Mechanical Behaviour of Materials
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Lecture – 31
Strengthening Mechanism in Crystalline Materials – IV

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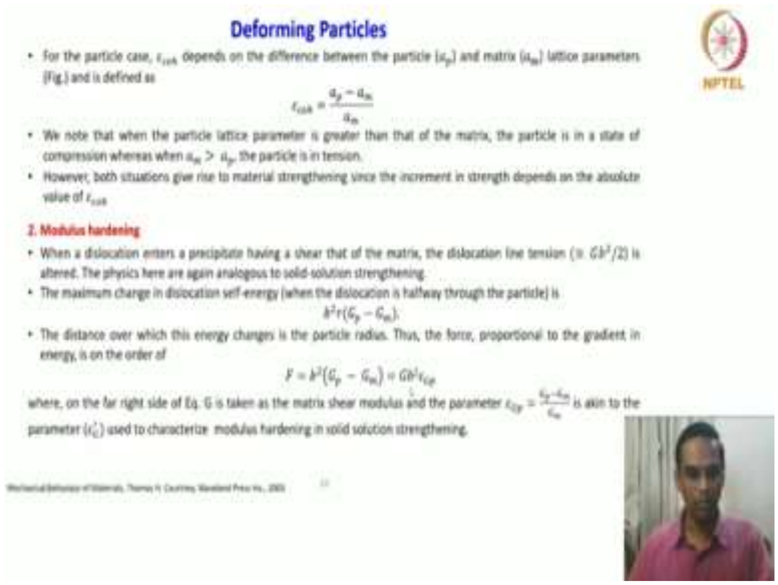

Hello, I am Professor S. Sankaran in the Department of Metallurgical and Materials Engineering. For the particle case $\varepsilon_{coherent}$ depends on the difference between the particle (a_p) and matrix (a_m) lattice parameters. So, a_p is lattice parameter particle a m is the lattice parameter matrix as shown in the figure you can write like this $\varepsilon_{coh} = (a_p - a_m) / a_m$. We know that when the particle lattice parameter is greater than that of the matrix the particle is in the state of compression whereas, when the a_m is greater than a_p the particle is in tension.

This is quite natural. However, both situations give rise to material strengthening. Since the increment in strength depends upon the absolute value of $\varepsilon_{coherent}$ .That is why, we said in the previous expression mod of $\varepsilon_{coherent}$ that is straight forward. We will look at the modulus hardening in a deforming particle type when the dislocation enters the particle having a shear that of the matrix the dislocation line tension ($\cong Gb^2 / 2$) is altered. The physics here are again analogous to the solid solution strengthening.

Since we have already looked at this modulus effect and so on this is not anything new, but only thing is we are bringing that idea to the deformable particle concept. The maximum change in the dislocation self energy that is when the dislocation is halfway through the particle is $b^2r(G_p - G_m)$, the distance over which the energy changes is particle radius, thus the force proportional to the gradient in energy is on the order of $F = b^2(G_p - G_m) = Gb^2G_p \varepsilon_{Gp}$.

Where on far right side of the equation G is taken as a matrix shear modulus and the parameter εG_p is $(G_p - G_m)/ G_m$ is akin to that parameter $\varepsilon G'$ used to characterize a model as holding the solid section. So, it is similar to what we have already seen in the models strengthening. So, nothing much to discuss here is all similar ideas and you are familiar with all this already.

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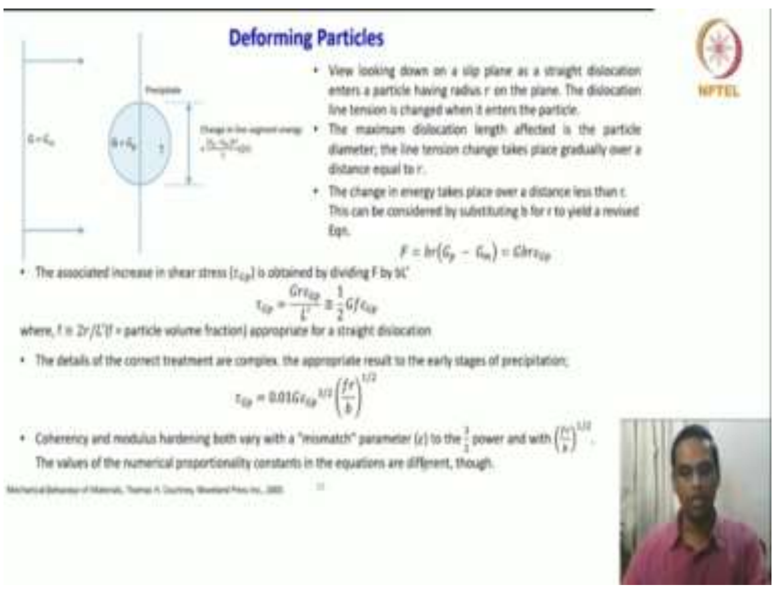

So, this is a schematic which shows that the deformable nature, so the dislocation line is there and it is moving in the matrix and this is a precipitate and the precipitate experiencing the dislocation entry and this is the line tension of the dislocation is altered and it is maximum when it goes to the distance radius here for the change in the line segment energy is driven by $\frac{(G_p - G_m)b^2}{2}(2r)$

that 2r is the maximum it could get across. So, that is what is given here.

So, the view looking down on the slip plane as the straight dislocation enters a particle having a radius r on the plane. The dislocation line tension is changed when it enters a particle; the maximum dislocation length affected is the particle diameter that is what is shown here it is it can travel from here to here. So, 2r the line tension change takes place gradually over the distance equal to r. So, the maximum changes can happen. The change in energy takes place over a distance less than r, this can be considered by substituting b for r to either revise the equation.

So, we can also consider you know the change in energy in the intermediate range, where we can use b instead of r. So, $F = br(G_p – G_m) = G p r \varepsilon_{G p}$. So, the associated increase in the shear stress is obtained by dividing F / bL. see this F / bL also we know this is a standard equation that force you know maximum force we are trying to find. So, $\tau G_p = Gr \varepsilon_{G p} / L'$ which is approximately equal to1/2 G f $\varepsilon_{G p}$.

Where $f = 2r / L'$, f equal to particle volume fraction approximate for a straight dislocation, we are simply substituting this 2r / L in this expression and putting it here and the details of the correct treatment are complex again, I am telling you we are only looking at the semi quantitative relations and approximate relations, the approximate result to the early stages of precipitation for modulus hardening is $\tau_{G p} = 0.01 G (\varepsilon_{G p}$^3 / 2) (fr / b)^1/2.

Coherency and modulus hardening both vary with the mismatch parameter ε. This is what is important idea, so the G p or the $\varepsilon_{G p}$ here and then this ε turn comes in all the coherency hardening as well as modulus hardening it comes there. And the ε the parameter ($\varepsilon_{G p}$ ^3 / 2) and (fr/b)^1/2, these two things are the parameters to look at. The values of the numerical proportionality constant in the equations are different. For the modulus and coherency that is understandable.

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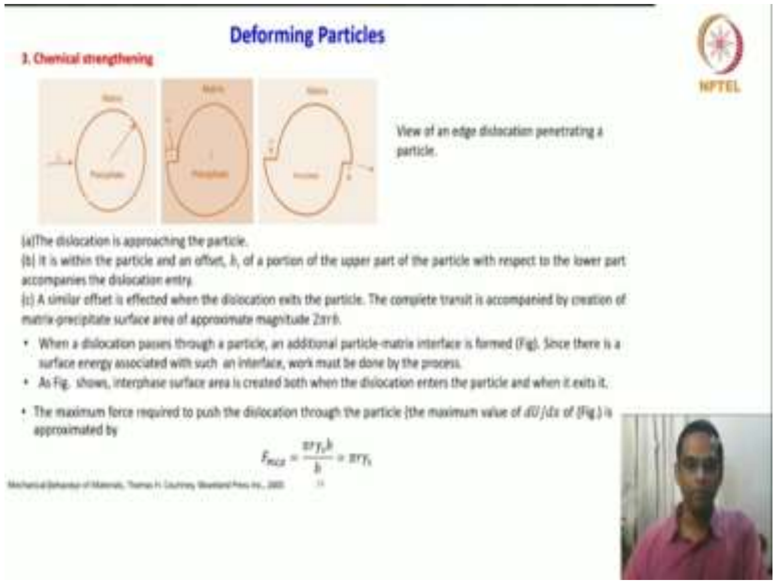

And the next one is chemical strengthening in this same domain, it is little fast because they are similar idea, but just subtle differences are there. That is why just rushing through but if you look at the equation, they are all similar equations; the parameters are all similar except the core differences only have to identify. So, the next one is chemical strengthening, what is chemical strengthening?

Same idea the dislocation is approaching a particle then what happens? It enters here and then creates a new surface this is spherical particle and then what dislocation enter the Burgers vector b and it creates the step here. So, that means a new surface is created. So, it is within the particle and an offset b of a portion of the upper part of the particle with respect to the lower part accompanies the dislocation entry.

And then once it comes out of this particle then it creates another step is equal to b. A similar offset is effected when the dislocation exists the particle the complete transit is accompanied by the creation of a matrix precipitate surface area of approximate magnitude of 2 πrb this is very simple right. So, 2πrb that surface area it has been newly generated because of the edge dislocation enter and then exit the particle.

So, how does this alter the energy that is what we are going to see, we are going to bring in this surface energy into the force when a dislocation passes through the particle an additional particles matrix interfaces are as shown in the figure, since there is a surface energy associated with such an interface, what must be done by the process. So, the figure shows the interface surface areas created both when the dislocation enters the particle and also exits.

So, the maximum force required to push the dislocation through this particle is the maximum value of dU / dx of the figure is approximately going by $F_{max} = \pi r \gamma_s b / b = \pi r \gamma_s$, so γ_s is the surface energy

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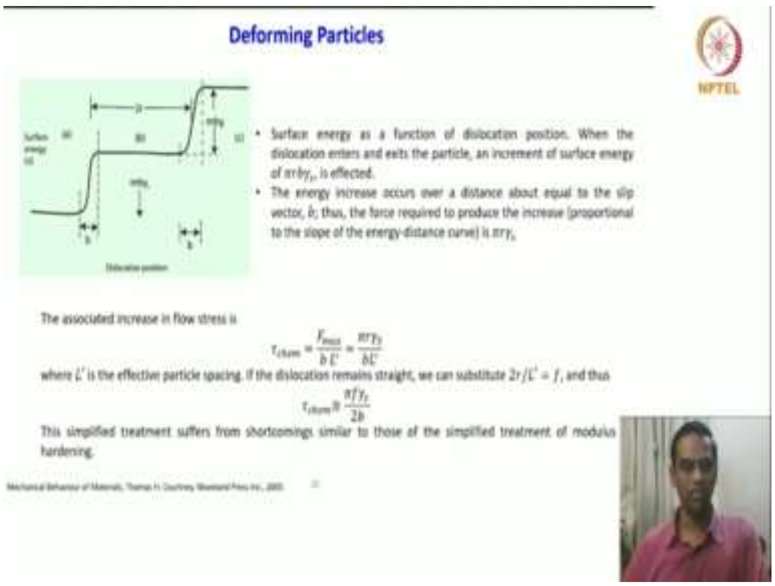

This is the schematic which shows the nice idea, how the surface energy increases the moment the dislocation enters the particle which creates the first offset in the front b the surface energy increases to this level. This πr b γ_s and then it travels inside and again it exists creates another surface again it creates πr b γ_s. This is 2r is a diameter of the particle this is nicely shown here. So, the energy increase occurs over the distance about equal to the slip vector b.

Thus the force required to produce increase that is proportional to the slope of the energy distance curve is $\pi r \gamma_s$. So, we can just simply substitute this the associated increase in the flow stress is $\tau_{chemical}$ here we are not seeing a plane, it is purely a chemical hardening component is given by F_{max} / bL, which is nothing but $\pi r \gamma_s$ / bL′, L′ is a effectives particle spacing, if the dislocation remains straight.

We can substitute to 2r / L′ that is equal to f and then we can rewrite this equation like $\tau_{\text{chemical hardening}} \cong (\pi f \ \gamma_S)/ 2b$, the simplified treatment suffers from shortcomings similar to those of the simplified treatment of modulus hardening. Again, I told you all these semi quantitative relations will give you some idea about the very specific change in the each of the mechanisms, the parameters which contributes to the applied stress.

That is all we have to look at it what changes in modulus hardening no coherency hardening and you know chemical hardening what are the new parameters coming to the force balance equation that is all you have to look for.

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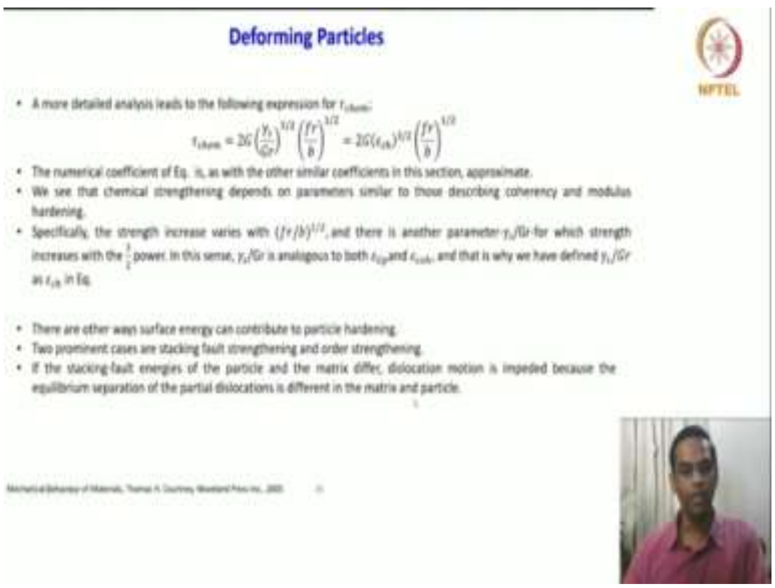

So, the final expression for this chemical analysis is given like this $\boldsymbol{\tau_{chem} = 2G(\frac{\gamma_S}{G_r})^{3/2} (\frac{f_r}{b})^{1/2} = 2G(\varepsilon_{chem})^{3/2} (\frac{f_r}{b})^{1/2}}$

So, we see that the chemicals strengthening depending on parameters similar to those describing the coherency and modulus hardening, they are all same here you are simply putting ε chemical instead of ε modulus you know coherence.

One important point the strength increase varies with $(\frac{f_r}{b})^{1/2}$ and then there is another parameter $\frac{\gamma_S}{G_r}$ for which strength increases with the 3 / 2 power. In this sense, $\frac{\gamma_S}{G_r}$ is analogous to both ε_{Gp}

and $\varepsilon_{coherence}$ and this is why we have defined $\frac{\gamma_S}{G_r}$ as is equal to $\varepsilon_{chemical}$ in that equation. So, this is all these three equations simple equations, though it looks you know, similar but it gives the it brings out that certain differences, the what way each mechanisms contributes to the τ that is the shear stress the flow stress directly.

There are other ways of surface energy or other ways of surface energy can contribute to particle hardening, they are two prominent cases are stacking faults strengthening the order strengthening. So, they are also related to the surface energy term. They are two prominent cases stacking fault strengthening and order strengthening they are very important. If the stacking fault energies of the particle and the matrix differ, dislocation motion is impeded.

Because the; equilibrium separation of the partial dislocation is different in the matrix and particle. So, now, whatever we have studied in the dislocation dynamics stacking fault and the partial when the partials are stable and when they are not stable all these ideas will come into plane and it is very hardening know. So, we are talking about the stacking fault energy the difference between particles and the matrix and its consequences on the strengthening mechanisms.