Creep Deformation of Materials
Modeling the useful Creep Life of Materials/Components Part 1

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Ok, so till the last portion we are talking about deformation mechanism maps, we are talking about how the maps can help in identifying or locating the region of dominance of a certain creep mechanism say Nabarro–Herring creep versus Coble, the map will tell you for a given material for a certain microstructure which will be the area where Nabarro–Herring creep will be dominant and will make greater contributions to the overall creep performance and where coble creep or dislocation creep or dislocation glide and thing is like that.

So that was about deformation mechanism maps and now we are coming to the portion related to modeling the useful creep life of materials or components so all the mechanisms of creep that we have discussed so far or being used by engineers and scientists to predict the creep performance of a material under certain set of temperature stress and microstructure conditions or parameters.

So the mechanisms of creep especially as you may recall we have in talking about steady state creep rates, so all the equations relating strain rate to stress, temperature, a grain size etcetera have been using the steady state creep rates or the creep rates coming from the secondary creep region, however there are a few methods which need not rely on predicting a creep life based on only the steady state creep rates.

So we in the coming few slides in this portion of the lectures we are going to talk about some of the different methods that people have developed in order to be able to predict the useful creep life of materials and components.

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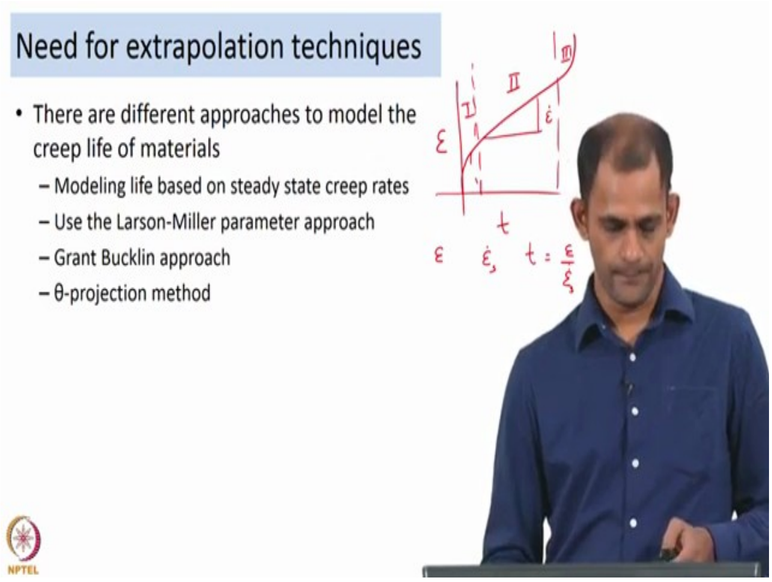

So just a quick introduction, so what I am listing down here is some of the different approaches that people have used so far, first approach like i said you get you could model the life of your component based on the steady state creep rates, so when I said modeling the life on steady state creep rates, so say you have a creep Versus time curve and this is the slope of the secondary creep region and what you could do is use this slope the strain rate from the secondary creep region and then say if you know how much strain that your material can be allowed to deformed to, so say if your strain that you are interested is epsilon and the strain rate that you are getting from the secondary creep rate is creep region is epsilon dot s then you know the time for which your component can run or work or for a particular application will be the strain divided by the secondary creep strain rate.

So that is the useful time or the useful life of performance of your components, so that is based on using only the secondary creep strain rates. Now there are other approaches also that people have developed, one of the approach which is very popular is the Larson-Miller parameter approach and there are a few other approaches such as Grant (Backlin) Bucklin approach and also theta projection method which is also been looked at very actively in recent times.

So what we are going to do in the next few slides is go through some of these different approaches and understand how these approaches can be used to predict the creep life of a material.

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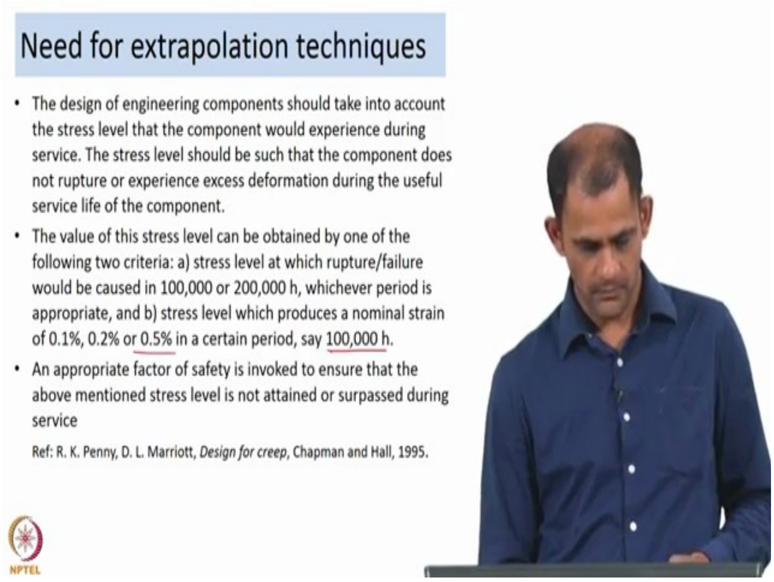

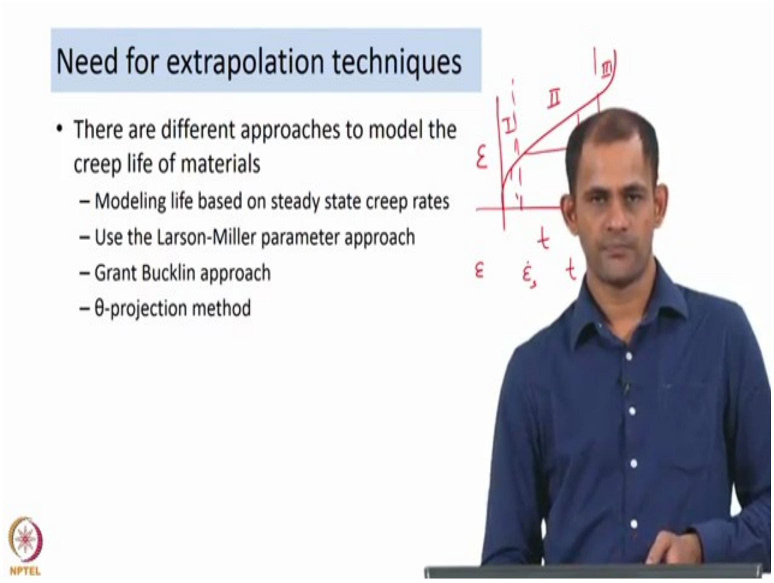

So why do you need these extrapolation techniques, so these techniques that I listed in the previous slides or all extrapolation techniques, so you are predicting the life of a component or a material based on certain data that you have generated for a certain combination of stress and temperature and using that data you are predicting the life by extrapolating this data to long term creep life, for a longer durations of time.

So these are all extrapolation techniques and so the question is why do you need this extrapolation techniques? The extrapolation techniques are needed so that you can predict the life of a component, the useful service life of a component and the extrapolation techniques basically rely on the stress level, the component would experience during service and some of the different extrapolation techniques or design parameters basically design parameters that people have come up with these, the design of engineering components will take into account the stress level that the component would experience during service and the stress level should be such that the component does not rupture or experience excess deformation during the useful service life of the component.

So what I am trying to say here is you are designing the component and in the design of your component you will have to tell what kind of stress the material will be able to sustain for a given creep life, so obviously the stress level that you are going to use for the component or apply during the service will be such that the component will not experience failure or sudden rupture or it should not experience a sudden or excess deformation while it is providing you the service that you want.

So basically the point is the design of the component should take into account the stress level. Now how do you determine this stress level? Well the value of the stress level can be obtained by one of the following two criteria, so this criteria have been listed down for by people who regularly do this kind of work, so the first stage the stress level should be such that the rupture or failure in case you are allowing your component to go up to rupture then the stress level should be such that you rupture life should be at least 1 lakh or 2 lakh hours of operation, so the stress level at which the rupture or failure would be causing 100000 or 200000 thousand hours whichever period is appropriate or required for your application.

Another way of looking at the stress level is also the stress level that produces a nominal strain of 0.1 percent, 0.2 percent or 0.5 percent, so if you are looking not at the rupture life but the time to certain strain for example when we talk of gas turbine engines you are talking of turbine blades, so even small strains, plastic strains, deformation strains can damage of the turbine blade can damage the working of the engine, so there in you are not waiting for the turbine blade to go till rupture, what you are more interested is knowing how much expansion that the turbine blade undergo over a certain period of time.

So there the stress level would be actually looked at from the strains point of view, so the strain the stress level which produces a strain in a certain period, so say you are looking at 100000 hours, so you are saying that this turbine blade that you have made should operate for at least 100000 hours so that you are getting the return on your investment and during this

100000 hours it should not exceed say 0.1, 0.2 or 0.5 percent deformation strain and so the stress level that your engine component should work at should not exceed the stress level corresponding to the strains.

Having said that once you come up with the stress level engineers tend to involve a factor of safety, so for example the stress level you identified from your study is 100 MPa and probably you are going to use a factory of safety say 1.5 then the actual operating stress of the material is going to be 100 by 1.5, so which is around 65 MPa, so you are going to allow your component to operate at 65 MPa that way you will be sure that your component is never going to reach the 0.1, 0.2 or 0.5 percent strain in the time or the duration for which you want the component to work, so that is the way people design their components.

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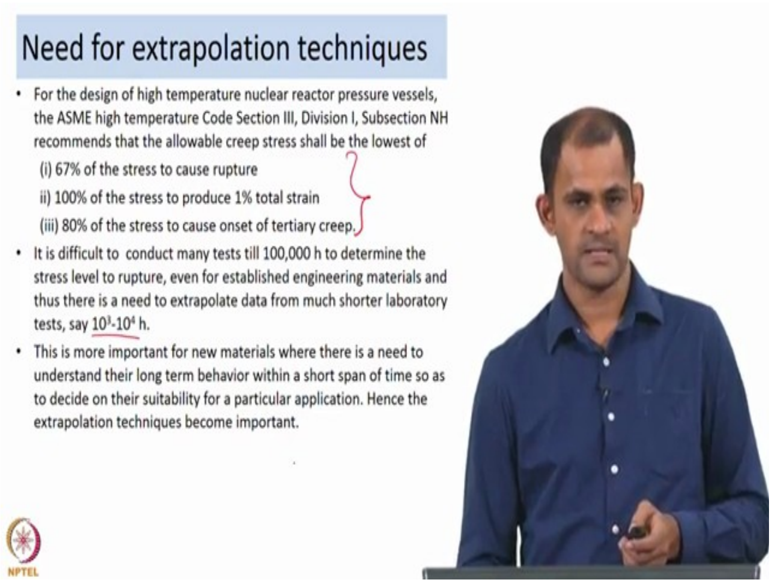

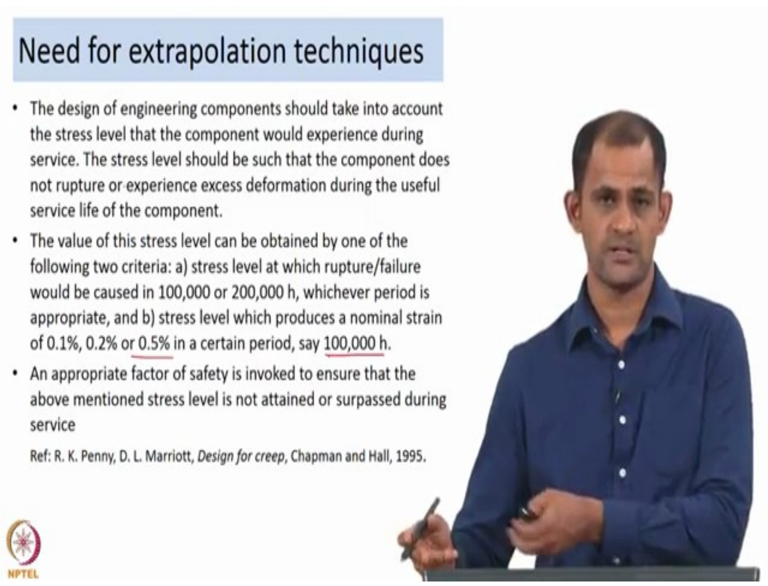

Now another way of looking at the design of component is also for example the design of high temperature nuclear reactor pressure vessels the ASME has recommended the following creep stress levels. So they say the allowable creep stress should be that which should be the lowest of the three mentioned here. So the stress creep stress either be 67 percent of the stress to rupture, so say stress to rupture the component requires at a given conditions of temperature for that application is 100 MPa then they are saying that the allowable creep stress should be 67 percent, so you cannot allow the component to experience more than 67 percent of the stress required to cause rupture or you could on the other hand take 1 percent total strain and then you will say that your allowable creep stress is the stress required to produce 1 percent total strain for the given duration of time.

Or in other cases you can look at 80 percent of the stress to cause onset of tertiary creep, so if you are saying tertiary creep is your limiting deformation, so if you are the moment it enters into tertiary creep whatever is a strain the material is going to experience up to that point that is your limiting strain that is the maximum strain that you are going to allow the component to experience.

Now these are the different ways, so this the previous slide and this slide we are talking about the different ways by which you can design your components against failure or for enabling useful performance of your component. Now one of the things is it is difficult to conduct tests till 100000 hours, so if you look at the previous case or this case we are saying that the test should run to you for determining the stress level you will have to do a test up to 100000 or 200000 hours, so this is a very long period of time.

So 100 hour is approximately say 4 days, so if you are talking about 100000 hours you are talking about 4 thousand days which is approximately 10 years or more of testing, so just to identify the stress level at which your material is going to fail or your component is in going to fail you may have to run test up to 10 years or more, now this is not practically feasible and hence for established engineering materials there is a need for extrapolating data from much shorter laboratory test to this long term performance.

So in order to know the stress level at which the material will fail in 100000 hours you may have to carry out a test say up to 1000 or 10000 hours which is significantly lower time, so you can carry your test for this shorter duration of time and used that data to predict the behavior of or use the that data to extrapolate and predict the behavior of the material for longer term properties.

Now such kind of a extrapolation technique is more important for new material, so if you coming up with new material say nanocrystalline materials so we are talking about nanocrystalline materials say structure materials, now there is not much data available as such for some of the other alloys or materials such as steel, aluminum alloys there is like decades of data on the creep performance of those materials but if you are talking about new materials such as nanocrystalline materials there is not significant data available, so for such cases where if you trying to develop a product using a new material or that has come up then you will have to rely on short term creep properties and use this extrapolation techniques to predict the long term behavior of these new materials.

So this is basically a justification of why extrapolation techniques are important and in the coming few portions we will talk about how these extrapolation techniques can be used.

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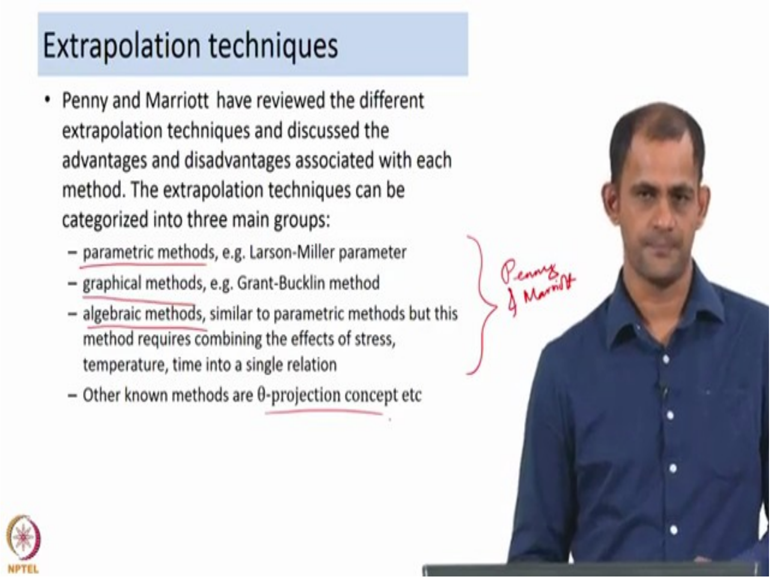

Now, Penny and Marriott they have basically reviewed the different extrapolation techniques and they discussed the advantages and disadvantages associated with each method and they have characterized the extrapolation techniques into mainly three groups, one is known as the parametric method, there is graphical method and third is the algebraic method. So this is what Penny and Marriott have come up with and based on literature survey I was also found out that if we look at theta projection concept as also another way of extrapolating the data to determine the creep life of a materials.

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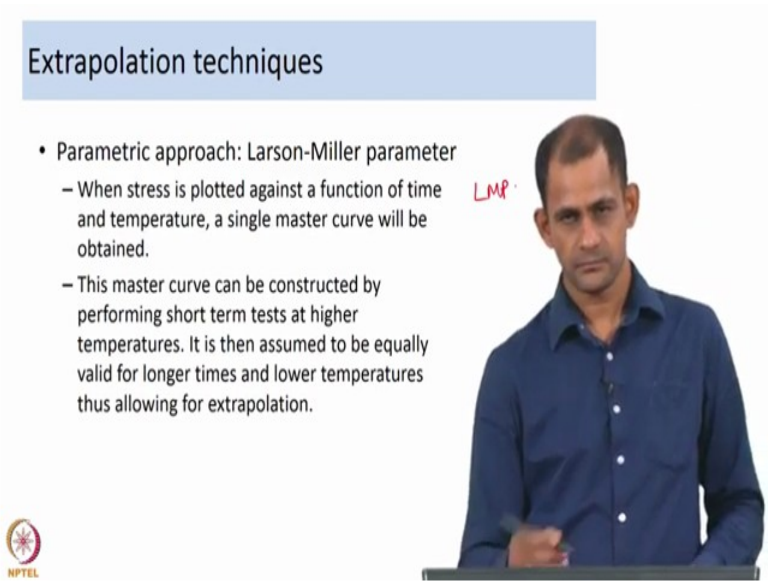

So let us look at the parametric approach, so Larson-Miller parameter comes under the category of the parametric approach of creep life prediction or useful life prediction. So what is the Larson-Miller parameter basically the Larson-Miller parameter is a parameter that is plotted against stress in a single plot and when you plot the stress against the Larson-Miller parameter as you will understand is dependent on time and temperature, so when you plot the stress against a function of time and temperature you will obtain a single master curve and this master curve can be used for predicting the performance of the component at different condition of stress temperature and time.

Now how do you construct this master curve? Well this master curve can be constructed by performing short term tests at higher temperatures and then what is assumed is that the performance is going to be consistent even at longer times and lower temperatures. So you keep quickly generating some data by carrying out short term tests at higher temperatures, now when you test a material at higher temperatures obviously the material is going to creep faster, if it is going to creep faster that means it is also going to fail faster.

So test at high temperatures will you give quickly data about the rupture life or the time to a certain strain, so you will get the data in quick time. Now you can use this data and then assume that the same data can be used to extrapolate the performance for longer times at lower temperatures. So that is the approach of the Larson-Miller parameter.

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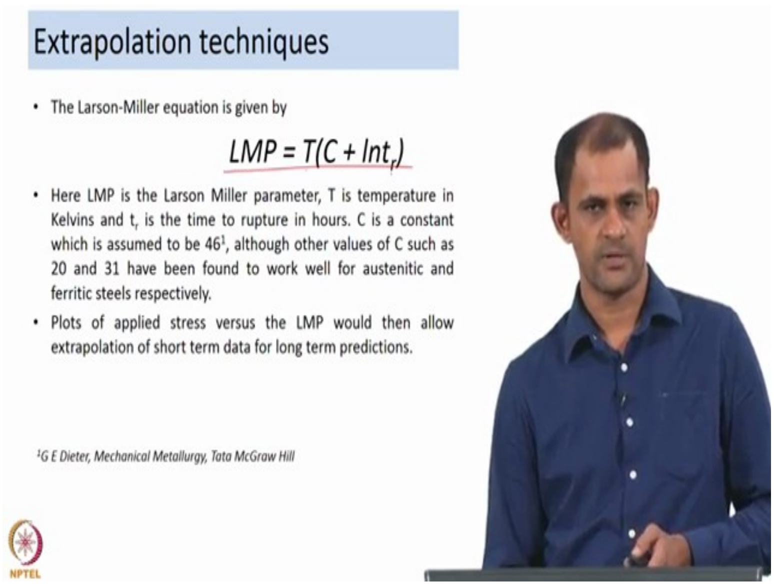

So the Larson-Miller parameter is given by the following equation, so LMP which is Larson-Miller parameter is dependent on the temperature and time to rupture and T is generally taken in kelvins and tr which is a time to rupture is taken in hours, C is a constant which is generally assumed to be 46, all the other values of C such as 20 and 31 have also been found such as for example 20 steel in austenitic steel and 31 steel in ferritic steels.

Now what the approach as like I mentioned is make a plot of applied stress Versus the Larson-Miller parameter and for carrying out extrapolation of short term data to long term performance.

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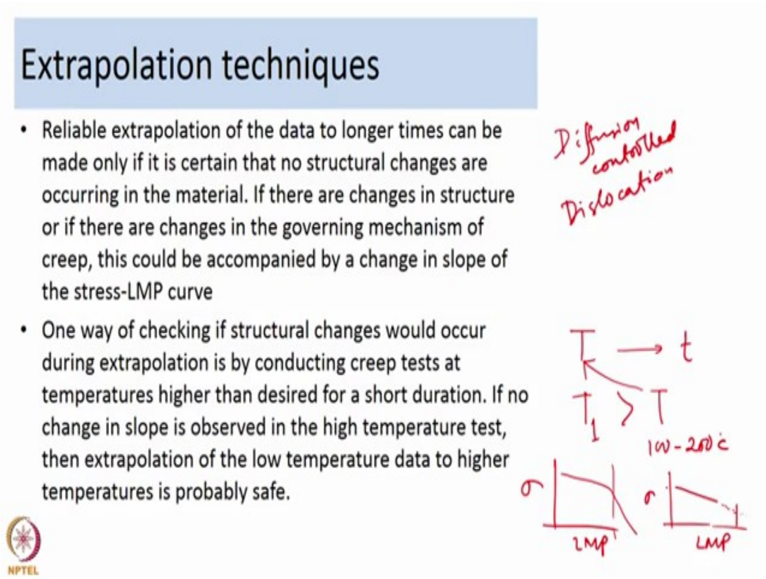

Of course such extrapolation is reliable only if it is certain that no structural changes are occurring in the material. Now when you are doing the short term test in you are using it for long term performance you have to be sure that the material behavior has not changed over the longer times, so for example if you have structural changes.

So for example you are talking about test at a certain temperature and time and you want to extrapolate it to another temperature and time you have to be very sure that say microstructural parameter such as grains size has not changed when you are going from this one set of temperature, time to another set of temperature, time conditions or say precipitates which we are present at a certain combination of stress and temperature a time and temperature they should not have dissolved at another combination of time and temperature, if such kind of microstructural changes or even for that matter dislocation arrangements, if these things change then you will not be very sure about the extrapolation process.

Also if there is a change in the governing mechanism of creep, for example for a certain combination of time and temperature the mechanism of creep is diffusion control and at another combinations of time and temperature if the mechanism of creep is dislocation control then you cannot be sure about your extrapolation you cannot carry out blind extrapolation without accounting for this change in deformation mechanism.

Now one way of checking if structural change would occur during extrapolation is by conducting creep tests at temperatures higher than that desired for a shorter duration. So you can carry out creep tests if you are interested in the performance of the material at say temperature T and you just to be sure that there are no structural changes that material will undergo over a certain duration of time T what you can do is you can test your samples at a test temperature of T1 but T1 is fairly greater than T, so at least say 100 degree centigrade or 200 centigrade greater than T.

Now once you test your sample said at higher temperature and if you do not come across any structural changes then you can be confident that the material is not going to undergo any structural changes at a lower temperature, ok. So if no change in slope is observed in the high temperature test change in slope is generally associated with structural changes or these mechanism changes, so if you do not see any changes slope in your data in a plot of stress Versus LMP say if will curve like that if you do not see any change in slope at different temperatures and time conditions then you can be sure of extrapolation technique and basically there is no change in slope you can take that the data and predict the behavior at higher values of LMP, so it is safe to do that.

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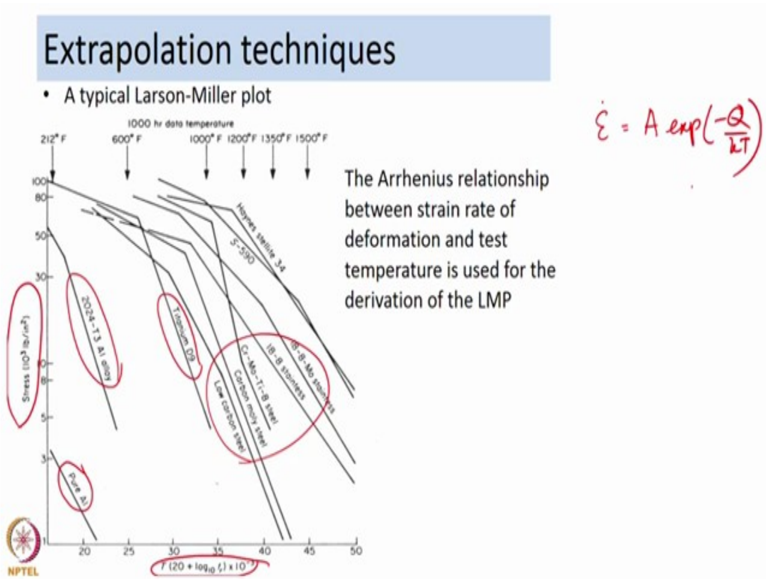

Now this is how a typical Larson-Miller parameter Larson-Miller plot will look like, so you have stress on the Y axis and the LMP on the X axis, in this particular plot we are showing the data for different materials such as pure aluminum or you have a aluminum alloys, titanium then some steels, so you have different kinds of alloys that have in plotted in this, I have been shown the performance of the these alloys have been shown in these particular plot.

Now creation of this plot we generally rely on the Arrhenius equation, so you have a strain rate, the strain rate depends on temperature as per this Arrhenius equation. So the Arrhenius relationship between strain rate of deformation and test temperature is used for the derivation of the Larson-Miller parameter.

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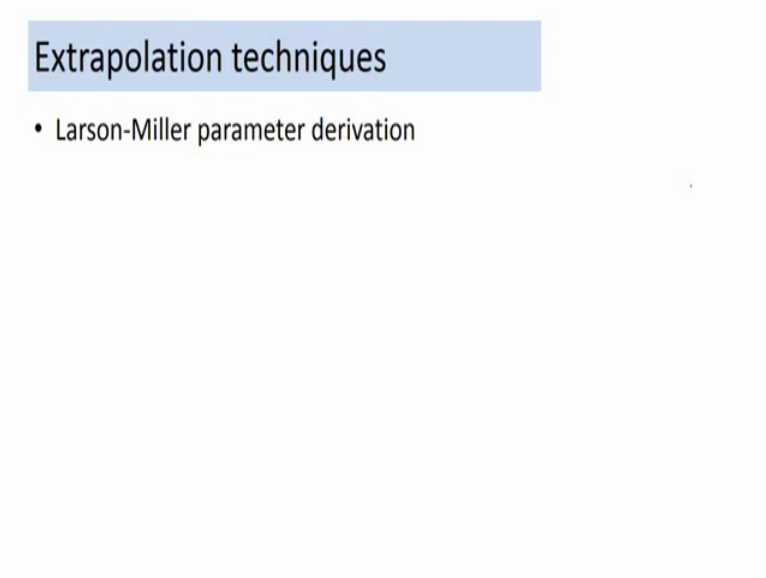

We will quickly go through this derivation to understand how the Larson-Miller parameter has been developed.