Mechanical Behaviour of Materials
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Lecture - 41
Mechanical Testing – IX

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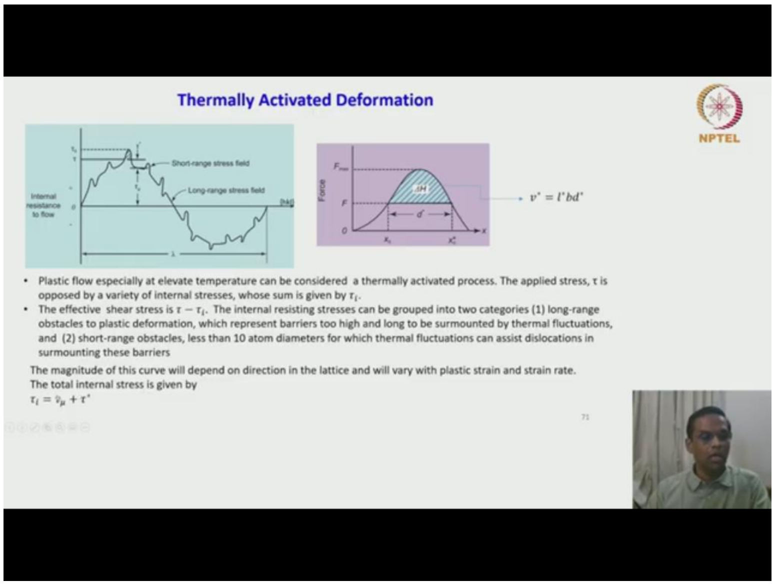

Hello, I am Professor S. Sankaran in the Department of Metallurgical and Materials Engineering. Hello everyone welcome to the lecture on mechanical testing, we have been looking at basically all the basic mechanical testing and the results and interpretation, especially in the last class we looked at high temperature tensile deformation activation energy how it is you know applicable to other type of materials especially on slide materials.

We looked at even deformation kind of mechanism maps for the metallic class how the temperature and the strain rate you know dictates the mechanical aspects of deformations and so on. So, in that connection I just want to complete one more aspect of high temperature deformation called thermally activated process. So, let us look at the points important points in this plastic flow especially at elevated temperature can be considered a thermally activated process.

The applied stress τ is opposed by a variety of internal stresses whose sum is given by τ_i. Before even getting into the details, this particular aspect of what we are going to look at now slides which is also formed a foundation for the high temperature deformation we are going to see the next chapter for example, you know stress structure and creep testing so on or creep formation we are going to look at from elaborately even super plastic deformation and so on.

So, this is very basic. So, in general this plastic flow at elevated temperature is considered thermally activated process. So, experimental study on the activation energy of plastic deformation and it is, you know the influence of temperature, strain rate; the deformation impurity etcetera is again your primary activity of studying the theoretical models of deformation are explicitly a dislocation process which is involved in the high temperature deformation.

So, that is the primary idea. So, in this context to the tensile test which is performed at very high temperature is directly connected to this people have estimated the activation energy and then try to connect the dislocation substructure is involved and then finding out the activation energy and so, on. So, we just I would like to just look at touch upon this aspect and then we can move on to the next topic. So, I thought it will form a foundation. So, the applied stress τ that is shear stress is opposed to a variety of internal stresses whose sum is given by τ_i, how do we understand this? So, the effective shear stress is $\tau - \tau_i$ the internal resisting stresses can be grouped into two categories one is long range obstacles to plastic deformation which represents barriers too high and long to be surmounted by thermal fluctuation and second short range obstacles, less than 10 atom diameter for which thermal fluctuations can assist dislocation in surmounting this barriers.

See, we have to just now understand these two classifications. Before we discuss further so, what it says a long range obstacles to plastic deformation. What is this long range obstacles? So, basically the long range stresses which is caused by it could be a dislocation, it could be precipitation or it could be a massive second phase particles and so on. So, their contribution, so in general they do not get affected by the temperature and strain rate except that the high temperature will results in the decreasing in the shear modulus of this constituents. So, other than that, it does not have anything to do. So, the contribution of this long range stress to the internal stress through the in terms of shear modulus what is called that? That is called $\tau\mu$ that that parameter we are going to see. On the other hand the short range obstacles what are the short range obstacles? If you look at the stress fields come from the other dislocations or dislocation intersections or dislocation climb, dislocation cross slip and intersection jogs and other things these are all will contribute to the short range obstacles, which can be easily surmounted by thermal fluctuations. So, the previous one in fact the long range obstacles are all called a thermal barriers because the temperature extended do not affect them directly I mean they are independent of the temperature strain rate and the short range obstacles are called the thermal barriers because the thermal fluctuations will surmount this and they will overcome this. That is the idea of these two classifications.

So, if you look at this schematic what does it show? This is an internal resistance versus the λ, I mean this is a shear stress a long range stress which is in the lambda which will act in the lattice depending upon I mean the lattice in arbitrary orientation and the magnitude of this long range stress depends upon the typical orientation some other factors like that we know from the earlier definition also right the magnitude of the shear stress it depends upon so many factors.

So, what is shown here is this long range stress which is represented by the lambda and then the small peaks they are all the overlapping short range stress field. So, you can see that the short range stress speed which is the magnitude is equal to τ_0 which is a shaded region about the applied stress τ. So, for a given temperature that means at the 0 Kelvin the τ_0 will be 0 because the thermally activated process is not there. So, the applied stress will be τ but even if there is a small increase in the temperature that will assist the τ decreasing the τ. So, even if you assume that small temperature increase and then that fluctuations helps to reduce the τ further and then when it reaches $\tau\mu$ which is I mean shear modulus which we talked about. Then you can see that it will surmount all the barriers thermal barriers which will take care of all this short range stress field.

See you have to just bring back all the old concepts which we have already studied to connect this, if you look at this what you are seeing the right hand side, so, force versus distance plot. So, exactly similar plot we have already seen where we looked at what is the thermally activated process with exactly we have seen that it is the same plot, but we are just trying to address the mechanisms in terms of high temperature deformation and we try to connect this with the dislocation substructure that is the only difference rest all are the same.

So, the magnitude of this term will depend on the direction in the lattice that is what given here and will vary with the plastic strain and the strain rate. So, the total internal stress is given by $\tau_i = \tau\mu + \tau^*$. So, the $\tau\mu$ the total internal stress which is resisting the applied shear stress is τ_i $\tau\mu$ is the shear modulus which is given by all the obstacles of long range obstacles. And τ^* is the short range obstacles like dislocation climb pulse Navarro force and dislocations cross slip and so on. So that is how we should understand this. So, this is the total internal stress.

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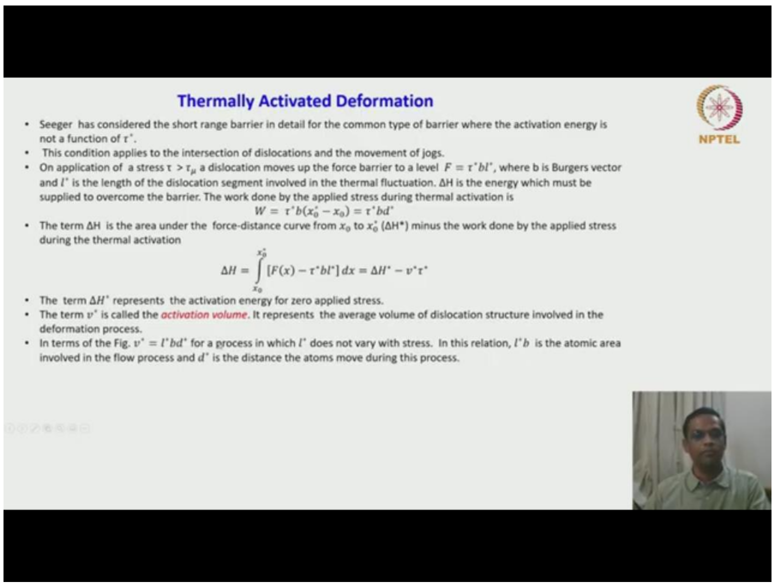

So, what we have to now understand is the following. Seeger has considered the short range barrier in detail for the common type of barrier where the activation energy not a function of τ^*. This condition applies to the intersection of dislocations and movement of jogs. On the application of stress τ which is greater than $\tau\mu$. So, that means what it is sufficiently enough this shear stress is sufficient enough to surmount all the secondary short range or local short range obstacles. It could be a thermal fluctuations dislocation moves up the force barrier which is shown in the previous slide to a level of $F = \tau^* b\, l^*$. So, these particular expression also quite familiar to us. So, it is given in a different slide different notation, but the meaning is same we have seen that $F = \tau\, b$ is a very basic equation we have been seeing from the beginning. Where b is a Burgers vector and $l^*$is the length of the dislocation segment involved in the thermal fluctuations.

So, we are now concentrating on the dislocation segment, which is involved in the short range obstacle, the shaded region of the small peak what means is overlapped with the long range stress lambda that is what it is. So, Δ H is the energy which must be supplied to overcome the barrier. The work done by the applied stress during the thermal activation is

$W = \tau^* b (x_0^* - x_0) = \tau^* b d^*$.

So, what is $x^* - x_0$? I go back. So, if you look at this force versus distance plot, so x_0 is here, x_0^* is here. So, this is the distance we are talking about. So, this is nothing but d, so this is the work done. So, the work done by the applied stress during the thermal activation is this given by this that is $\tau^* b d^*$.. The term Δ H is the area under the force distance curve that is a total area under the force distance curve from x_0 to x_0^*. Which can be also written as Δ H star minus the work done by the applied stress during this thermal activation, for $\Delta H = \int_{x_0}^{x_0^*} [F(x) - \tau^* b l^*] dx = \Delta H^* - v^* \tau^*$. So, this is a very simple expression to visualize the thermal activation energy, the term Δ H star represent the activation energy for 0 applied stress, the term v * is called the activation volume.

It represents the average volume of dislocation structures involved in the deformation process. If you recall we have used this term activation volume even in in the deformation maps of not dislike material that metallic glass etcetera. We have used the term activation volume there again we talked about the dislocated region the amorphous region that completely dislocated that total area was calculated I mean taking into account here it is a similar concept, but except that it is since being a crystalline material. We talk about the dislocation substructure which is involved in that process, so, that is only difference but the concept is the same. In terms of figure, we have seen that figure $v^* = l^* bd^*$, So, which is a hatched area that is Δ H what we have shown in the previous source distance plot which is you can relate this with the b*, that hatched Δ H* can be compared with this for a process in which l* does not vary with stress in this relation l* b is the atomic area involved in the flow process and d star is the distance the atoms move during this process.

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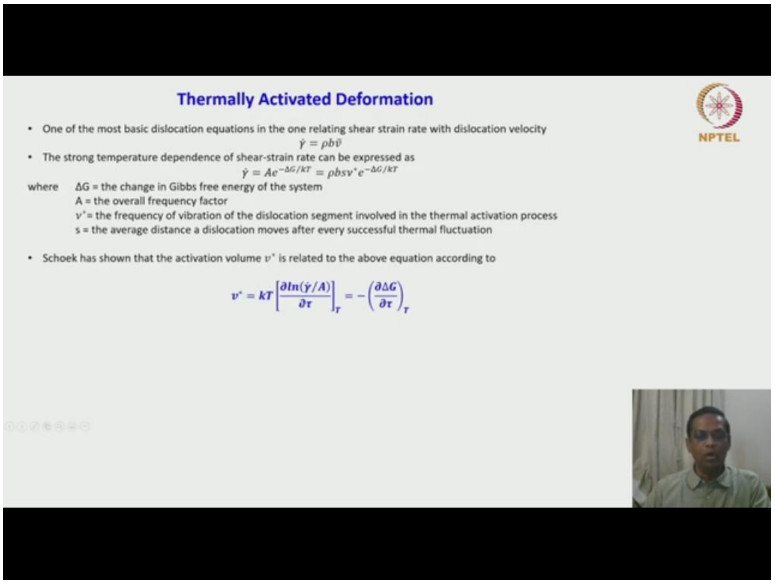

So, one of the most basic dislocation equations in the one relating shear strain rate with dislocation velocity is this $\dot{\gamma} = \rho b\overline{V}$ this equation also familiar to us. We have when we looked at the dislocation density we have looked at this and also some tensile deformation we have use this. The strong temperature dependence of shear strain rate can be expressed as $\dot{\gamma} = A e^{-\Delta G / KT}$, which is nothing but if you relate these 2 $\dot{\gamma}$ can be rewritten like ρbs v* $e^{-\Delta G / KT}$.

What are these terms Δ G the change in Gibbs free energy of the system A the overall frequency factor and v* the frequency of vibration of the dislocation segment involved in the thermal activation process, it is almost like we are saying that it is an activation volume, s is equal to the average distance, a dislocation moves after every successful thermal fluctuation. Schoek has shown that the activation volume v star is related to the above equation.

According to $v^* = KT [\partial \ln (\dot{\gamma} / A) / \partial\tau]$ at constant temperature which equal to $-(\partial \Delta G / \partial\tau)$ at constant temperature. So, this is one expression which can be experimentally found out we can find out the activation volume through experiments that is high temperature tensile deformation and then you get this quantities. So, that is why these two equations are being brought.

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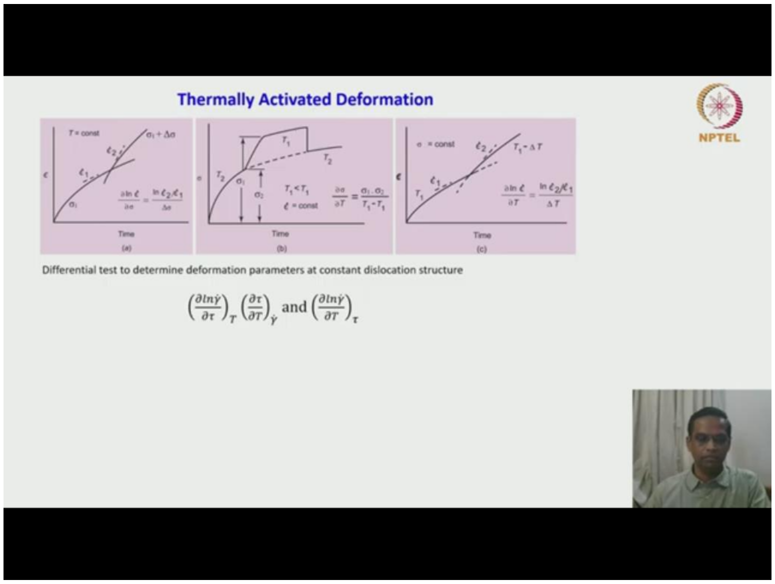

So, how do they find this quantities people do test tensile test and then create this strain versus time plot at constant temperature then you get these quantities. And then you can perform the test at constant strain rate then sigma versus time plot will give these quantities. And you can also perform constant stress test and then create this ε versus time plots and then to derive these quantities. So, this is a differential test to determine the deformation parameters at constant dislocation structure this is an assumption.

So, these are the quantities which you can find out from this simple high temperature tensile test and then grade these quantities and then relate this with the activation volume. This is just I just want to bring this because how do we people find the activation energy and then what is the meaning of activation volume and how it helps in understanding the high temperature deformation. So, that is why I just brought these concepts to this lecture.