Creep Deformation of Materials
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Part 4
Creep and different Factors That Influence Creep Deformation-Part 4.

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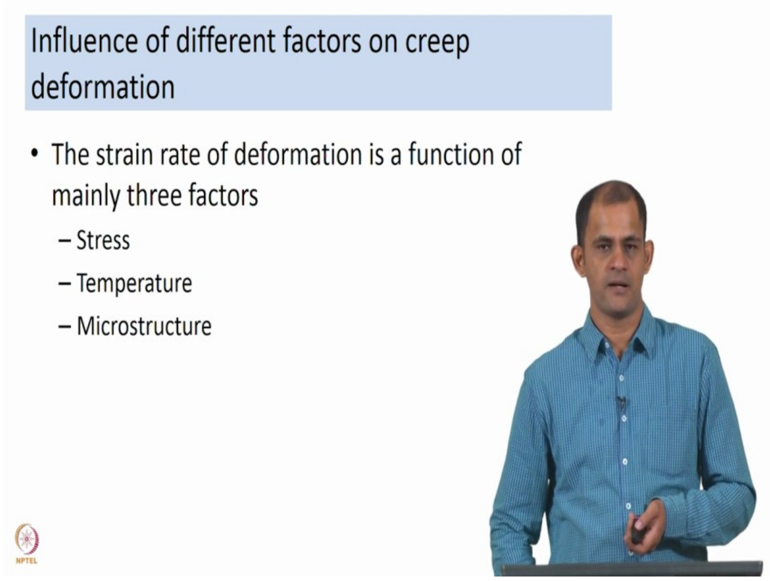

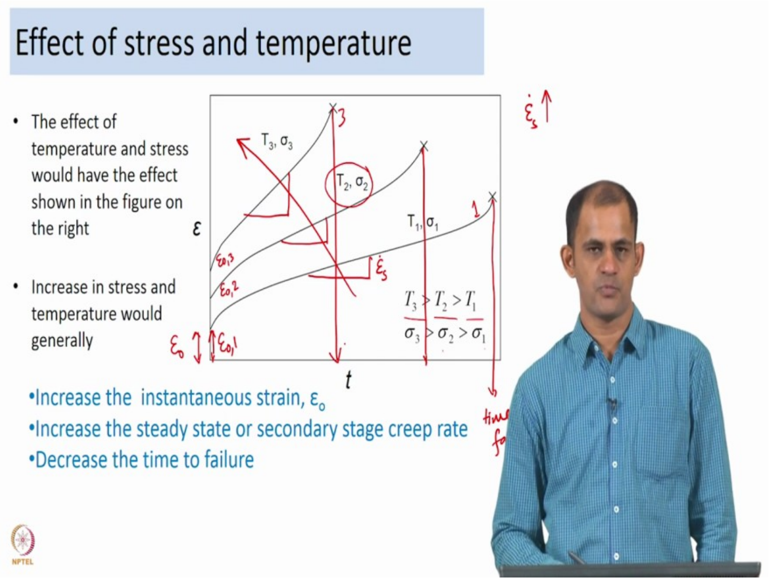

Broadly the strain rate of deformation is a function of 3 factors stress, temperature and microstructure. Of course there are some other factors such as elastic modulus, etc. but by and large stress temperature and microstructure are things that you can play around with and to understand how it influences creep deformation. So now let us look at the case of stress and temperature. So we looked at effects of stress and temperature on strain rate. So what is the corresponding effect of stress and temperature on the creep curve itself?

So here we have the 3 creep curves, the 1st one corresponds to applied stress Sigma 1 and distributor of T1, the 2nd one corresponds to applied stress Sigma 2, temperature T2 and the 3rd one corresponds to applied stress Sigma 3 and temperature T3. Now Sigma 3 is greater than Sigma 2 is greater than Sigma 1 and T3 is greater than T2 greater than T1. So, what we are clearly seeing is when we are increasing the stress and temperature, so this is the direction of increase in stress and temperature.

So there are things, these are the following things that are happening. When you increase the stress and temperature, 1st thing that we are noticing is an increase in the instantaneous strain Epsilon 0. So the instantaneous strain Epsilon 0 is also increasing, so this is corresponding to curve 1, say Epsilon 0 1, this is corresponding to curve 2, Epsilon 0 2 Epsilon 02 and this corresponds to Epsilon 03. So, as you increase the stress and temperature instantaneous strain is going to increase.

What is also increasing is the slope of the secondary stage or the steady-state creep stage. So the slope is increasing, which means the strain rate of deformation is a second-rate creep state is also increasing. So if you see the slope is gradually increasing as you go from curve 1 to curve 3. So this minimum creep rate for the secondary stage creep rate or the steady-state creep rate, all 3 remain the same, so that value also increases as you increase the strain rate, and increase the temperature and stress.

What we also see is the time to failure. So this is, this corresponds to the time to failure, the cross indicates the point where the sample has failed. The time to failure is also coming down as you increase the stress and temperature. So these are family the 3 things that would happen when you increase the stress and temperature. You will have an increase in the instantaneous strain, you will increase the steady-state creep rate and you will decrease the time to failure.

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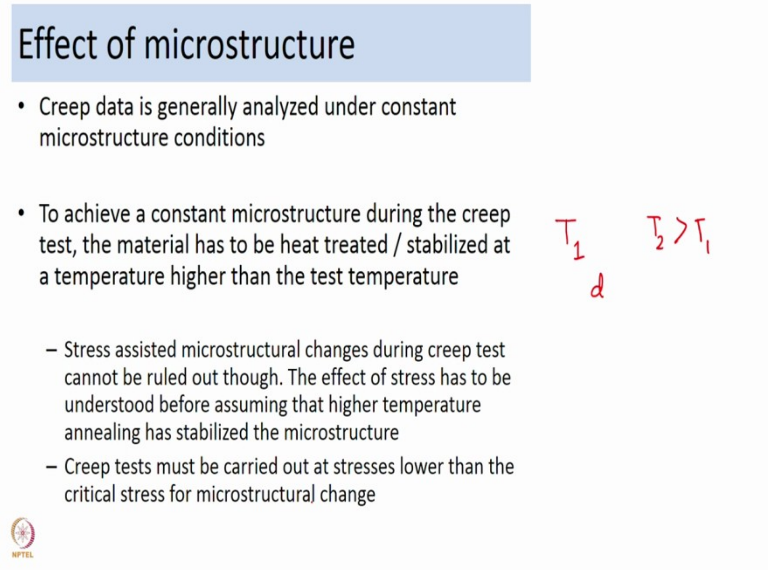

Now let us look at the effect of microstructure. Now, effect of microstructure, so one thing to remember is when your optimal creep data, in order to predict the life of a material or the life of a component, it is important that the microstructure stays constant. So creep rate is generally analysed under constant microstructure conditions. And to achieve a constant microstructure during the creep test, the material has to be heat treated or stabilised at a temperature higher than the test temperature.

So, say if you are planning to do a creep test at a temperature T1, then for the microstructure to stay stable during the course of the creep test, the material should have been heat treated or annealed at a temperature T2, where T2 is greater than T1. So if you do that, for example if you want to carry out a creep test on a material with grain size of d1. Now the grain size should have been attained by annealing at a higher temperature. So we should have, so let us say d, grain size d, so this d should have been attained by annealing at a temperature T2.

And so that when you do your tests at T1, the grains do not grow. Because as we know, as we increase the temperature, the grains tend to grow. So you are creep test temperature should be lower that the temperature at which you have stabilised your grains. Of course having said that, one cannot rule out stress assisted micro structural changes, since creep happens under both stress and temperature conditions. So stress assisted microstructure changes could happen sometimes during creep test.

And the, so what this means is that the effect of the stress has to be understood before assuming that higher temperature annealing have stabilised the microstructure. So for certain materials, stress can lead to micro structural change. For example, nano crystalline material, so it is an evolving area of research and development. So, in nanocrystalline materials, the grain tends to be unstable and even though you have stabilised the grains at a higher temperature, but in the presence of stress, sometimes stress is, stress assisted grain growth could happen.

And hence one needs to be careful while assuming that the grains or the microstructure is stable. So, what is the effect of microstructure? This is so, this part is about stabilising the microstructure, so you want to keep the microstructure constant for carrying out your creep test and analysing your data. So what exactly is, what exactly happens when the microstructure is different? So if you have, say finer grain size, or a coarser grain size, how does it affect the creep data?

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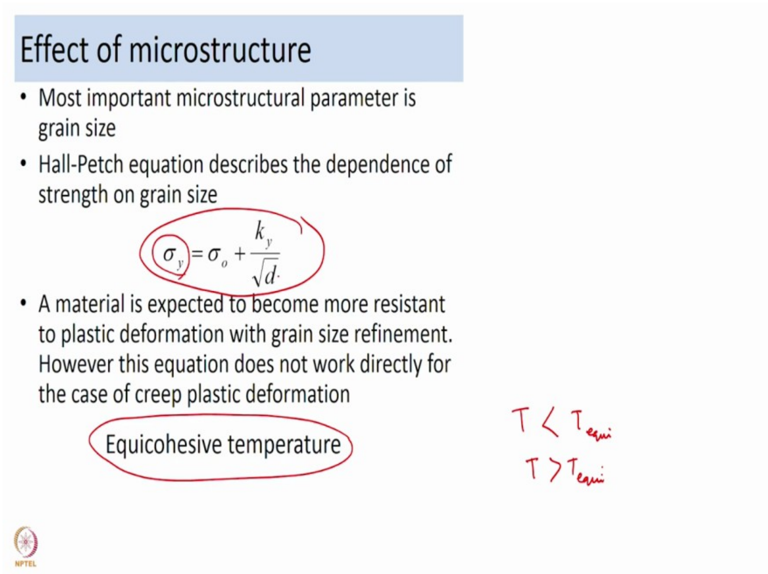

So if, microstructure could mean different things, but the primary microstructure descriptor is the grain size. It is the most important micro structural parameter. So now we know, we all know very well that the Hall Petch equation describes the dependence of strength on grain size. So, so this is a classic Hall Petch equation, which tells that as you reduce the grain size, the strength of the material is going to increase, which means that the material is more going to become more resistant to plastic deformation with grain size refinement.

So if the material is going to become stronger and more resistant to plastic deformation, then that would automatically mean that it should also be resistant to creep deformation, because creep is a type of plastic deformation. However what is very interesting is the Hall Petch equation does not directly work when you are talking about creep deformation conditions. So this equation fails to explain the kind of behaviour the material exhibits during creep conditions.

So what happens is, in during creep conditions it has been observed in a vast, from large number of studies that has refine the grain size, in fact the material is going to creep more. So the strain rate of deformation, creep deformation is going to increase as you reduce the grain size. And to understand this, I would want to talk about the concept of Equicohesive temperature. So, Equicohesive temperature is basically a temperature, it is a temperature below which it finer grain size materials are stronger and above which finer grain size materials are weaker.

That is because at temperature lower than the Equicohesive temperature, the grain boundaries tend to be stronger, whereas when you exceed the Equicohesive temperature, the grain boundaries become weaker. So the important thing here is, since creep is a high temperature process, so the temperature is somehow causing the grain boundaries, the grain boundaries which are known to be barriers to plastic deformation actually start helping plastic deformation.

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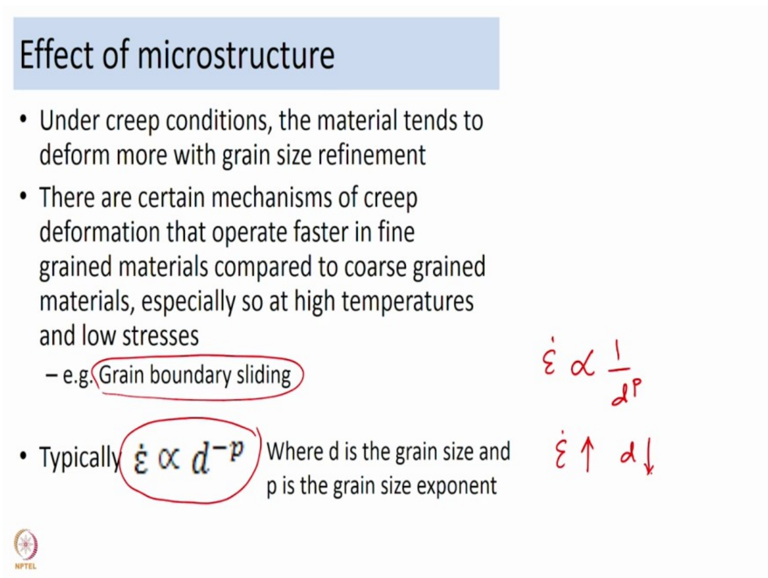

So that is why when you talk of creep deformation at high temperatures, the grain boundaries are not exactly barriers to plastic deformation anymore. And that is why the behaviour of a material that is not follow the Hall Petch equation, when you talk of creep conditions. So, under creep conditions, the material tends to deform more with grain size refinement. Of course there are certain, there are certain mechanisms of creep deformation that operates faster in fine-grained materials, to coarse-grained materials, especially so at high temperatures as low stresses.

So one of the examples is grain boundary sliding. So, this is a mechanism of creep and we are going to talk about this mechanism of creep in the coming portions. So, by and large, the relationship between strain rate of deformation, creep deformation and grain size can be given by the following, can be described by the following equation. So, Epsilon dot is proportional to the d to the power - p, where d is the grain size and p is the grain size exponent. So what this means is when you reduce the grain size, so Epsilon dot is 1 by d to the power p.

So when you reduce the grain size, Epsilon dot increases when d decreases. Strain rate of deformation increases when the grain size is brought down. So, if we consolidate all of these, so we have looked at basically the effect of stress, we have looked at the effect of temperature and now we spoke about the effect of grain size. So, all of these have a role to play in the deformation rate, so if you bring all these information together, in general the strain rate of deformation is related to applied stress, temperature and grain size by the following equation.

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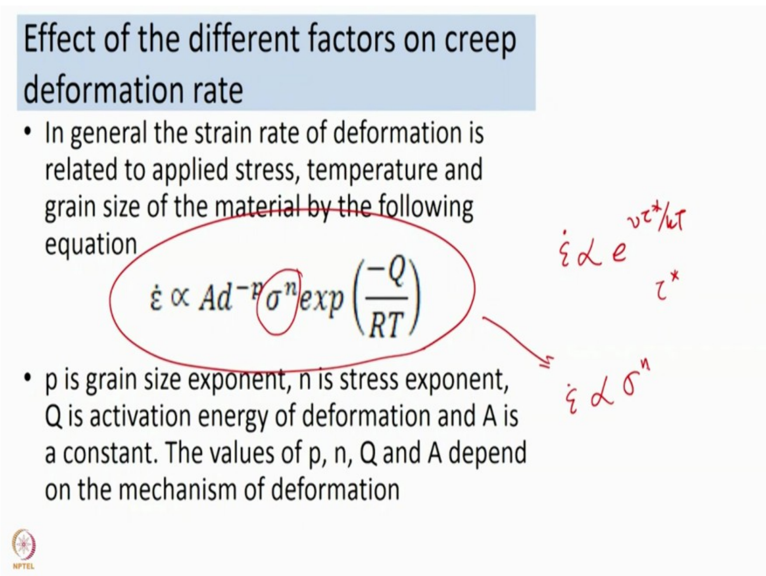

So Epsilon dot is proportional to d to the power - p is proportional to Sigma to the power n additive R exponential of - Q over RT. Like I mentioned earlier p is grain size exponent, n is stress exponent, Q is activation energy of deformation and K is a constant. Now, what people have observed is the values of p and Q and A vary with the mechanism of deformation. So if your creep deformation is happening by diffusion of vacancies, then you have a certain set of values for p and Q and A.

But if you are mechanism of deformation is happening by dislocation based mechanism, then they will have a different values, certain set of p and Q and A values. So what this basically tells as, if you wanted to find out which mechanism of deformation is controlling creep, then what you have to basically do is find out the values of p and Q and A and from there you will get insights about which mechanism or deformation is controlling creep. So, that is basically the effect of different factors.

Of course one point to note here is Sigma to the power n dependence, if you remember in the previous line I was talking about Epsilon dot being proportional to some, a function like that but by and large what people have noticed is this is the kind of relations that works. And depending on the value of your applied stress and depending on the dependence, depending on how nu is related to the applied stress and some other factors. The final equation that people have by and large noticed is of this form.

This is the dependence of strain rate over Sigma, at very high stresses, this relation also changes and that is something that I am going to cover in the coming portions. At very high stresses, the dependence of strain rate, Epsilon dot on Sigma can take it exponential form and this is generally known as a power law breakdown which will be discussed in the coming sections.