Mechanical Characterization of Bituminous Materials
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Lecture-56
Mechanical Characterization of Bituminous Material-Summary

So, hello everyone, this is the final lecture on the NPTEL course mechanical characterization of bituminous material.

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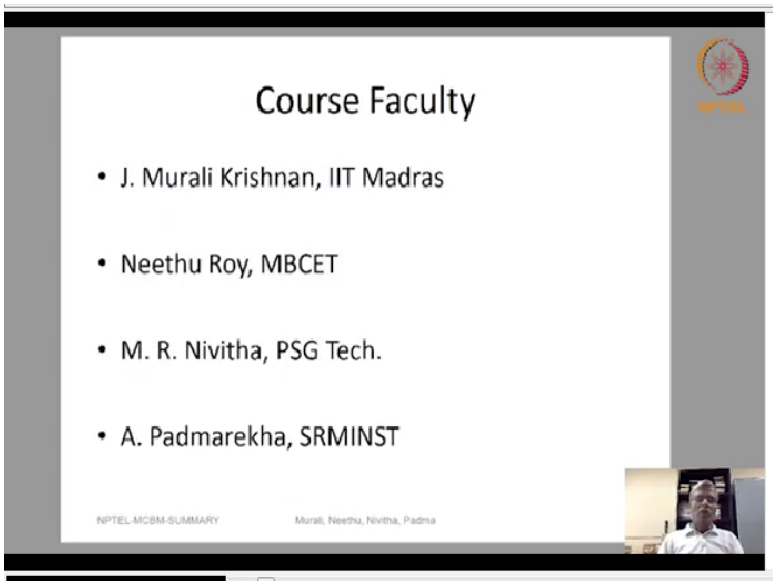

This course was taught by 4 of us Murali Krishna, myself, Neethu Roy, Nivitha and Padmarekha, okay.

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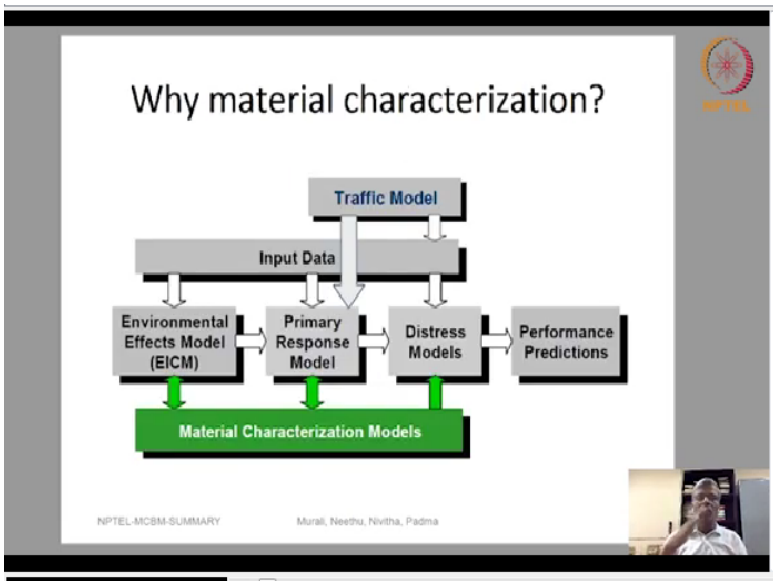

So, let us quickly use this next 50, 50 odd slides to understand what this course was about. So, what I am going to do is to go through each and every lecture and show the snippets of what we intended to cover. So, first and foremost the thing is why should we even do material characterization. So, what you see here in your screen is the design framework for mechanistic empirical pavement design.

There are many models, the traffic model, the environmental effects model, the primary response model, the distress model, and the most important thing that is shown in the green color is the material characterization model. And in fact, it is useful for the environmental effects model, it is the related to the primary response model, distress response model everything okay. So, unless and until we really understand how a bituminous material responds when it is subjected to loading.

And we are really talking about for the design purpose as well as the distress purpose. So, the primary response model is for the design purpose. The distress model is for the distress purpose and the environmental effects model clearly tells you how the response of the material can vary as a function of temperature, right.

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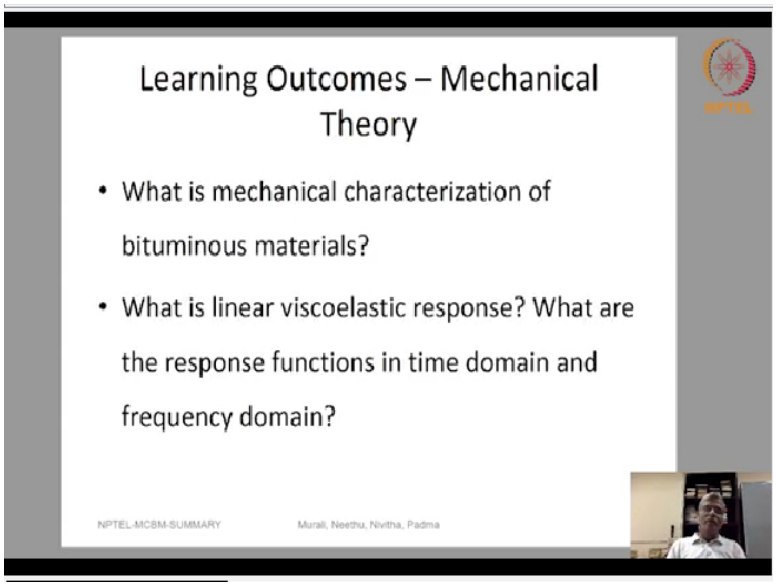

What really was the learning outcomes for this particular course. So, I grouped it under many heads and I am just going to go through it once more. First and foremost, thing is the mechanical theory, what exactly is this mechanical characterization on the bituminous materials. So, if you recollect, I mentioned it clearly as one laboratory investigation, second is analytical models or what are called as constitutive models.

So, these two things go hand in hand together, whenever we use the term mechanical characterization of bituminous materials, right. Now, what is the model that we choose for describing the response of bituminous material. We selected linear viscoelasticity, right. And so, what exactly is linear viscoelasticity response, what really are the response functions in time domain as well as in frequency domain is something that we should have understood by the time we finish this course.

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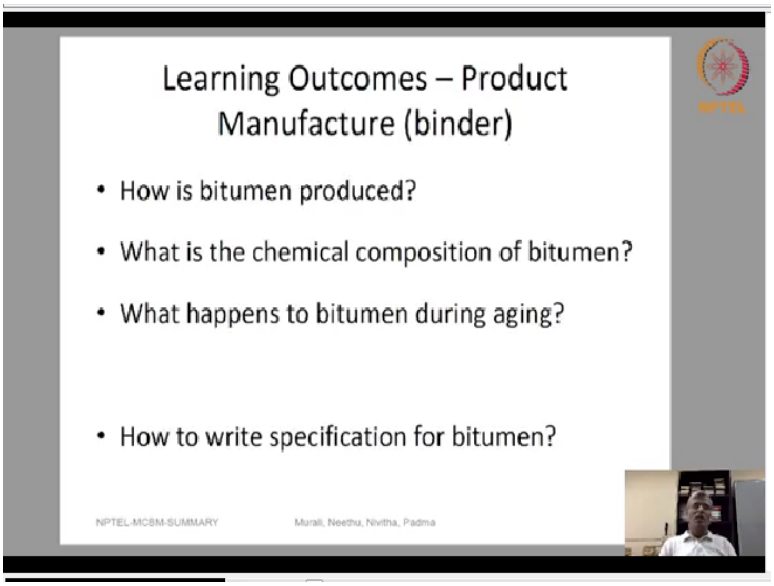

The second is having mentioned the platform on which we are going to build our characterization study, we also need to know a little bit about our material, what is the product the main product, the main product is bitumen, how it is produced, what is its chemical composition, what really happens to the bitumen during aging and taking into account all these things with the linear viscoelasticity background. How do we really write specifications for bitumen?

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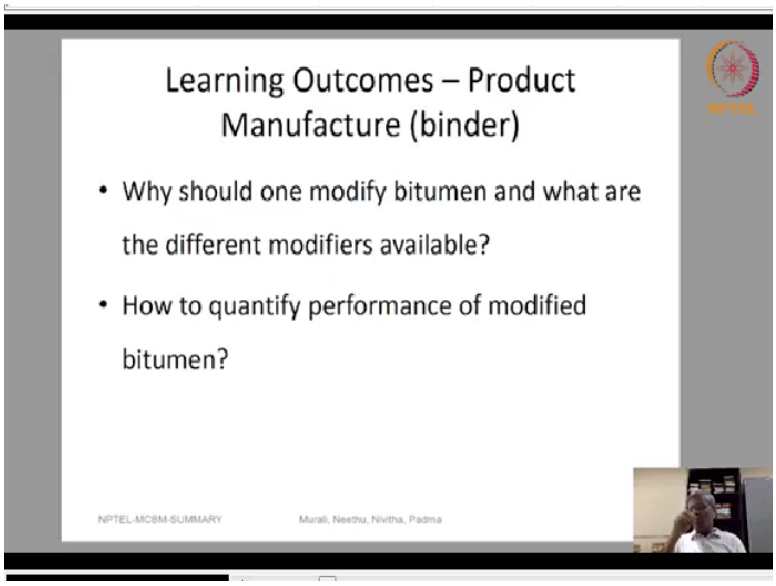

And there are many instances in which one should really modify the bitumen and when we modify the bitumen, what are the different modifiers that are available. And after you modify the bitumen, how do you really quantify the performance of the modified bitumen right.

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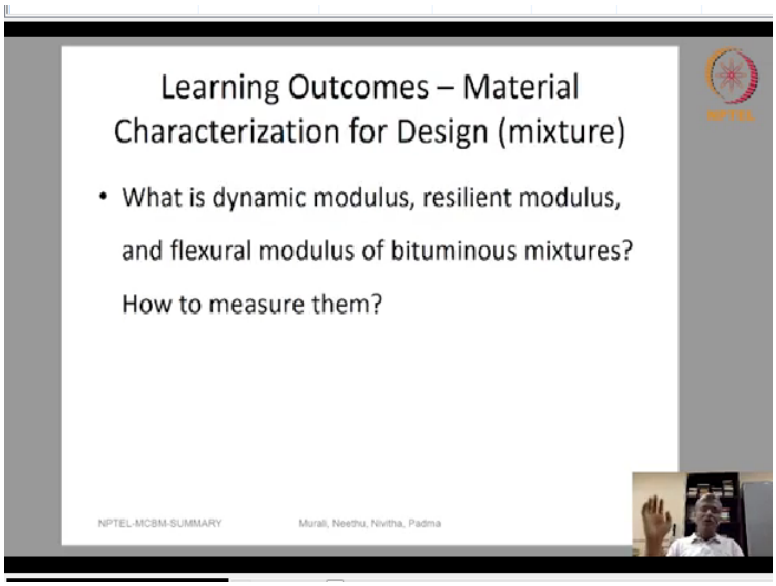

So, now once we have finished with the binder, we go to the mixture for the purposes of design in a pavement, there are different types of moduli that are available dynamic modulus, resilient modulus, structural modules, how do we really measure them. What is the underlying theory associated with each of them right?

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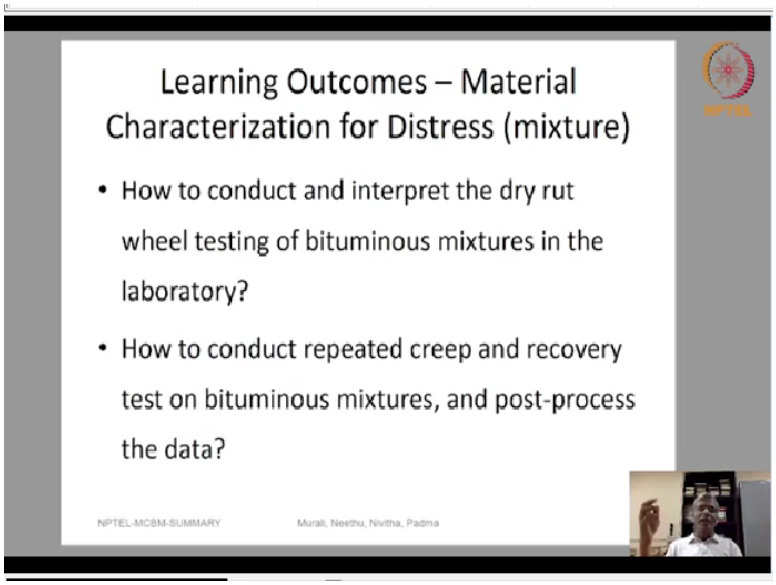

And similarly, for the distress characterization, we are going to look at only at 2 distress, one is rutting, and another is fatigue. In the rutting we want to talk about the direct field testing of the bituminous mixtures. And then in the second one, how do we really do the creep and recovery test on bituminous mixtures and post-process the data.

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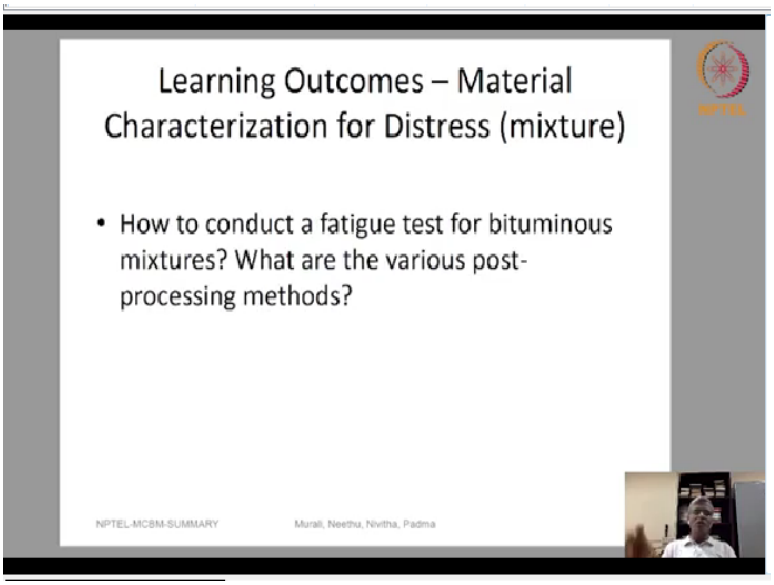

And similarly for fatigue, how to really conduct with the fatigue test for bituminous mixtures and what are the various post-processing methods. So, by the time you finish this course, including this summary lecture, you should be able to find answers to all these questions. You should be able to give answer to all these questions and if you are not able to even immediately give a response at least you should be able to know where to look for such information.

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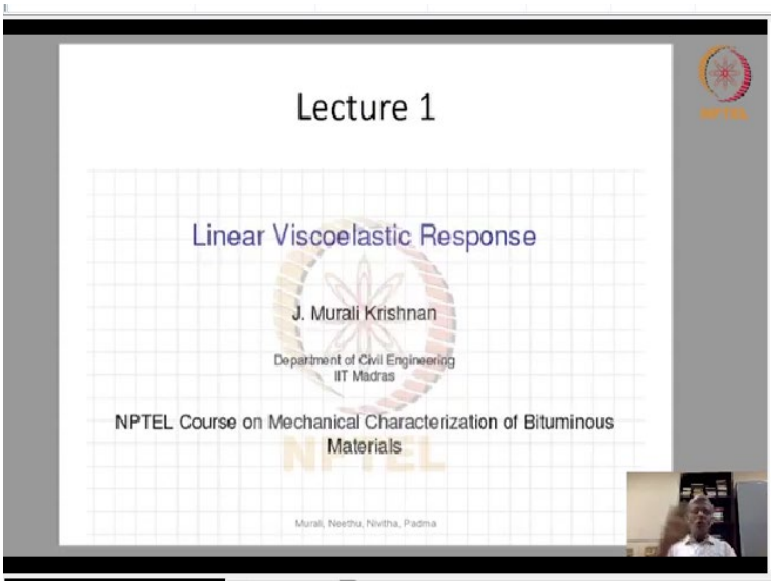

So, what I am going to do is I am going to talk about I have divided this into each lecture into 3 parts. First and foremost, the thing is, what is the title of the lecture.

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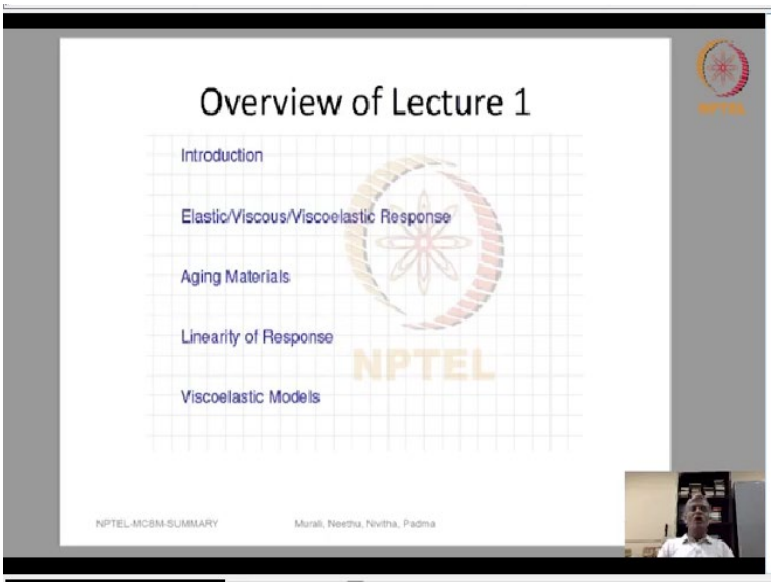

What is the overview of the lecture?

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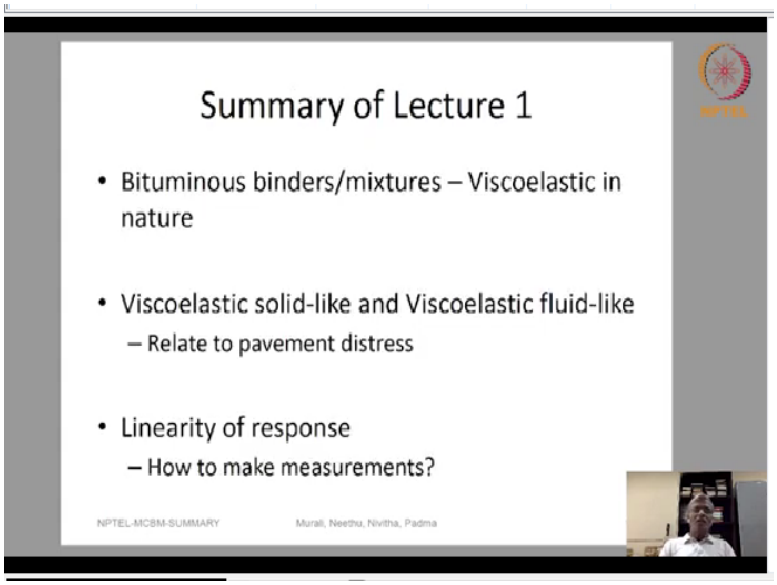

And what is the summary of the lecture, okay, the very first lecture in which we dwell in detail is about linear viscoelastic response and here, what we did, we talked really about the elastic response, viscous response, viscoelastic response and the viscoelastic response, we talked in detail about for viscoelastic solid like response, viscoelastic fluid like response, we did some simple experience thought experiments in which we applied load.

And then we looked at how the material will deform for the elastic as well as for the viscous as well as for the viscoelastic response. So, depending on the type of test that we did, we classified

them under two categories, what is really called is creep compliance and stress relaxation. So, these are the two material functions that we introduced. So, when you apply a load and measure that deformation, the material function associated with that was called creep compliance function.

And when you hold the strain constant and find out how the stresses are varying, we call it a stress relaxation response. And similarly, when you are working in frequency domain, we also defined different material functions again that creep compliance functions, stress relaxation functions. And in addition to that, we also had a phase lag function. Then we talked about the materials that ages. So, when the moment you are talking about the material that are aging, you are also going to take into account the influence of the material creation time.

In addition to the actual time, running time that happens, you are also going to have the material creation time. Then we discussed that under what circumstances one can even define the stress relaxation function or the creep and recovery creep compliance function, that is the linearity of response, then we introduced few viscoelastic models. So, what really is the take home message for lecture 1.

The bituminous binders and mixtures or viscoelastic in nature, the viscoelastic solid like and the viscoelastic fluid like can be used to relate to the pavement distress and the third and the most important thing is all the measurements that we are making, all the calculations that we are doing for pavement specific binder specification or pavement design uses only linear parameters.

So, when we are using linear parameters, we should be in a position to make measurements in the laboratory that are linear. If we are talking in terms of elastic like material, linearity is reasonably defined in a simple manner. The moment you start talking about the linearity of response of a material whose response is also time dependent, then things can become extremely complicated. That is the summary of the lecture 1.

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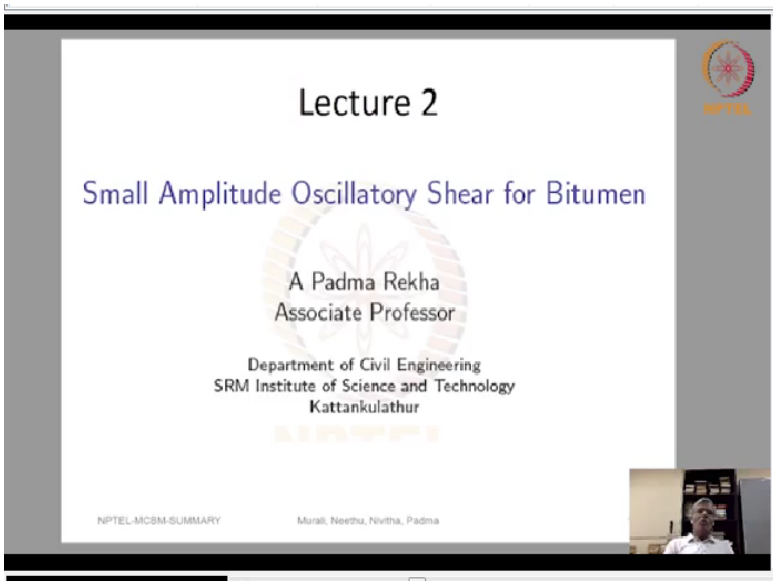

So, what did we do in lecture 2. This lecture was given by Professor Padmarekha from SRM institute of science and technology. So, she discussed in detail about the small amplitude oscillatory shear for bitumen.

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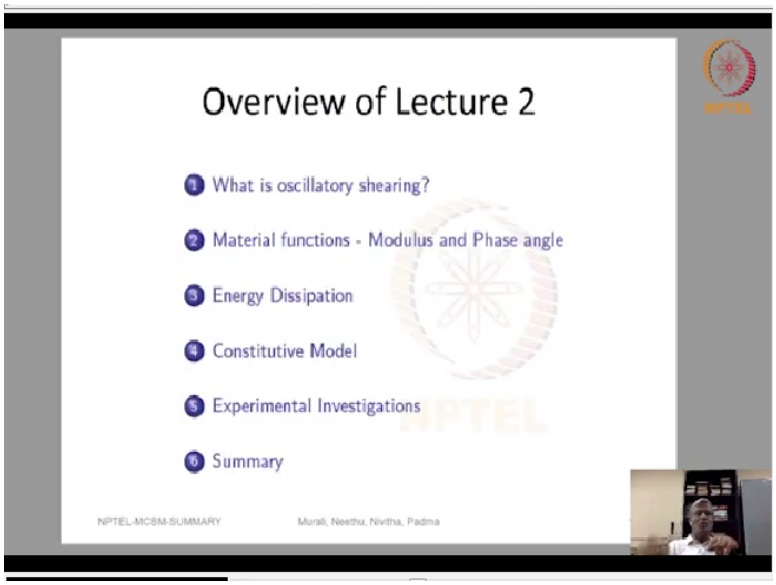

What she did was she first defined precisely what is oscillatory shearing, then she introduced material functions, the modulus as well as the phase angle functions, then she also told little bit about the energy dissipation okay. And she introduced something about the constitutive models, the experimental investigations, and finally, there was a summary. Now, first and foremost thing we need to understand all the specification parameters that are given right now for binder, for unmodified bitumen.

Test the material only in oscillatory shearing or small amplitude oscillatory shearing, in a nutshell, a small amplitude oscillatory shearing means, if you take a material oscillated in a dynamic shear rheometer and subjected to the assigned waveform, the stress or the torque that is required to induce a sinusoidal waveform will also be a sinusoid of the same nature. So, that means, there are not going to be higher order harmonics.

Now, depending on whether you are controlling the stress or controlling the strain, you can have G', G" or J', J" okay and all these are possible within the Boltzmann superposition principle. So, that means the linearity of the response has to be always matter right.

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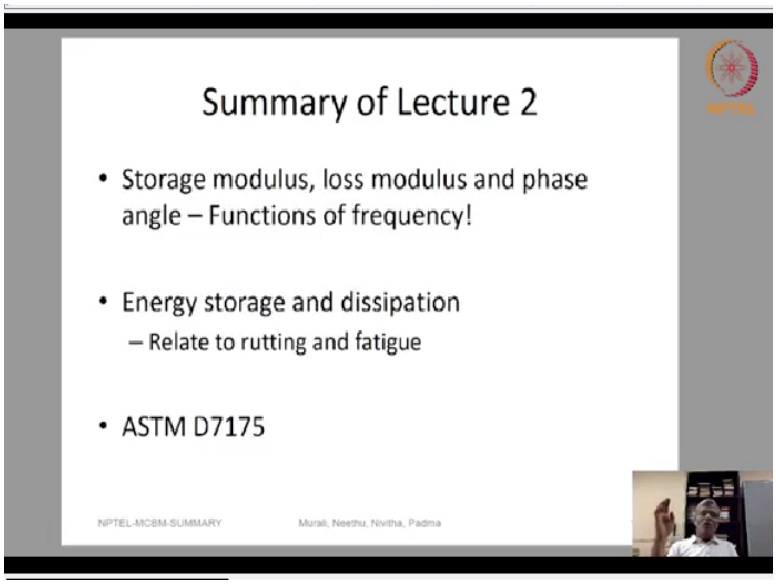

Now, what is the summary of lecture 2, the summary of lecture 2 is about storage modulus, loss modulus and phase angle and these are basically functions of frequency. So, that means, as the frequency keeps increasing the storage modulus keeps increasing okay. And similarly, the same case for the loss modulus also. Now the phase angle typically if the response of the material is purely linear, viscoelastic solid, you can actually expect that the phase angle will start decreasing.

But it is not necessary for the case where the material is showing viscoelastic solid and fluid like behavior okay, the next thing is how do we really compute the energy storage as well as the

energy dissipation. Now, if you do it in the large amplitude oscillatory shear, you get the complete waveform and you can compute it, but when you are doing it in a small amplitude oscillatory shear, what we need to do is how do we really find out since the applied load and the resulting string are always sinusoid.

All we can do is to integrate and compute the energy storage and energy dissipation. And this is going to be very useful to us when we write specifications using performance grade and the most important standard that you should use is ASTM D7175 right okay.

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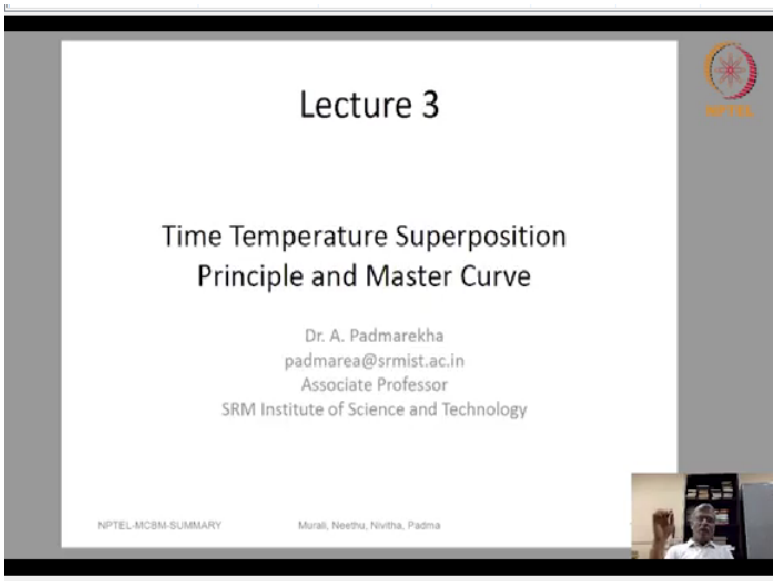

Now comes the third lecture, where Dr. Padmarekha talked about time temperature superposition principle and what is really called is master curve.

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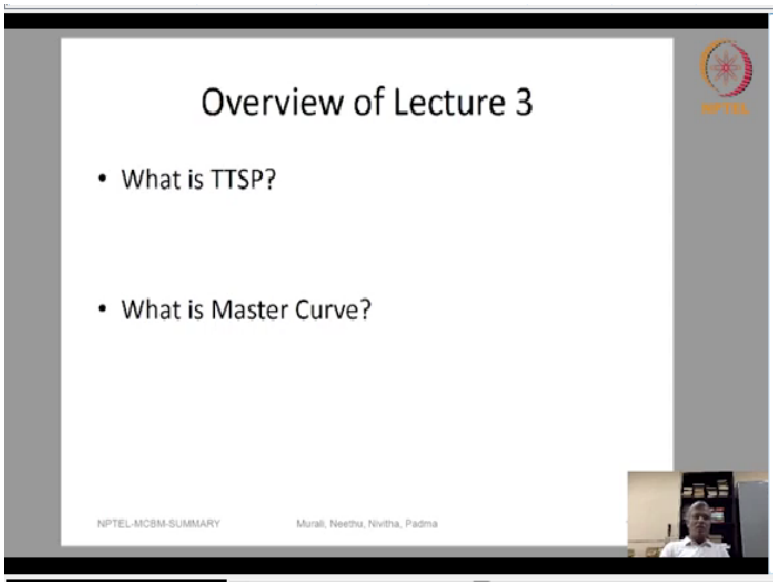

Now, what exactly is this time temperature superposition principle. Now, since you have a material whose responses are time or frequency dependent, what one can do is when you are making measurements at different temperatures, you can always start making a relation between the temperature at which you tested and the frequency at which you tested it. So, this gives us phenomenal advantage in trying to compute what are all the various material functions at different temperatures and different frequencies in which we do not have any measurements.

This also comes in extremely handy when we are doing the pavement design. So, to give an example, if you have recorded measurements at 15 degrees, 25 degrees, 35 degrees centigrade. And if you have made measurements that let us say 4 different frequencies in each of these temperatures, let us say 1, 2, 5, 10 hertz frequency and if you really want to find out the material functions at let us say 27 degrees centigrade for 3.2 hertz frequency by using time temperature superposition principle.

One can find out an appropriate material function at any intermediate temperature or intermediate frequencies. Now, for this we have to construct a master curve. So, when you construct a master curve, we also need to write something about the shift factor. There are many ways, many shift factors, functions that are available. The most common one are the William Landel Ferry shift factor as well as the Arrhenius shift factor okay.

So, once you have the shift factors by shifting from the reference isotherm any other way, given isotherm we will be in a position to find construct what is really called as the master curve.

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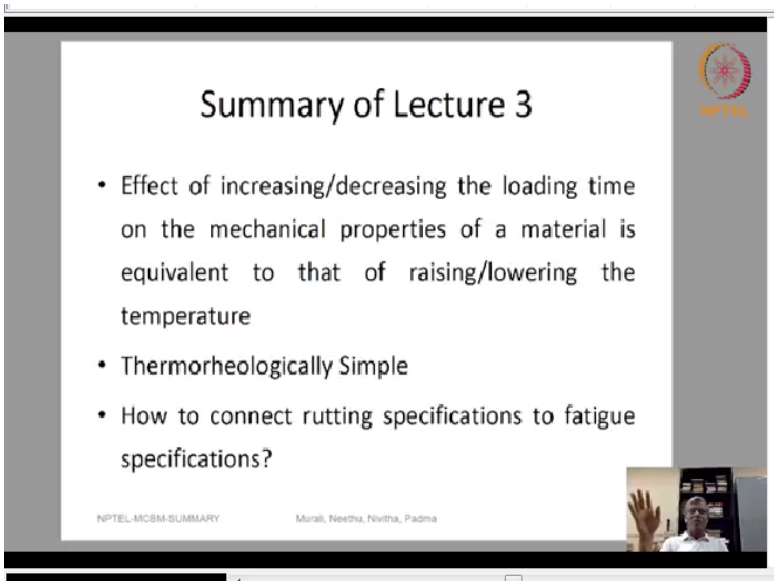

And in fact, the summary of the lecture 3 is given in 1 single sentence, what it means is effect of increasing, decreasing the loading time on the mechanical properties of a material is equivalent to that of raising or lowering the temperature. So, if you understand this first sentence, you have more or less understood what is called as time temperature superposition principle. Now, the most important thing is, this time temperature superposition principle is rarely only if the response of the material is thermorheologically simple.

If the response of the material is thermorheologically complicated, complex you really cannot construct a master curve, what it means is at 65 degrees centigrade if your responsible of the material is predominantly viscoelastic fluid showing a completely different relaxation spectrum and at 15 degrees centigrade if your response of the material is predominantly viscoelastic solid and it shows a completely different relaxation spectrum.

There is no way you can construct your master curve from 15 to 65 degrees centigrade using one single shift factor approach okay. Now, why is this useful to us, this will be useful to us because, when we are writing specifications for bitumen using performance grade, whatever is the rutting

specifications that we write for the particular binder we should also be in a position to estimate, quantify compute its response at intermediate temperature.

So, that means we have to make the connection across 4 decades of the temperature. So, that is where this is really needed.

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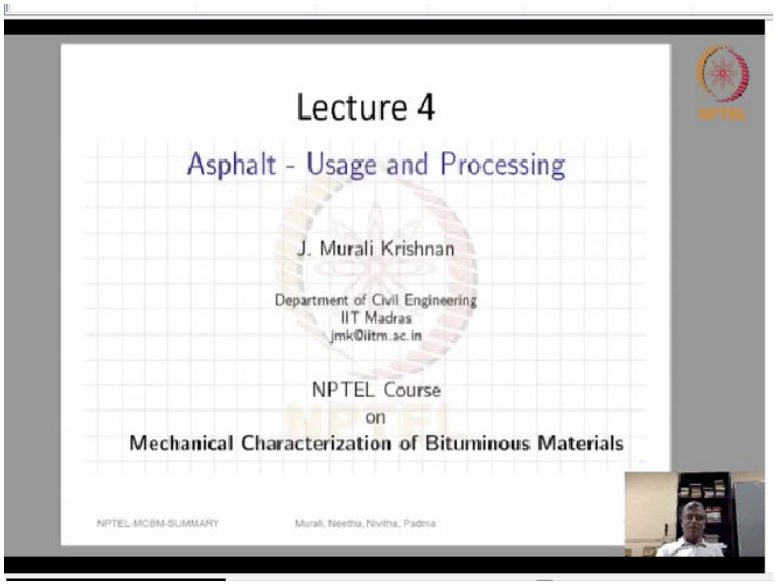

Now, having set the theory for continuing with this course, then we stepped inside to find out how asphalt is produced, what are its historic usages.

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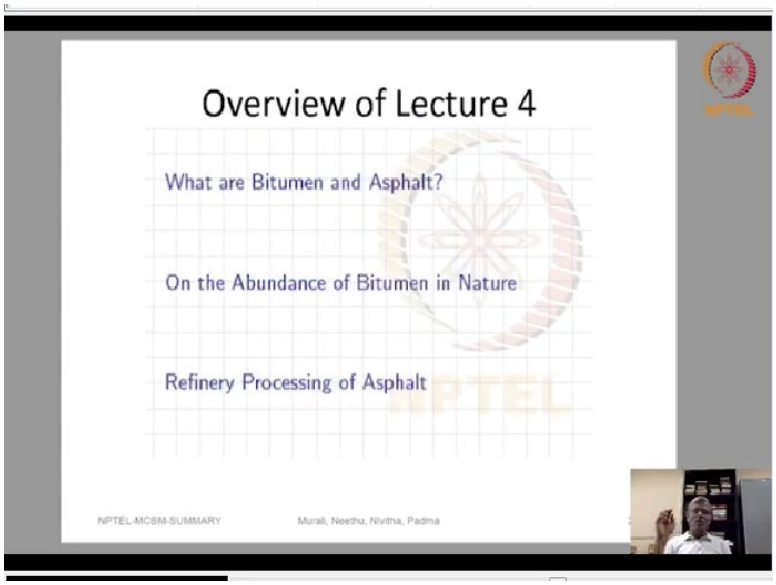

And what we did here was we talked about the refinery processing of asphalt. Before that I also mentioned the abundance of bitumen in nature and the historic information very, very exciting and interesting information about bitumen was discussed.

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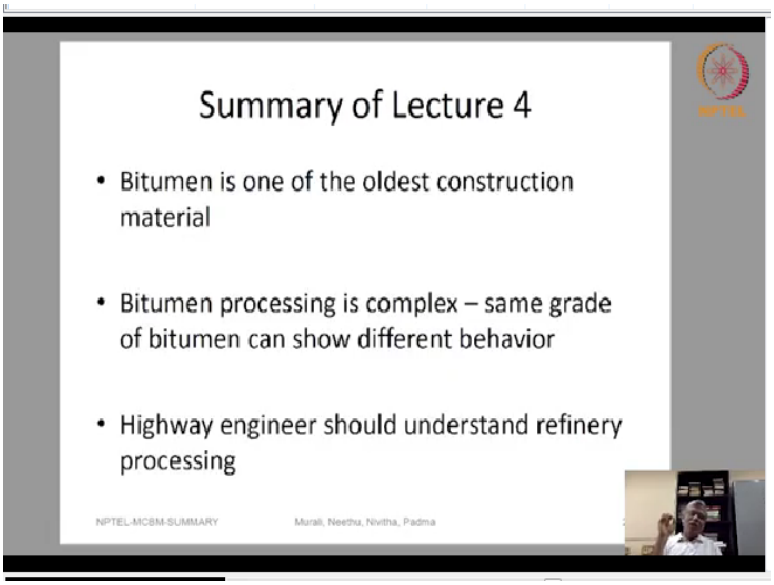

Now what it basically tells you is at least this is something as a take home message every one of you should have it in your mind is a VG 30 bitumen produced by Mathura refinery is not the same as the VG 30 bitumen produced by Visakhapatnam refinery they are different. The refinery processing is different, the crude oil that is used for producing this bitumen can be from different sources.

The proportions of different mixtures that are used can also be completely different. So, unless a highway engineer understands the complexity of the refinery processing, we will not be in a position to write clear specification, so that the refiner can produce the bitumen that we are looking for okay right.

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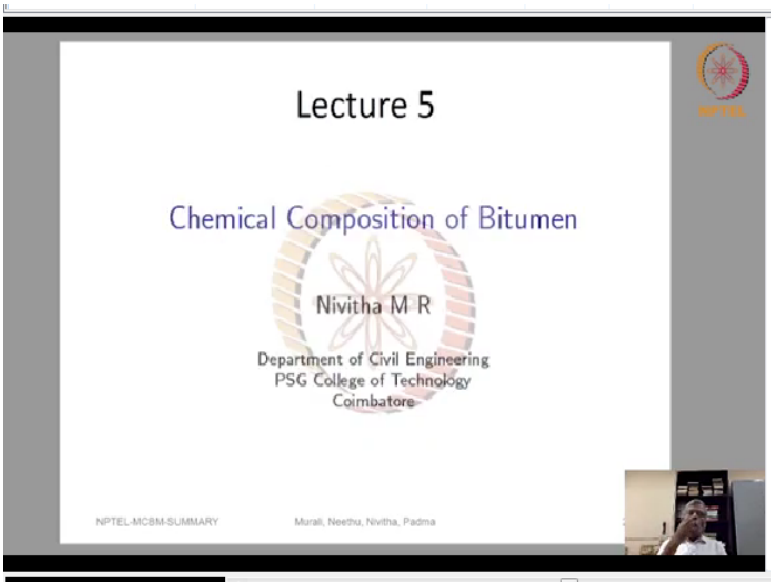

Then comes the chemical composition of bitumen. This lecture was given by Dr. Nivitha from department of civil engineering PSG college of technology.

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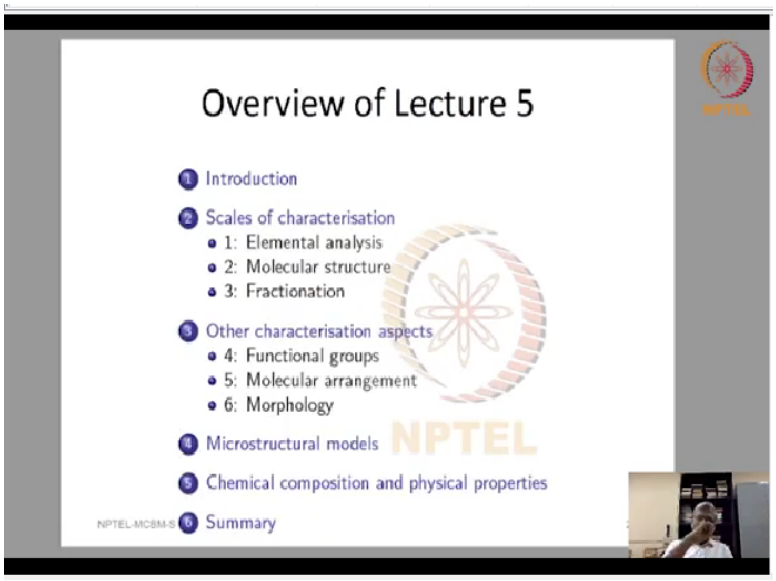

So, what basically she did was she was looking at the scales of characterization. You can have elemental analysis, okay. You can have molecular structure analysis; you can have fractionation analysis. You can also do something based on functional group analysis. You can look at molecular arrangement. You can also look at the morphology, then she showed some interesting microstructural models.

And she was also trying to convey to you the relation, if that exists between chemical composition as well as the physical properties. Now, we need to understand few things. In my opinion, this particular lecture given by Dr. Nivitha is something in which you may have to spend lot of time to try and understand them, because she has given abundant of information about the chemistry of bitumen.

The chemistry of bitumen is exceedingly complex. In fact, if you recollect her lecture, she would have mentioned something about the isomers. So, it is not one constituent, or one cannot write any chemical formula for this material. You can do analysis based on carbon, hydrogen, sulfur, nickel, vanadium, and all those things. You can look at it from the chunks of molecular structures.

But the most important type of studies that are normally carried out for this material in essence unfortunately is the solubility-based classification system or what she has written as fractionation scheme. So that means you take this material or run it through a specific solvent and depending on the various cuts that you get, you talk about different constituents. So, she introduced about asphaltenes and maltenes.

And the maltenes she would have talked about naphthene aromatics, polar aromatics as well as saturates right. So, these naphthene aromatics or polar aromatics are themselves a mixture of thousands and thousands of different types of molecules.

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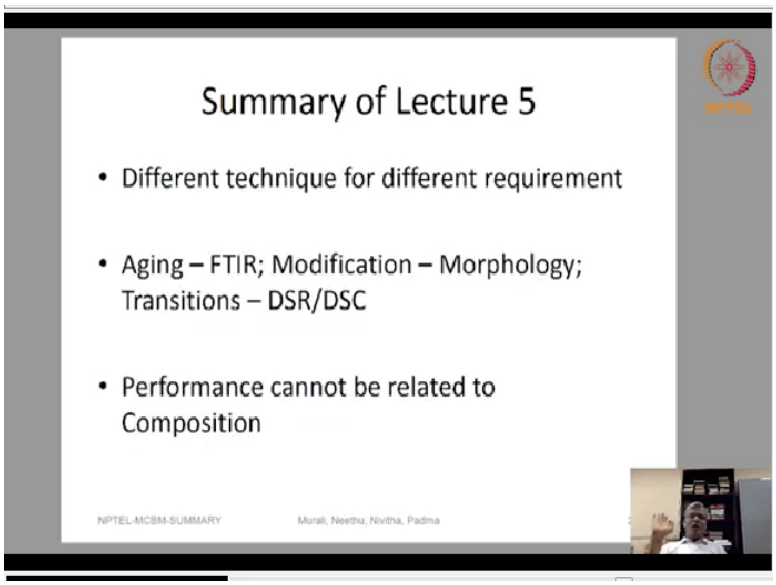

So, what it means is we need to understand that there are different techniques that are available for different requirement. In fact, a highway engineer or a person who is working on bitumen should ask the simple question, what is the chemical composition that technique that I really want to use. So, if I am talking in terms of aging, I can use IR, IR will give me sufficient information about the aging that is really happening.

If you are talking about how the modifiers have developed an internal structure, I could do a morphology. If I am interested in the transitions, solid to solid transition, solid to fluid transition, I can do a combination of a DSR, DSC study. Now, one important thing that all of us have to understand is the performance cannot really be related to the composition of the material chemical composition of the material. So, this is something that one needs to understand very clearly.

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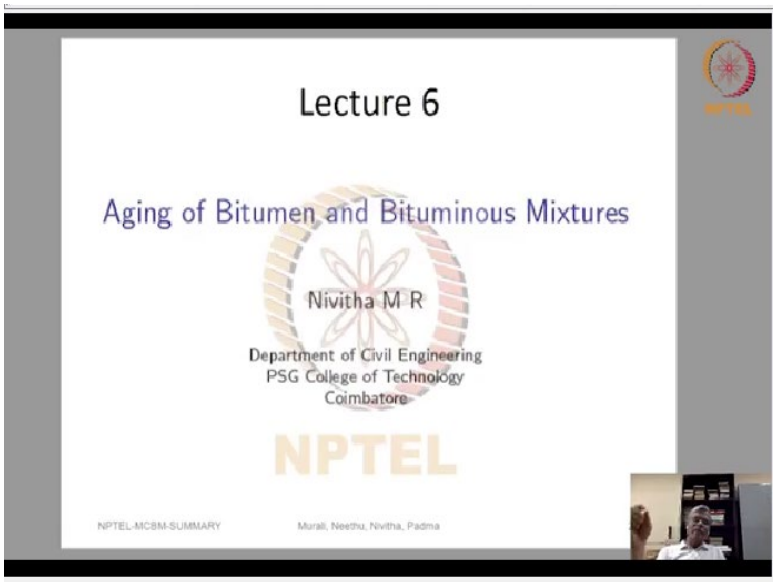

The lecture 6 was on aging of bitumen and on bituminous mixtures this lecture was given by Dr. Nivitha department of civil engineering PhD college of technology.

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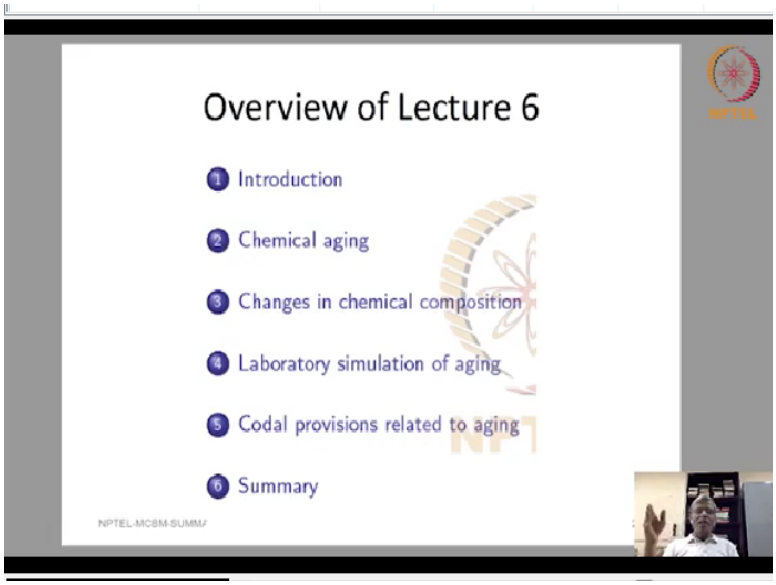

In fact, what she did here was she clearly defined it in terms of the chemical aging. And what are all the changes in the chemical composition that happens during aging. What is the laboratory simulation of aging? What really are the codal provisions related to aging and then she summarized it, to come from a different perspective when you take bitumen, heat it, mix it with aggregate particles, lay it in the field.

There is some amount of aging that happens in the material, what we really call as the short-term aging, as the material is exposed to the weather during its service. There is another kind of aging that happens which is really called as the long-term aging. So, there has to be some simulation that needs to be done in the laboratory to find out the state of the material at different stages in each service period only then we can make some statement about the expected performance of this material.

Now the aging that you are interested is more or less in my opinion is the aging that happens due to oxidation, okay you can have reversible aging, you can have irreversible aging, in the reversible aging there are what are really called as reversible aging that happens during the room temperature, that is really called as steric hardening reversible aging that happens at low temperature, what is really called as a low temperature physical hardening okay.

And from the perspective of measurement, it is necessary that the engineer ensures that the material that he is testing has reached a steady state, because if you do not condition the material property your data is going to be spoiled due to the steady hardening or the low temperature physical hardening right.

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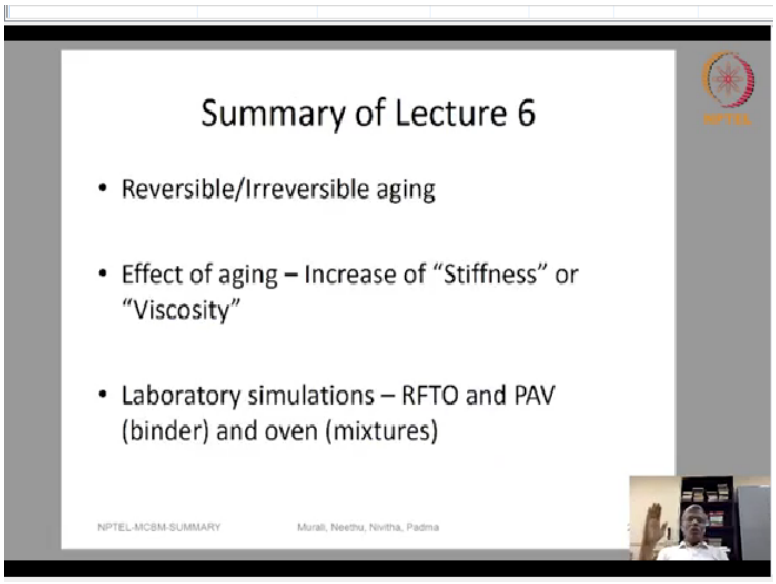

So, the effect of aging can in essence lead to increase in the stiffness or viscosity of the material and laboratory simulations exercise for RTFO as well as PAV and oven mixtures where detail here.

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Then comes the lecture on viscosity grading of bitumen, okay.

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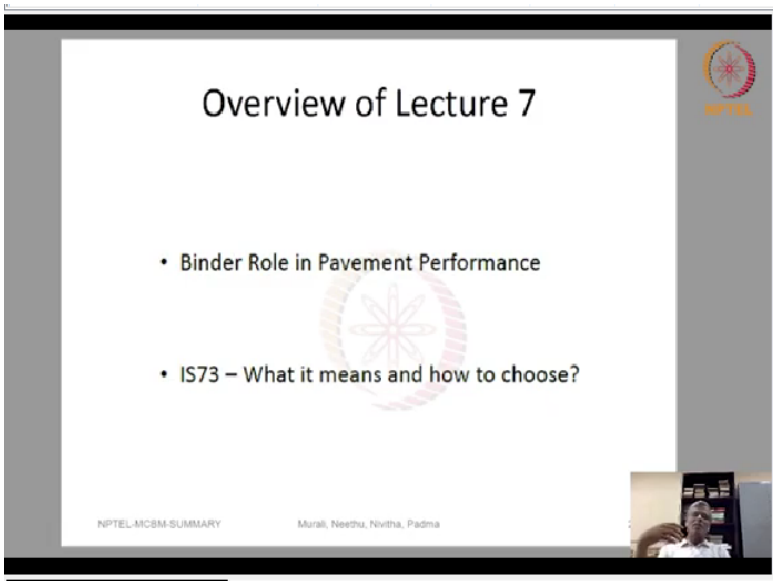

So, this lecture more or less introduces put together all the details that we have talked till now, okay, one is about the physical properties, rheological properties as well as the chemical composition and the aging. How do we really put it together in practice? The very first step that

people did was to do what is called as a viscosity grading. What do you really do in viscosity grading, you make measurements at viscosity of the material at 60 degrees centigrade?

You make measurement for the viscosity of the material up to 135 degrees centigrade and then you also have a penetration test carried over 25 degrees centigrade. So, basically you are touching at 4 different temperatures, this penetration at 25 degrees centigrade, softening point which depending on the grade the bitumen that you get may be 48 to 52 degrees centigrade, viscosity at 60 degrees centigrade and viscosity at 135.

Now, if you come from the other side that viscosity at 135 degrees centigrade is kinematic viscosity. This is something to do with the viscosity of the binder during the compaction process. Viscosity at 60 typically the 60-degree centigrade is considered sacred by the highway engineers, it tells you what should be the viscosity of the material depending on the geographical location in which you are going to use. So, that one can in a sense, prevent rutting that happens.

Softening point clearly tells you the solid fluid transition, but it is more like a consistency test in addition to penetration, there have been many attempts that have been made to relate penetration as well as softening point to the performance, but not much has actually achieved.

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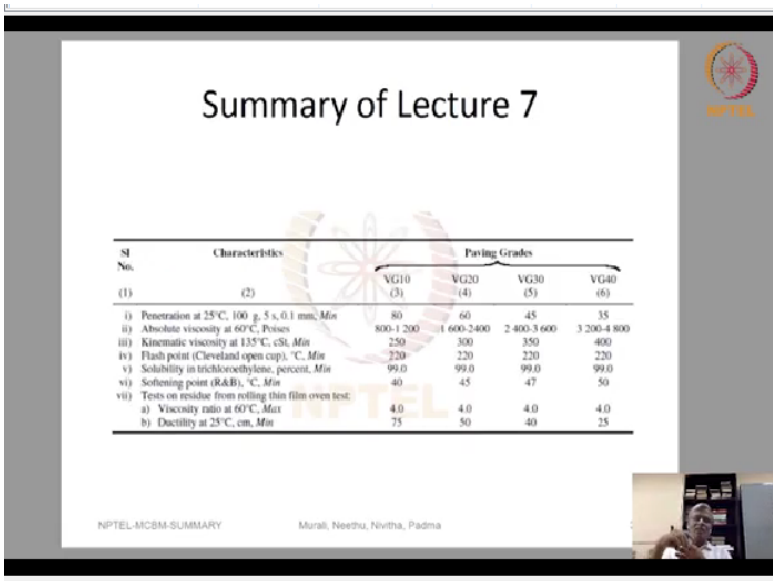

So, what is the summary of the lecture 7, and in fact in that particular lecture, I gave you a complete detail about how IIT Madras wrote VG10, VG20, VG30, VG40 grade of bitumen and clearly you can see the manner in which this specification was formulated. We also discussed in detail about some of the statistical issues that one needs to consider when you are looking at this specification.

Because there seems to be a general opinion that the VG30 and VG40 grades are overlapping, I discussed that also in detail, I request you to kindly go take a look at it. And in addition, we also discussed about how this specification should be put in practice, right.

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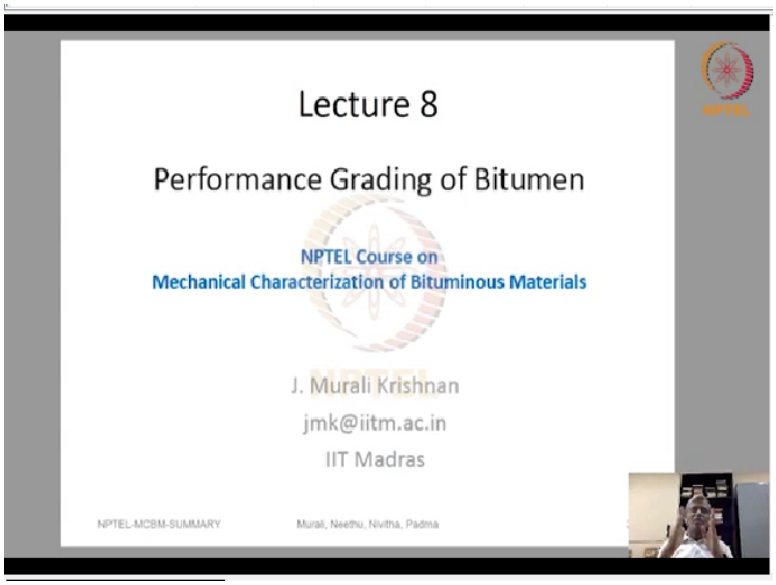

Then what we did was we stepped on to performance grading of bitumen. Now what really is the issue related to viscosity grading of bitumen in viscosity grading of bitumen, you make measurements at a fixed temperature 60 degrees centigrade. Now, what if the geographical location in which you are going to use is not having a critical temperature of 60 degrees centigrade.

What you might really want to ask the question is no, no, no, I am not really interested in the performance of the material at fixed temperature. But I want zero rutting at the critical temperature in my geographical location. So, what it means is, you should first identify the parameter that you could prescribe for rut assistance or fatigue and then checks whether those

values will be available at your critical location. So, this is really called as the performance grading.

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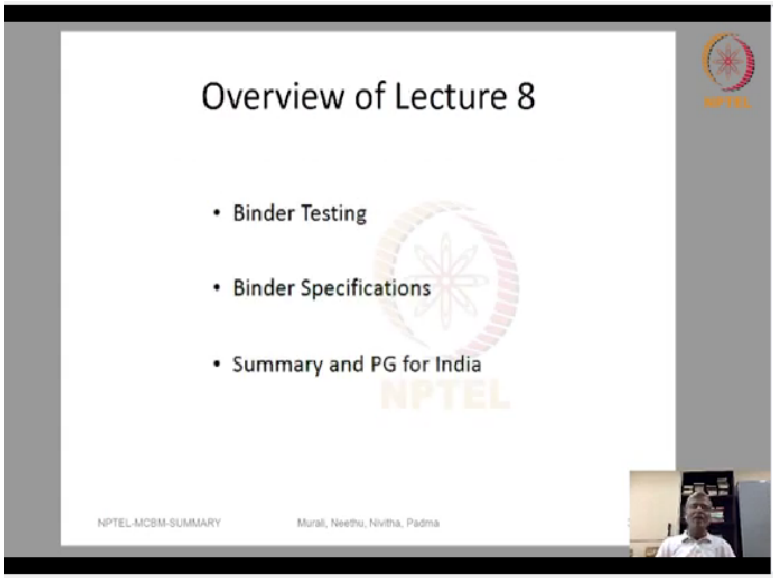

So, I looked into it from binder testing protocol, binder specification protocol, and how what we will be doing in fact, if you write PG for India.

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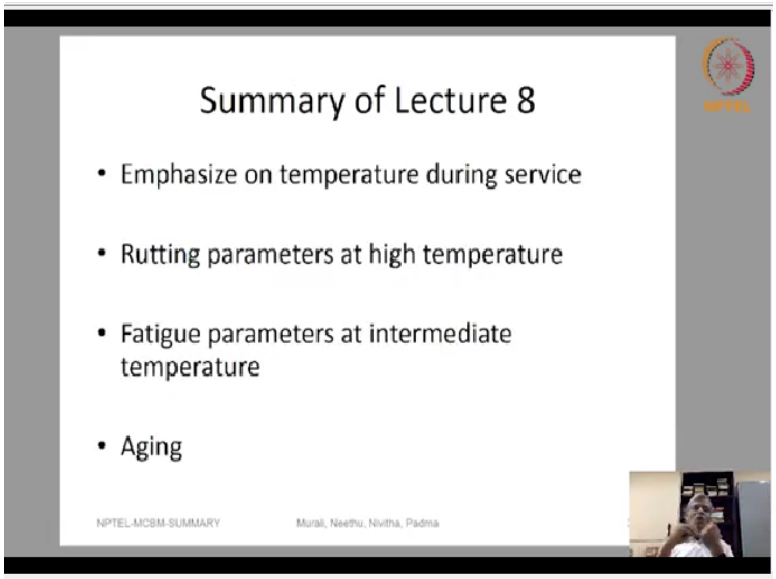

So, what is the main emphasis here is you have to emphasize on temperature during service and in fact, please go back and take a look at a ASTM D6373 as well as IS73, the specifications are written in a completely different way. In one case, the temperature is listed on the left-hand side

and the spec values are written on the right-hand side, in the performance grading the spec values are written on the left hand side and the temperature is written on the right hand side.

So, we talked about rutting parameters at high temperature, fatigue parameters at in intermediate temperature in addition to aging.

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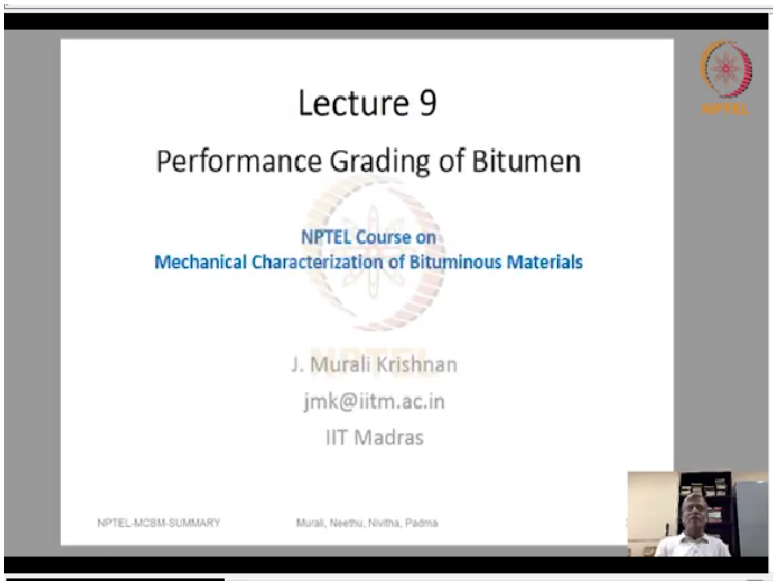

Then this lecture continued in 9

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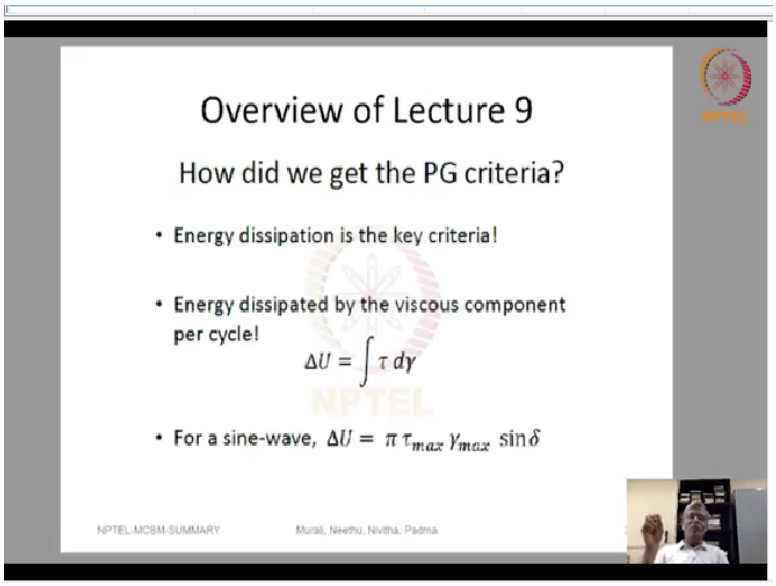

And because I wanted to show you how from the fundamentals, we got this PG criteria, because you use G star sine delta, G star by sine delta. So, you really need to understand that this is

coming from. So, what it means is energy dissipation is the key criteria. So, in fact, we want to find out what is the energy that is dissipated by the viscous component per second. So, if you try to work how do you really define energy dissipation.

If you take a many material and if you do a lot of work on the material, how much of the energy and when you unload it, how much of the energy that is you are able to get it back and how much is completely dissipated. That is what it really means, if your material is going to dissipate more energy, what it means is you are going to expect substantial amount of rutting at a high temperature and the same goes for intermediate temperature also.

Because a fatigue or the coalescence of the micro cracks to form a macro crack involves energy dissipation. So, the energy dissipation is going to be substantial you need to understand that there is imminent failure due to fatigue damage is going to be there.

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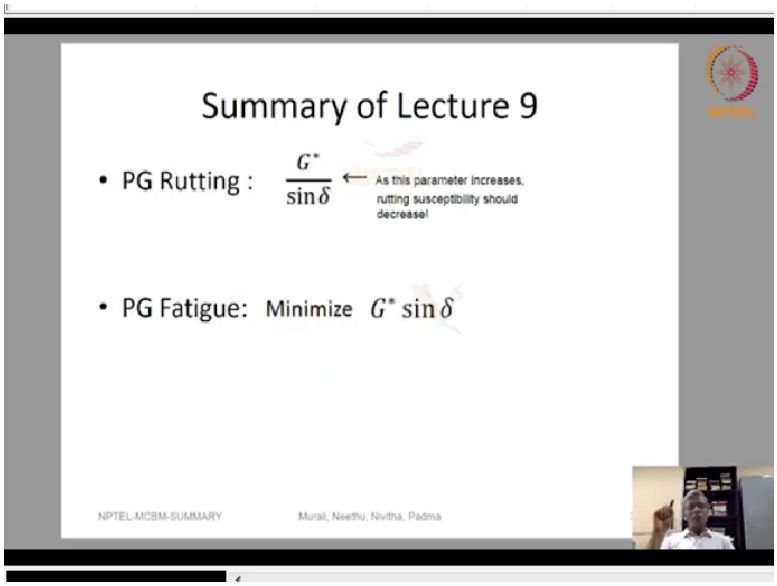

Now, if you really look at the specifications very carefully, there is all possibility for you to get confused, okay. I have mentioned it that G star should come with 2 vertical lines, but the way in which it is written in ASTM is incorrect. And in fact, the FHWA report also very clearly says that this symbol was dropped. So, it is G star by sine delta. So, they wanted to use this G star by sine delta because it gives a sense of modulus term to the highway engineers.

So, this particular value is kept as a minimum, ideally it is sine delta by G star. So, it is a maximum. So, that means, it limits the amount of dissipation that can happen at high temperatures. So, that one can minimize the rutting. In the similar way G start times sine delta tells you something about the fatigue right.

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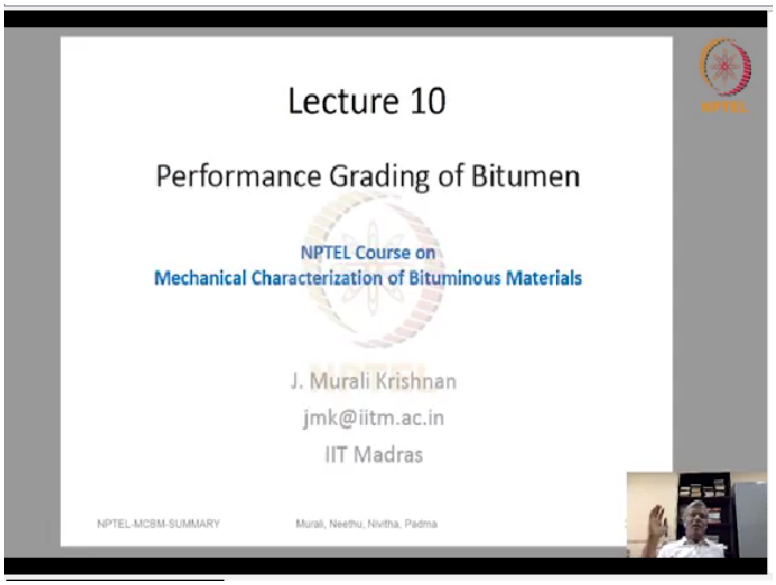

Then we continued our lecture about the fatigue performance grading of bitumen.

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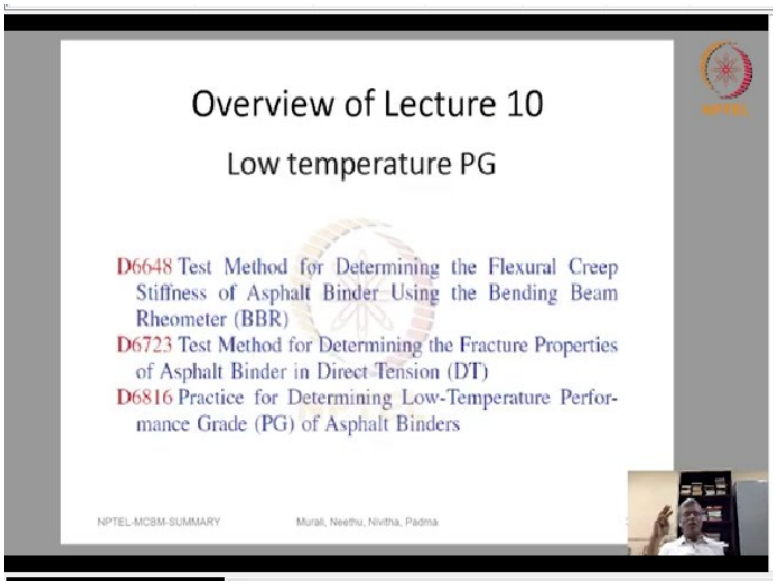

In which we looked at 3 different testing methods for low temperature PG. Now, what is interesting here as far as the low temperature PG is concerned, we only carried out test and in fact there are two test methods that are available, one is the direct attention test, another is the

bending beam rheometer okay, one is a fracture test, but another is a load control test okay. So, there is yet another procedure that is available D6816. That tells you how to find out the low temperature performance grade of asphalt binders.

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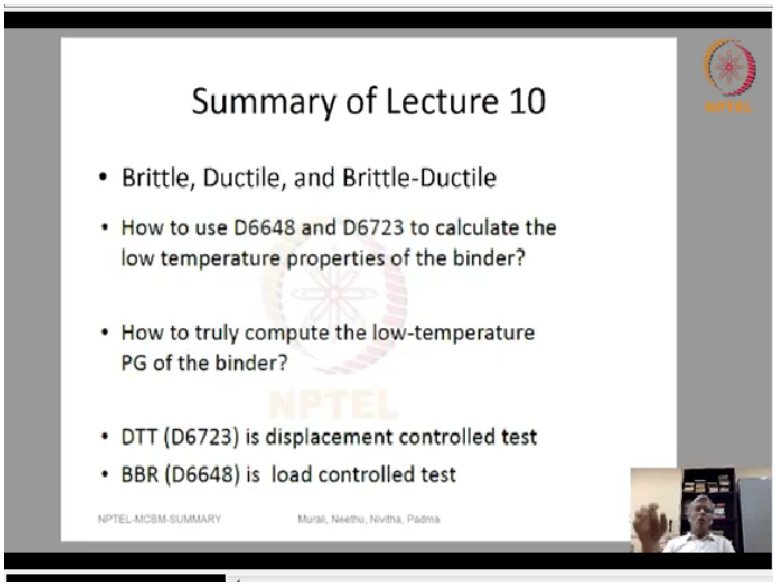

So, when we are talking about this particular lecture, we need to talk in terms of the brittle, ductile, and brittle to ductile transition, and how do we really use these two standard 6648 as well as 6723 to calculate the 2 low temperature properties of the material. So, and again one is a low displacement control test, another is a load control test, one fractures the material, one is just applying the load and allowing the material to deform.

So, putting together all these things, we actually find out what is the low temperature PG of the material. This was explained in this lecture.

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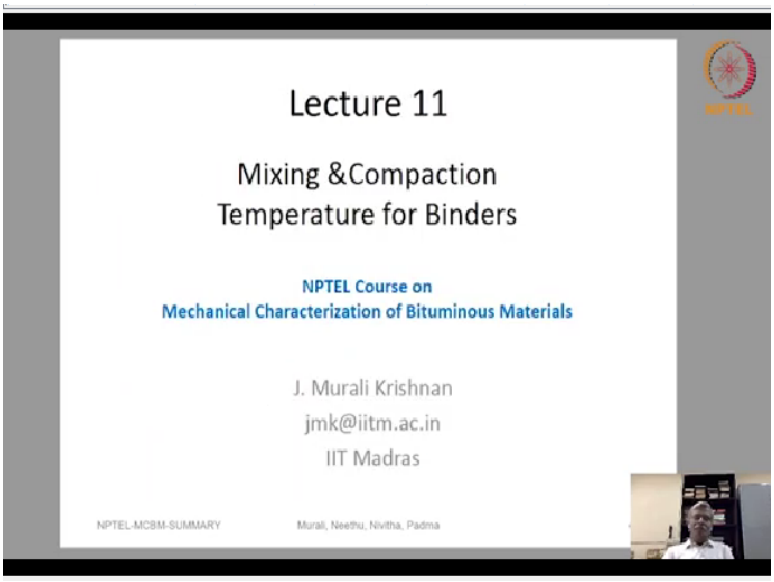

In the lecture 11 mixing and compaction temperature for binder, we wanted to ask only one simple question.

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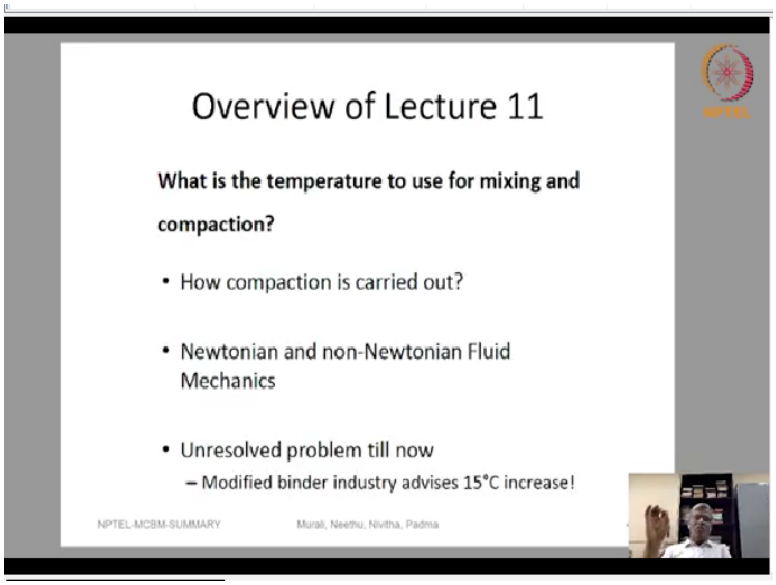

What is the temperature to use for mixing and compaction and here we wanted to find out how is the compaction carried out and when the compaction is being carried out what is the status of the material, binder. So, the reason Newtonian, non-Newtonian transition is there and as far as unmodified bitumen is concerned there is basically no issue, but for modified bitumen what really happens the non-Newtonian regime extends even at high temperatures.

So, fixing a precise temperature for starting the compaction becomes extremely difficult. So, most of the time the modified binder industry will just advise you to increase the temperature by 15 degrees centigrade.

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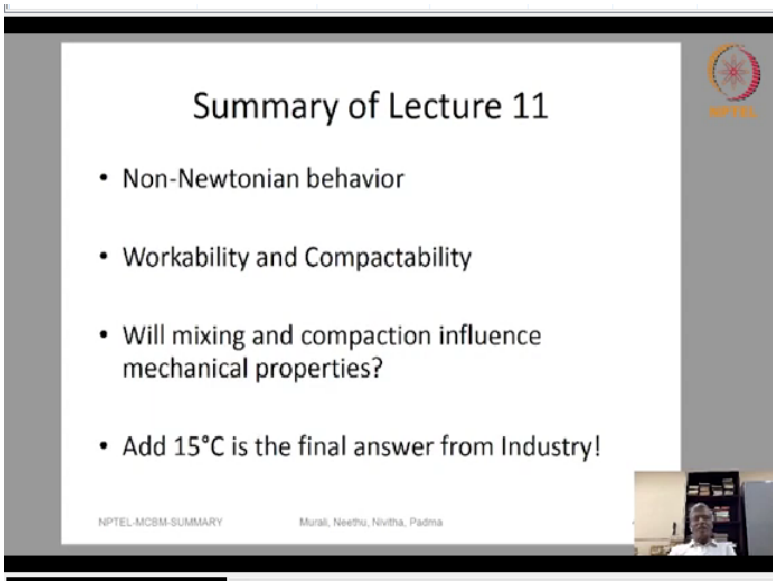

So, what really was the issues that were discussed here, we talked about the non-Newtonian behavior. We talked about workability and compatibility and then we discussed 3 different testing methods for different testing methods for finding out the mixing and compaction temperatures. Two testing methods used rotational viscometers and the 2 testing methods used the dynamic shear rheometer okay.

And one question that we need to really answer and in fact, it will be very, very interesting for some of the students who are taking this course to try and understand and maybe find an answer is whether the mixing and compaction will influence the mechanical properties.

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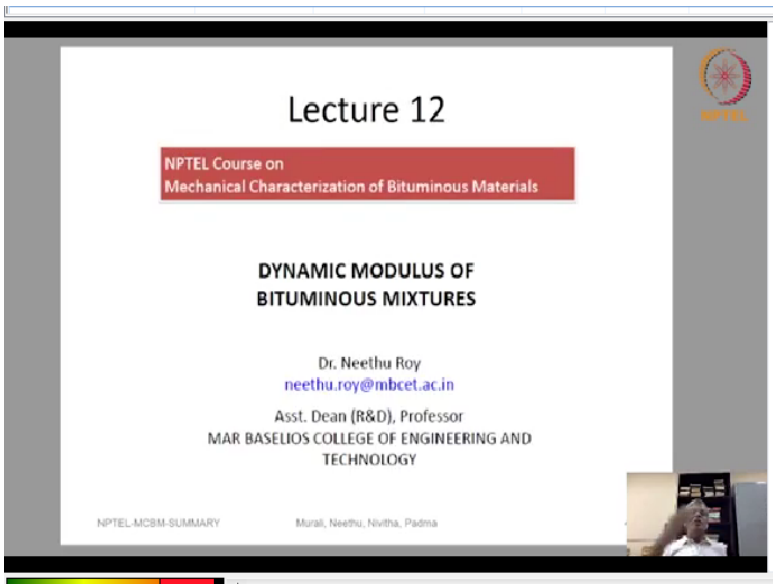

Then we switch the gears, now that we have understood, how to write specifications for bitumen, how to even heat the bitumen, the temperature to which it has to be heated, we went on to finding out the various modulus parameters for bituminous mixtures. The series of lectures here were given by Dr. Neethu Roy from Mar Baselios college of engineering and technology, right.

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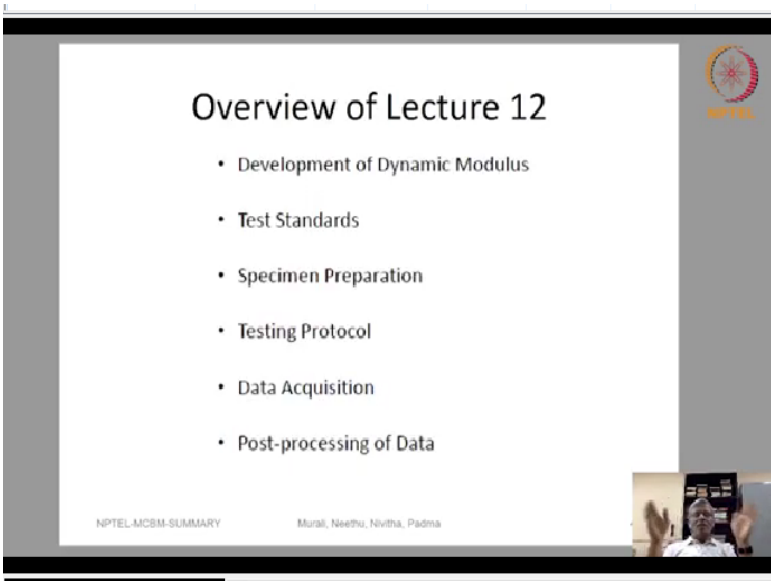

So, in the dynamic modulus lecture, what she nearly did was, she gave clearly the development of dynamic modulus, what are the testing methods, how the sample has to be prepared. What is the testing procedure, how to do the data acquisition and finally, what is the post processing of the data? One needs to very clearly understand that this dynamic modulus test is more or less the de facto standard in Northern America, and people are now increasingly using it even in Europe.

There are advantages of doing this test because we can go from the low temperature all the way up to 60 degree centigrade, one can do the test for a range of frequencies from 25 hertz to 0.01 hertz frequencies. So if you recollect that this discussion related to master curve, given by Dr. Padmarekha, you will understand that you could use this data to fit a master curve, once you fit a master curve, they depending on the location in which you are planning to construct your payment depending on the temperature and the frequency.

You can actually have the modulus straight away extracted from the master curve, there are a few basic assumptions that are made in this dynamic modulus test, one is the linearity it is assumed that the response of the material can be taken as linear if the strain levels are between 75 to 125 micro strength number 1. Number 2 in the post processing method, you are not fitting any linear viscoelastic model rather a regression approach is used.

And based on the coefficients of the regression equation, one computes the dynamic modulus and phase angle okay.

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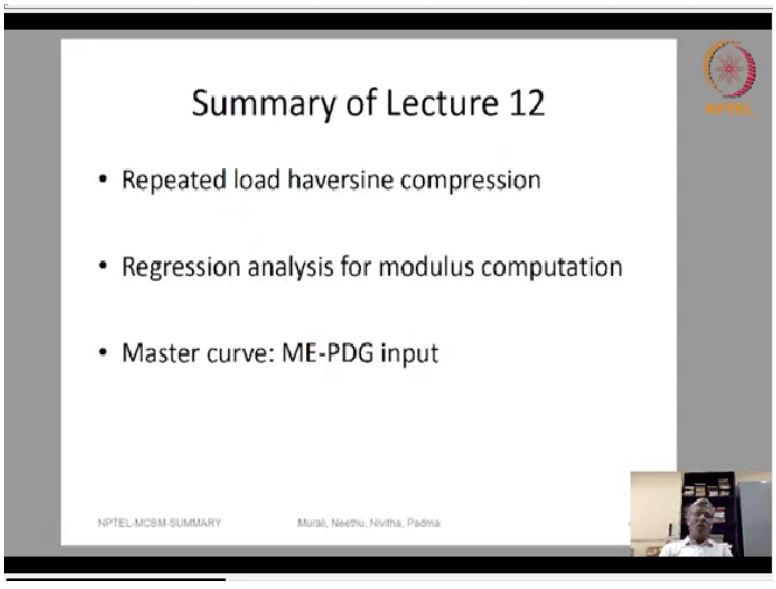

So, this is the summary related to this particular lecture.

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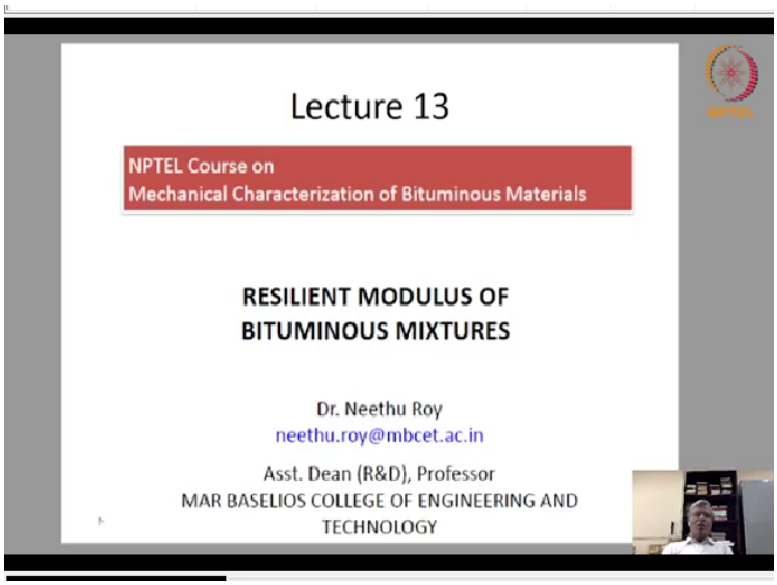

Now, the next lecture is given by Dr. Neethu Roy again on resilient modulus of bituminous mixtures. This is a very what you can say an exciting topic for Indian highway engineers because for our IRC 37 pavement design guideline, we prescribe resilient modulus of bituminous mixtures and there is not much awareness in the country, be it with the students or with highway engineers on how to really go over to doing it.

And so, most of the time, what we do is we try and take the values that are provided in the design guideline, and the design guidelines very clearly tells you that the highway engineer should actually test, make the measurement right.

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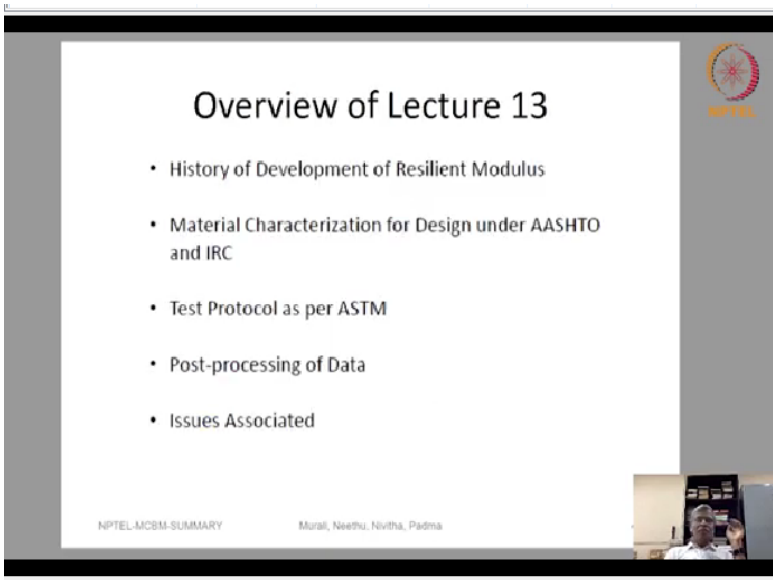

So, Dr. Neethu Roy gave a history of the development of resilient modulus, material characterization for design under AASHTO and IRC, she gave the complete difference and the test protocol as per ASTM, and post processing of the data and issues associated with it.

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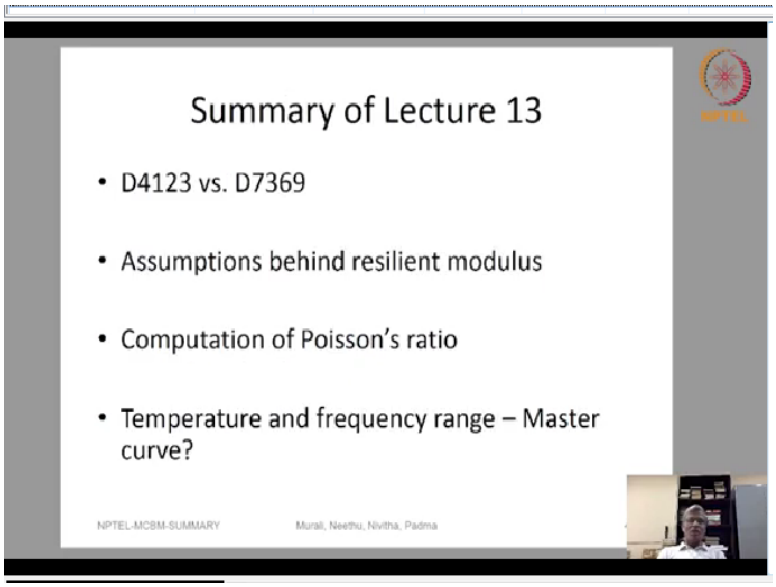

So, the summary is there was originally a standard ASTM D4123, in which you made measurement only in the horizontal direction, and then you used it to compute the resilient modulus. No measurement was made in the vertical direction also. So, most of the time, the Poisson's ratio was just assumed. In ASTM D7369 you not only make measurement in the horizontal as well as the vertical direction, you also do it on either side.

In addition, we also rotate it by 90 degrees, one needs to very clearly understand the assumptions behind resilient modulus. The moment you talk about resilient what he really mean is after applying many, many, many cycles of loading, if you take the total strain which consists of irrecoverable strain as well as the recoverable strain, the recoverable strain is called as the resilient elastic strain, they reach a steady state.

So, what do you really want to do is to compute your modulus based on the resilient elastic strain, okay? Now, there is a problem here because this particular test is conducted in the split tensile mode, okay. What is really called is the Brazilian test method. Now, there are limitations related to doing this test for a wide range of temperature and frequency.

In our laboratory, we have not been able to do it more than 35 degrees centigrade, even at 35 degrees centigrade, the gauges will pop up, then there are issues related to the gauge length, there are issues related to the number of cycles to be used for reaching the steady state okay. See, these are all some of the details that was given by Dr. Neethu Roy and in fact some of you have you and asked the questions, when these lectures were given, can you do it for cold mix.

Can we do it for different types of mixes. Now, the answer to this question is yes or no. What do I mean by yes if you understand how is this test method is conducted, the assumptions behind the theory and if the material that you are planning to use is more or less following these assumptions that are made you can do it. But when they say no what it means is the standards, the procedure that is prescribed here is more tuned towards bituminous mixtures.

Is it for cold the mixtures, if you are doing research and development yes, you can do whatever you want, but if you are a practicing engineer, and if you want to really find out whether one can use it for cold mix I will advise caution here. Because the cold mix can also behave like a granular material. So, this particular testing method may not necessarily the suitable to you right.

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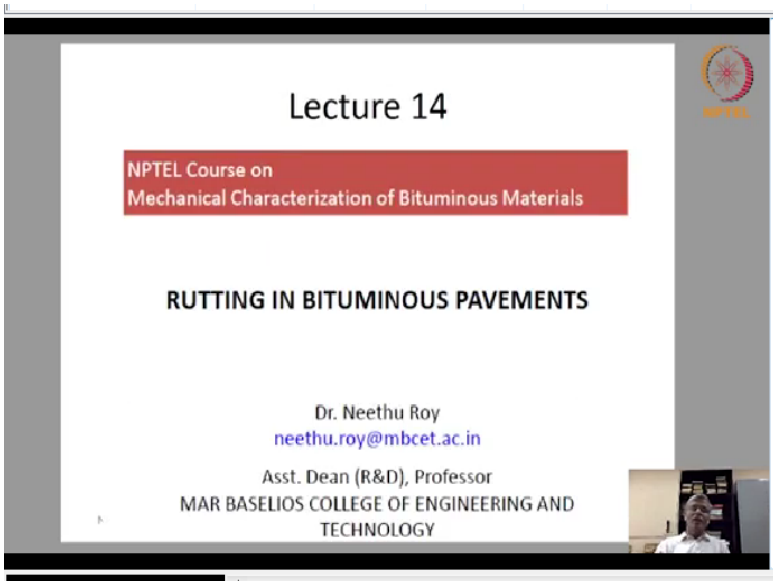

Then Dr. Neethu Roy started talking about the distress. So, she was here talking about rutting in bituminous pavement.

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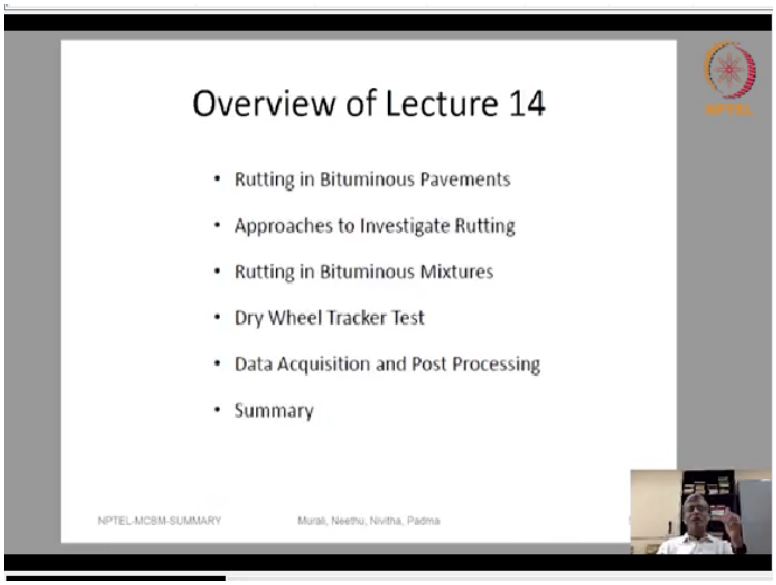

So, she talked about the various approaches to investigate rutting okay, so you can have a test track similar to what you see in NCAT. You can have a controlled test role, what is really called as an accelerated loading facility in which the temperature everything is correctly, precisely controlled or you can have a laboratory test method in which you could do at the laboratory you can do it.

Now we need to understand clearly things, please focus your attention on the first and the third one. Rutting in bituminous pavement is different, rutting in bituminous mixtures is different. When you are talking about rutting in bituminous mixtures, you are talking about making measurements at the laboratory on one sample, then the dryer at wheel track wheel tracking test was discussed and the data acquisition as well as the post processing method was also discussed here.

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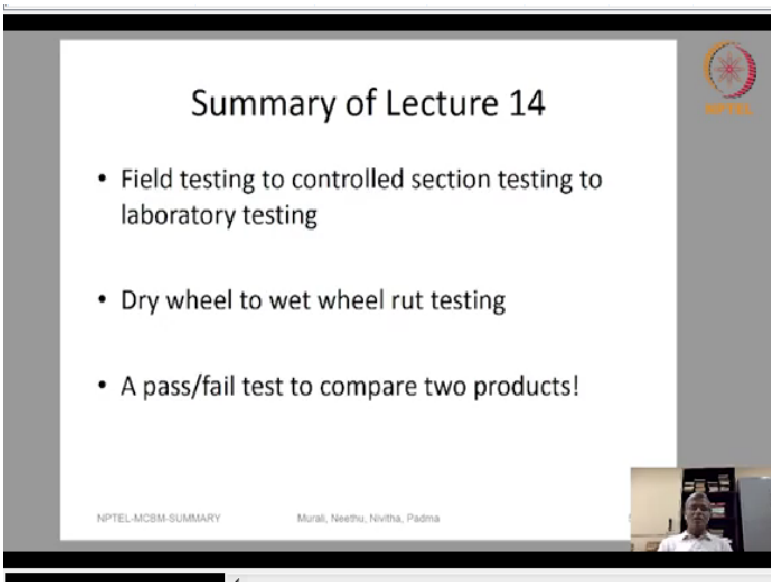

So, first and foremost thing is we need to understand the field testing to control section to section in laboratory testing and she discussed about the dry wheel testing. Now in my opinion, or in the opinion of most of the highway engineers, this dry rut wheel testing or the wet dry wheel testing can be considered as a very nice clear pass-fail test okay nothing more nothing else. That means if you have two products.

And you want to evaluate which product will show better performance compared to the other product okay. We can run the test on this and then we can rank it.

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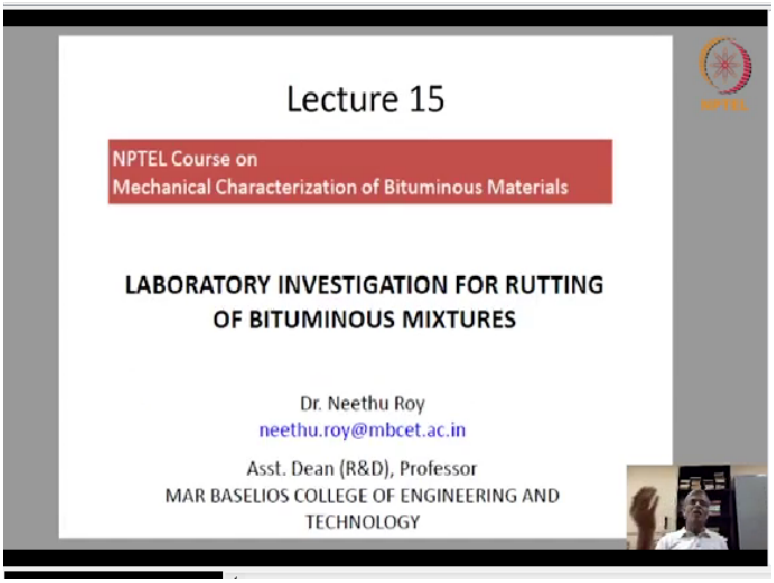

So, let us start extraculative, and in the final lecture given by Dr. Neethu Roy she talked about how to do the flow number as well as the flow time test to compute what is really called as rutting for bituminous mixtures.

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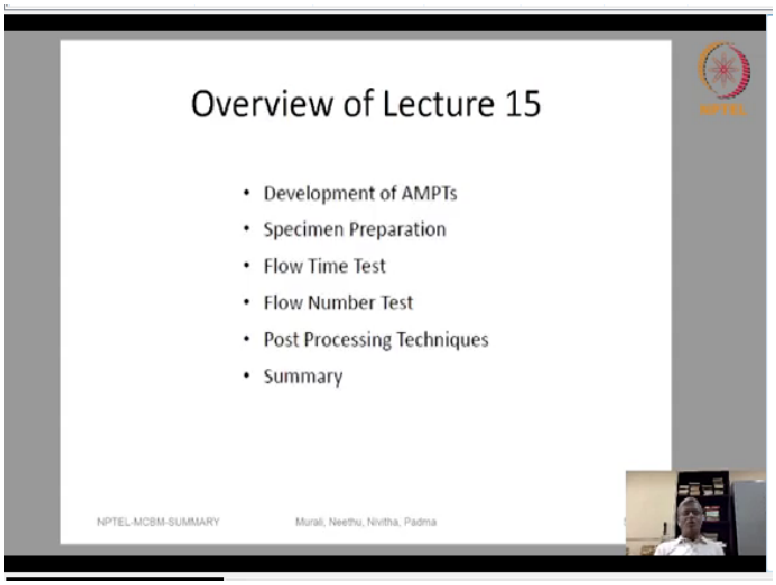

So, she talked about the development of AMPT and in fact AMPT is the one that basically helped us to compute the measure the dynamic modulus flow time and flow number. So, she discussed the flow time test, flow number test, and the associated post processing conditions.

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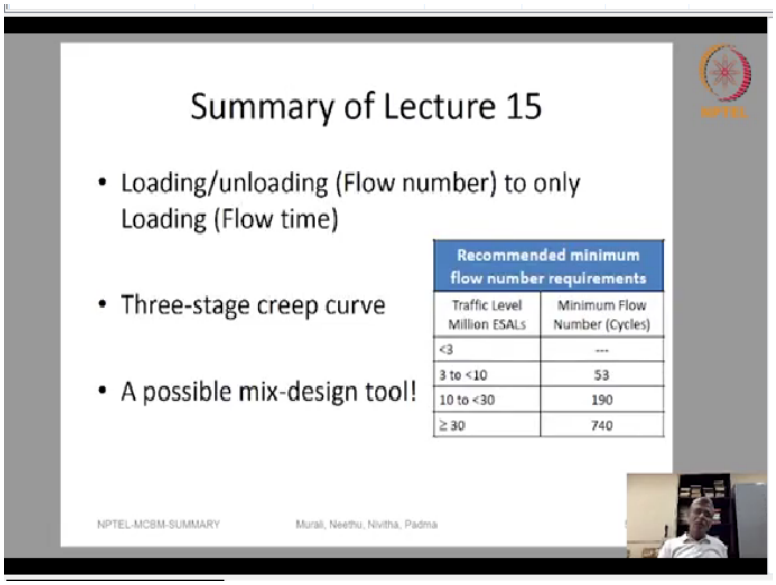

So, what is the most important way in which you will say, a flow number test is where you load it and unloaded, whereas in the flow time test you just only apply a load. The basic model that is

used here is a three stage creep curve, and the corresponding secondary to tertiary is taken as the flow number, and it could be used as a possible mix design tool and in fact, I will strongly suggest the Indian highway engineers that they start measuring the flow number. And integrate it as part of their Marshall method of mixed design that they are familiar with using right.

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The final, very final lecture on this particular topic about rutting distress was given by fatigue, Dr Padmarekha she talked about the fatigue here.

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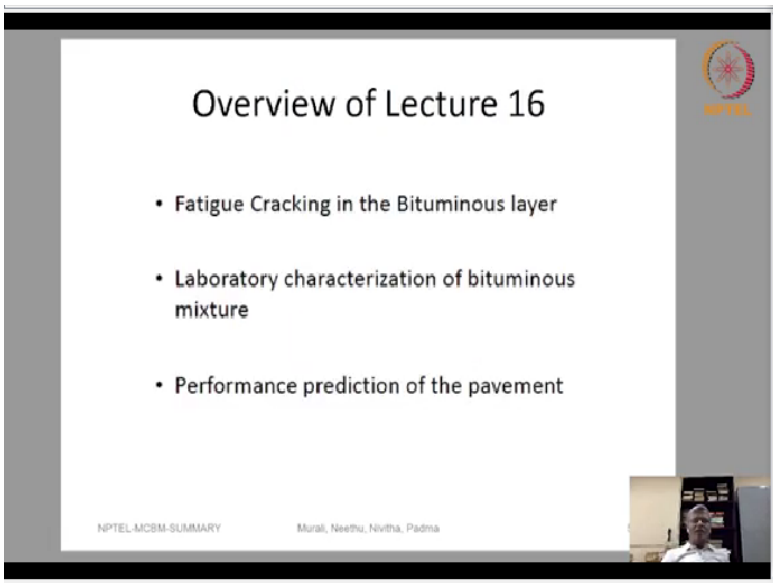

Again, she talked very clearly about the fatigue in bituminous layer to the laboratory characterization of the bituminous mixtures in fatigue, on how to use it in a performance-based pavement.

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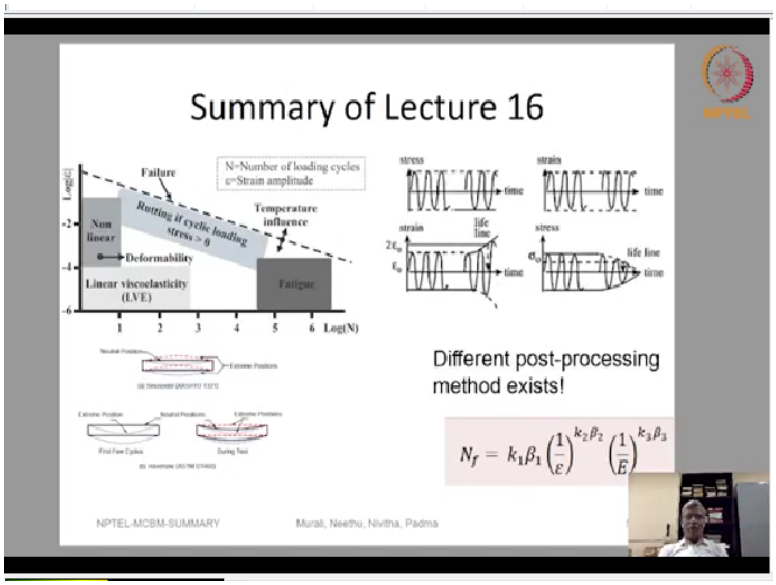

So, this is more or less the clear way in which I will put together the summary of the lecture. So, one need to very clearly understand, if you look at the top left picture, the strain versus the number of cycle, fatigue is always at the center, which means the load application that you give will result in strains that are substantially less, and the number of cycles will be more and there is a linear viscoelastic regime that we will see at the starting point.

Because there is going to be in essence energy dissipation due to the viscoelastic thing. And if you go slightly up, you are getting into the nonlinear deformation, and the temperature influence is also indicated. Now you should look at the top right picture. You can do this test in terms of the stress control, or you can do it in the strain control. When you do it in the stress control what will really happen, the strain keeps on increasing.

Because you are applying continuous loading cycles and the strain increases. On the other hand, if you do the under strain control, you will actually see that the stresses starts decreasing because the material is getting completely damaged. Now there are some issues related to doing the test

with beam bending wave, and it is given in the bottom left, there are 3 different configurations that are shown here.

So, what can happen is because of this repeated loading the neutral positions can also vary in a way. And finally, if you look at the bottom right, you will see that I have written different post processing method exists, in essence, how do we really compute the fatigue life. We can do it in many, many different ways. And finally, this equation that is shown here will help us to write distress equation and this could be, one can find out some portion of it by analyzing the fatigue test okay.

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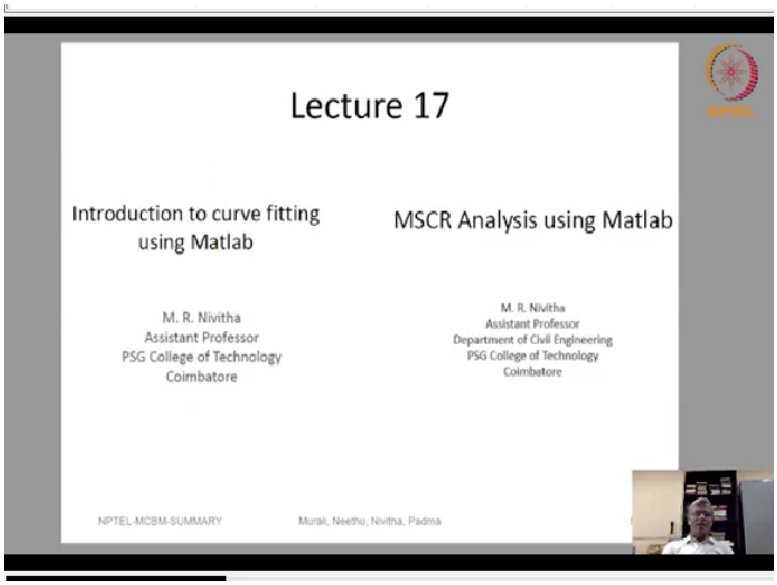

And in the 17th lecture Dr. Nivitha gave you an introduction on curve fitting using Matlab and she also told you how to do the analysis, MSCR analysis using Matlab, right. So, thank you very much for paying attention. We acknowledge, Government of India for making this possible. And IIT Madras, as well as the amazing team of NPTEL at IIT Madras. Please feel free to get in touch with any one of us if you have any questions related to this course.