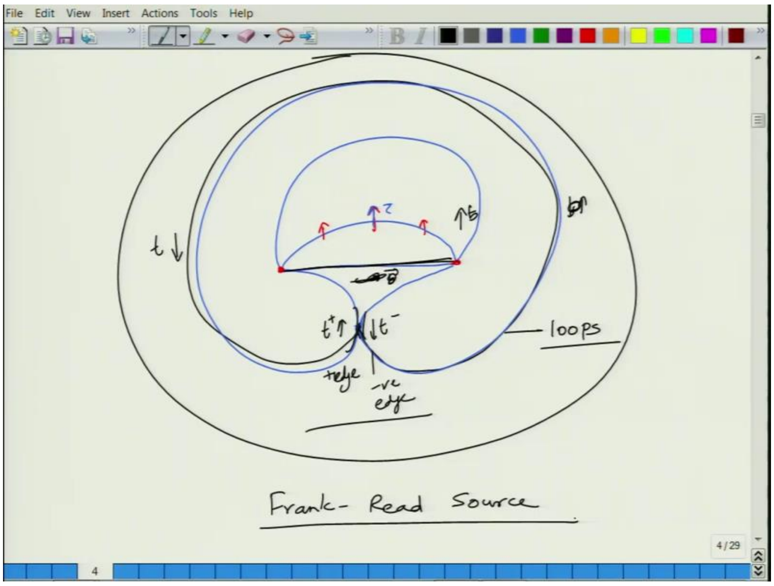

So, you start like this, then the first as you increase the stress tau it goes out but it remains pinned at this sites, so these are pinning sites it does not leave these places. So, the stress is there on these and then when you, when you further apply the stress further application of leads, stress leads to again bulging.

So, this is further bulging and then when you bulge it further then, it sort of, when you keep doing it after a, for a while then, it sort of, leads to in this fashion. So, eventually what will happen is that these two will cancel each other. So, it will look something like this. So, this line will remain like this and the dislocation will appear as if it's, this line goes back where it was and this is the dislocation loop.

So, these are the dislocation loops, that we keep creating and you can see that wherever Burgers vectors, so if this is the Burgers vector let us say these are the edge components. So, if this is the Burgers vector b, then let us if this a, I do not know, this is the Burgers vector in this direction let us say b. So, here its b positive here its. So, the b, so this is t positive, this is t negative, this is t, in this case so you can say that this is one is positive one is negative.

So, depending upon the orientation of t with respect to b one will be positive edge another will be negative edge and they will cancel each other or eliminate each other giving rise to a dislocation loop. So, as you keep deforming the material you create, keep creating these loops and this is called as basically Frank Read source to create dislocations. So, we will just do a brief analysis of how. So, last time we looked at the stress that is required to move a dislocation. So, create a dislocation basically.

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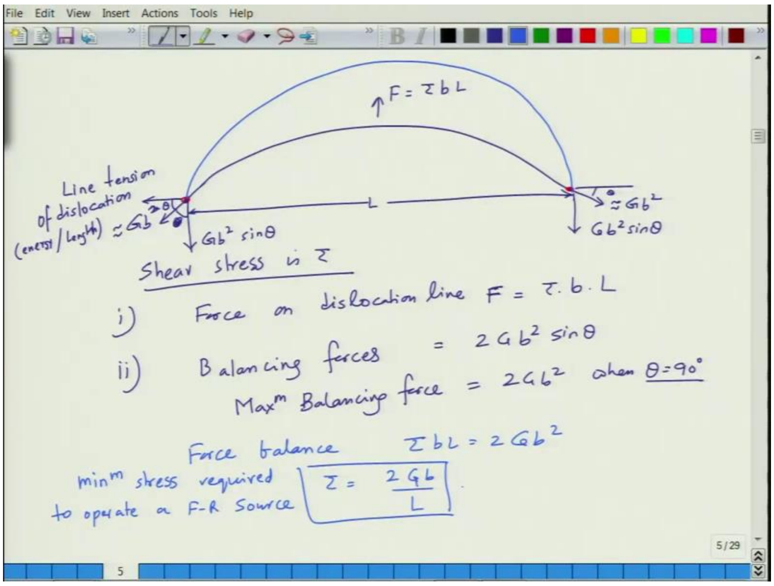

So, you have a loop like this and these are pinning sites and the distance between these is given as L. So, the force on the, so the distance is L and these are the pinning sites. So, the force from the dislocation when shear stress tau is applied. So, shear stress is shear stress is tau.

So, basically now we are going to do force balance. So, first thing is force on dislocation line this is basically F that is equal to tau into B into L. So, this is the force on the dislocation when your shear stress tau is applied. So, tau into b into L is the force in the forward direction. So, this is F is equal to tau into B into L. Now this is balanced by forces, so let us say a dislocation has line tension of which is line tension of dislocation is basically you can say energy per unit length.

So, this is basically Gb square approximately equal to Gb square. So, this is Gb square this is Gb square in this direction. So, if this angle here is theta, this will become Gb square, if this angle is let us say theta this angle is theta and this will, this will become Gb square sin theta and this will also become here Gb square sin theta. So, these are the balancing forces, so basically the balancing forces are 2 Gb square sin theta. The maximum balancing force will be 2 Gb square when theta is equal to 90 degree.

So, this will be the maximum. So, when the loop really becomes like this. So, the segment will be basically like this. So, when the segment is vertical basically. So, maximum Gb balancing force will be 2 Gb square. So, now force balance requires tau bL is equal to 2 Gb square. So, basically the minimum stress that is required to operate the Frank Read source is equal to 2 Gb divided by L. So, this is basically you can say the minimum stress required to operate a Frank Read source.

You can see that this stress will increase as the shear modulus goes up that makes sense and this stress also reduces when your L value decreases. So, when dislocation line becomes very large then the stress that is required to operate the Frank Read source decrease.

So, this basically suggest an idea and the pinning sites are closer to each other then, the stress required to move to operate a Frank Read source is larger and this we will see comes handy when we learn about the precipitation strengthening or particular strengthening in these materials. So, never the less. So, this is the stress that is required to move a dislocation tau is equal to 2 Gb divided by L.

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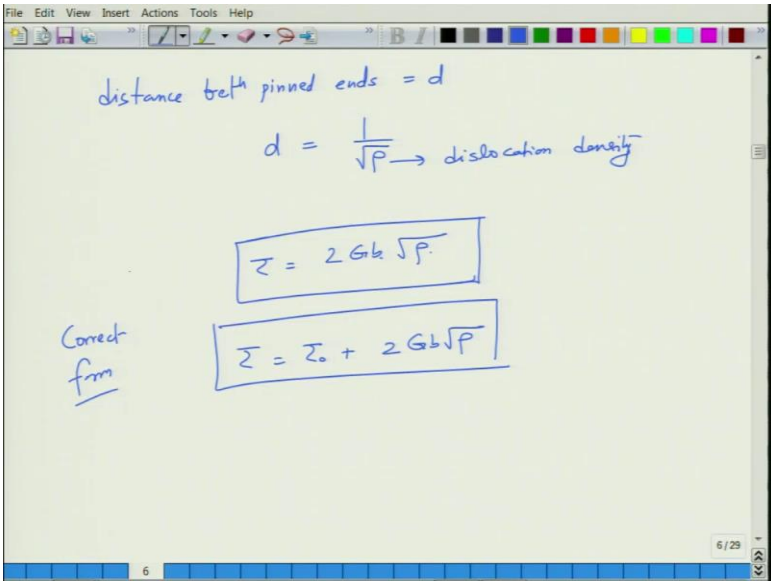

And says that distance between pinned ends is d and this d is related to dislocation density as 1 over square root of rho. So, this is rho is dislocation density, so because dislocation density the unit is number of dislocation per meter square, so it goes as 1 over. So, basically rho as 1 over d square or you can say that d goes 1 over square root of rho. So, if you write this stress then it becomes 2 Gb into square root of rho.

So, this is what the stress required to move a. So, essentially this, empirically this equation will be tau is equal to tau naught plus 2 Gb square root of rho. So, this is what basically the stress the correct form will be. But what it suggest is that, that as your dislocation density goes up the stress required to operate deform of material also goes up. So, this basically the minimum stress goes up as your dislocation density increases. So, this is basically about the Frank Read source operation.

Let me show you a video which shows you basically how Frank Read Sources look in reality when you looked at under microscope. So, by the way this video is also taken from doitpoms.ac.uk. So, which is university Cambridge website. So, we acknowledge their role in having this video available to you.

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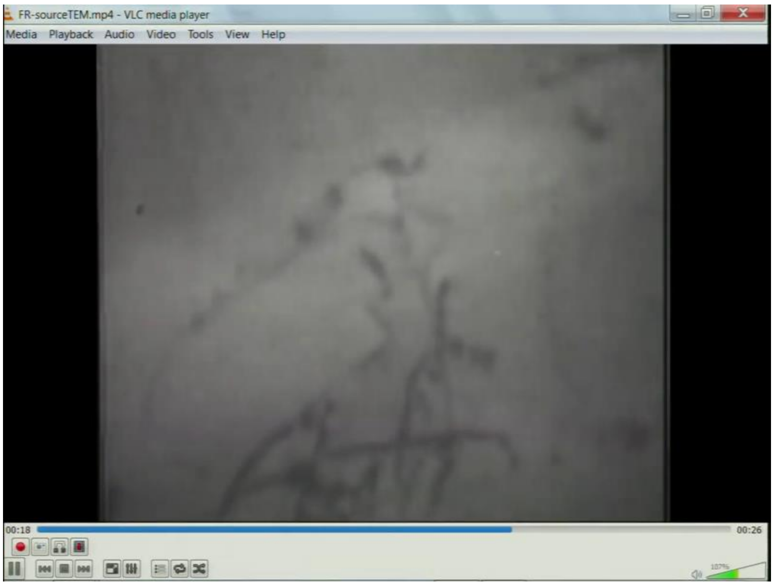
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So, this is what the video is. So, you can see that these are the dislocation which are getting created. So, you can see the continuously loops are being generated and they spread in the material newer loops are getting generated because you can see these black things which are nothing but pinning sites. So, as the stress is being applied you create more and more dislocations and they give, they basically lead to increase in the dislocation density further in the materials. So, this is essentially the operation of Frank Read source.

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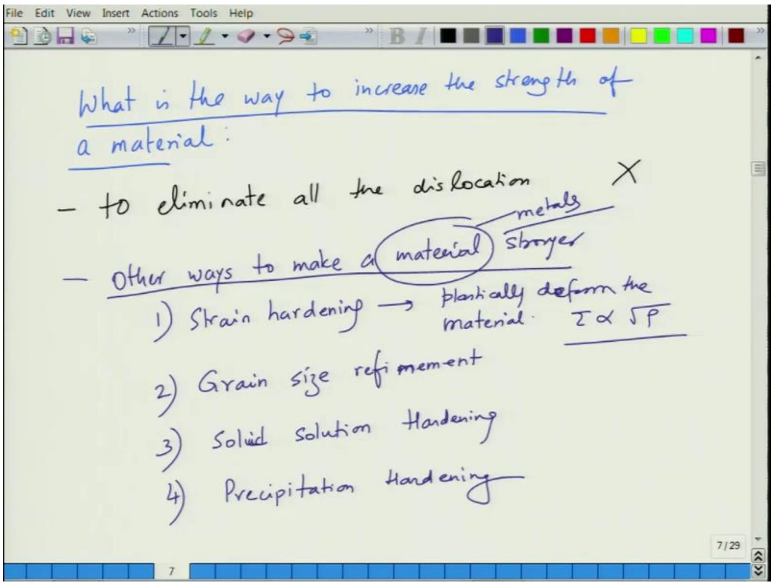

So, basically what we are saying is that now what is the way to increase the strength of a material. Now, one way of course is to eliminate all the dislocations which is not easy it is very difficult because removing the dislocations possible but it is impractical it’s very difficult to do that. You have to grow materials in every special manner and which is not easy. So, it is going to lead to lot of processing cost and may still not lead to tangible required outcomes.

So, what is the other way? There are other ways of making the materials stronger that is by doing the. So, there are other ways to make a material stronger, so we saw what we have seen that when the plastic deformation takes place because the dislocations move out of the crystal the dislocation.

So, that is a driving force for that is a driving factor for reducing the dislocation density. But on the, at the same time the dislocations are not, the dislocations pinned at various sites which could be because of their movement in various planes and they cannot move in all the planes with ease they could be pinned by let us say precipitate or some other external entities which causes them to behave the sources of dislocations such as Frank Read source which leads to creation of dislocation.

So, dislocation increase and multiply in number as you apply the stress and as you apply the stress when they increase in number the stress required to operate the source also keeps increasing. So, basically we have seen one mechanism that one mechanism as you increase the dislocation density the stress also increases.

So, the first mechanism that we have seen we will still, we will go again about it little bit more the first one is the strain hardening which is the simplest one basically you plastically deform the material and create more and more dislocation. So, we will see little bit of this in next few minutes.

Second way to deform, to make the material strong is to make grain size smaller or do the grain refinement. Third method of increasing the strength of a material is by doing solid solution hardening and the forth way to increase the strength of a material is by doing precipitation hardening.

So, these are the four methods by which generally metals. So, when we say materials generally we are talking in the context of metals. How do we make metals stronger? So, basically strain hardening is nothing but doing more and more plastic deformation, we will see, we have got some clue as of now.

The tau is proportional to square root of rho, so as you increase the dislocation density which increases by increasing the extent of plastic deformation the strain should go up. So, we will see little bit of that in next few minutes then of course we have the next thing called as grain refinement we will see as we reduce the grain size in the material the material becomes stronger, third thing is about solid solution strengthening.

So, without forming any external phases if you put little bit of impurity in a parent phase. So, you do not so you have to look at phase diagrams ensuring that you do not form the second phase the impurity remains within the solid solution whether it is intertitles solid solution or substitution solid solution the formation of these solid solution leads by strengthening and forth is precipitation where you create precipitate which are hard which are fine, which are smaller in size and they act as pinning sites for dislocations to causing strengthening. So, we will look at this this mechanisms one by one.

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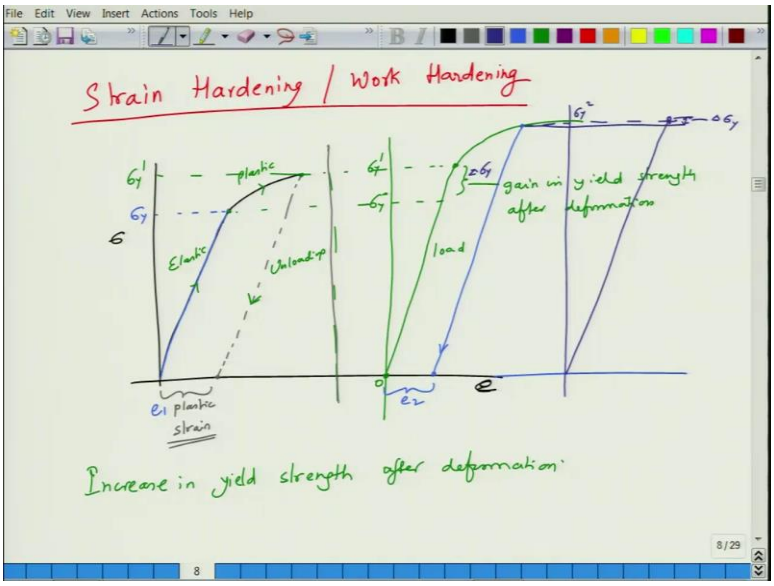

So let us first deal with the first mechanism that is strain hardening we also call it as work hardening. So, essentially what it means is that if you plot the stress strain curve of a material, so this is stress strain curve, let us say E and when you make stress strain curve in this fashion this is the elastic region then you go to plastic region.

So, up to this point you were in elastic region then you shift to the plastic region. Now after let us say, so this is the sigma y and this is some plastic strain that you have. Now let us say if you reach this plastic strain and you suddenly unload when you unload this much strain is the plastic strain you will recover the elastic strain but material will remain plastically deformed with this is permanent strain.

So, when you want to restart when you want to restart you will again restart at this point and when you again restart at this point you will re-join this curve. So, if you want to now, so this is let us say one ways second step, third step and when you want to restart, so when you want to restart let us say at this similar value of strain, let us say then you will re-join this curve basically at the same point.

So, when you re-join you will re-join this curve at same point. So, this will be the essentially strain, so basically earlier strength, stress that was required to a deform material was this, now the material is going to deform at this stress. So, you have increase yield stress of a material. So, basically the yield stress, so this is elastic deformation, this is plastic deformation, this is unloading, then when again you load. So, at this point let us say this is initial point let us say 0 again you will reach, you will not get back here.

So, this was the initial strength rather you go here which is sigma y let us say prime. So, you will go to this point. So, basically this much is the gain in yield strength after deformation. So, this is what will happen. So, your curve will now proceed like this. So, this is called as basically you can say the increase in yield strength after deformation.

So, basically if you further let us say, if you go along this plot and if you now further stop at this point and you unload it you will she will come here. So, this much is the extra strain, so this is e1 this is e2 if you again want to restart this material you will reach a stress level which will be this. So, now you will reach here, so this will be sigma y2.

So, this is again the extra increase in the, so delta sigma this is delta sigma y let us say. So, every time you stop the deformation you will again go back to the same point that you were that you were at earlier. So, this is basically because of plastic deformation causing the yield strength of material this is also called as work.

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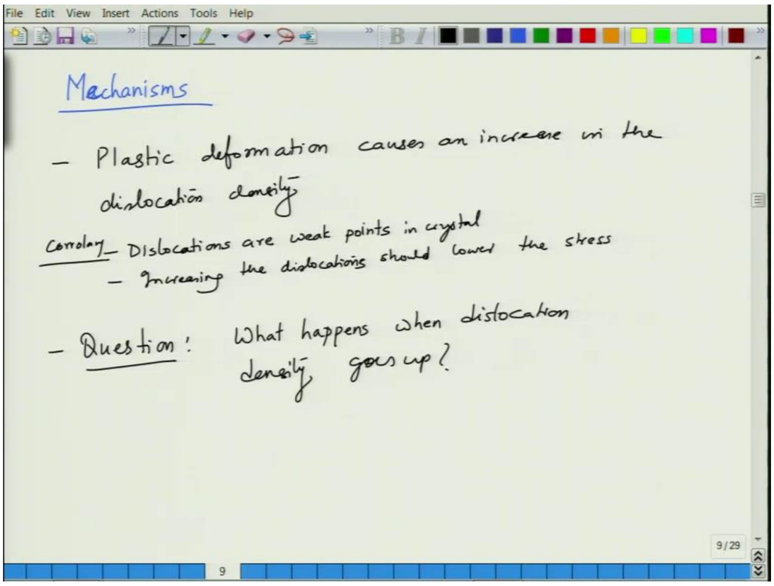

So what happens? Basically what happens the mechanisms first thing we know is that as we do plastic deformation we know that it causes an increase in the dislocation density and so all though we say dislocations are weak points in the crystals because they reduce the stress that is required to deform a material. But so this is this is something we can say a corollary or this is something we stated earlier that dislocations are weak point.

So, increasing the dislocation should lower the stress. So, question is what happens when dislocation density goes up? So, we know that dislocation density goes up, so why is that when dislocation density goes up the strength increases instead of coming down, so we will look at the reasons of that in little detail in the next few lectures.

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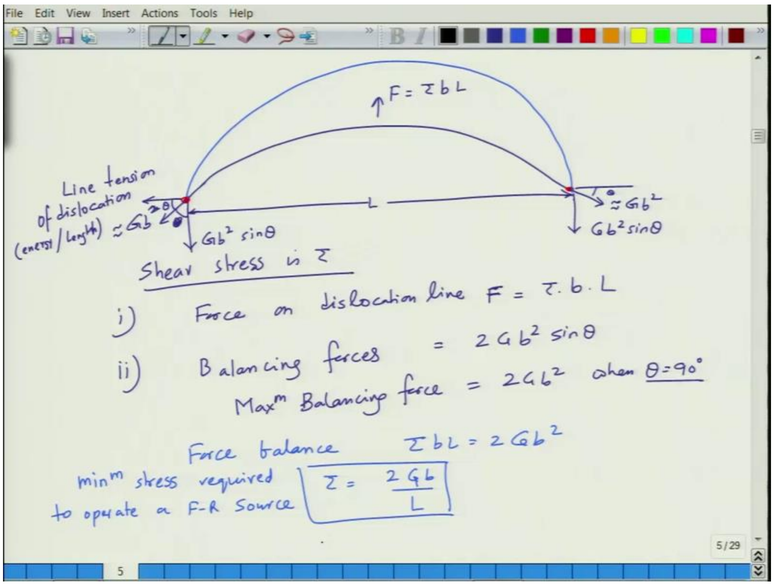

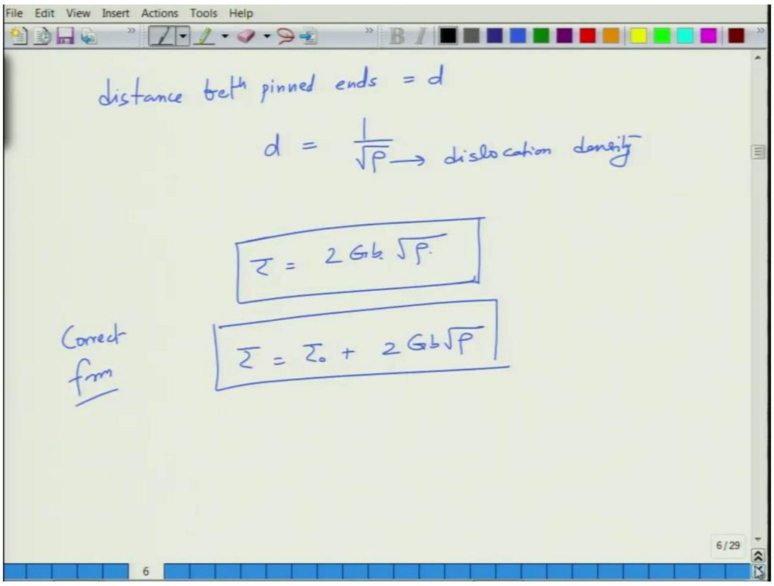

So, basically what we have done in this lecture is, we have looked at the sort of semi quantitative analysis of stress that is required to operate a Frank Read source this we have done by doing a simple force balance.

So, when you apply a shear stress tau the force on the dislocation line is tau bL which is balanced by the line, which is balanced by the line tension of the dislocation and the maximum line tension that you can have is 2 Gb square. So, when you equate these two we get a equation that is tau is equal to 2 Gb divided by L and this distance between dislocation and the pinning end is d which is proportional to 1 over which is basically square root.

So, you can say d is equal to 1 over root rho or you can say rho is equal to 1 over d square. So, when you substitute in the above equation basically the stress required to operate a Frank Read Source is basically square root of dislocation density or so this is, so this says that the stress increases as you increases the dislocation density.

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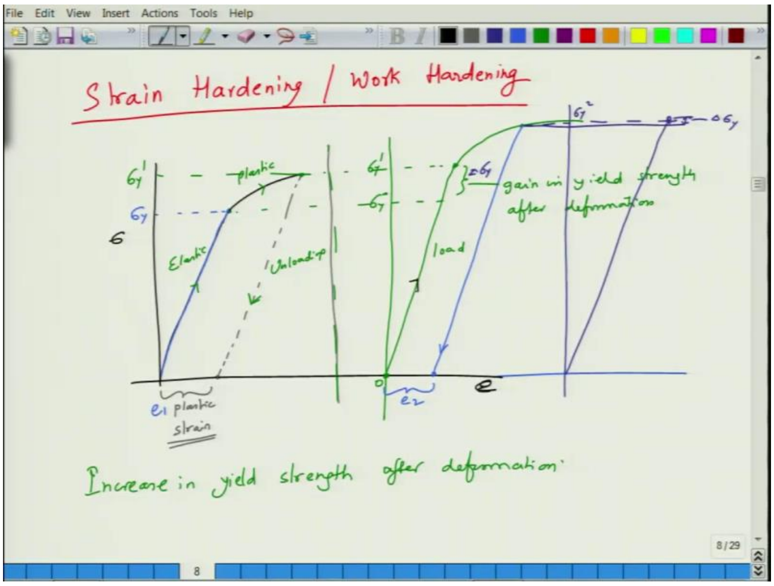

So and we see this experimentally because when you do stress strain curve wherever you stop the deformation and when you again restart deformation. So, this is restarting the deformation again when you restart the deformation you increase the yield strength by little bit corresponding to how much you where you were on the stress strain curve at the end of previous deformation.

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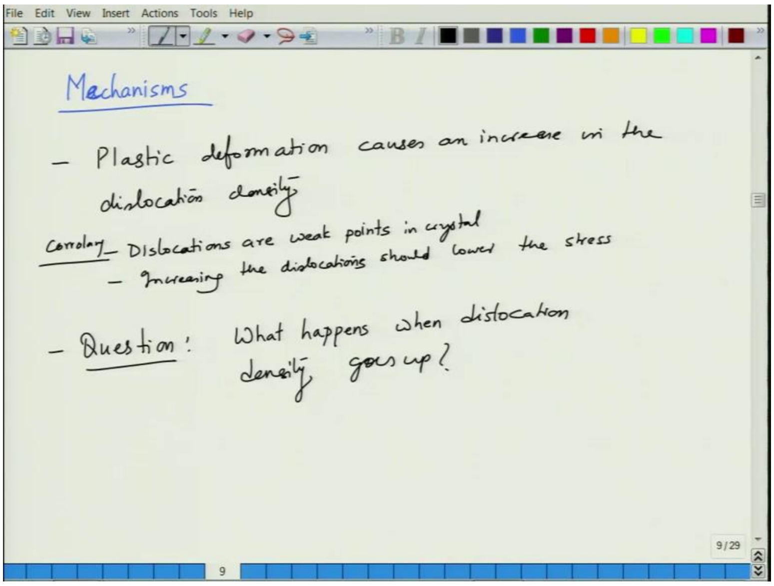

So, we know that stress increases dislocation density increases which is counterintuitive as we said that dislocation of weak point, they should have reduced that stress so, why is that? That we will see in the next lecture, thank you.