Creep Deformation of Materials
Modeling the useful Creep Life of Materials/Components Part 2

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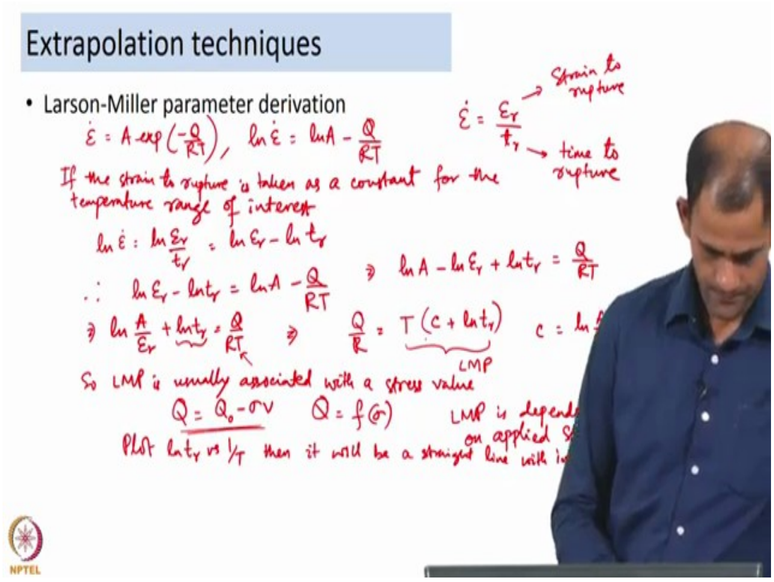

Here I am going to talk about the derivation of the Larson-Miller parameter, so like I said the strain rate of deformation is dependent on the temperature in the following form, so this is the Arrhenius equation, so if you take log of strain rate that gives you log A minus Q over RT and if you are talking about rupture then basically this is the strain rate of a deformation leading to rupture, so the strain rate of deformation can also be written as epsilon r over t r, so epsilon r is the strain to rupture and t r is the time to rupture.

Now if the strain to rupture is taken as a constants, so if you take the strain to rupture as a constant for the temperature of interest, so if you are talking about a certain temperature range, so if you in for that strain temperature range you are going to take the strain to rupture as a constant, for the temperature then what happens is log epsilon dot which is can be written as log epsilon r by t r, so that becomes log epsilon r minus log t r, so therefore log epsilon r minus log t r is equal to log A minus Q over RT.

So since epsilon r is going to be taken as a constant so this implies log A minus log epsilon r plus log t r is equal to Q over RT and log A by epsilon r since epsilon r is taken as a constant so you can take A and epsilon r together, so log epsilon r plus log t r is equal to Q over RT, so if you take temperature into the other side so what you end up with it is Q over R is basically

T into c plus log t r, so T into c plus log c r t r this is known as the Larson-Miller parameter where c is equal to log A by epsilon r so that is the value of c.

Now the Larson-Miller parameter is generally given for a certain value of stress, so LMP is usually associated with a stress value that means if the stress value changes then the LMP also changes this is because whenever you apply a stress the activation barrier is going to come down on account of the work done by the applied stress, so this stress is assisting you in overcoming the barrier easily, so that is why LMP is dependent on applied stress, so as a stress value changes the LMP value also changes.

Now what we can also notice here is if you plot log t r Versus 1 by T then it will be a straight line, so if you plot log t r Versus 1 over T then it will be a straight line, so it will be a straight line with intercept c, ok. So what we have done here is we have derived the Larson-Miller parameter equation and we are also showing that the Larson-Miller parameter why is it dependent on the applied stress and we have also talked about how you can determine the value of the constant c, so for determining the value of the constant c you can basically take the semi logarithm, natural logarithm of the rupture time and plot it against the inverse of temperature in kelvin and it will be a straight line and the intercept of the straight line with the (y axis) the intercept of the straight line is what will give you the constant c.

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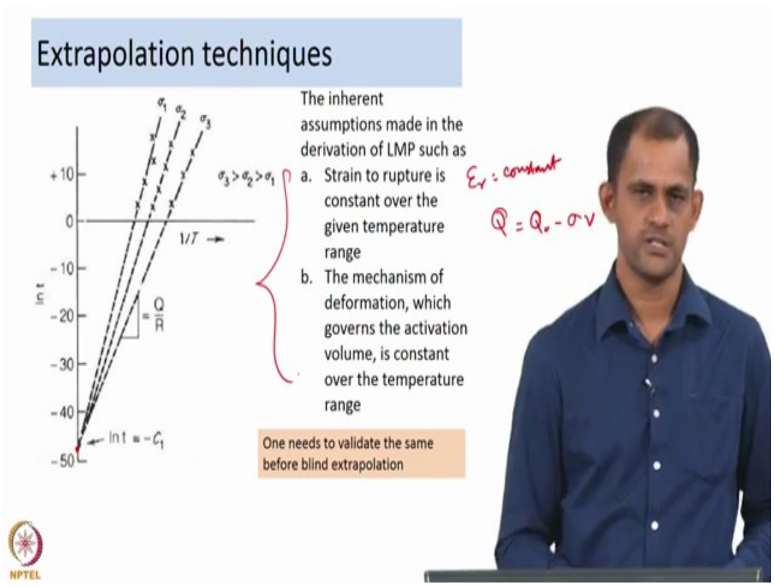

So that is what I am showing in this particular slide, is you can plot log t r Versus 1 over T for different values of sigma and they all intersect the Y axis at the same location and this gives you the value of c which is the constant in the Larson-Miller parameter equation. Now one thing to notice in the derivation of the Larson-Miller parameter is we have made a few assumptions the inherent assumptions are 1 is the strain to rupture is constant over the given temperature range.

So assuming that for whatever temperature you are determining your LMP for those temperatures the strain to rupture that is epsilon r is equal to constant, so first assumption. So the second assumption is mechanism of deformation, so we are also assuming the mechanism of deformation which is what will govern the activation volume is going to be constant over the temperature range.

So we are talking about Q is equal to Q_0 minus sigma v and v is the activation volume, so if the activation volume changes over the temperature range you are assuming it is constant so when we are doing the extrapolation you have to be sure that the mechanism of deformation has not changed because if it has changed then you will also have a change in the v value or the activation volume value and similarly when you talking of extrapolation you have to be also sure that the strain to rupture has not changed during extrapolation.

So during extrapolation you have to be sure that the strain to rupture has not changed, well the strain to rupture could change because when you are extrapolating data to say different temperature the mechanism of oxidation as an example could change so that means your loss of cross-section or is going to be change the material could become more brittle and if it becomes more brittle then the strain to rupture will also come down.

So these are some things could happen, so before you do a blind extrapolation of your short term data to long term performance you have to be careful that these things have not changed.

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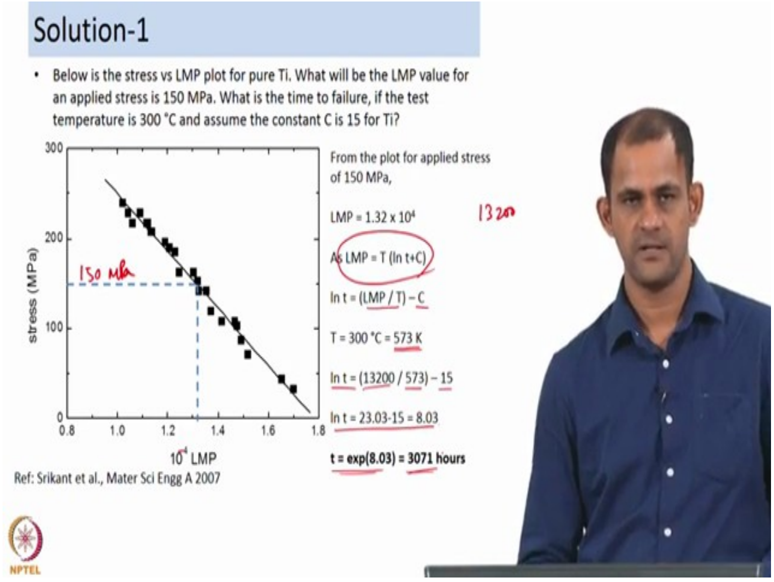

So here is an example of how you can use the Larson-Miller parameter, I have Larson-Miller plot to predict the performance of your component for different temperatures and time conditions. Now in this particular question you have two aspects first is I am asking you to determine the LMP value for an applied stress of 150 MPa and then using the LMP value you have to determine the time to failure if you know that the test temperature is 300 degree centigrade and the Larson-Miller parameter constant c is 15.

So first what is the LMP value for the applied stress if the applied stress is 150 MPa? So if you look at the plot this is 150 MPa, so corresponding to 150 MPa you have LMP of approximately 1 point 32 into 10 to the power 4, so you have an LMP value of 13200. Now using this LMP value you have to find out the time to failure if the test temperature is 300 degree centigrade and the constant c is 15.

So if you look at the Larson- piller Miller parameter relation you have LMP is equal to 2 T log t plus c, so log T is can be written as log t is equal to LMP by T minus c, so when T is 300 degree centigrade you convert it into kelvins it becomes 573 kelvin, so log t is equal to 13200 divided by 573 minus 15, so what you end up with is 8 point 03, so t is exponential of 8 point 03 that is basically 3071 hours.

So the time to failure can be determined as 3071 hours, so basically what this tells you is if you have a stress Versus LMP plot you can use the information given in the plot, so you can basically use the plot for determining the performance of your component for different time and temperatures.

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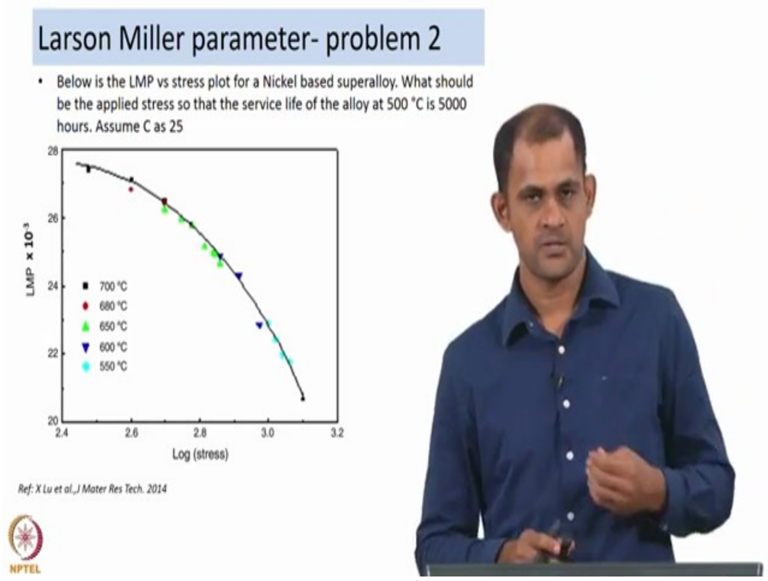

Now let us look at another problem, so here this is a problem, this a plot for a Nickel based super alloy and you have LMP on the Y axis and stress on the X axis and the question is what should be the applied stress, so that the service life of the alloy at 500 degree centigrade is 5000 hours, so basically the point is use the data and using the data given in this plot find out the maximum applied stress? So that the service life of the component or the alloy is at least 5000 hours, so here you can use C is equal to 25.

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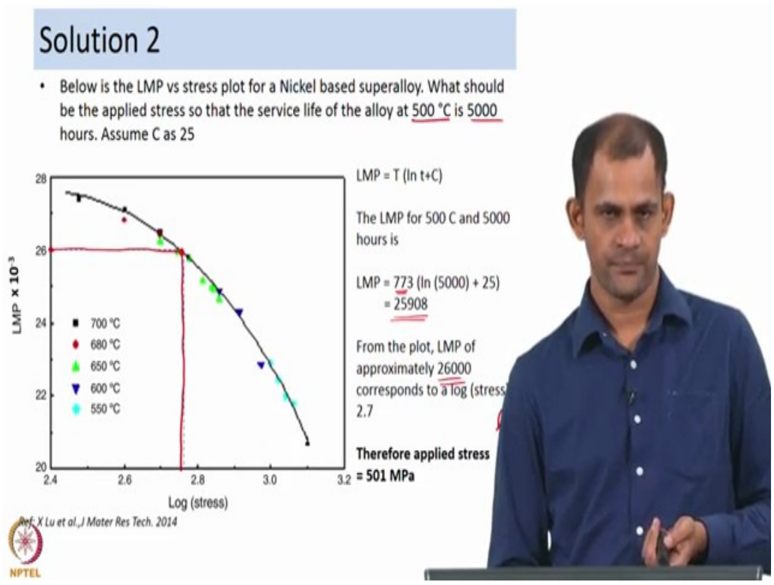

Now this is how the solution will look like, so first you determine the Larson-Miller parameter for this temperature and time condition, so T is 500 degree centigrade, so you convert it into kelvins, so it is 773 kelvin and then you have 5000 hours, so log of 5000 plus

25, so that gives you LMP as 25908, so on this plot to so it is more or less equal to 26000, so if you look at this plot so you will have 26000 as LMP at this point and if you and that would correspond to a stress value of approximately log stress is equal to 2 point 75, so therefore the applied stress the maximum allowed stress will be 10 to 2 point 7, so that gives you 501 MPa.

So we have looked at two aspects of using the Larson-Miller parameter in first case we knew the applied stress and from there using the Larson-Miller parameter we found out the time to failure at a given temperature. In the second case we knew the time and temperature and using the Larson-Miller plot we were able to determine the maximum allowed stress. So these are two approaches by which these are two problems to highlight the approach needed for using the LMP plot for design of components.

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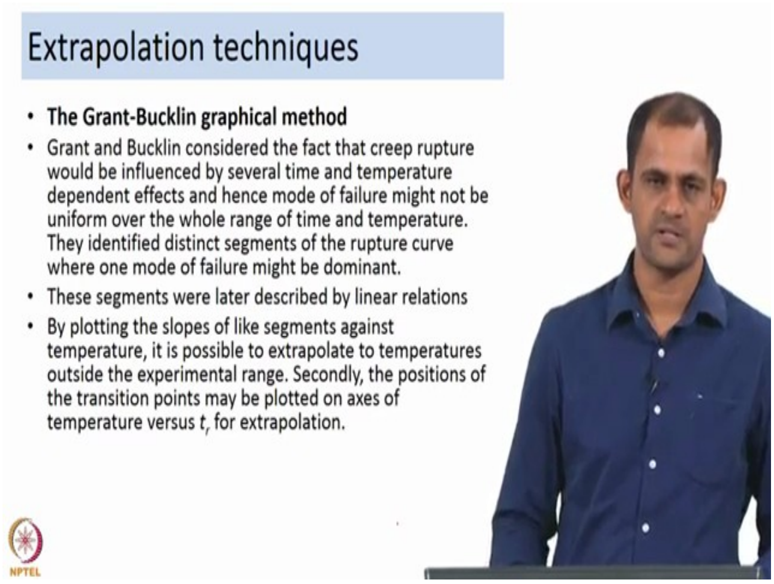

Now talking of an extrapolation techniques we said one is the parametric technique and the second one is graphical methods, so here I am going to give you a brief overview of the graphical method, so there are definite methods under the graphical methods but one of them is Grant-Bucklin graphical method, so here in a Grant-Bucklin consider the fact the creep rupture would be influenced by several time and temperature dependent effects and hence mode of failure might not be uniform over the whole range of time and temperature, this something that we already spoke about we said the mechanism of creep may change and the strain to rupture could also change depending on the time, temperature window you are operating in.

So Grant-Bucklin considered that and then said that the creep rupture would be influenced by that and so it is not going to be uniform, so what they said is the whole data that you have the LMP Versus stress data they identified distinct segment of the rupture curve where one mode of failure might be dominant, so they are talking about time, temperature data and they are talking about distinct segments of the rupture curve and so they are saying when there is a change in slope then the mode of failure could also be changing.

Now they also said these segments can be described by linear relations and then by plotting the slopes of line segment against temperature it is possible to extrapolate to temperature outside the experimental range and for doing this they also used the positions of the transition points and on access of temperature Versus t r for extrapolation.

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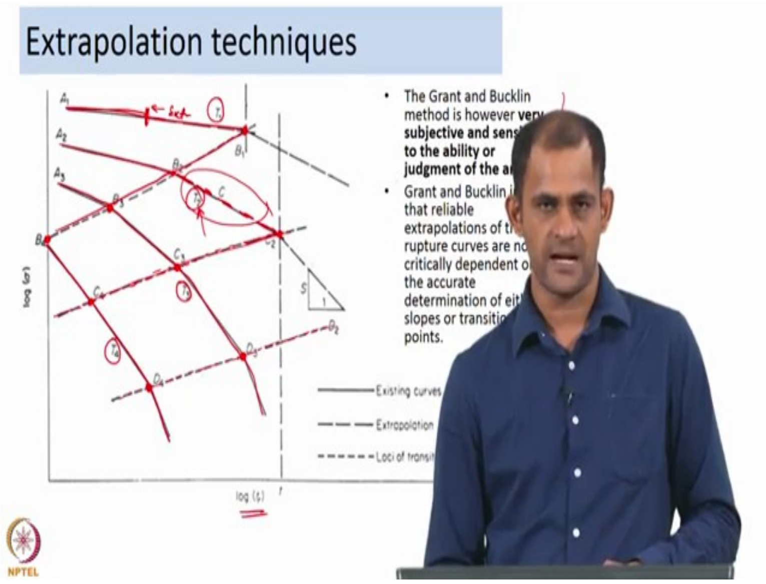

So I will just use this graph to explain what I am trying to say here, so this is a graph that is use by Grant for using the Grant-Bucklin method. So you have log sigma Versus log t r, so the time to rupture changes as a function of sigma for different temperatures, so you have T 1, T 2, T 3 and T 4, so if you see there is a change in slope depending on the applied stress temperature and time.

So what Grant-Bucklin are saying so you can look at this curve you can look at this curve as a combination of linear segments. So they are saying this is one linear segment, this is another linear segment, this is another linear segment and this is another linear segment so this is data corresponding to temperature 3 T 3 and similarly for temperature data corresponding to temperature T 4.

They are saying you can take this has 1 linear segment, this has another and this is so, so on this in this segment you have these points which are the transition points, so say let us talk of curve corresponding to T 3 and curve corresponding to T 4, so you can see this transition points on this curves, so this transition points they are proposing that you join them, so you can join this transition points and you can extrapolate the line joining the transition points forwards, so you there calling them as the loci of transitions, so you can connect this transition points and extend them forward.

So say you have C 3, C 4, C 3 connected and then you extrapolate it to C 2, now what they are saying is say for T 2 you have data only from A2 to B 2, so you have only one linear segment A 2 to B 2 and what they are saying is once you have the loci of transitions so you are extending this loci of transitions so then B 2 is going to me to meet C 2 there, so this is now the extrapolation of your data.

So you can use A 2, B 2 and use that data and extrapolate so that you meet the at this point C 2, so now you have created a new set of data basically by extrapolating A 2, B 2 for this temperature T 2, so similarly for A 1 so you have say the data up to only this point in temperature T 1 but you know the loci of transitions from B, so you have B 4, B 3, B 2 connected and you can extend up to B 1, so you can use this data and connect it up to B 1, so you can extrapolate data that was available till here extrapolate it to B 1.

So this is basically the approach that Grant-Bucklin developed, so they said you can use the loci as transitions and use that for connecting different segments and extrapolating different segments. Now obviously this process is very subjective because what one may consider as a transition 1 percent may considered as a transition point or another person may not, so it depends on who is the person doing this exercise.

So that so basically it depends on the judgment of the analyst, so that is the one criticism against this approach however Grant-Bucklin claim that reliable extrapolation of the rupture curves are not that critically dependent on the accurate determination of the slope or transition points. So one may raise the question of subjectivity of the extrapolation but Grant-Bucklin say it is not that difficult and even if there are some variations or differences that will not influence service life performance.

So that was the extrapolation technique by brant Grant-Bucklin.

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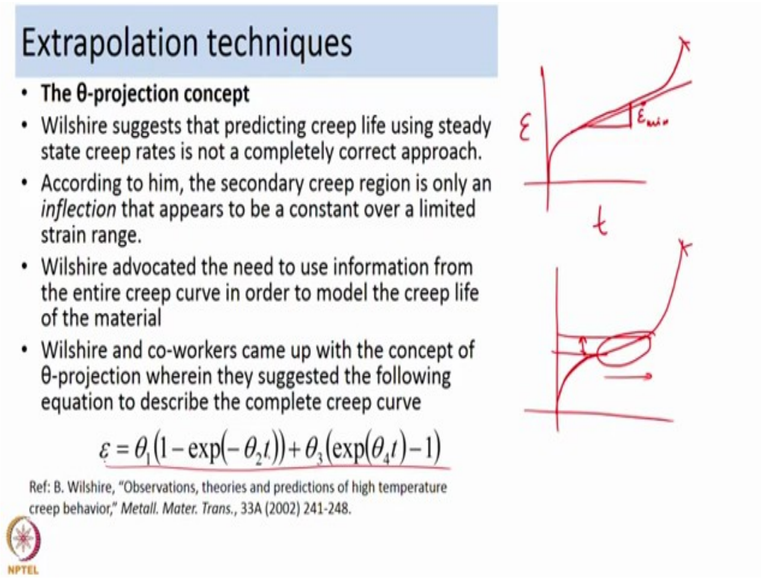

So the last technique that I am going to talk about extrapolation is recent one developed by Wilshire and coworkers, so this the claim this is the theta projection concept method. So Wilshire suggest that predicting creep life using steady state creep rate is not a completely correct approach, so if you remember I was saying strain Versus time you have steady state and you can predict the performance by using the slope of the secondary creep region the epsilon minimum and then based on that you can predict the useful creep life of a material.

So Wilshire suggest that this is not exactly a correct approach a completely correct approach, so according to him the secondary creep region is only an inflection that appears to be a constant over a limited strain range. So for hi there is a change from change in slope from one end and the (incr) decreasing slope leading to increasing slopes and for him is basically an inflection region from a decreasing slope region to an increasing slope region, so and this inflection happens over a limited strain range value, so for him relying overly on steady state creep rates to perform creep performance or predict creep performance is not a completely correct approach.

So he advocated the need to use information from the entire creep curve so Wilshire says rather than only relying on epsilon minimum, epsilon dot minimum we should use information coming from the entire creep curve and use that data to model the creep life of the material. So with this concept they came up they developed this theta projection concept where in the suggested that the creep curve could be described by the following equation.

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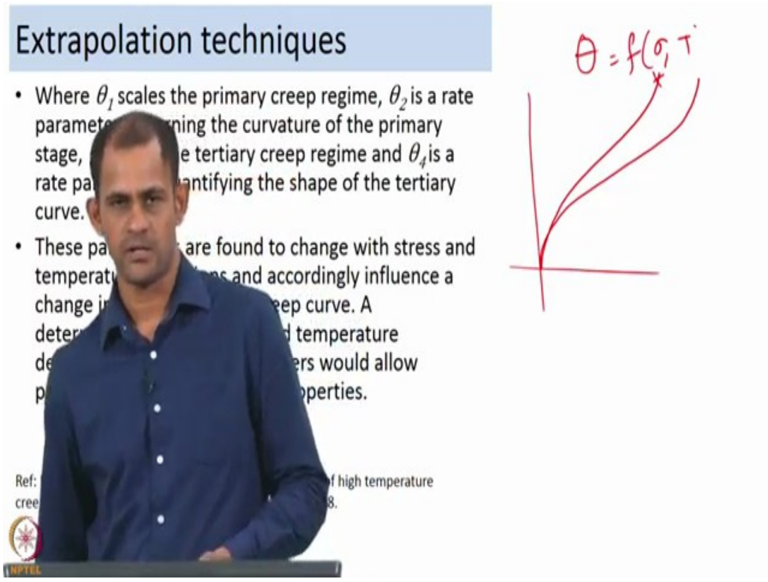

So you have epsilon Versus t related by the following equation, so you have this theta parameters theta 1, theta 2, theta 3 and theta 4 where theta 1 corresponds to the primary is creep region, so it scales the primary creep region and theta 2 is a rate parameter corresponding to the curvature of the primary creep region, theta 3 is basically scaling the tertiary creep region and theta 4 is a rate parameter corresponding to the tertiary creep region, so they have these 4 parameters and what they have notice through their study is these parameters are found to change with stress and temperature conditions and accordingly can influence a change in the shape of the curve.

So this theta values are a function of stress and temperatures so the shape of the creep curve can change depending on the theta values corresponding to the stress and temperature. So that is why they believe a determination of the stress and temperature dependence of the theta parameters can be used for predictions of the long term creep properties.

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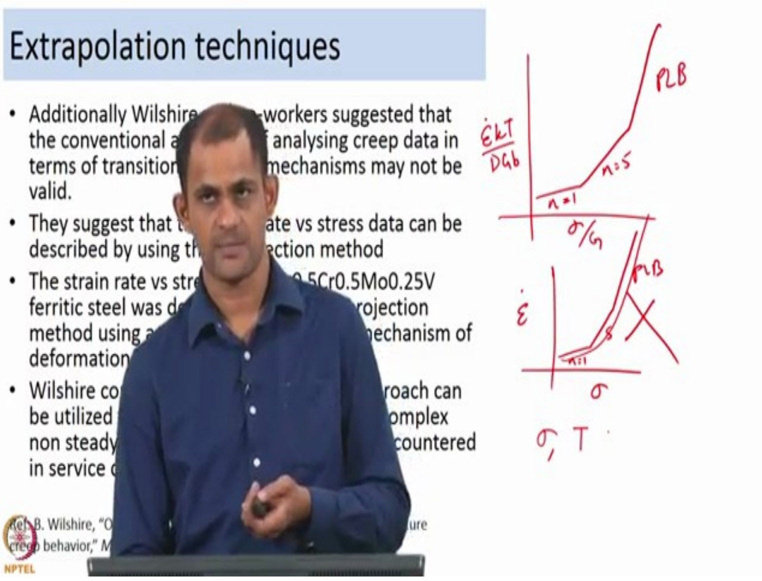

In addition to this they also suggested that the conventional approach of analyzing creep data in terms of transitions of creep mechanisms may not also be correct, so when you are talking of transitions you are talking about a dimensionaless plot between epsilon dot k T D G b or sigma by G, we are talking about transitions happening as an example from say n is equal to 1, n is equal to 5 and then power law break down or another way of looking at it is epsilon dot versus sigma similar so n is equal to 1, 5 P L B etcetera.

So they are saying this is not a completely correct approach and for them there is no real transitions in deformation processes that are happening, so they say again the theta projection method can also be used to describe this data, so what to them what appear as transitions are actually a result of change in some values of the theta value, so they demonstrated their concept through data on strain rate Versus stress data for a ferritic stainless (ste) ferritic steel and they suggested instead of looking several mechanism such as diffusion creep, dislocation creep, power law break down as different mechanism you can use a single dislocation base mechanism and describe your entire data.

So Wilshire contends the theta projection approach can be utilized to quantify material behavior and complex non steady stress the temperature conditions encountered in service conditions, so all the modeling of creep life assumes a constant stress and temperature during operation but it is rarely true because materials undergo thermal (exp) fluctuations as well as probably change in stress conditions during service, so that is why your creep modeling should account for that and Wilshire says that the theta projection concept can be a better way of modeling the creep performance under this complex non steady stress test stress temperature conditions.

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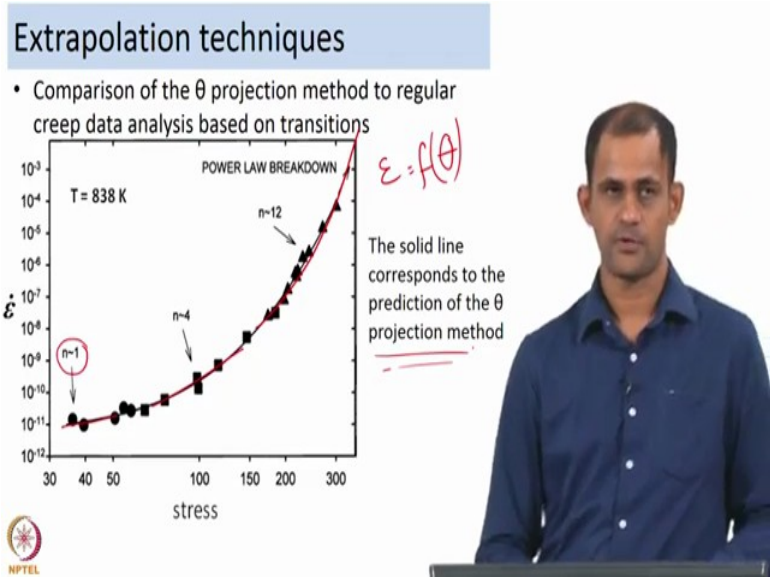

So this is example of how the theta projection method has been used, so if they have plotted strain rate Versus stress so in conventional way you basically look at the low stress region as n is equal to 1 the intermediate stress as n equal to 4 and then you are talking about the power law break down what they say is the entire data that they have for the steel the entire data can be simply described using the epsilon as a function of theta, so from using that concept epsilon as a function of theta so they are used that and describe the epsilon dot strain Versus stress temperature using the theta projection method.