Dynamic Behaviour of Materials
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Lecture-37
Plastic Deformation at High Strain Rates 4

Hello everyone, so we were discussing the dislocation dynamics at high strain rate, so we have discussed thermally activated dislocation motion and drag controlled dislocation motion. Now we will talk about the third mechanism that is relativistic effects on dislocation motion.

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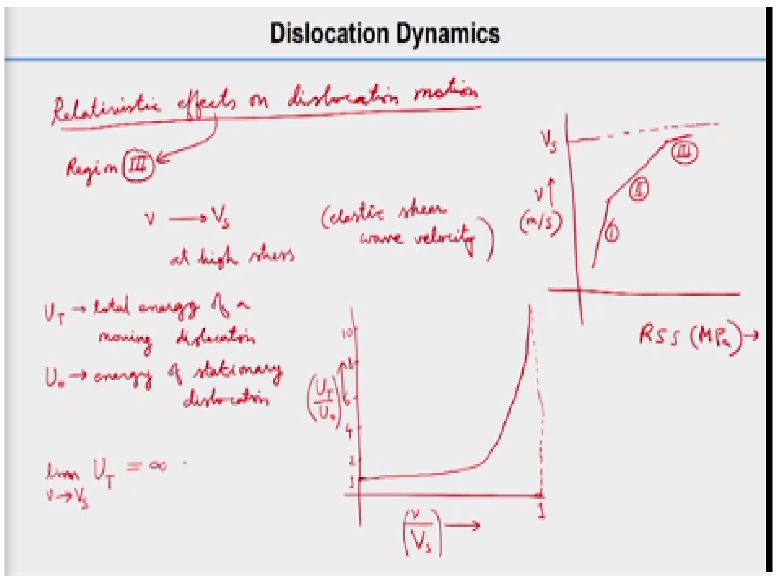

So this is the third one relativistic effects on dislocation motion, so very quickly we will draw this diagram whatever I have drawn probably couple of times this is resolve shear stress that is the applied stress. And this is the dislocation velocity we are keeping it as small v in meter per second. So for nickel, so it shows like 3 part, here the part 1, part 2 and part 3 from this point onwards.

And as we can see that this has the limiting value, so this is V s that is the elastic shear wave velocity. So in the region 3, so we are talking about the region 3, so region 3 the relativistic effects will be dominant here. So what happens is the dislocation velocity small v approaches V s this is capital V, so that is as you know elastic that you know that is elastic shear wave velocity.

So that we approach V s at a higher stress, so that at very high actually stress that is applied stress or here we are showing resolve shear stress. So this relativistic effect is with the help of another plot we can show that, this is another plot. So the velocity of dislocation small v divided by capital Vs is in the x axis, and then U T by u 0 I will tell you what is that, this is in the y axis.

So U T here is total energy of a moving dislocation and U0 is the energy of a dislocation at rest or energy of we can write stationary dislocation. So what happens if we plot it so let us say we have here the limit is 1. So that means when dislocation velocity approaches the shear wave velocity and here let us say our ratios are 2, 4, 6, 8, 10 like this.

And then what will happen is, so this will rise and it will rise kind of to infinity. So this is the energy the ratio of energy total energy moving dislocation divided by the energy of a stationary dislocation which is lower. If you see that it first start with from 1 because that means that the total energy of the dislocation is at rest and that is both U T = U0 here. And so what the plot says is if you take a limit from dislocation velocity V to V s.

If it approaches elastic shear wave velocity, then the total energy of a moving dislocation is infinity, it tends to infinity.

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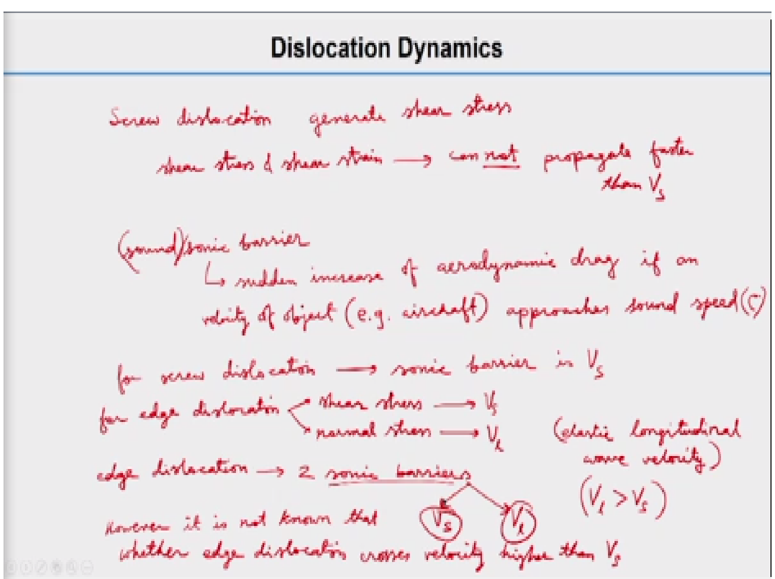

If you see Einstein's relativity theory, so that says that mass at a velocity small v is related to a mass at rest. So here this mass is or you would write mass at rest, so here this mass at rest is we can call m0 and here it is m. So I would better write a mass, so this will be is equal to m0 just 1 - v both square v square - C square. So as you know that C is the velocity of light.

So if the velocity of the mass is approaches the velocity of light the mass m will be kind of infinity, so that is the Einstein's relativity theory. So very analogous this is our dislocation velocity is also analogous to it. So here we can call that so analogous that means what we are saying for dislocation. So what is that is, this is m0 1 - small v dislocation velocity divided by capital V s square the elastic shear wave velocity square of that.

So here m is equivalent or effective mass of the dislocation ok, so this is analogous that is why we recall this a relativistic effect. So this is known as relativistic effects on dislocation motion. So as we know that we have not discussed much but just to let you know that dislocation particularly the screw dislocation generate shear stress. And these are shear stresses and even it will produce shear strain.

So these shear stresses and strains cannot propagate faster than shear wave velocity elastic shear wave velocity. So it is kind of sound or sonic barrier, so we can call this even break it sound that is called sonic barrier I think you probably have heard about this. So what happens the sonic barrier means the sudden increase of aerodynamic drag and other effects. If an object for example an aircraft ok, so approaches sound speed so if yeah if the velocity of object approaches the sound speed.

So like for this screw dislocation, so we can say that this is sonic barrier for a screw dislocation is V s like what we had for a ordinary sound sonic barrier is the sound wave velocity is let us say C. So here we are saying that for a screw dislocation the limiting velocity is V s the elastic shear wave velocity. However for edge dislocation, so we have both shear stress and normal stress, so as dislocation generates both shear stress and normal stress.

So the limit of this dislocation velocity should be V s for shear stress and V l which is a velocity of elastic longitudinal wave or I would write elastic longitudinal wave velocity. So probably it is dislocation has 2 sonic barriers, so 2 sonic barriers right. So first maybe first one is let us say it maybe first V s and then V l as we know that the V l is longitudinal wave velocity is higher than V s the longitudinal wave velocity is probably 2 times that of sound wave velocity.

It is believed that there are 2 sonic barriers for edge dislocation, however it is not known that whether as dislocation crosses velocity higher than V s that is not well established. But still is believed to have 2 sonic barriers one is a shear wave velocity for shear stresses and for normal stresses it is V l that is longitudinal wave velocity.

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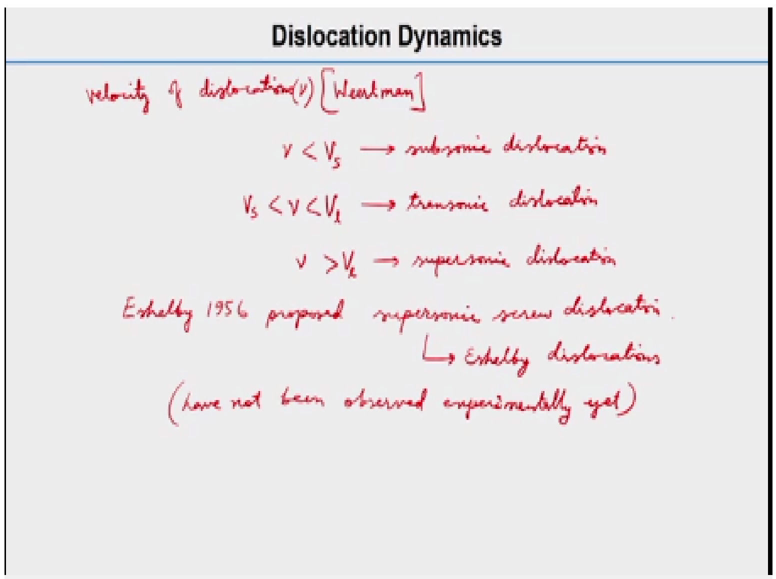

Velocity of dislocations where defined by Weertman defined as small v that is velocity of dislocation, I would write small v here as well. So that is if it is smaller than shear wave velocity that is called subsonic dislocation. And if this is higher than shear wave velocity but lower than the longitudinal wave velocity. So then it can be called as transonic dislocation and if dislocation velocity is higher than V l then we can call as supersonic dislocation.

So the famous researcher Eshelby in 1956 proposed that supersonic screw dislocations are available, however ok these supersonic dislocations are known as Eshelby dislocations. However these dislocations have not been observed experimentally yet, so this is just a classification of dislocations in terms of velocity proposed by Weertman and also the subsequent researches.

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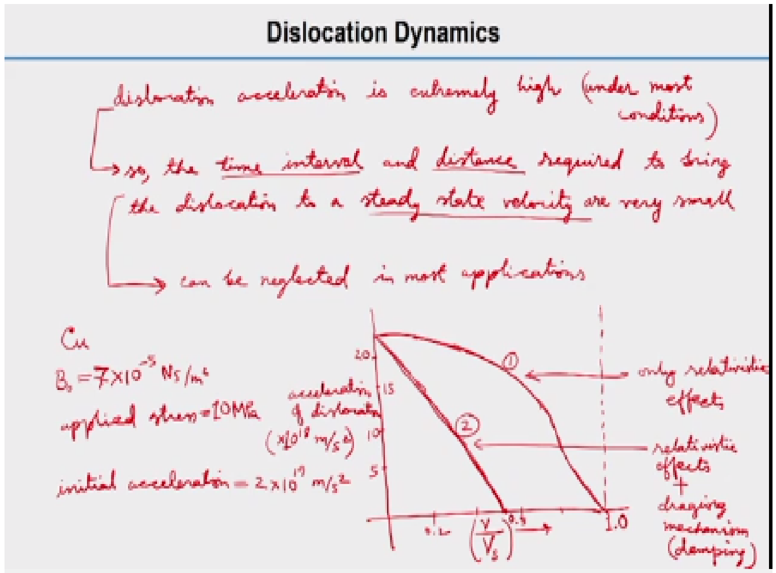

Dislocation has very high acceleration, acceleration is very high I would write extremely high under most conditions. So the time interval and the distance required to bring the dislocation to a steady state velocity is very small. That means what is small or rather I should write are small. So the time interval and distance required to bring the dislocation to a steady state velocity, it is very small.

So because the acceleration is very high and so and mostly these time required and distance can be neglected in most applications not all applications but most applications. So this can be plotted in the X axis dislocation velocity small v divided by shear wave velocity capital V s and in the Y axis acceleration of dislocation ok. So this is in terms of 10 to the power 18 meter per second square very very high value.

So let us assume that 5, 10, 15, I would write here and then 20, so and in this case we will write thus limit this is 1 when the dislocation velocity will approach shear wave velocities. So here I would write these 0.8, 0.6, 0.4, 0.2, it is a 0.4, so what will happen is. So there are 2 possibilities we can have 2 approximations one is a straight line like this and the other one is it is something like this ok this may not be very perfect but you just please check the Mark Meyer's the diagram.

So there are 2 possibilities of approximations here the first one the straight line ends here around 0.5. So I would say this first one this is curve number 1 let us say and this is 2, so first one is considering only relativistic effects. And the second one both relativistic effects + damping that is dragging mechanism or simply we can write this as even damping. So this is the curve is for copper Cu and then the damping coefficient B0 is 7 10 to the power - 5 Newton second meter square.

And applied stress is 10 mega Pascal. So this is the information related to the plot and initial acceleration you can see it is very high it is from the plot you can see it is almost 2 into 10 to the power 19 meter per second square very high value. So what will happen, we will have both the curve so we will go to the next slide and we will show you. So and the curve 1, this first curve what happened is acceleration steadily decrease and becomes 0 and then if drag is present and a number 2.

So what happens the steady state velocity will be 0.5 times of that of the shear wave velocity at that applied stress level, so we have a 10 mega Pascal here.

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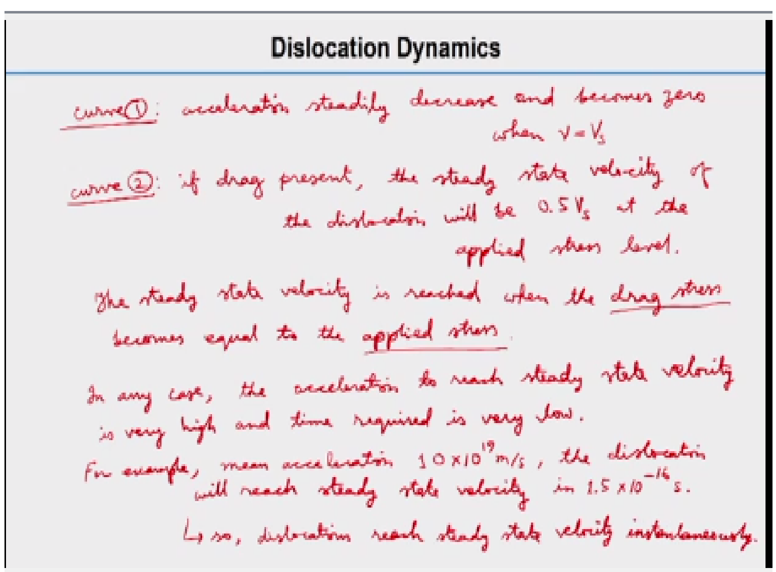

So I would just write for the curve 1 that is only relativistic effect, so the acceleration steadily decrease and become 0 when dislocation velocity is equal to V s, the shear wave velocity or it approaches the shear wave velocity. Number 2, if drag present, if we consider drag mechanism the steady state velocity of the dislocation will be 0.5 times of V s at the applied stress level.

And also one important point the steady state velocity in the case 2 is reached when the drag stress becomes equal to the applied stress. So this is drag stress and this is applied stress if they become equal the drag stress becomes equal to the applied stress steady state velocity is reached. In any case, so whether it is case 1 or case curve 1 or curve 2 the acceleration to reach steady state velocity.

That means acceleration of the dislocation is very high and time required is very low. So for example we just will give an example for example suppose the mean acceleration in this case whatever we have seen in the earlier slide that from the curve the mean acceleration if it is 10 to the power 10 into 10 to power 19 to the power 19 meter per second. And then the dislocation will reach steady state velocity in approximately 1.5 multiplied by 10 to the power - 16 second very very small time.

So 1.5 10 to power - 16 second. So that means dislocations reach steady state velocity instantaneously. So with that, so we are closing for today, so we have discussed about the 3 mechanisms of dislocations motion. So first one is a thermally activated motion and second one is drag controlled mechanism and the third one is relativistic effects at very high stress. This is all for today and I think we will discuss a little bit of more about constitutive formulation at high strain rates and then we will go to the next chapter, thank you.