Pavement Materials
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Lecture No. 23
Physical Properties of Bitumen (Part-1)

Hello friends, welcome back. If you remember in the last presentation we have discussed about the chemical properties of bitumen. In that particular presentation, we discussed the broad chemical composition, the broad molecular groups present in the bitumen and how these groups are related to the intrinsic properties or the rheological aspects of the bitumen.

We have also discussed that bitumen being a complicated hydrocarbon it is very difficult to characterize the actual chemical composition of the bitumen and relate it directly to the performance and therefore, the chemistry or the chemical properties of the bitumen are not popularly used for characterizing the performance of the bitumen in the in service field conditions.

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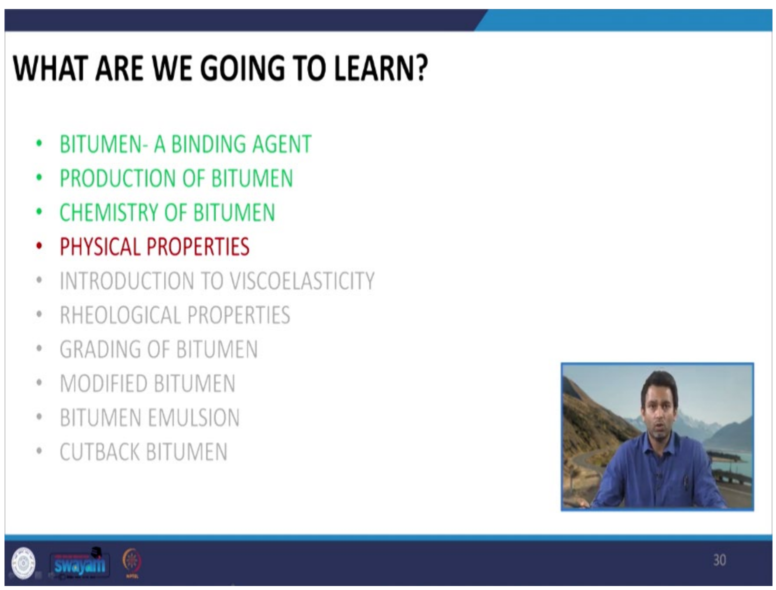

So, today we are going to talk about the physical properties of bitumen, which are more popularly used to characterize various properties of bitumen and also these physical properties have been related to the actual performance of the hot mix asphalt in the field.

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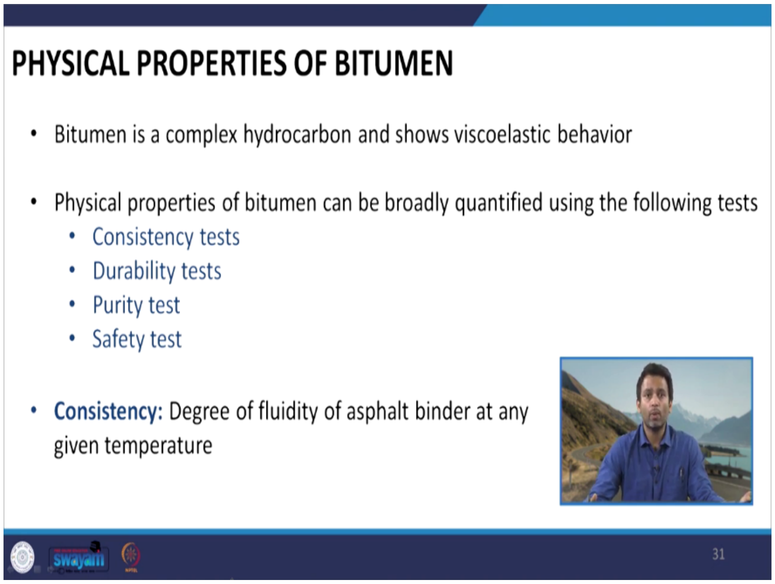

Bitumen as we discussed is a complex hydrocarbon and it shows a viscoelastic behavior. And if you remember that we defined viscoelasticity as a property in which the response of the material to any given loading condition is a function of both temperature and the rate of loading. Therefore, while studying the physical properties be it any physical property of the bitumen through any laboratory test we conduct we have to remember that, when we are comparing different bitumen's with each other, the tests which we need to perform should be at identical temperature and it identical loading conditions.

Broadly, the physical properties of bitumen are quantified through several category of laboratory tests. Under this category comes the consistency tests on bitumen, the durability tests on bitumen purity tests and safety test. We will be discussing about each of these test methods and different experiments under each category one by one.

So, let us start with understanding the consistency properties of bitumen high and how we define the consistency of bitumen. Consistency in general is defined as the degree of fluidity of the asphalt binder at any given temperature, it tells us that at a particular temperature, what is the indirect stiffness of the binder, for pavement application for road engineering applications, there are various temperatures we are interested in.

For example, if you see how bitumen undergoes exposure to different temperatures during the in-service period, let us try to understand the entire process in the hot mix plant, the bitumen is exposed to very high temperatures when it is mixed with the hot aggregates, the temperature of mixing approximately ranges from 150 degrees Celsius to approximately 170 degrees Celsius, then this particular heated mixture is brought from the plant and it is laid and compacted in the field using rollers.

During this instance, the temperature of the mix is approximately greater than 100 degrees Celsius, but let us say less than 130 to 140 degrees Celsius. Once the hot mix asphalt is compacted, we allow for the temperature to come down to the normal air temperature and then subsequently the pavement is open to traffic.

Now, during the in service life of the pavement, the hot mix asphalt or you can say the bitumen is exposed to a varying degree of environmental and temperature conditions. If we talk about temperature, the average temperature of the pavement depending on the location we are talking about can be around say 25 to 35 degrees Celsius.

During summers in tropical climates, typically, the pavement temperature can go up to 60 to 70 degrees Celsius or even higher sometimes, and when it is winter in the northern climates. The lowest temperature to which the bitumen can be exposed to can be as low as minus 10 to minus 20 degrees Celsius.

So, this range of temperature will determine how the bitumen which we have used for construction will respond to any given loading conditions. These consistency tests about which we are going to talk about now have also been developed considering the in-service application of bitumen.

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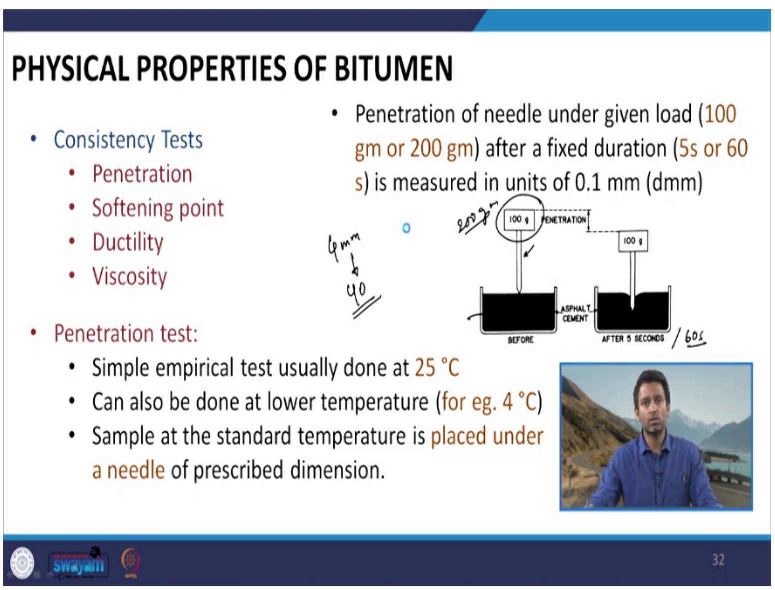

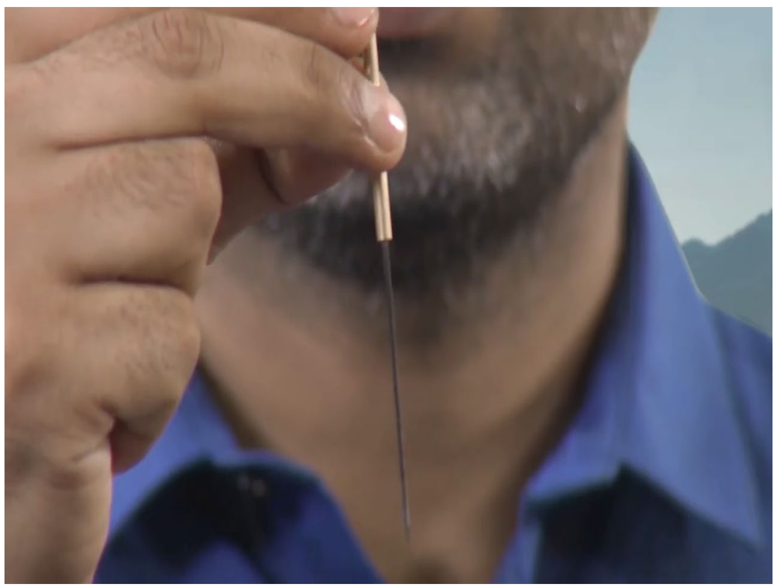

So, let us start discussing about the consistency properties one by one in our list we have several conventional properties, which are tested in the laboratory, like penetration of bitumen, we have softening point test to be done on bitumen, we have ductility test and we have viscosity test talking about the penetration test, this is a simple empirical test which is usually done at 25 degrees Celsius.

Now, an important point to note here is that why they have chosen 25 degrees Celsius as this test temperature, this test since was developed in US they considered 25 degrees Celsius as the average pavement in surface temperature for their locations. Therefore, this temperature have been chosen to study the consistency property of bitumen at the average pavement temperature researchers and agencies have also done penetration test at other temperatures for example, 4 degrees Celsius.

In this particular test, what we actually do that we place a sample of bitumen under a needle of prescribed dimension and weight, this can be seen in this particular picture, which is shown in the presentation. So, we have a sample of bitumen and then we have a needle having a specific weight which is allowed to penetrate in the sample for a specific period of time and after the penetration has taken place for that particular period of time, we measure the depth of penetration and this depth is used as a measure of consistency of bitumen.

I have here a bitumen sample with me which you can see I hope, so, this is a container having the sample of bitumen which you can see here and this particular container is placed under the action of a needle. If you see here, I have a needle with me of prescribed dimension, this is attached to this particular arrangement. And then we have a standard weight which we keep during the test.

This particular needle is kept in touch with the sample of bitumen before starting the test. Once the bitumen has attained, the respective temperature for example, if you are testing it at 25 degrees Celsius, we allow this needle to penetrate for 5 seconds under the given weight. And after 5 seconds, we measure the depth of penetration, which as I said is used as a measure of consistency of bitumen.

If you are doing these tests at 4 degrees Celsius, instead of 100 grams, we will use a 200-gram weight and the sample is allowed to penetrate for 60 seconds instead of 5 seconds, we generally report penetration in Deci-millimeter for example, if the needle has penetrated 4 mm, we will report the penetration as 40 and this is how the penetration test is done.

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These images it shows a laboratory arrangement for the penetration test, you can see the penetrometer here; this is the needle arrangement along with the weight, we have the sample kept here. And this is the entire system during the test process talking about the importance of penetration tests.

Now, we have to remember that whatever tests we perform in the laboratory, there is a reason for it, there is a meaning to it. Finally, we want to relate this property this consistency which we are measuring with some performance indicator in the field. So, researchers they generally try to relate these properties with the infield observation of various distresses, talking about distresses in flexible pavement, we are interested in fatigue cracking, we are interested in seeing the permanent deformation on the rotting.

So, these are the critical distresses for which we are actually designing the pavement. For pavements in extreme northern climates, we are also interested to see the low temperature cracking performance of the pavement. So, ultimately, whatever test we are doing on the materials for example, bitumen, we will try to see how it is related to the occurrence of these distresses in the actual field.

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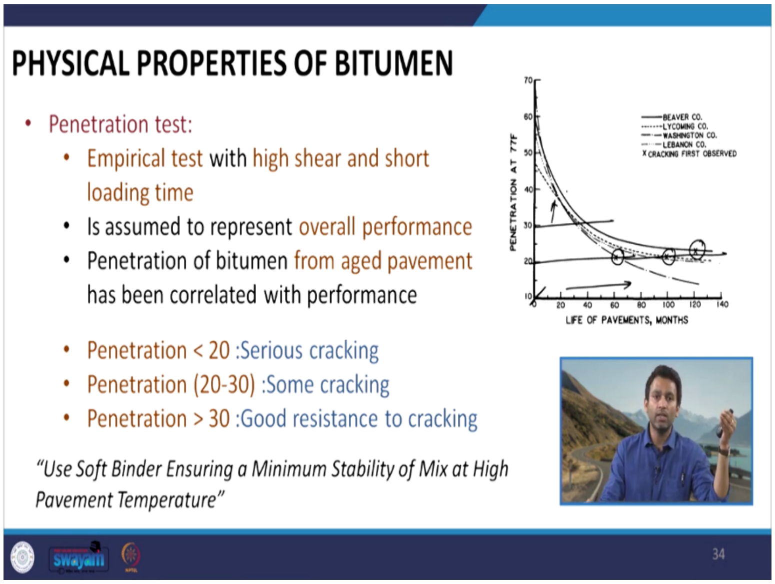

Penetration test is an empirical test. And in this particular test, if you see how the test is performed, we will see that the bitumen is exposed to very high shear for a very short loading time, which may not be a peculiar observation to the vehicular movement in the field. However, since it is an empirical test, we are only interested in the results which we have to see if it can be related to some distresses in the field.

Usually, researchers have tried to relate it with the overall performance of the pavement because the temperature which we choose typically 25 degrees Celsius is the average temperature of the pavement earlier reports have indicated that penetration of unaged bitumen is not well correlated with the observations of the distress as in the field. The distress which people have tried to relate here is the fatigue cracking, because fatigue cracking is a distress which typically occur at the average surface temperature of the pavement.

But, unfortunately, the penetration values of different bitumen's are not found to be well correlated with the actual observation of occurrence of cracking in the field. But, there are evidences where it is found that penetration values of the bitumen collected from aged pavement have been correlated with the occurrence of cracks in the field. Few research studies have indicated that when the penetration of bitumen drops to less than 20 in the actual field.

So, after that time serious cracking starts coming on the pavement. If the penetration value of the aged bitumen it ranges from 20 to 30. Some cracking's have been observed. And if the penetration of the bitumen from the aged pavement is usually more than 30, it is not very stiff, it is still in soft condition, and those pavements have been found to be crack resistant.

This figure has been taken from one study conducted in US and here you see that the researchers have measured the penetration values of the bitumen from different periods of bitumen extraction from the field. They measured it in the unaged condition, when they have just used the bitumen for the production of hot mix asphalt and after the bitumen was laid in the field, at different periods, they collected the sample and they measured the penetration and it is obvious that as the bitumen ages its defense and the penetration of the bitumen will be lower in comparison to the initial penetration.

So, here they have marked the location where the cracking initiated and based on this graph also we will see that typically when the penetration drops below 20 More number of cracking starts occurring in the pavement and if the penetration value of the bitumen is kept above 30 Typically no cracking is observed in those pavements. So, a general suggestion is that we should use soft binder for construction of pavement ensuring that the bituminous mixture has the minimum stability at the highest pavement temperature.

For example, if you are constructing the pavement where you are expecting the pavement temperature to go around 60 degrees Celsius during summers, you have to ensure that at 60 degrees Celsius the bitumen you have used is stiff enough so, that the stability of mix is appropriate. So, the thumb rule is we should try to use a soft binder, but at high pavement temperature we have to ensure appropriate stability of the bituminous mixture.

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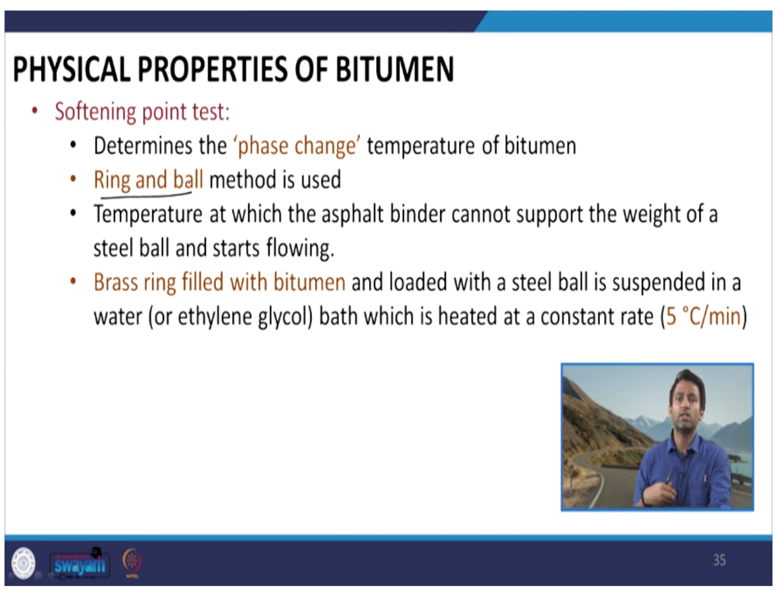

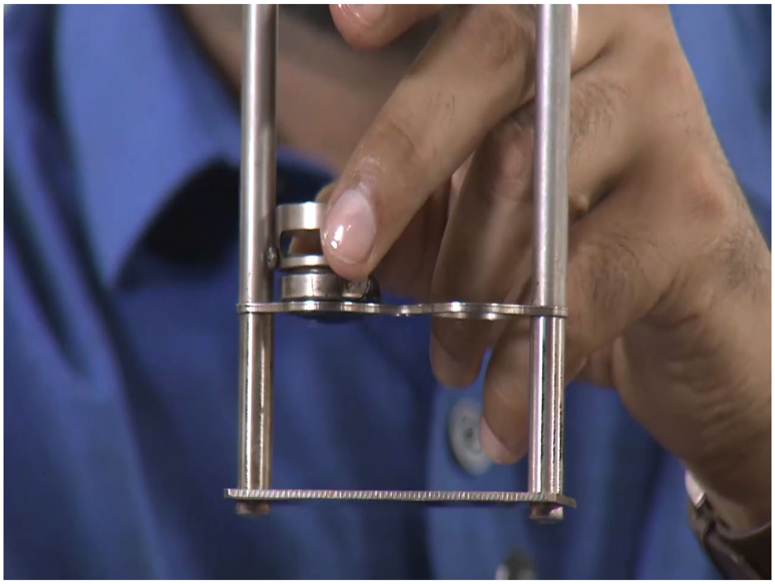

The next test which we are going to discuss is the Softening point test. In this particular test, we are trying to find out the temperature at which the bitumen changes its phase if you remember we have discussed that bitumen is a viscoelastic material. So, at lower temperature it is like an elastic solid and we when we start increasing the temperature the viscosity of the bitumen reduces and it becomes softer and softer and at very high temperature it typically behaves as a Newtonian fluid.

So, there will be a temperature at which the bitumen will convert itself from a face which we can say to be a solid two semi solid state to a liquid or flow able state and this particular temperature is indirectly measured using the softening point test. Here we use a ring and ball apparatus. So, we have a rink and we have a ball and we have a sample of bitumen in this ring and ball test we are measuring the temperature at which the bitumen cannot support the weight of a steel ball and it starts flowing.

Here what we do is that we have a brass ring I hope I have brought some parts of the softening point test. So we have small brass rings here and this is filled with bitumen. Once we fill the brass ring with bitumen, you will have a sample which looks something like this you can see that there is a bitumen sample inside the brass ring.

Then we have a holder the softening point holder where we place this particular brass ring it is placed here, we have a space for two samples to be placed in this particular folder, then we place another mold over this particular sample on which we will keep steel balls, I hope you are able to see this particular ball though the size is very small. So, we keep the steel ball over this particular sample.

Presently, you can see the ball is intact at the top and it is because the stiffness of the bitumen is relatively high, this entire arrangement is kept on this particular holder and this arrangement is further kept inside a beaker which is filled with some form of solvent, this particular solvent can either be water or it can also be ethylene glycol or glycerol if the expected softening point of the sample is very, very high.

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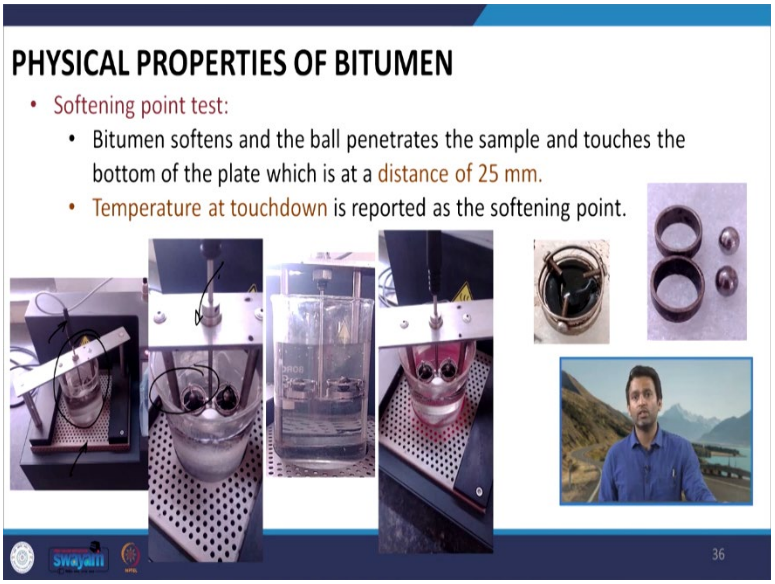

Then we place this entire assembly under a heater, which is heated at a standard rate of 5 degrees Celsius per minute. When the temperature increases, of course, the bitumen will soften. Once the bitumen softens this ball which is kept at the top, it will start penetrating the sample of bitumen and it will travel a particular distance which is a standard distance of 2.5 centimeter. So, if you see this particular arrangement here, so, this distance from here to here, it is 25 mm and this we observe that at what temperature this particular ball which is kept at the top of the sample touches the bottom of the plate and this temperature is reported as the softening point of the bitumen.

This picture shows some typical arrangement of the ring and ball apparatus in the laboratory. Here you can see that we have a softening point apparatus, where we have a display which shows temperature of the sample and here we have an arrangement where we have a heater here and then we are placing sample at the top, we can continuously monitor the temperature using a thermometer, this is a closer view of the beaker, which shows the ball kept at the top of the bitumen sample.

This is the front view of the same beaker along with a ring and ball apparatus. This shows heating of the sample and this is a closer view of the arrangement, which is used for conducting this particular test. Since the softening point test measures the phase change property of the material researchers have tried to relate this temperature to the high in service performance of the bituminous mixture. So, the softening point value is an indication of the temperature the bitumen inside the bituminous mixture can sustain without becoming excessively soft.

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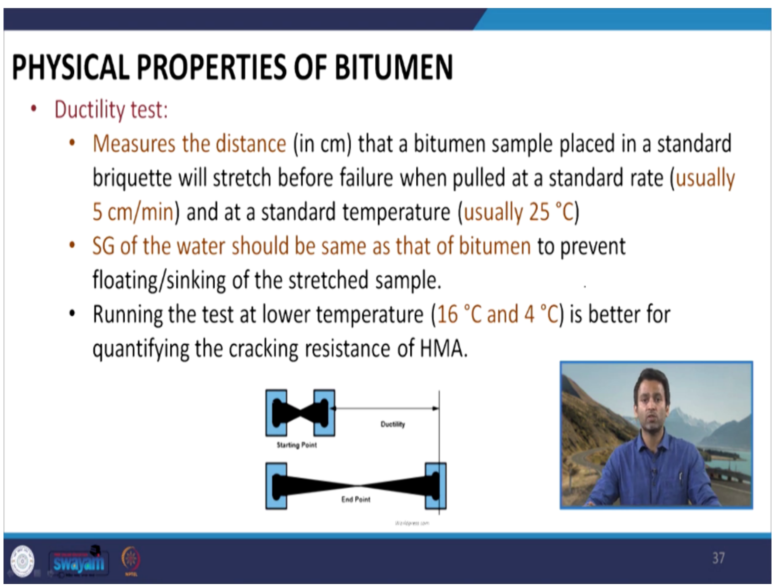


Moving on the next test which we will discuss is the Ductility test. In the Ductility test, we measure the distance in centimeter that a bitumen sample in a standard briquette will stretch before failure when the briquette is pulled at a rate of 5 centimeters per minute at a standard temperature which is usually taken as 25 degrees Celsius. For understanding the test or for visualizing the test in a better way, I have a briquette filled with bitumen here, you can see that this is a briquette arrangement with the bitumen sample poured inside the briquette.

If you see the geometry, the briquette has a lower surface area in the middle portion. In this particular location, the area is approximately 1 centimeter square. After preparing the sample, we will take out the bitumen out of the briquette in this form which you can see here. And this particular sample inside the ductility machine is pulled from both the end at a standard rate of 5 centimeters per minute at the standard temperature which is typically 25 degrees Celsius and this is stretched until the bitumen sample breaks from the middle portion and the distance to which the sample has traveled. Just before braking is reported as the ductility value.

This test is carried out typically under a water bath so that we can maintain the uniform temperature of 25 degrees Celsius. Here an important point to remember is that the specific gravity of the water should be approximately similar to 10 of the bitumen sample. Why? Because this will prevent the floating or the sinking of the spread sample. In order to increase the specific gravity if required. We can add salt if you want to reduce the specific gravity Any form of alcohol can be used.

Researchers have also tried running these tests at other temperatures typically lower temperatures for example 16 degrees Celsius and 4 degrees Celsius. So that they could use the results to quantify it with the cracking resistance of the hot mix asphalt based on the field observations.

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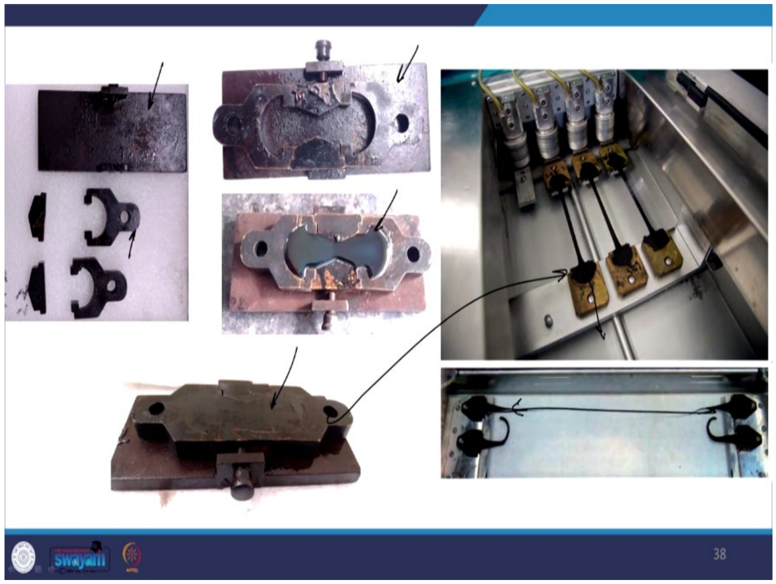

This picture shows some typical arrangements done in the laboratory for conducting the test, this is the mold on which the bitumen sample is prepared, you can see how the mold is attached here, we have the port sample and we have the trimmed sample, this trim sample is kept under the ductility machine which is placed in a water bath. And then we are stretching the sample from one side at a standard rate. And we measure that to what distance the sample has traveled before failure.

Significance of the ductility test with respect to the distresses observed in the field has been debated mostly because of its empirical nature and poor reproducibility. As I mentioned, previous researchers have tried to do this test at lower temperatures than the standard temperature of 25 degrees Celsius and the results obtained at lower temperatures have been correlated to the observations of cracking in the field.

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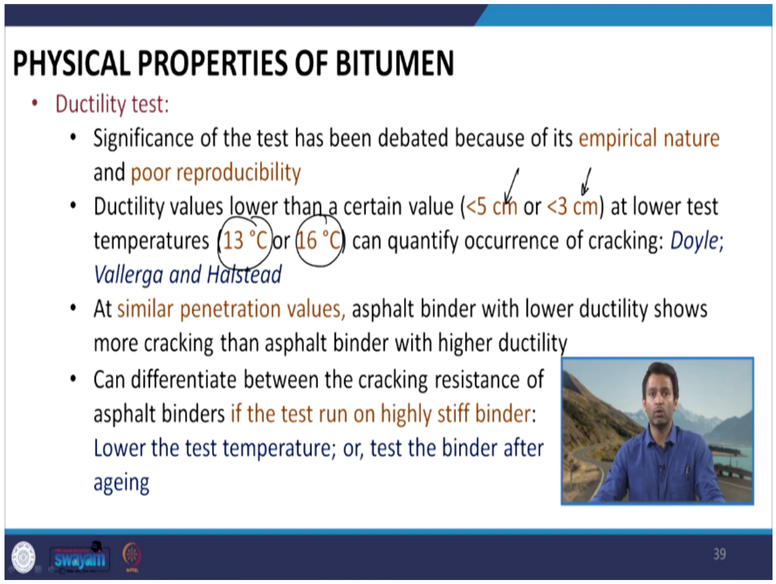

For example, few researchers have observed that if the ductility test is conducted at 13 degrees Celsius and the ductility value is less than 5 centimeters. So, those bitumen will have or will show more cracking in the field. Few other researchers have indicated that if the ductility value is less than 3 centimeters when the test is done at a temperature of 16 degrees Celsius, those bitumen will also have a tendency to show cracking in the field. It has been generally found that if we have bitumen with similar penetration values, then those bitumen having lower ductility shows more cracking in comparison to the bitumen having higher ductility values.

A general recommendation given in the literature is that this test should ideally be done on stiff binder. For example, either we can do the test at lower temperatures or we can do the test at 25 degrees Celsius. But under aged condition, in IS 73 2013 which we use in India, for characterizing the properties of bitumen, the ductility test is done on short term age specimens, this can be one of the reason why aged specimen is used instead of an aged specimen to do this particular test.

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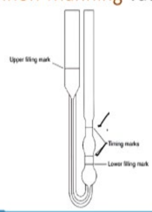
PHYSICAL PROPERTIES OF BITUMEN

- Viscosity test:
  - Fundamental consistency measurement that is not affected by changes in test configuration or geometry of the sample
  - Defined as resistance to flow of a fluid
  - For bitumen the measurement is done at 60 °C, 135 °C and/or at 160 °C
  - At 60 °C capillary viscometer is used to measure the absolute viscosity.
  - Cannon-Manning vacuum viscometer is typically used




Moving ahead, let us now talk about the viscosity test, viscosity unlike other consistency properties, which we have discussed is a fundamental property of the material. This means that the viscosity value at a particular temperature and at a given shear rate will not be affected by changing the geometry of the test specimen or changing other test configurations. Generally, viscosity is defined as resistance to flow of any fluid. When we talk about bitumen, we typically measure the viscosity at either 60 degrees Celsius or 135 degrees Celsius and also at higher temperatures such as 160 degrees Celsius.

Again here the fundamental question is why these particular temperatures are chosen to do the viscosity test, why not at other temperatures 60 degrees Celsius has been generally considered as the average maximum temperature of in-service pavement. Therefore, it is important to know the stiffness of the binder at this particular temperature definitely we do not want excessively soft binder. Otherwise, the pavement can show excessive flushing, excessive softening and occurrence of permanent deformation.

Therefore, 60 degrees Celsius is of interest to us. At higher temperatures, especially at temperatures which are typically in the mixing plant, we want good workability of the hot mix asphalt since bitumen is the binding agent in the hot mix asphalt, it is considered as the primary ingredient that provides workability characteristics to the mix. So at higher temperature, we want the bitumen to be soft enough so that it can be easily mixed with the mineral aggregates and it can be well compacted in the field.

Therefore, ensuring that bitumen is not excessively stiff at very high temperatures which is at the mixing plant we are interested to do the viscosity test at 135 degrees Celsius. I will explain later in the presentation that at higher temperatures and other temperature is chosen, this is done to assess the mixing and compaction temperature of the hot mix asphalt. Let us take up the discussion on viscosity of the bitumen at different temperatures one by one at 60 degrees Celsius.

Generally, a capillary viscometer is used to measure the absolute viscosity of the bitumen. Popularly canon-mining viscometers have been used for measuring the viscosity of the bitumen at this temperature. So, in this particular test, we have a YouTube viscometer which is shown in the presentation as well as you can see here in my hand, here, we have two sides, a larger side and a thinner side.

So, bitumen is typically poured from the larger end opening and it is poured till it reaches a mark which is given in the viscometer. Once the bitumen has reached the filling Mark, we stop and now, we condition this entire tube to the standard temperature of 60 degrees Celsius at which we are interested to find out the viscosity and this can be done inside a water bath or an oil bath.

Here, you also see we have some timing marks in the viscometer. I am not sure if you are able to clearly see with this particular tube, we have timing marks in different locations of the viscometer tube, what is done here that after the bitumen sample is poured from the larger end, it is kept for conditioning and to start the test from the lower end we apply a vacuum a partial vacuum.

Now this vacuum is required because it is 60 degrees' Celsius bitumen is very stiff to flow on its own due to gravity. Therefore, application of vacuum is important then, we record the time required for the bitumen to flow this timing marks in the given viscometer tube this recorded time is then multiplied by the calibration factor of the tube to calculate the viscosity in terms of poises or centipoises or whatever unit we are interested in.

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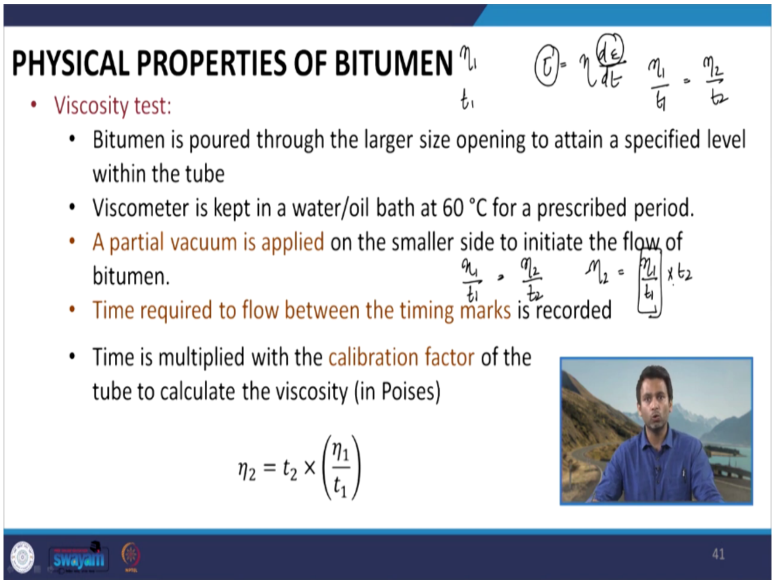

Here one question which usually arises that why time is used multiplied with a calibration factor to calculate the viscosity. So, the concept is that if you see that the general equation of viscosity it can be written as to $\tau = \eta \frac{d\varepsilon}{dt}$. Now, the stress which we are applying here in different bitumen sample is same is constant. And also since the timing marks are already fixed, the distance which the bitumen has to travel is also fixed. Therefore, we can say for two different bitumen's $\frac{\eta_1}{t_1} = \frac{\eta_2}{t_2}$ here the U-tube which is generally used is calibrated using some standard fluid and this depends on the manufacturer.

So, we have a standard fluid or oil whose viscosity is already known. And for that particular oil, we measure the time which is required for the flow, let us say that particular oil has a viscosity of η_1 and the time required is t_1. Since, we say that $\frac{\eta_1}{t_1} = \frac{\eta_2}{t_2}$ where η_2 is the viscosity of the bitumen we are interested to evaluate and t_2 say is the time required for the bitumen to flow over these timing marks. So, η_2 can be simply calculated as $\frac{\eta_1}{t_1} \times t_2$ here $\frac{\eta_1}{t_1}$ is considered as the calibration factor for the viscometer tube.

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This slide shows some typical pictures taken during the laboratory investigation for the measurement of viscosity. Here you see that we have a viscometer to filled with bitumen, this is kept inside the water bath and the test is started the bitumen flows, the timing is recorded and then the calculation is done. So, we will stop here and we will continue discussing about the other aspects of viscosity from the next presentation. Thank you.