Mechanical Characterization of Bituminous Materials

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Lecture-51
Fatigue of Bituminous Mixtures Part 4

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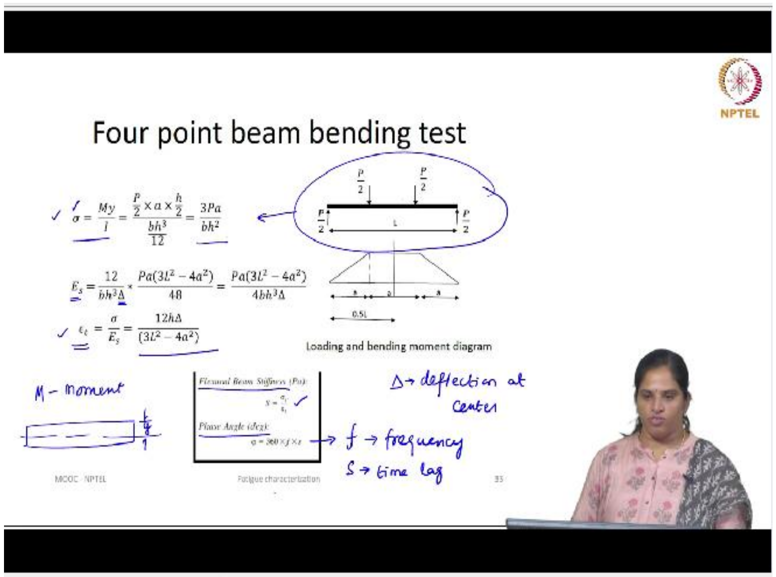

Using this expression ***sigma t*** by ***epsilon t*** where ***sigma t*** is the stress amplitude, ***epsilon t*** is the strain amplitude. And here phase angle, which is a lag between the stress and the strain is given by ***360 into f into s***, where ***f*** is the frequency of testing, ***s*** is the time lag between a stress and a strain. So, the ***f*** is frequency of testing and ***s*** is the time lag between stress and strain. So, now here for repeated loading, we calculated modulus called a flexural beam stiffness and the phase angle using this equation. This flexural stiffness and the phase angle is further used in determining the fatigue life of a bituminous mixtures.

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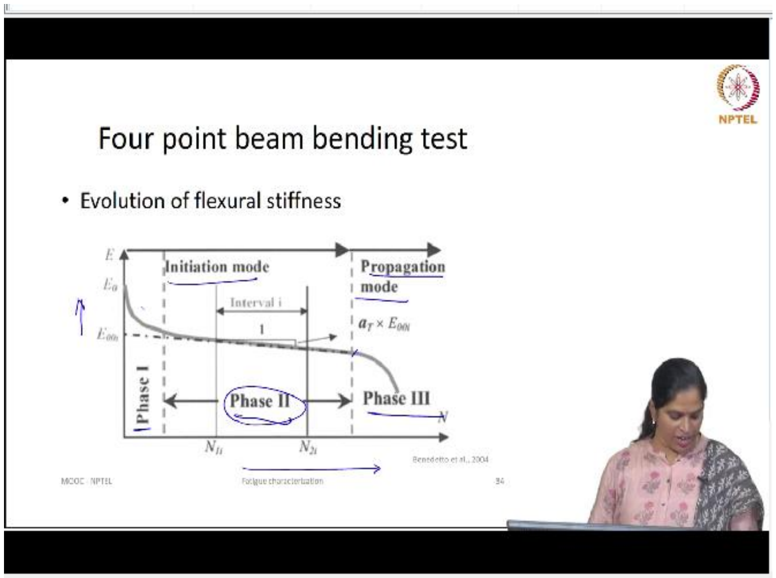

So, now we know what is flexural stiffness, but if you see the evolution of a flexural stiffness it exhibits a 3 phases. So, flexural stiffness as given in a Y axis, we have function of number of load applications, you can see a 3 phase, phase 1, phase 2 and phase 3. So, in the initial phase, there is a drastic decrease in the flexural stiffness. And in the second phase, the decrease in the value is uniform and it is gradual.

And in the third phase again the flexural stiffness value decreases. So, we expect a decrease in the flexural stiffness as the damage accumulates. The initial phase is not due to a damage accumulation, this initial phase decrease in flexural stiffness may be attributed to steric hardening of a sample or due to initial temperature thermal changes that is happening due to beam loading.

So, this ignoring this initial decrease in the flexural stiffness, now, if you see phase 2 you have a gradual decrease, we say that this gradual decrease and micro crack starts in this gradual decreasing phase that is in phase 2, the micro crack starts forming. So, the micro cracks coalesces to form a macro crack when it moves from phase 2 to phase 3. So, we say this is the initiation mode and the crack propagation mode as of phase 3.

And again it is a hypothesis, initiation mode is a phase 2 it is hypotheses all it is assumed that in the phase 2 the micro crack starts forming and in a phase 3 all this micro crack coalesces and the propagation of a crack occurs and this due to that the stiffness reduces drastically.

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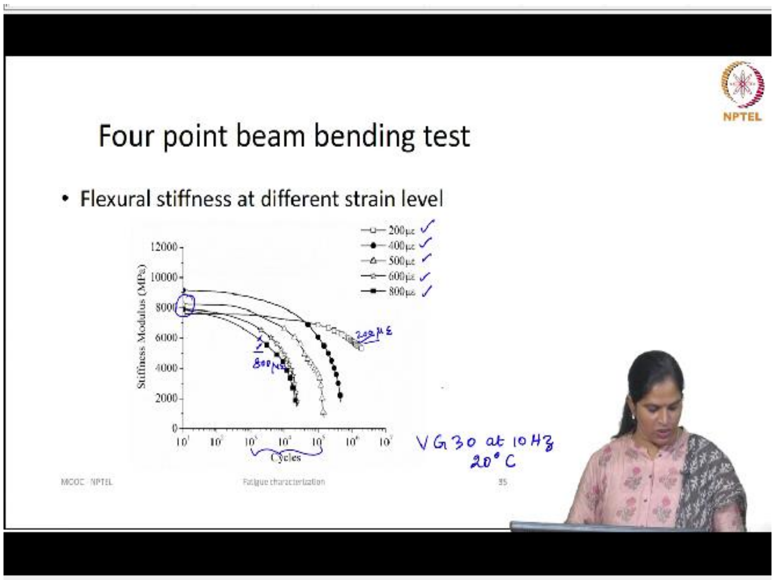

So, you can see a flexural stiffness calculated for different strain levels for this is for refer time bituminous mixture prepared with VG 30 sample at 10 hertz frequency when tested at 10 hertz frequency and 20 degrees Celsius. So, the test was conducted at 200, 400, 500, 600, and 800 micro strain. So, you can see that the refer time fitness modulus decreases with the loading and you have to note that this is a logarithmic scale.

So, refer time initially there is no much difference in stiffness and saw when you test it a different strain level, but as the damage progresses, higher strain level this 800 micro strain if you see the damage occurs or the modulus decreased at a faster rate when you test it higher strain level and the rate was lower at the lowest strain level, say for example, comparing this 800 and the 200 micro strain.

So, damage accumulates at a faster rate as a modulus is decreases at a faster rate the 800 micro strain when compared to this 200 micro strain. So, this is how the flexural stiffness varies. So, the reduction in flexural stiffness depends on the strain we use.

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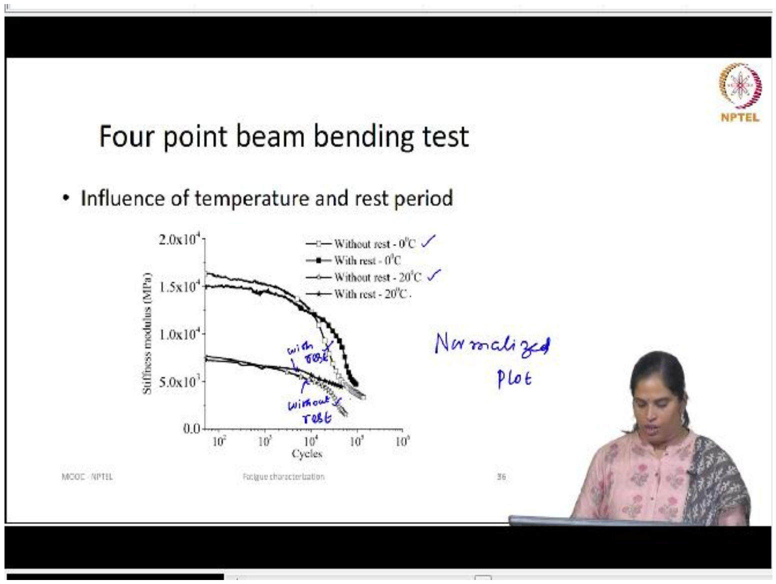

Again that the evolution of flexural stiffness also depends on the test temperature. If you see test temperature at 0 degree and 20 degree. So, this is refer time the test conducted without rest period on continuous loading at 0 degree and this is a test conducted without rest period at 20 degrees. So, 0 degree has a high flexural stiffness compared to 20 degree as expected and again the rate of decrease is also not same that you will observe when you plot a normalized plot.

Normalized value, you can normalize the value and plotted and check whether how the rate of decrease in modulus occurs. So, when you compare again with the rest and without rest, you can see when this is a 20 degree Celsius with the rest and this is without rest. So, when you compare with rest and without rest data, you can see that rest period has improved the rate of decrease in stiffness modulus.

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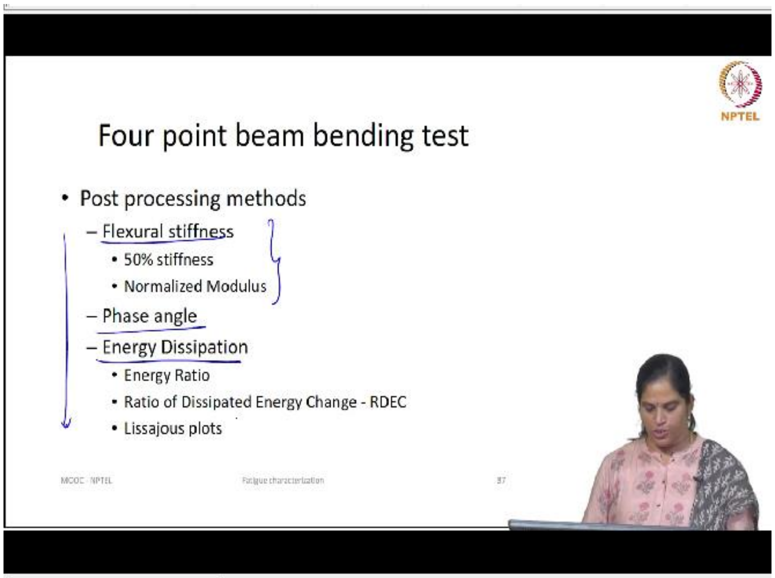

So, now we have calculated the stiffness modulus for different loads cycles. Now, we need to find out from the stiffness modulus value, we need to find out what is the fatigue life of a bituminous mixtures. There are various post processing method available to calculate the fatigue life of a bituminous mixtures. So, few of the post processing methods but not limited to this are listed here.

It can be broadly classified under 2 group, flexural stiffness or even 3 group, one is determining the fatigue life based on the flexural stiffness, determining the fatigue life based on the phase angle and then determining the fatigue life based on the energy dissipations. So, we will see in detail how this post processing methods are.

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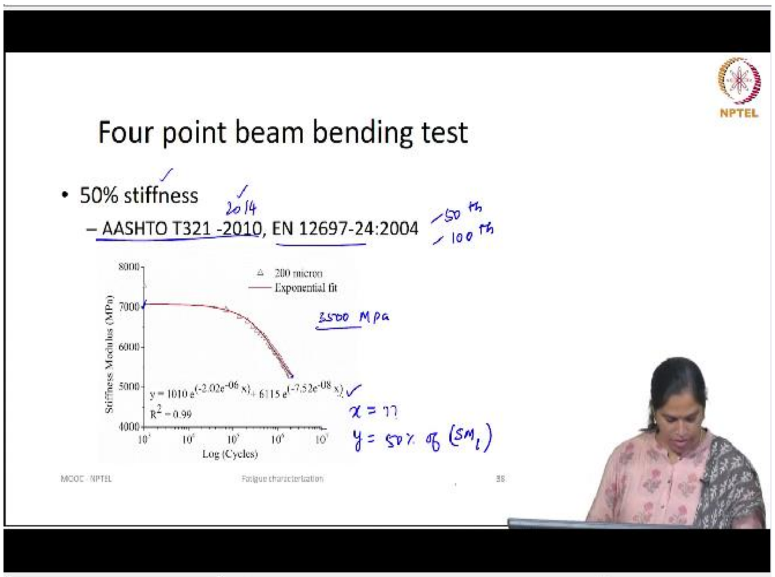

So, refer time fatigue life calculated based on the stiffness. So, then the AASHTO T321 10 now, we have 2014 revision recommends are different method of fatigue life calculations as well as per AASHTO T321 2010 and as per the EN standard fatigue life was estimated using a stiffness a value or a flexural stiffness value. It says that damage in a payment occurs when the flexural stiffness falls less than 50% of the payment.

Identify a number of cycles corresponding to the 50% flexural stiffness. So, we should know what is an initial stiffness here, initial stiffness as you saw there is a phase 1 progress just to avoid a phase 1 progress, initial stiffness as per AASHTO is taken as 50th cycle and as per EN standard is taken as 100th cycle. So, pick the initial cycle find out what is a number of cycle corresponding to the 50% of stiffness of initial striker.

And that number gives you the fatigue life of a bituminous mixtures. In case if you need to extrapolate the value say for instance, the initial stiffness here is 7,000 50% of initial stiffness which is 3500 occurs somewhere here below. So, now it has that during testing the step the test was dropped to below before it reach the 50% stiffness. So, now in this case you can use a exponential fit and estimate the fatigue life corresponding to the ***x*** value here or you need to find out what is ***x*** value for the corresponding ***y*** of 50% of initial stiffness 50% of initial stiffness or stiffness modulus at i^{th} initial cycle.

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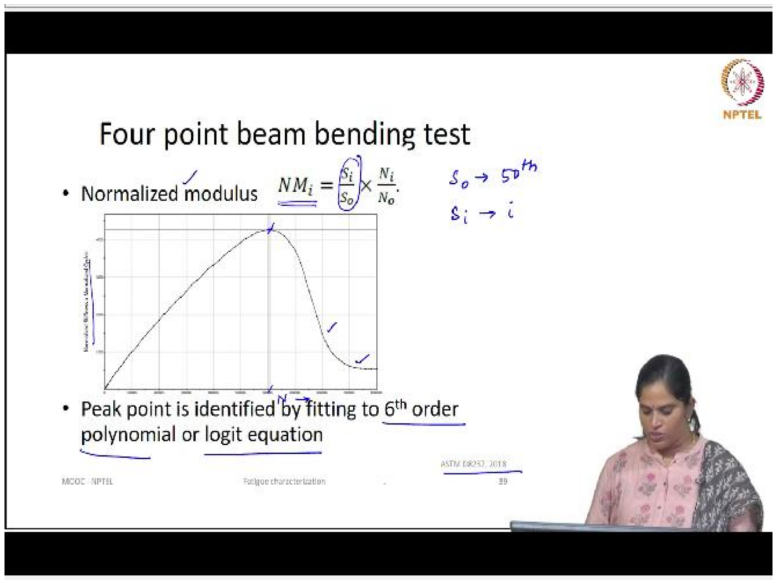

And ASTM D8237 recommends a normalized modulus for calculating the fatigue life. The normalized modulus is nothing but the normalized value of stiffness modulus where ***Si*** is measured at the initial cycle, that is at 50th cycle and ***So*** is at the 50th cycle which is at the initial cycle ***Si*** is at the ***ith*** cycle. So you normalized value with respect to the initial stiffness.

So and multiply by the product of ***Ni*** by ***No***. If you do this we call this as a normalized modulus. So, when you plot a normalized a modulus as a function of number of cycles, the x scale here is N, you will get the normalized stiffness plot to be of this trend, identify the peak point and this peak point is assumed as a failure point. So, in case time if you find it difficult to identify the peak point, you can fit a normalized modulus to the 6th order polynomial function.

And differentiate that 6th order polynomial function and after differentiating find the number of cycles corresponding to the maximum function, you will get a value of N. You can also use logistic equations to determine the fatigue life of bituminous mixtures.

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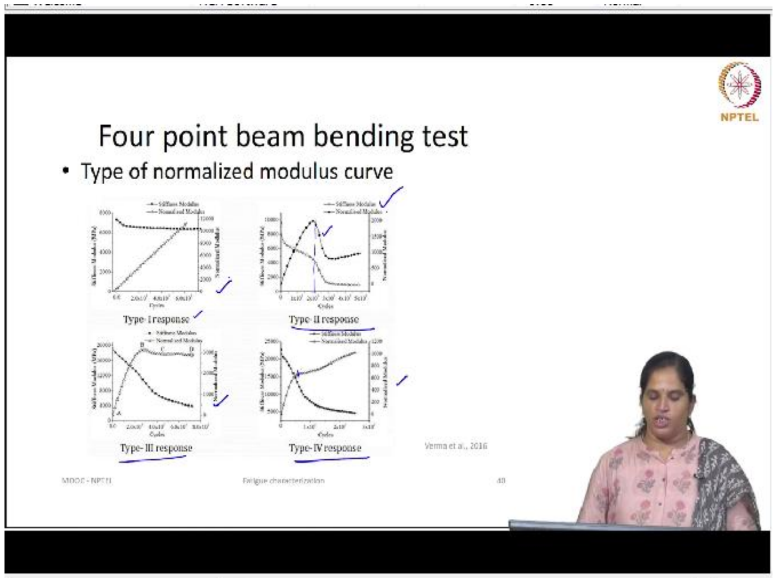

Now, if you see a normalized modulus curve as per ASTM recommendations that typically normalized modulus curve looks something like this type 2 response. So, you have normalized modulus curve type 1 type 2 type 3 type 4 response, that typically ASTM code normalized modulus curve looks like this. It increases reaches a peak value then decreases, will identify the point corresponding to the peak point as a fatigue failure point.

Now, if you see a type 1 response, the test was terminated before it reaches the peak value, type 3 response it reached a peak value but further there is no decrease in the normalized modulus value. In a type 4 response, not clear here, which is the peak point. So, there is even after turning up one specific you have a localized peak and there is still increase in the modulus value. So, it is not clear how to determine the fatigue life of all these 2 conditions. But here for this conditions, we can use a weibull fit for determining the normalized modulus.

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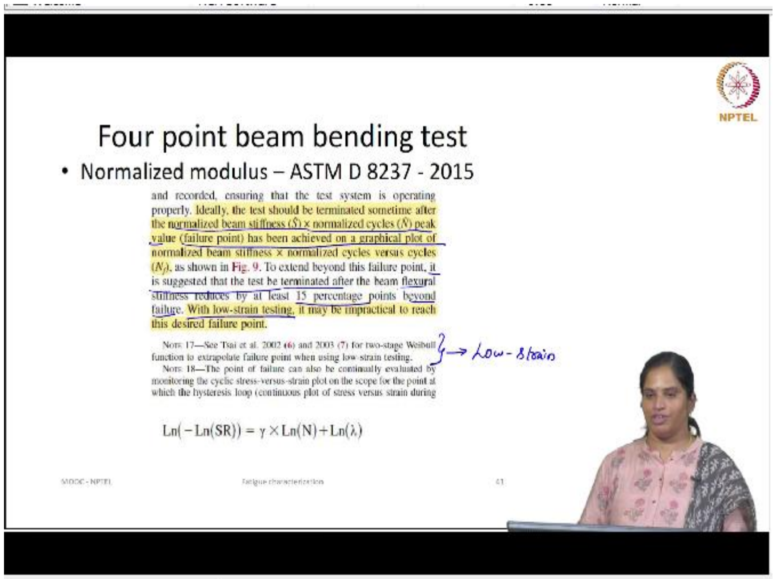

So, ASTM says that, ideally that test should be terminated sometimes or after the normalized beam stiffness and the product of normalized beam stiffness and normalized a cycle P value has the failure point that is peak value has been achieved on the graphical plot. If this is not achieved, you can use a weibull distribution as described in this note. So, this generally occurs weibull distribution conditions fitting generally occurs when we test it at very low strain level.

ASTM also gives the point when to stop testing. So, if you see that it is suggested that the test to be terminated after the flexural stiffness reduces 15% beyond the failure point. So, this is the conditions given for termination of a test period.

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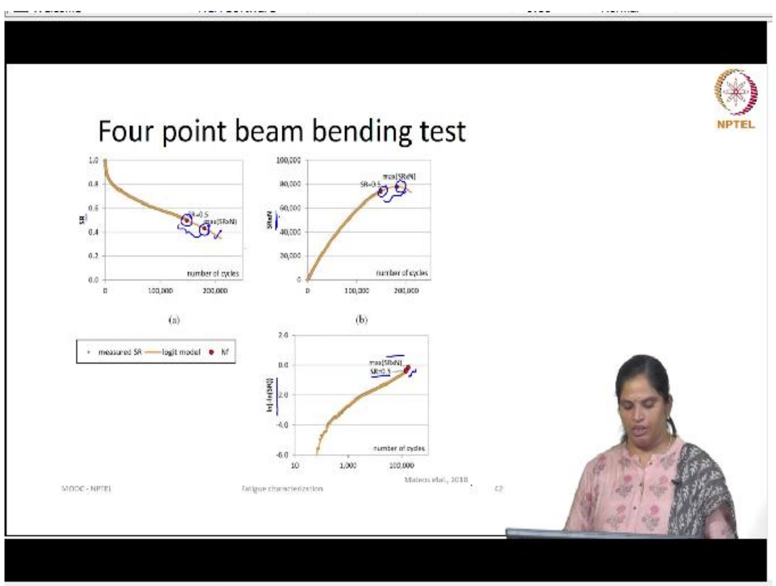

So, there is a small comparison between fatigue life obtained from a 50% stiffness and logistic model or using a weibull distribution fit. Now, if you look into this first equation, SR equal to 0.5 this fatigue life is based on the 50% initial stiffness. Now, if you see this maximum of S is based on a logistic or sorry based on the peak point of a normalized modulus plot and the fit here is the logistic fit model.

Here the second plot again it shows that 50% modulus is here the maximum point is here, this is SR into N, this is stiffness modulus, and this is into N same functions. Now, if you see a weibull fit. So, based on the weibull fit if you calculate, you can see that 50% stiffness and the maximum point occurs almost near. But if you do it based on the logistic equation you can see a difference in the fit. So, depends on what fitting equations we predict the fatigue life also varies with the equations.

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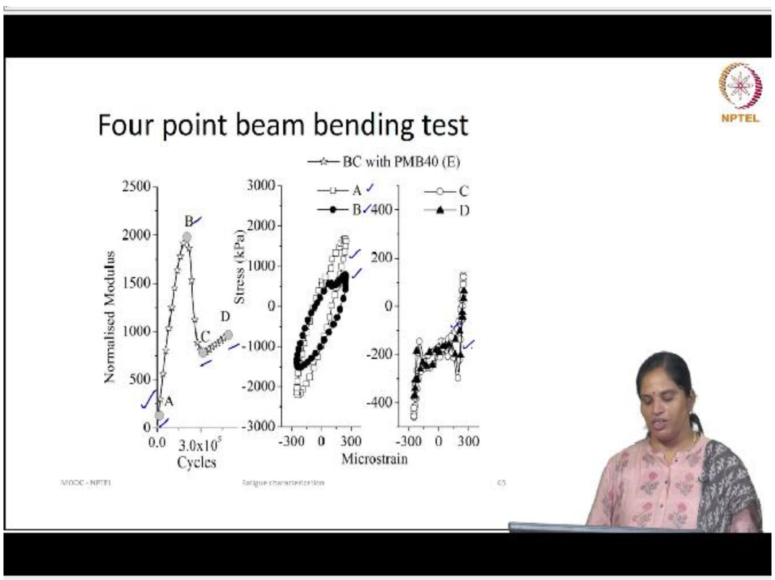

So, this is our normalized modulus curve. Now if you want to see a damage that occurs at a different stage of a normalized modulus, the damage can be seen by plotting Lissajous plot, if for an undamaged sample the Lissajous plot will be an elliptical and for as the damage progresses the Lissajous plot will be an disorient from an elliptical shape to a non elliptical shape.

So, now, if you take a 3 or a 4 points mark 4 points in the normalized modulus, one of the initial state, next at the peak stage and C and D at the nearing the end of the sample life. Now, if you see at A and B, the Lissajous plot one is elliptical and other B is also nearing elliptical at C and D you can see the Lissajous plot to a non elliptical shape. So, this non elliptical Lissajous plot can be used as a factor to identify the damage or it also shows the damage in this extent of damage in this sample.

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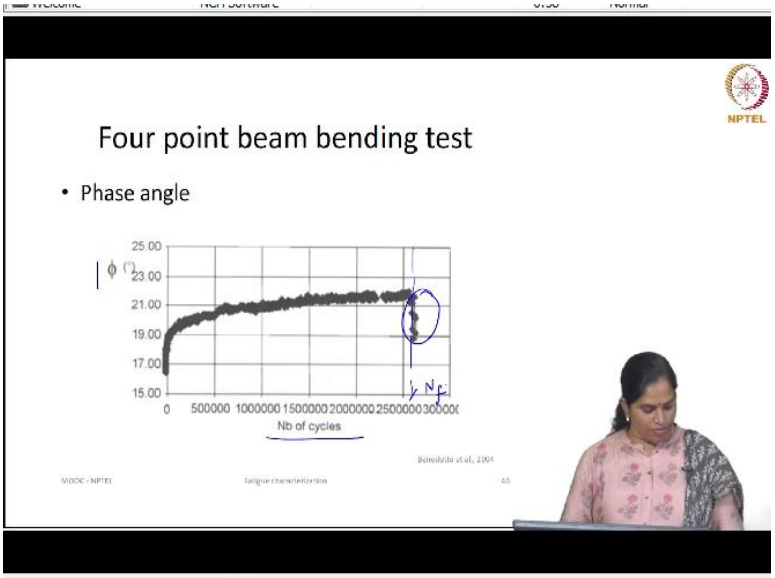

The next method of identifying or determining the fatigue life of a bituminous mixture, this using a phase angle value. So, phase angle value as the damage progresses, the phase angle is plotted as a function of number of cycles refer time, at the point of damage or the extreme point of its damage you can see the decrease in the extreme sharp decrease in the phase angle and this is taken as a fatigue life of a bituminous mixtures.

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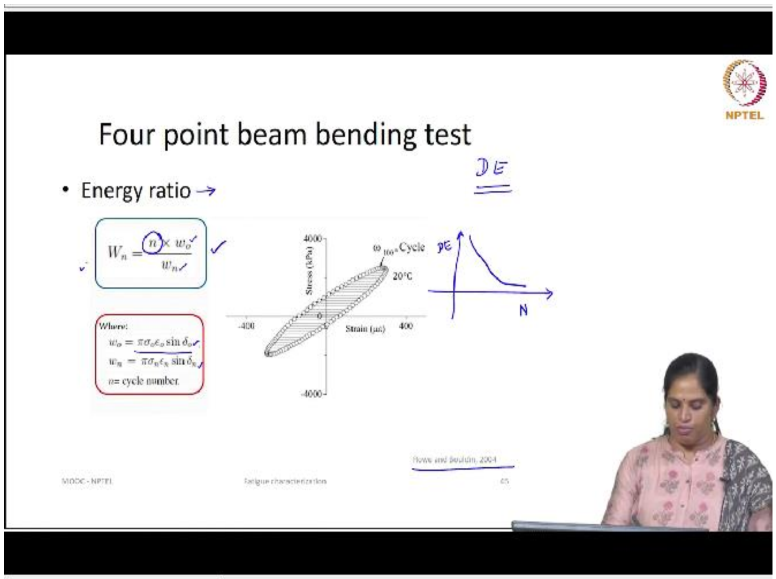

The next approach of determining the fatigue life is using an energy dissipation value, dissipated energy, which in a short form can be noted as DE. So, this dissipated energy generally, we get or we find it using an equations, we are all familiar with this dissipated energy, which is function of a stress amplitude and the strain amplitude and delta here is the phase angle, the suffix ***O*** is given for an initial cycle and the ***N*** is given for an ***Nth*** cycle.

So, with this equation you can calculate the energy dissipation per unit volume per each cycle. So, this ***W*** gives you energy dissipation per unit volume per each cycle. Now, calculate the energy dissipation and if you plot a energy dissipation, as we already saw energy dissipation for a strain control test, this is for a strain control test decreases with number of cycles. So, energy dissipation for a strain control test decreases with a number of cycles.

So, calculate this energy dissipation value and find the ratio called energy ratio. This method of post processing approach was suggested by Row and Bouldin. So, find the energy ratio, which is nothing but the ratio of initial energy dissipation value at the initial cycle to the ***Nth*** cycle and multiply by ***N*** here.

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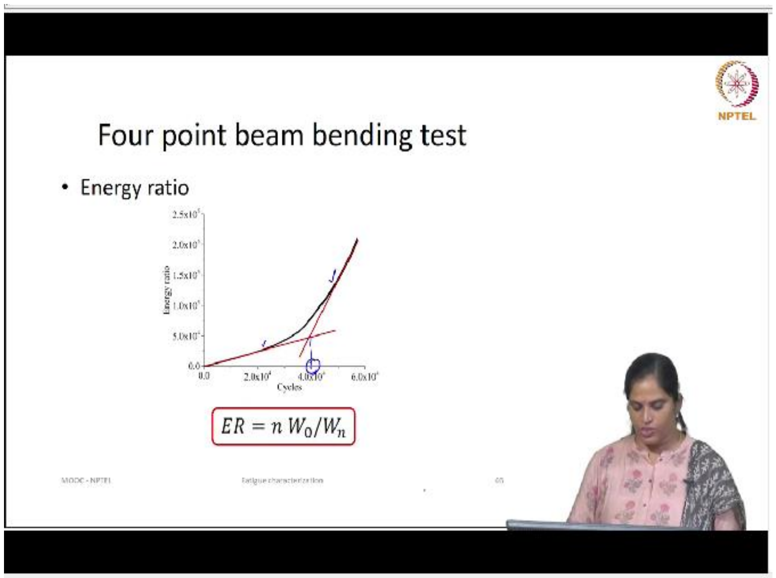

So, this energy dissipation ratio when you look into the trend of energy ratio, you will see energy dissipation trend exhibiting a two stage slope, one is a refer time where the slope is very small, second is as the slope increases. So, this 2 stage slope the point of intercept of this 2 stage slow this determined as a number of cycles to failure. So, this is the energy ratio method.

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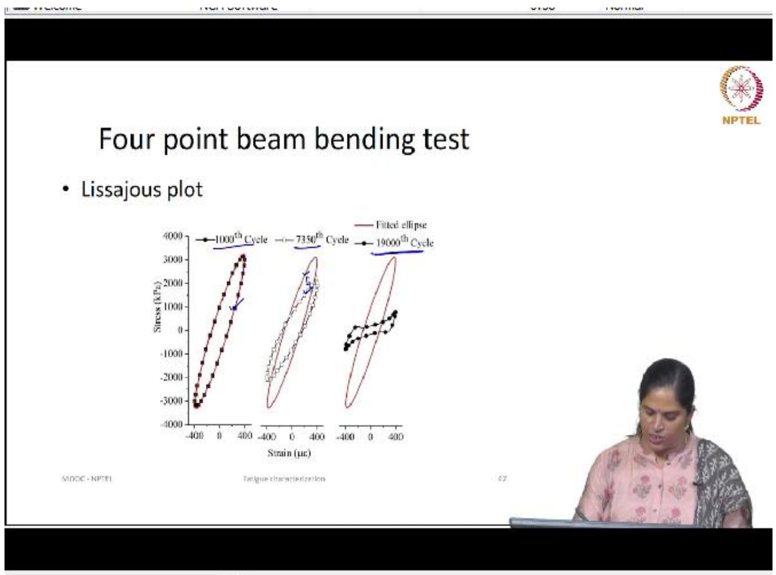

And as we said already Lissajous method in you this. So, you have Lissajous plot if the Lissajous method in this. So you have a Lissajous plot if the Lissajous plot here at the initial cycle is perfectly ellipse we assume that there is no damage in a material and as the Lissajous plot that deorient from the ellipse over as the loading cycle increases the damage occurs slowly.

Now, if you see the extreme cycles of loading the Lissajous plot is not an elliptical shape. So, now, comparing the regular ellipse with the stress strain plot, you can measure a regular extent of fitting using an R square value.

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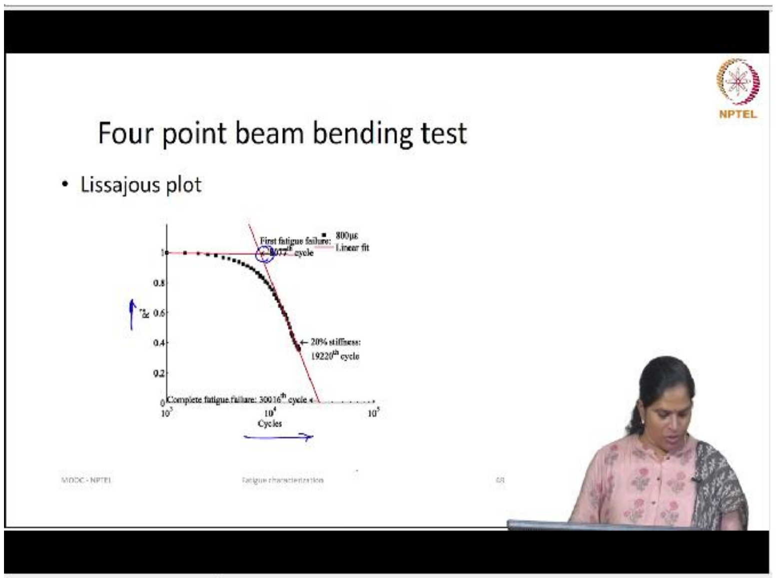

So, now, if you plot a R square value as a number of cycles you will have a trend something like this. So, again this trend here the point of change in slope is used in determining the fatigue point.

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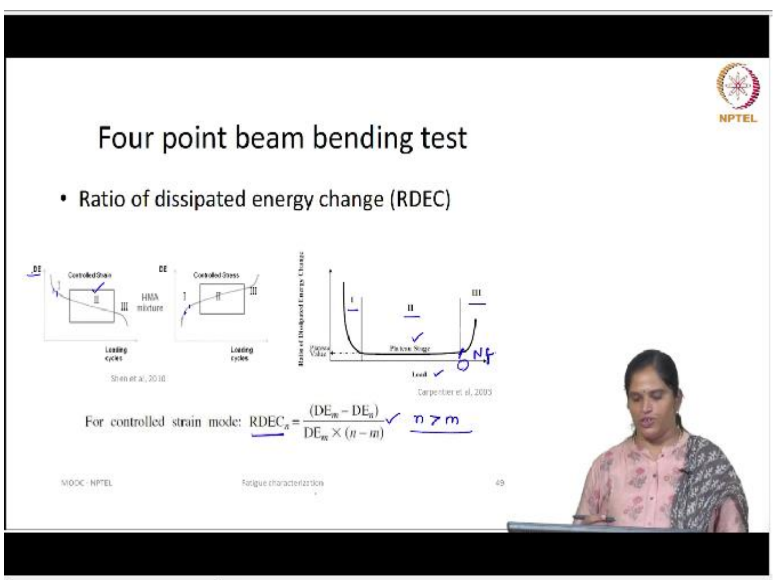

So, this is again a hypothesis what we mean. So, in the next method we use the energy dissipation ratio for calculating the fatigue life. So, as we said already in a strain control test, the dissipative energy decreases and in the stress control test the dissipative energy increases. So, now, if you compare a dissipative energy between 2 consecutive cycles either in a stress control test or a strain control test.

Compare a dissipative energy between 2 consecutive cycles and take a ratio you will get a plateau region something like this at the second range. So, this is a ratio of energy dissipation or the issue of dissipated energy change. This calculated using this expression. So, in as you will see in a strain control mode, ***M*** and ***N*** represents the number of cycles, previous cycle being more than refer time next consecutive cycles.

So ***N*** is greater than ***M*** in a strain control mode. So, it calculate the RDEC based on this value and plot it as a number of load cycles, you will see this RDEC curve to be a tub shape. Now, you have 3 phases here, phase 1, phase 2, phase 3. So, the point where the phase 3 starts represents the damage in the bituminous mixture and we take this as a fatigue life of bituminous mixtures.

So, we have seen a different post processing method of four point beam ending test. Now, the next is, we will see how to conduct the indirect tensile strength of bituminous mixture and what are the post processing. We will also discuss the post processing methods available and finally we will relate all these laboratory test results to the mix design. Thank you.