Mechanical Characterization of Bituminous Materials
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Lecture – 10
Small Amplitude Oscillatory Shear – Part 4

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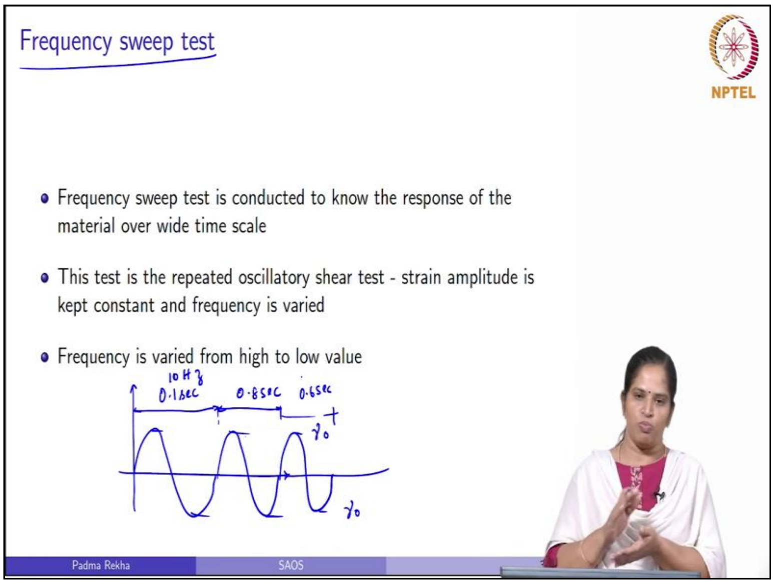

So, the next common test width which is conducted for bitumen in an oscillatory shear testing is a frequency sweep test. So, frequency by varying the frequency it is like we are trying to understand the behaviour of bitumen over a wide range of temperature so a inverse of frequency as a time. So, if you want to know the behaviour of bitumen over a wide ask time scale we do this frequency sweep test. So, in this frequency sweep test we keep a strain amplitude to be constant and vary the frequency.

Frequency is generally varied from a high to low value for especially when you test a bitumen. So, what you do is in a frequency sweep test so initially you may subject the bitumen to a sinusoidal shearing if this frequency time is 0.1, 1 second or high frequency which corresponds to 10 Hertz. So, next cycle will be like a less time say 0.8 seconds. So, the other cycle again will take a lesser time lesser time say 0.6 seconds.

So you vary the frequency and give a repeated oscillatory shearing keep the strain amplitude constant and vary the time of shearing time of completion of one cycle. So, if you do this frequency sweep what will be the response of a material.

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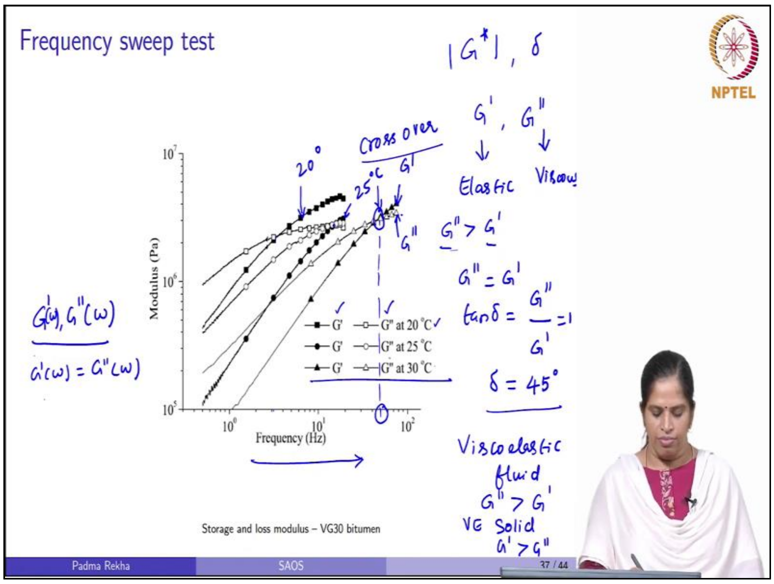

So, as we know that when you do an oscillatory shear testing we either measure a dynamic modulus and phase angle. We need a minimum 2 parameters to define one it can be a dynamic modulus and a phase angle or storage modulus and the loss modulus. The storage modulus represents the elastic response and the loss model represents the viscous response. So, we need 2 material functions to define a viscoelastic characteristics property of a material.

So, here let us see how storage modulus and the loss modulus varies with frequency. So, let us understand this graph very carefully we will pick one temperature first maybe at 30^0C you have G' and G" at 30^0C, this value is G' elastic modulus and this is viscous modulus G" . Now when you look at the at lower frequency G" is greater than G' .

So, what does it mean if G" is greater viscous behaviour is dominating the elastic behaviour. So, this happens at a lower frequency as the frequency is increased you can see a flip over at one specific point this point we call it as a cross over. So, at crossover point G" is equal to G' or otherwise tanδ which may define it as a ratio of G" by G' since both these are equal tanδ value is 1 or δ value is 45^0.

So this crossover point δ value is 45 so after this crossover you can see an elastic modulus dominating the viscous modulus so in this conditions before crossover at low frequency it is a viscous modulus dominating the elastic response after crossover at high frequency it is a elastic modulus that is dominating the viscous response. So, we call this response at a low frequency as viscoelastic fluid response or a fluid like response where G" is dominating G' .

In case after crossover where viscoelastic solid like response is dominating or where G" is greater than G" we call it as a viscoelastic elastic solid like response so the transition is happening and you can identify a transition that is it is a one of a method to identify a transition is identify a frequency corresponding to a point where G' and G" is constant or tanδ value is 45, tanδ value is 1 and δ value is 45.

So this frequency crossover frequency in a way will tell you when does the bitumen respond as a viscoelastic or fluid like or a solid like. So, now as a temperature varies from 30^0C to 25 ^{0}C this 25 ^{0}C response you can see that there is an increase in the modulus as a temperature decreases. And you can see that the crossover point this is a crossover point at 25^0C occurred even at a lower frequency.

So at again lower temperature still lower temperature at 20 ^{0}C again the crossover occurred, so the modulus value here G' and G" depends on frequency they both are dependent on frequency. We can see that as a frequency increases the modulus value increases. so are there is a frequency at which both this G' value and G" value is equal and that frequency is what we call it as a crossover frequency. So this value G' and G" also depends on temperature.

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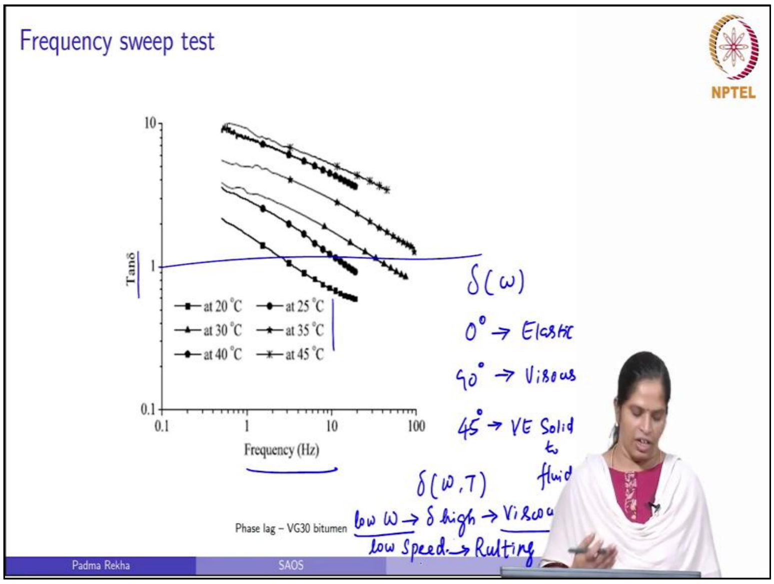

So, you can see a variation of phase angle with respect to frequency. So, tanδ value is also frequency dependent As we said earlier 0^0 represents inelastic response and 90^0 represents the viscous response and 45^0 is a point where the transition occurs between the Viscoelastic elastic solid to fluid so tan 1 this point here, so you can see a different kind of response when you test it at different temperature over a different range of frequency.

So, tanδ again it depends on frequency and it also depends on temperature at low frequency when the response of a material is viscous δ value is high and it is like viscous behaviour dominates compared to the elastic behaviour. So, you know that the low frequency represents low speed of a vehicle so at low speed material starts rutting this is if you want to relate the speed to the distress of the material.

So rutting is more critical at a lower speed, so if you want to simulate the rutting behaviour like it is advisable to know the response of the material at a low frequency. So, we pick or select the frequency depending on the our requirement if you want to characterize it for a rutting response you characterize at the low frequency and if you want to characterize a rutting cracking response you do it at a for a high speed or a high frequency.

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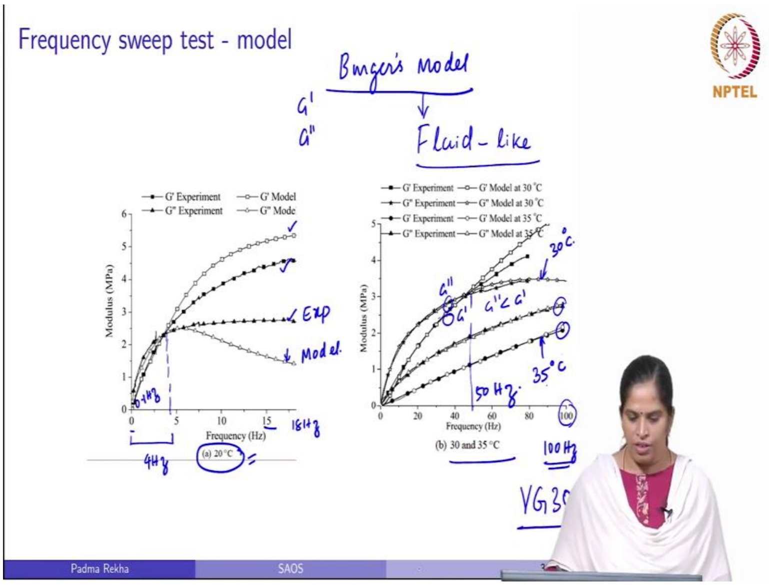

So this is a frequency sweep test experiment and that is compared with a model the model used here is a Burgers model. You know the burgers model relations for a G' and G" we have already obtained that relations in the last lecture. Now if you see the burgers model prediction so one is an experimental value data here and the one without fill is a model data at different temperature.

So now if you see this is a at 20 ^{0}C so the frequency here is from 0 to 15 Hertz or in all the way even up to 17, 18 Hertz and the modulus value was varied from 0 to 6. Now if you see this a comparison between an experiment and a model you can see that a 20 ^{0}C both this G' and G " predictions this is valid only up to a certain range of frequency. See that is a model could predict the experimental data only up to a certain range of frequency maybe here up to 4 Hertz. experiment was conducted from 0.1 Hertz.

So from point 1 Hertz to 4 hertz so this happen at 20^{0}C but when you see the same model prediction at higher temperature 30 and 35 ^{0}C so this data that responds to 35 ^{0}C and this data that responds to 30^{0}C. So, at 35^{0}C burgers model could predict the experimental data very well even up to 100 Hertz. At 30 ^{0}C the experimental data and model data matched nearly 40 Hertz, nearly 50 Hertz.

So we can see that the model prediction is or above this model could predict the response of a bitumen within a stipulated frequency range that range also depends on the temperature. So, we can say that it can predict response of a bitumen the when it exhibit a fluid like behaviour. So, if you see here below 50 Hertz you can see a loss modulus or a viscous modulus dominating the storage modulus or an elastic modulus.

So in this range you have a clear good predictions of a model and experimental data. Now as a frequency increases when there is G" becomes less than G' so that there is a deviation between the model and then experiment in 35 ^{0}C we did not see a crossover up to even 100 Hertz frequency so you can see that loss modulus is always higher than a storage modulus at 35 ^{0}C for this particular type of bitumen and this bitumen is VG 30 bitumen.

So if Burgers model predicted the response even up to 100 Hertz frequency. In this case if you see at 20 ^{0}C the crossover occurred that nearing 4 Hertz frequency a burgers model has a closer predictions of experimental value less than 4 Hertz frequency as a frequency increase the experimental prediction and the more experimental data and the model prediction varied to a larger extent.

So we can see will tell that the Burgers model could predict the fluid response or we already know that burgers model is more a fluid-like model.

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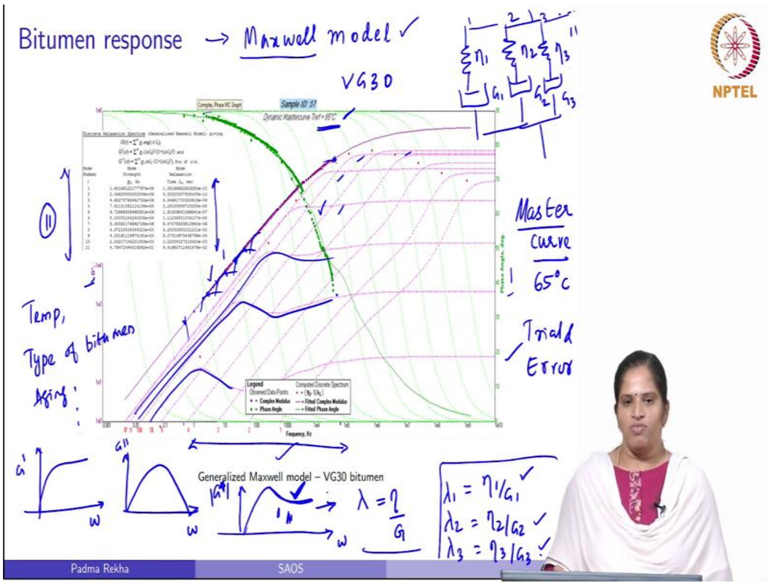

So, the next material response prediction model used here is a Maxwell model but it is not a one-component Maxwell model it is a with different relaxation mode. So, we used a Maxwell model with a different relaxation mode arranged in series something like this for this model prediction 11 relaxation mode is like this so you have a you have a 11 component like this with a η_1 G_1 η_2 G_2 η_3 G_3 and goes like this.

So now if you look into this Maxwell model pins here we have given a dynamic modulus and phase angle. In last case we have seen a storage modulus and loss model as predicted together in this case you can see a dynamic modulus and the phase angle prediction together. You can do it in a both away but you have to do both the parameters simultaneously. So, now if you do a model predictions for this data so the data then only with the legend gives you the experimental data and the line gives you the predicted value.

So if you see a single element Maxwell model we have seen that the storage modulus loss modulus response for a single element Maxwell model was something like the storage model is increased with the frequency and asymptotically reached a constant value loss modulus increase with a frequency and then decreased this is what we have seen in the last class.

So learnt if you combine both together storage modulus and loss modulus the dynamic modulus value as a frequency will show and increase something like this. Now this is for a Maxwell model with one relaxation mode lambda where λ is defined as η by G viscosity function by modulus function. Suppose if you have a different relaxation function like λ_1 where λ_1 is η_1 / G_1 η_2 / G_2, η_3 / G_3 etc well how the response will be?

Or in otherwise will the single relaxation modulus or a single relaxation time sufficient enough to predict the response of a bitumen. So, this plot it shows that the bitumen exhibits a different relaxation function in this case it is 11 relaxation functions at this specific temperature. So, this is a master curve data what is master curve and how to plot this master curve that we will see it in the few lectures down.

So, this is a master curve data at the reference temperature of 65 ^{0}C. So, let us assume that this is a data for a bitumen at a 65^{0}C temperature collected over a wide range of frequency. So, you have a dynamic modulus data here and the phase angle data here so this is the actual behaviour of a bitumen actual experimental data here is given in the just with a legend without any line. So, now if you see the actual experimental data actual experimental data where is something like this but the single relaxation model varies some varies are shown here in this picture.

So, if you compare this experimental data and the single relaxation mode data we are very clear that a single relaxation mode will not predict the complete experimental set of data. So, for this if you use a Maxwell model with a different relaxation time, so now you see here the pink line ,so these are with a different single relaxation mode with a different relaxation time we will see the viscosity function by modulus function η_1 /G_1 η_2 /G_2 , η_3 /G_3 so you have a 11 relaxation time combined together to predict the response of a bitumen.

So at this temperature for this specific type of a bitumen which is again a VG 30 Bitumen at 65^{0}C 11 relaxation time or a 11 relaxation functions could combine together to predict the dynamic modulus value and the phase angle value. So, you combine 11 relaxation functions this pattern. So, you combine it together so this is a range of frequency which is predicted for a specific the relaxation time that was combined together to predict the response of a bitumen.

So, now these relaxation numbers or the relaxation mode it depends upon the temperature we are interested in and depends upon the type of bitumen ageing conditions and many other factors. So, there is no fix to factor but here it is clear that bitumen exhibits and more relaxation time and it is just not a material that has a simple 1 relaxation mode it has a many relaxation mode. So, if you want to capture a behaviour of a bitumen you can use a generalized to Maxwell model the number of component in this generalized my actual model has to be fixed only by trial and error.

So, how do you fix this number of relaxation mode we have to do only based on the trial and error and see that it fixes to the wide range of frequency here. So, we have seen 2 model predictions comparisons with an experimental data one is Burger's model another is a Maxwell model a generalized two Maxwell model. So, Burgers model we have seen that it could predict only in the fluid-like response a generalized two Maxwell model can predict the response of a bitumen over a wide range of frequency but the number of relaxation mode has to be selected based on the temperature type of bitumen we use and aging characteristics and many other factors.

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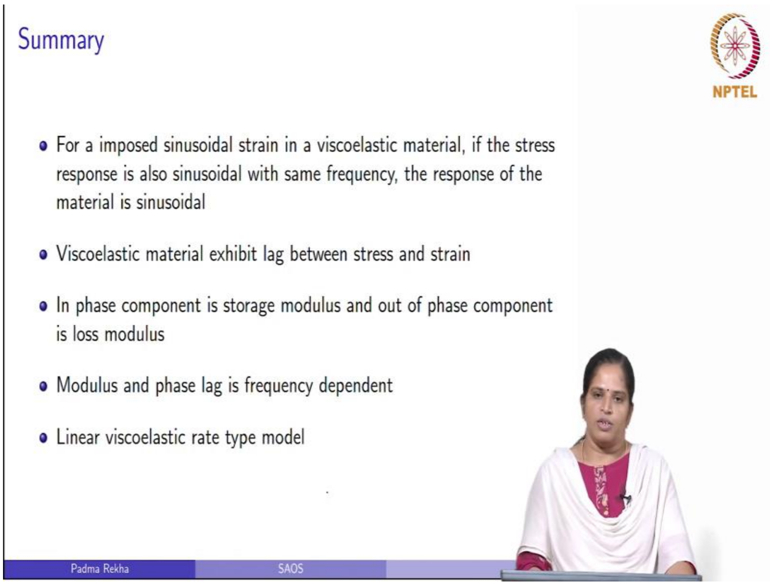

So let us summarize what we have learnt in a two classes so oscillatory shearing is nothing but imposing a sinusoidal oscillation on a material so by imposing a sinusoidal oscillation we are controlling either a strain or stress functions. So, it can be a stress control loading or it can be a strain controlled loadings. So, when the when the control is in a sinusoidal pattern we expect the response also to be in a sinusoidal pattern with the same frequency only then we can call the response of a material to be a linear.

So we call here as a small amplitude oscillatory shear because the response of the material is linear. So, if the material behaves as a viscoelastic material it exhibits the lag between a stress and strain and this lag between the stress and strain depends on the frequency and it also depends on the temperature. So, elastic material has a phase angle of 0^0 viscous material has a phase angle of 90^0 and the viscoelastic material has a phase angle varying between 0^0 to 90^0.

To define a material functions for than oscillate shear we saw storage modulus and the loss modulus and now both the storage modulus and the loss modulus are a dependent functions. We can also use a dynamic modulus and a phase angle value for defining a characteristic behaviour of the material or we can use a storage modulus and the loss modulus. And we have seen these modulus functions and the lag functions are a frequency dependent we have seen few rate type model especially three models one is a Maxwell model and Kelvin model and above those model predictions for a linear viscoelastic response.

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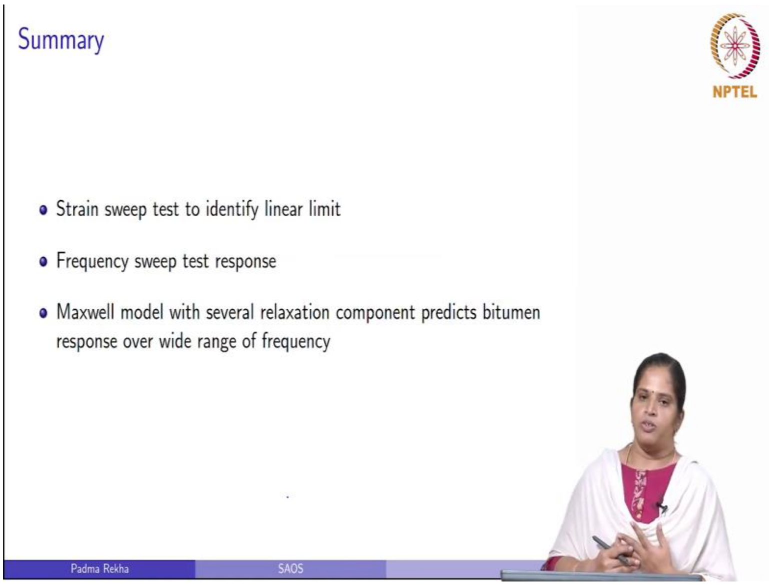

So and we have also seen that application of this oscillatory shear testing for a bitumen. So, we have seen how to conduct a strain sweep test and identify a linear region for the testing and after identifying a linear regime keep this amplitude constant and vary the frequency for conducting a frequency sweep test. Frequency sweep test is a common test that we use it for characterizing a bitumen in an oscillator a shear testing.

So using a frequency sweep test we can identify whether the response of the bitumen is viscoelastic fluid like for a solid like behaviour and we have seen that the burgers model predicted a viscoelastic fluid like response of the material. But it is not good and predicting a viscoelastic solid response of a bitumen a generalized Maxwell model will be able to predict the response of a bitumen over a wide range of temperature.

But that let us even then if the generalized Maxwell model can predict the response the number of relaxation mode in the model depends on the temperature and depends on the bitumen we use and it has to be fixed to based on a trial and error we have to do iteration process and find out what is the number of relaxation mode in it, so thank you for your time