Creep Deformation of Materials
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Part 3
Creep and Different Factors That Influence Creep Deformation-Part 3.

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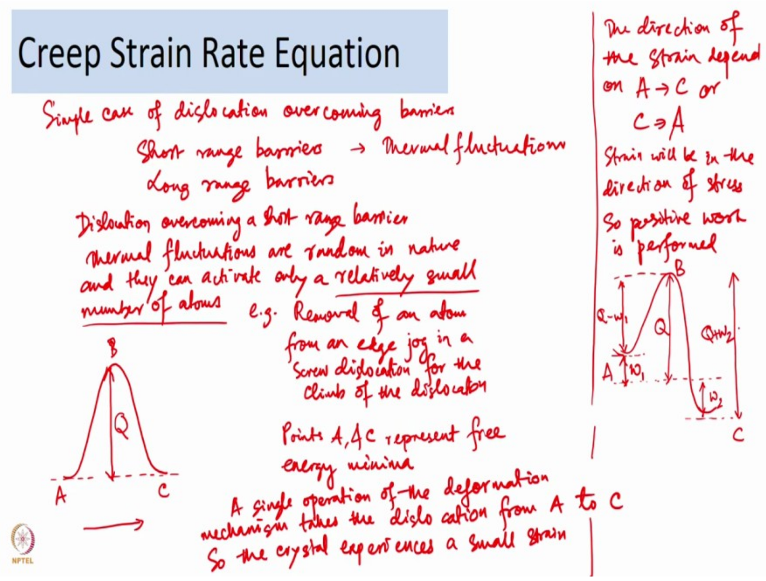

If you are interested in determining the strain rate of deformation, then this is the following approach, this is the approach that we are going to use. So most creep mechanisms, either they happen by diffusion of vacancies or they happen by, the involve dislocation motion. So now for the derivation of the creep strain rate equation, let us assume a simple case. Simple case of dislocation overcoming barriers. So, if you remember in the previous lecture in one of the slides I was talking about the barriers to this location motion or barriers to plastic deformation and we were talking about 2 types of barriers.

You have, just as a recall you have short-range barriers and you have long-range barriers. And short-range barriers, is it remember we said it is possible to overcome these barriers by thermal fluctuations alone. So the barrier is such that just a temperature fluctuation, just thermal energy provided by providing you can overcome the barriers. Now for the case of dislocation overcoming barriers, we are going to do talk about a simple case of dislocation overcoming a short-range barriers.

Now, one of the things about thermal fluctuations, thermal fluctuations are usually random in nature, so these are stochastic processes. And they can activate, the thermal fluctuations can activate only a relatively small number of atoms. And that is why it is a short-range barrier, right, because we said short-range barriers are those where the atomic distance is involved, typically if you atomic parameters. Maybe a couple of atomic diameters or 5 atomic diameters, whereas when you talk of language barriers, you are talking distances which are significantly larger, maybe 300 or 1000 atomic distances.

So thermal fluctuations can activate only a small number of, relatively small number of atoms, when the distances are small. So the example, if you remember, one of the few examples is removal of an edge jog in a screw dislocation for the climb of the dislocation. So for the dislocation to overcome the barrier, the energy is being provided by thermal fluctuations, so let us now look at a simple diagram. So say this is a barrier, you have position A and say position C.

To go from position A to C position, you have overcome a barrier and the top of the barrier is position B. And points A and C represent free energy minima. So in the material, the dislocation is in a low-energy condition in the configuration at both points A and C. And it is now trying to go from A to C, it favours either, in either case it is comfortable, whether it is in A and C, because a free energy is low, so it is comfortable. But it has to overcome this energy barrier described by point B.

Now a single operation, so if there is a mechanism, that a certain mechanism which helps the dislocation overcome this barrier. So a single operation of the deformation mechanism takes the dislocation from A to C. So because the dislocation is moving from one point to another point, so there is going to be some amount of plastic strain associated with it. So because of this motion, the Crystal experiences a small strain. And the direction of the strain, the direction of the strain depends on whether the dislocation is going from A to C or from C to A.

In this case we are talking about the dislocation going from A to C. Now let us assume the case where the stress is acting in the direction which pushes the dislocation from A to C. So there is a stress which is trying to push the dislocation in this direction and we know that typically strain will be in the direction of stress. And so positive work is performed here. So, work is performed and this is positive work, so the stress is making the dislocation move.

There is some strain that is generated in the process, so you have stress and strain, the product of that will give you energy. So basically because of the presence of stress, what is now happening is the energy barrier is getting lowered. So this is B, this is A and this is C. So the original, with respect to the original locations A has moved up, so say by a quantity W1, that is the work performed and say C has come down by a quantity W2.

And the activation energy barrier, so to go from A to B, that is an energy barriers so Q is going to remain the same but the activation energy barrier for moving from A to B is going to come down. So, it is going to become, so it is going to become Q - W1. And because the system is driving, because the presence of stress is driving the system forward, so it is going to become even more difficult for the dislocation to move in the opposite direction.

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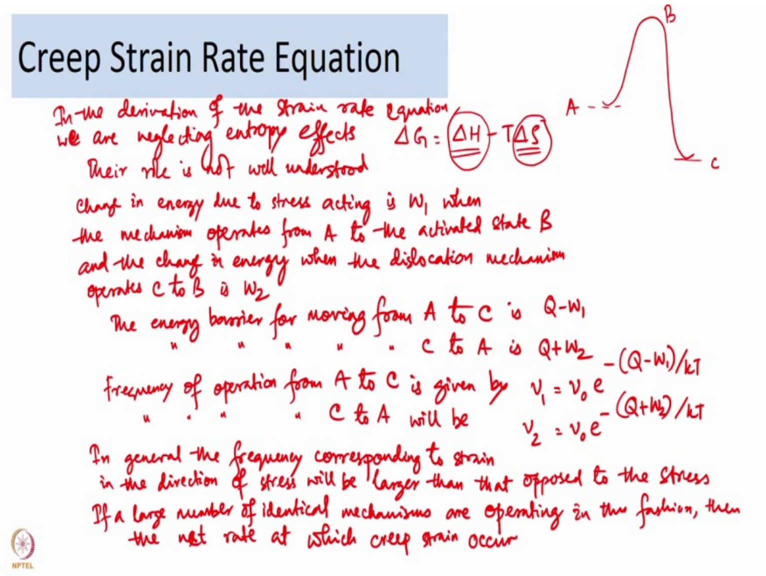

So C is going to come down and so now the barrier for the dislocation to move from the nu position of C to B will be Q + W2. So, in the derivation of the strain rate equation, we are neglecting entropy effects. So we are talking about point 1, point A and point C and we said that they are at a low energy configuration, both A and C. So, when A moves, when the point, when the dislocation move from A to C, we are talking about a free energy change. And generally when we talk of free energy change, we said Delta G and Delta G is Delta H - T Delta S, so this is the enthalpy change and this is the entropy change.

But in creep conditions people generally ignore the role of Delta S. So whatever free energy change that is happening is generally described in terms of Delta H only. So the strain rate, we are neglecting entropy effects, one of the reasons of neglecting entropy effects is because their role is not well understood. So, coming back to the drawing, so you have a situation. So

A to C in the presence of a stress, so the change in energy is W1 when the mechanism operates from A to the activated state B.

And the change in energy when the dislocation mechanism, so when we talk of mechanism, we are talking about the dislocation mechanism, the mechanism by which the dislocation is moving. The change in energy when the dislocation mechanism operates from C to B is W2. So, the moment you climb up the Hill, so A, the dislocation climbs up the hill to B, then it is going to be easily go back, easily go down to C because that is law of thermodynamics. So it is going down the energy barrier, so it is going to be easy.

So for A to move to C, the energy barrier effectively is, so the energy barrier for moving from A to C is effectively Q - W1. And the energy barrier for moving from C to A is effectively Q + W2. Now, from reaction rate kinetics, it is known that the frequency of operation, the frequency of operation from A to C is given by nu one is equal to nu 0 c to the power - Q - W1 over kT. And the frequency of operation from C to A will be nu 2 is equal to nu 0 e to the power - Q + W2 over kT.

So this is coming from reaction rate kinetic. So B is the activated state, A, in reaction rate kinetics when you are talking about those reactants reacting with each other to form the product, so they go through an intermediate stage which is the activated stage before they reach the product state. So similar thing here, similar concepts that work here. So the, in general the frequency corresponding to strain in the direction of stress will be larger than that oppose to the stress.

So since the stress is aiding in the dislocation motion, so the probability of dislocation moving from A to C is going to be higher than the reverse of it which is coming back from C to A. So that is because of the presence of the stress. So, if a large number of identical mechanisms are operating. So imagine a large number of dislocation is moving and in this fashion are operating in this fashion, then the net rate at which creep strain occurs.

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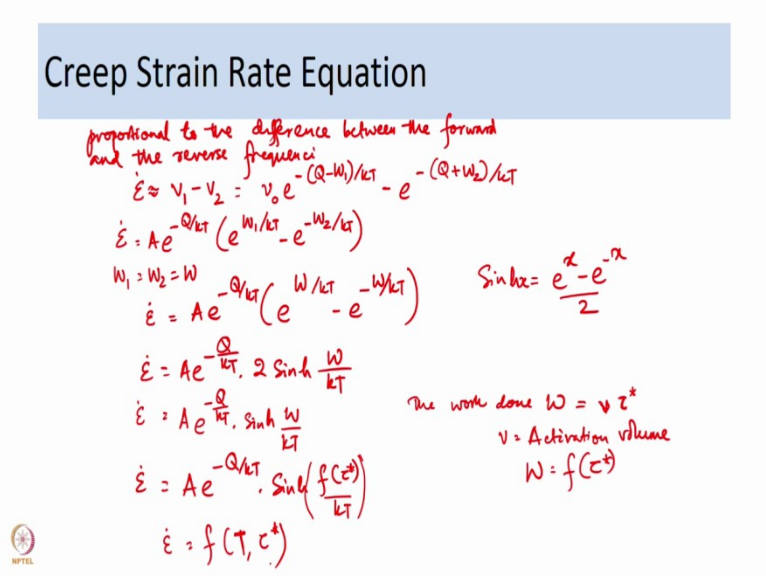

So the net rate at which creep strain occurs is going to be, so the creep strain rate, that rate is going to be proportional to the difference between the forward and the reverse frequencies. So we are talking about thermal fluctuations, besides it is kind of random, the dislocation can go from A to C or it could come back from C to A, both are possible. But when you have a stress present, then the stress is going to, the motion of the dislocation is going to be in the direction of the stress. So there will be the number of jumps possible from A to C will be higher than the number of jumps possible from C to A.

So the net strain rate of deformation is going to be dependent on the number of forward different jumps - the number of reverse jumps. So in this particular case, so you can say strain rate of deformation is going to be approximately the difference of the number of forward jumps - the number of reverse jumps. So since nu one and nu 2 have already been given, so it is going to be nu 0 e to the power Q - W1 over KT - e to the power, so this makes strain rate is equal to some constant e to the power - Q over KT into e to the power W1 over KT - e to the power - W2 over KT.

So then strain rate becomes A e to the power - Q over kT into e to the power W1 over KT - W over KT - e to the power - W over KT. So if you know the hyperbolic sine function, sinh is e to the power X - e to the power - X divided by 2. So we invoke that here, then strain rate becomes A e to the power - Q over KT into 2 times sinh W over KT. So here Sinh X is equal to e to the power X - e to the power - X by 2.

So we invoke that here, so then that makes Epsilon dot is equal to A e to the power - Q over kT into 2 types Sinh W over kT. So we can take 2 into A, so that becomes, basically it becomes strain rate is equal to Epsilon dot is equal to A e to the power - Q over KT into Sinh W over KT. So the work done W can be basically described as the product of the activation volume V into the stress acting tao star. So V is, so basically W can be considered as a function of Tao star, so this makes strain rate is equal to A e to the power - Q over KT into Sinh some function of Tao star by KT.

So what we have arrived at is basically a relation between the strain rate of deformation, so we are getting a relation that strain rate of deformation which is a function of Tao, function of temperature T as well as the applied stress Tao. So this is a very important equation that we have arrived at and we are going to come back to this equation in a slightly different form. So we are going to look at this equation again, so this equation is the heart of creep deformation. So it basically tells you the relationship between the strain rate of a deformation and temperature T and the applied stress Tao.

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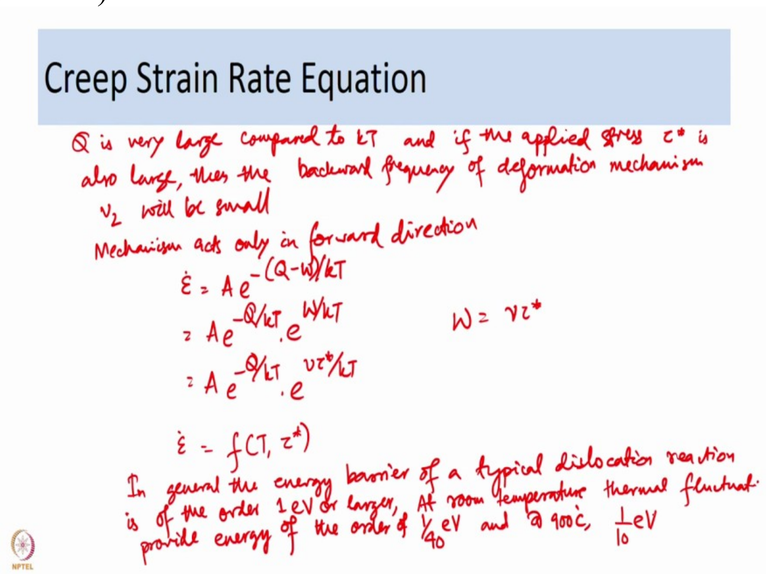

There will be slight variations of this equation but the concept is going to be the same. So, here we were talking about the forward and the reverse frequencies but, so here we were talking about the forward and the reverse jumps but if under certain conditions, so the conditions where Q is very large, so the activation energy of deformation say it is very large compared to kT. And if the applied stress which we considered as Tao star, if the applied stress is also large, then the backward frequency of deformation nu 2, backward frequency of deformation mechanism nu 2 will be small.

So in that case what would happen, is the mechanism to acts only in forward direction and Epsilon dot is going to become A e to the power - Q - W over kT. And that becomes Epsilon dot is equal to A e to the power - Q over KT into e to the power W over KT. We already said, W is activation volume into Tao star, so that makes it A e to the power - Q over KT into e to the power nu tower star over KT. So, so this is another form of the equation, so strain rate as a function of temperature and Tao star.

So this describes the dependence of strain rate of deformation on temperature and stress. So in a, in general the energy barrier of a typical dislocation reaction. So we are talking about the energy barrier Q, so in general, typical dislocation reaction, the energy barrier is of the order of 1 kilo, 1 electron volt or larger. So at room temperatures the thermal fluctuations provide, as the thermal fluctuations provide energy of the order of 1 by 40 electron volts. And around, at high temperatures, say around 900 degrees centigrade or so, the thermal fluctuations provide around 1 over 10 electron volts.

So what this tells is that as you keep increasing the temperature, the energy provided by thermal fluctuation is also going to increase. And that is why it becomes easier for the dislocation or the defects, the dislocations to overcome the energy barrier at higher temperatures. So of course, since the contribution from thermal fluctuation is only 1 over 10 electron volt, it is only smaller compared to the barrier height.

So you also need to stress to play a role, so that is why both stress and temperature together will help you in, help the dislocations overcome the barriers to plastic deformation. And that is how both have a role to play.