Mechanical Characterization of Bituminous Materials

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Lecture - 45
Dry Rut Wheel Testing of Bituminous Mixtures

Now let us discuss the simulative tests in detail. So I will be discussing the dry wheel tracker test in this lecture.

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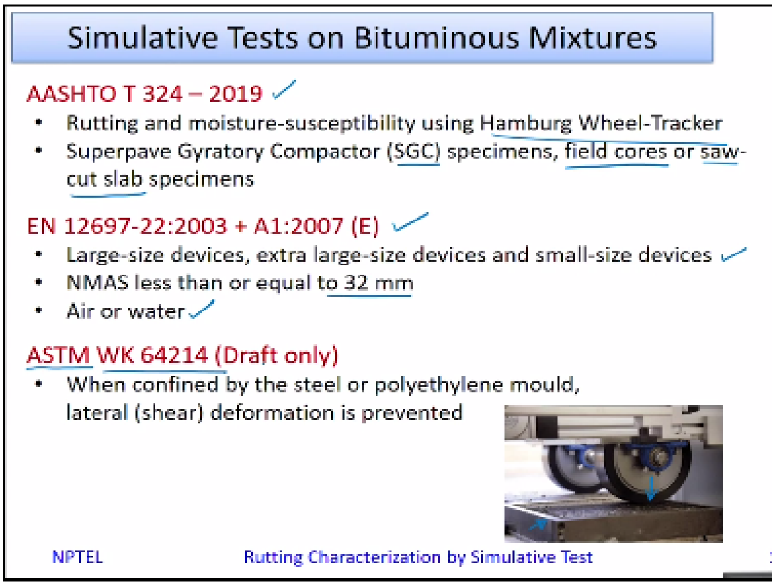

So there are various test protocols for a simulative test or a dry wheel tracker test. One is the AASHTO protocol which is AASHTO T 324, which uses a Hamburg wheel tracker for the testing wherein rutting as well as the moisture susceptibility of the material can be determined. So you can do the testing in the dry condition as well as in the wet condition.

Now the specimens for this testing are either cast using Superpave Gyratory compactor, or you can have field cores also that are taken from the field or you can have saw-cut slab specimens also can be used in this test as per this test procedure. And the next is the European standards EN 12697, which suggest the use of large size, extra-large size and small size devices, wherein the rutting susceptibility of materials with aggregate size more than less than 32 mm can be determined. Again the test can be conducted in air or water.

Now in both these tests, how they differ is the way in which the load is applied or the sample preparation and things like that. In both the test what is done is that the sample is prepared in a fixed mould. As you can see here, so this is a steel mold in which the sample is cast either a slab or a cylindrical specimen and then the wheel load traverse on top of it.

Now the major problem with is that this the mould that is there, it offers a very rigid confinement to material. So even if the material tries to flow it will not be able to do so since the edges are fixed in nature. Now this aspect is considered in the ASTM studies. And they have, they are trying to refine the code with considering this aspect as well to have a mould which is which does not offer a very rigid confinement or which offer a confinement which is as prevailing in the field condition.

But this ASTM standard is only a working standard, the draft only is available. So I will not be discussing this standard in this lecture.

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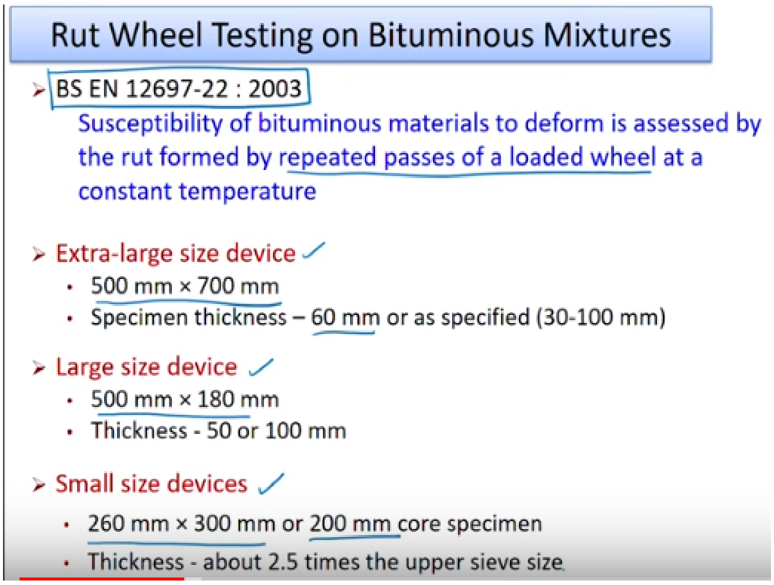

So let us discuss the European standard. So I will be discussing the rut wheel testing using the European standards. So I will read from the code. It says that the susceptibility of bituminous materials to deform is assessed by the rut formed by repeated passes of a loaded wheel at a constant temperature. So this is what is done in this test.

As I said you can have three specimen sizes, one is an extra-large device, next is a large size device and then is a small size device, okay. So in the extra-large size device, the specimen is rectangular in shape with 500 by 700 mm and the thickness is specified as 60 mm. Otherwise you can have it at different thicknesses of say 30, 40, 50, 100 etc. based on what is the thickness in which you are going to lay the material in the field.

And in the large size device also, the specimen size is of rectangular in shape with a specimen size of 500 by 180 mm. And the thickness as I said can be 50 mm if your layer thickness is going to be 50 or less in the field. Or you can have a 100 mm thick specimen if you are going to lay the layer with more than 50 mm in the field. Then you have the small size devices with 260 by 300 mm or rectangular specimens or you can have 200 mm core specimens also.

Again the thickness is decided based on the nominal maximum aggregate size of the mixture. The specimen size should be at least 2.5 times more than the upper sieve size of the material.

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Rut Wheel Test - Loading

Criteria	Extra-large size device	Large size device	Small size device
Load	10000 ± 100 N (600 ± 30 kPa)	5000 ± 50 N (600 ± 30 kPa)	700 ± 10 N (600 ± 30 kPa)
Loading wheel	Wheel with pneumatic tyre without tread pattern	Wheel with pneumatic tyre without tread pattern	Treadless tyre with solid rubber
Track width	110 ± 5mm	80 ± 5mm	50 ± 5mm
Frequency (outward and return)	2.5 ± 0.5 Hz	1.0 ± 0.1 Hz	26.5 ± 1.0 load cycles per 60 s

So this is a comparison of the different devices, the extra-large size, the large size and the small size device. The loading in each case is, in the case of an extra-large size device, you go for a loading of 10,000 Newton plus or minus 100 Newton. But the pressure applied through the wheel load is 600 kPa. Whereas, in the case of a large size device your loading is 5000 Newton and in the small size device it is 700 Newton. Whereas the pressure remains the same of 600 kPa.

Now the loading wheel in the case of an extra-large as well as large size device is a wheel with pneumatic tyres without any tread. Whereas in the case of a small size device you use a treadless tyre with a solid rubber outer covering. Then the track width, when I say track width it is the width of the wheel which passes on top of the surface. The track width for extra-large size is 110 mm whereas for large is 80 and for small size device it is 50 mm okay.

And the frequency of application of the load which indicates the onward and the return movement. So these together the forward to backward movement comprises one cycle and the frequency of cycle is 2.5 Hz if it is a extra-large size device and 1 Hz for a large size device.

Whereas in the small size device it is 26.5 load cycles per minute is a frequency that has to be provided.

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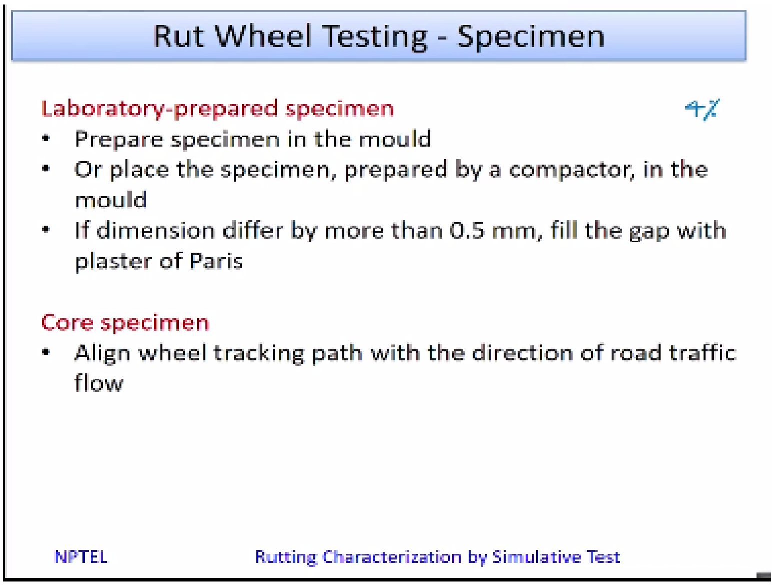

Now the specimen, you can have the specimen being prepared in the specified mould for the testing. You can use any compactor to compact the specimen to the required air void content. We normally do the testing at a 4% air void. So at this air void you can cast a specimen in the mould itself or you can cast the specimen using any other compactor. Say you can use a shear compactor to prepare the slab specimens.

And if the size of the sample is less than the mould, you have to fill in the extra spaces using plaster of Paris so that it fit properly inside the mould. Now if it is a cored specimen, so you want to study the rutting of the material in the field, you take a core from the field and you have to ensure that the specimen is placed in the mould so that the direction of load application is same as the direction of the traffic in the field.

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Rut Wheel Testing - Specimen

Table 1 — Minimum set of specimen

Device	Minimum set of test specimen
Large or extra-large size device	2
Small size model A testing in air	6
Small size model B testing in air	2
Small size model B testing in water	2

NPTEL Rutting Characterization by Simulative Test

And you should have more number of specimens to check the repeatability. In the case of extra-large size device and the small size device you need at least two specimens to check the repeatability. Whereas in the case of, there is a small size device of type A in air it requires at least 6 specimens to be used.

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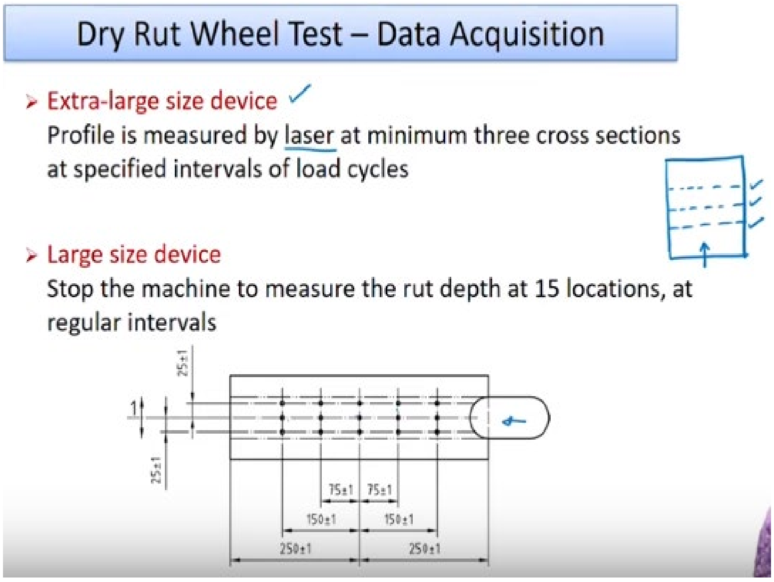

And how this data is collected or how the deformation is measured on the surface of the specimen? So you have a specimen and a wheel traverses on the top of the specimen. In the case of an extra-large size device, the profile of that surface is measured using lasers. Now suppose this is a specimen, at three different locations you will have the lasers. So this is the direction of movement of the wheel.

So at three locations you collect the profile of the surface. Initially you take the initial profile and then after regular intervals of test cycles, you take this profile using the laser at three different locations so that you can get the entire top cross section at three locations. Whereas in the case of large size device, the measurements are made either using an LVDT or any other dial gauges.

But what you have to do is that you have to take the measurement at 15 independent locations. See, as you can see in this figure, see this is the wheel load. Along the center you have five locations and 25 mm to the left and 25 mm to the right of your specimen, you have five locations. So altogether there are 15 locations at which you have to measure the profile or the deformation.

So what you have to do is that, initially you have to take the measurement and then after a specified number of load cycles, say 100 cycles, you have to stop the machine and take the measurements and then close the chamber and then repeat the test. And at regular intervals as I said after 100 you can go for 200 and 500, 1000 cycles of tests you can take these measurements at these 15 locations. So this is a case of a large size device.

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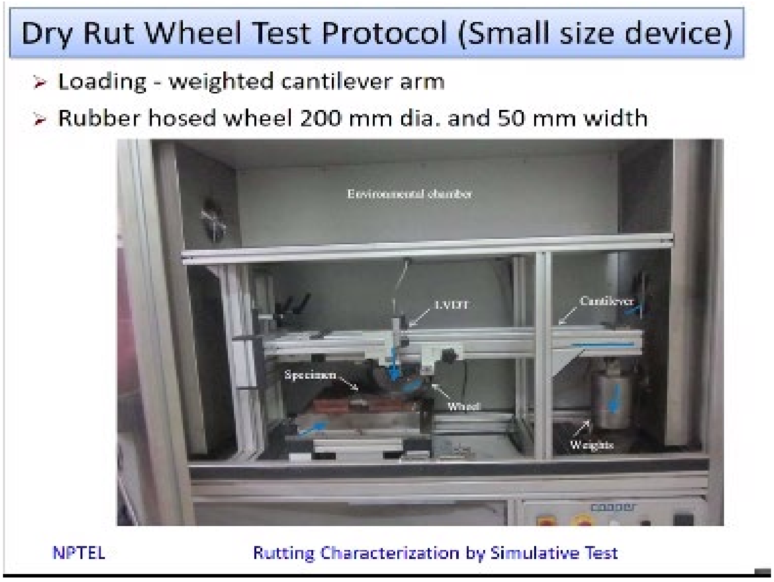

Now I will discuss about how the testing is done in a small size device in air. So this is a chamber or an environmental chamber where the test is being conducted. As you can see here, this is the bottom plate in which the specimen is kept. You can see the wheel here. And then the wheel load is applied using a cantilever arm.

So you can see the cantilever arm here with a load applied at the end so that the equivalent required wheel load will be applied through the wheel on the surface. Now as I said the wheel is a rubber hosed wheel of 200 mm diameter and the wheel path is a 50 mm width.

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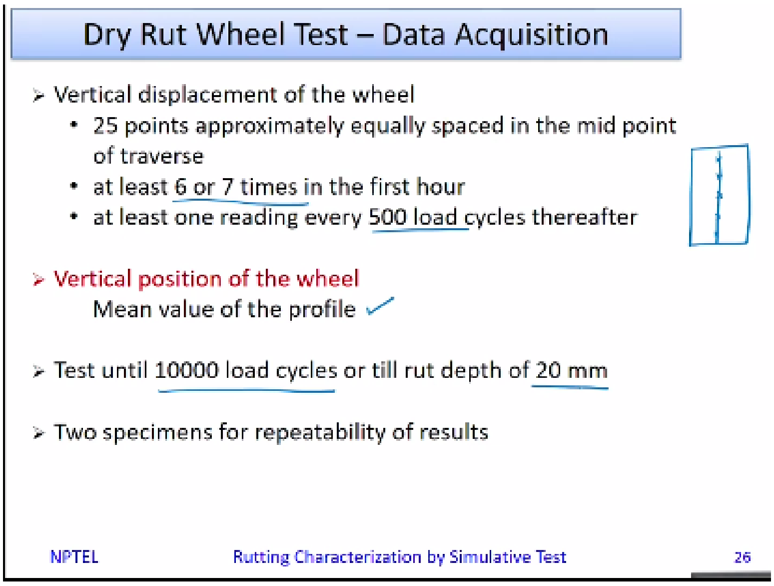

Now the test temperature based on your requirement, you have to choose the test temperature. So as we are discussing about rutting, rutting is something which happens at a higher temperature. So normally we do the testing at 50 or 60 degrees Celsius. And when you, you have to condition the specimen to that test temperature. So if your thickness of the specimen is less than 60 mm, you have to condition it in the environmental chamber for at least four hours.

And if the thickness is more than 60 mm you need to condition it for at least six hours, but to a maximum of 24 hours. If you continuously condition it at this test temperature for more than two days or so what can happen is that the agent will creep in. So it the maximum time period duration of conditioning of the specimen is 24 hours. And if you are doing the test in water bath, it has to be conditioned for at least 1 hour.

And I said the frequency of testing in a small size device is 26.5 cycles per minute and one to and fro motion constitute one cycle. So you can say it is actually 53 passes per minute. And in this small size device you use an LVDT to collect the data at different points in the specimen. And this is how the data is collected in a small size device in the sample. Along the central path of your wheel, you collect the deformation at 25 equally spaced locations.

During the first 1 hour of testing you will take the readings at 6 to 7 times in the first 1 hour and thereafter, at least one reading is taken for every 500 load cycles. You need not close the, you need not stop the test for collecting this data. The LVDT will automatically collect it during this test cycles without stopping the machine okay. Now after taking these 25 deformations or the profile at 25 locations, average of these 25 values will be the main profile of the specimen.

Now this test the small size test is conducted for 10,000 load cycles or till you see a rut depth of 20 mm. Now as I said for repeatability at least two tests are to be conducted.

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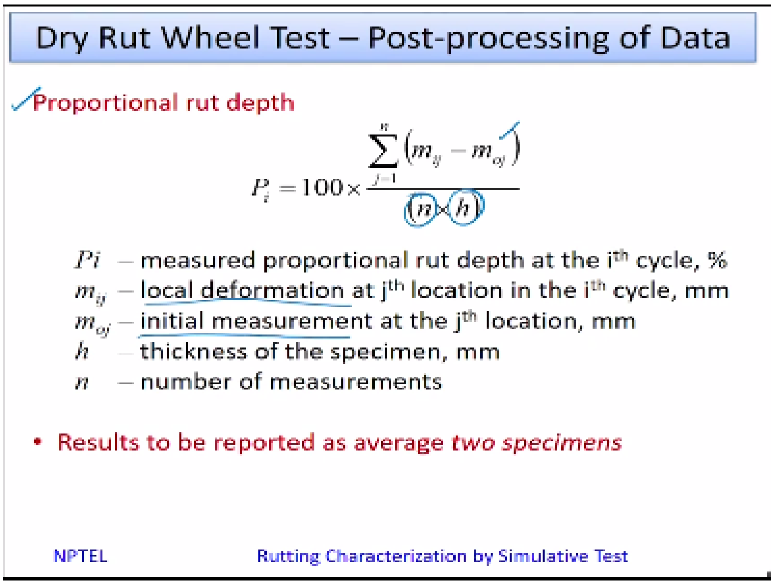

Now how do you process this data? Now as I said you have collected the rutting or the deformations from the original profile for a number of cycles and you have tested it for at least 10,000 test cycles. So the one attribute that you collect to find its rutting potential or rutting susceptibility is called the proportional rut depth okay.

Proportional rut depth or you can say it as the strain. So this is calculated like this $(m_{ij} – m_{oj})/n \times h$ where m_{ij} is the deformations that are collected from the j^{th} location in the i^{th} cycle. Suppose, I am considering 100 cycles, so as I said I have 25 locations. So from the j^{th} location what is the deformation that is collected and subtracted from the initial measurement. So that you will get the rut.

Then divided by n, that is the number of measurements, that you have taken. So that will give you the average profile and divided with the specimen thickness. So that will give you the proportional rut depth. So this is one way of estimating the rutting potential in terms of the proportional rut depth. And again this value has to be computed for both the test specimens and you can take the average.

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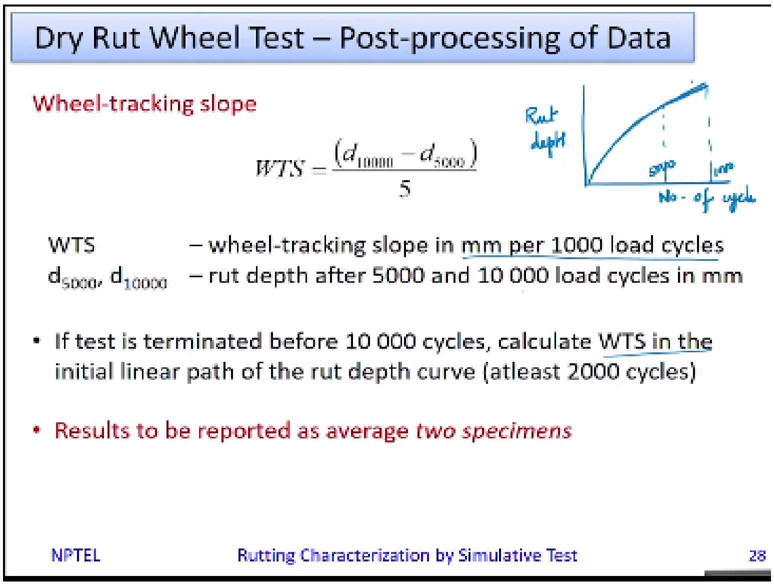

And the second aspect that you collect is the wheel tracking slope. So this essentially is the slope of the rutting or the rut depth progression towards the end of your test cycles or towards the last 5000 test cycles. So suppose you have, this is your rutting progression, say this is rut depth versus the number of cycles. You measure the rut depth at the 5000 cycle and then the 10,000 cycle.

And the slope of this portion is denoted as the wheel tracking slope. So it is ($d_{10,000}$ - d_{5000}) / 5000 x 100. Now if in a case that the test is terminated before 10,000 load cycles, then you can calculate this slope again at the, towards the end or when you see that straight line portion of rutting happen. See initially there is a curved portion and somewhere it reaches a straight line.

So in that straight line portion you can take the slope, but for that you need at least 2000 cycles to be completed in the test, okay. Again, this also has to be reported as an average of two specimens.

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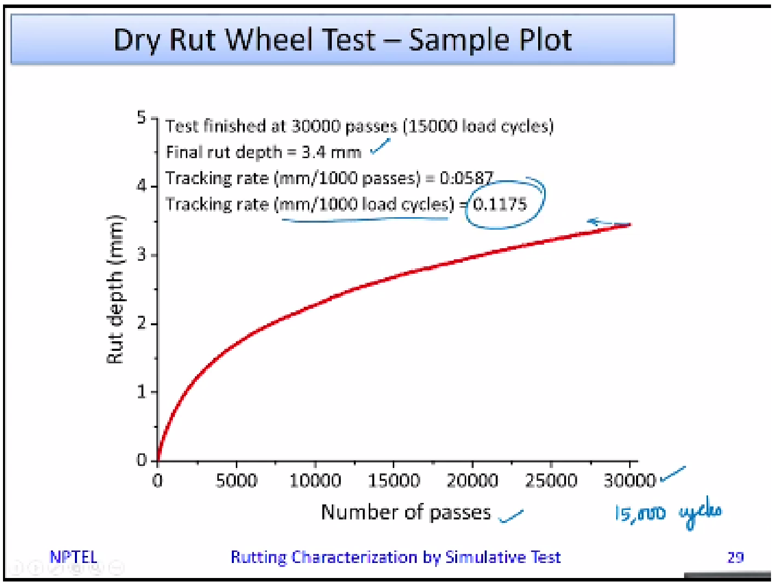

Now this is a sample plot of the rut depth versus number of passes. As you can see here, this is number of passes. So the test is continued for 30,000 passes or you can say that this is 15,000 cycles and you see the progression and the final rut depth that has reached that is this value is 3.4 mm and the tracking rate in millimeter plus 1000 load cycles you got it as 0.1175.

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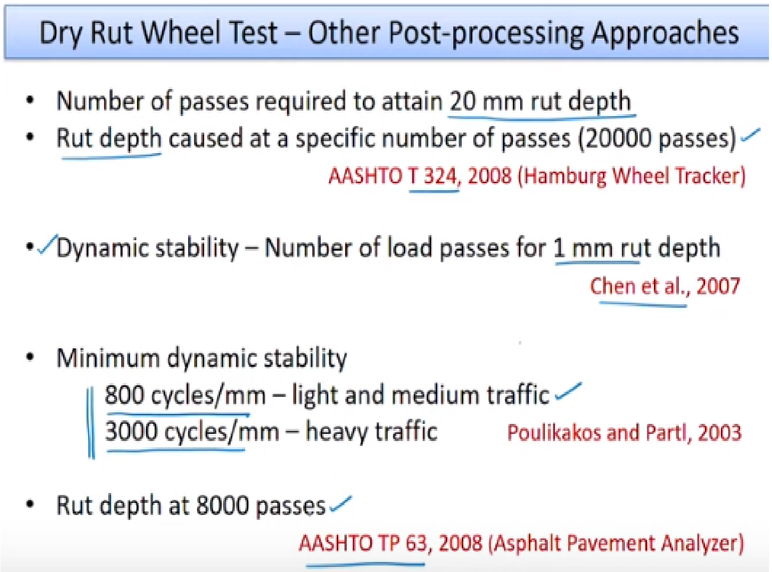

Now this is one way in which you can post process the data. There are other approaches by which you process the data and you set failure criteria for these materials. As per the AASHTO T 324 which uses the Hamburg wheel tracker the number of passes required to attain a 20 mm rut depth is taken as the criteria.

Or you compute the what is the rut depth which is cast after a specified number of passes say for example, your test is for 10,000 cycles or 20,000 passes, what is the rut depth, the final rut depth that is reached at the 20,000 passes. That is taken as the criteria. Whereas, in a study by Chen et all in 2007 they have established a criteria called dynamic stability.

So it is defined as what is the number of load passes that is required for a 1 mm rut depth. And there are failure criteria that are set by other researchers say for example, if you want to use that mixture in a lighter medium traffic you need a minimum dynamic stability of 800 cycles per millimeter. And if you want to use it in a heavy traffic you need a stability of 3000 cycles per millimeter and so on.

One can arrive at such criteria provided you have sufficient amount of field data as well. Now there is as per AASHTO TP 63 using an asphalt pavement analyzer it specifies that a rut depth at 8000 passes is taken as the criteria for comparing your mixes.

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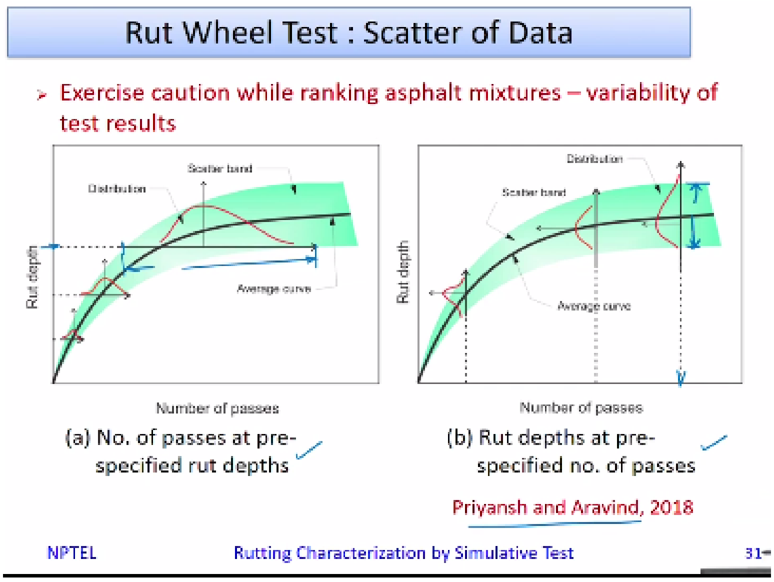

Now this is a word of caution. When you use this kind of a test as you know that this is a highly heterogeneous mixture and the repeatability is going to be very high or the scatter of data will be very large. So this is a study by Priyansh and Aravind who have tried to see how much will be the variability when you use a test like a rut wheel testing.

So you can see here that in the first figure, we are trying to find out what is the number of passes at, to reach a particular rut depth as you can see here. To reach a rut depth of this much, the variability is from here to here. So there is a such large variability of results when you use a wheel tracker test, the green portion shows the variability.

Whereas in the second figure you can see what is a rut depth which is corresponding to a number of passes as you can see here. For this number of passes, the variability of rut depth is from here to here. So such wide variability one can expect when you do a wheel tracker test, and this variability can follow certain functions like you can have a normal distribution, Weibull distribution or a log normal distribution and so on.

So one has to be very cautious while using such kind of information to correlate it to the performance in the field.

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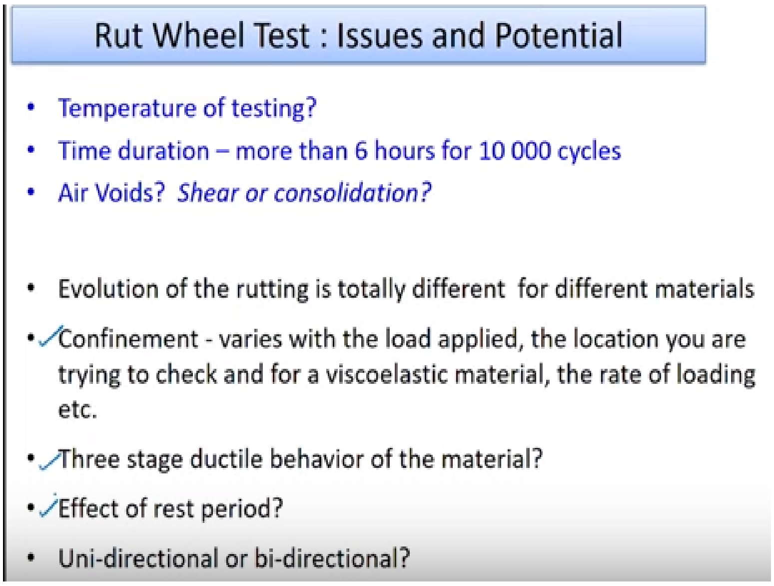

So let us discuss a little bit about what is the potential of this test and what are the issues associated. So one aspect is regarding the temperature of testing. You can do the testing at a higher temperature of say 50 or 60 where in this the rutting or the possibility of rutting is more. So you can do a testing at that temperatures. But again it can be done at a constant temperature alone for a particular test.

And this is a test which will take a little amount of time say for example, 6 hours is required for 10,000 load cycles. And you can do the testing at different air void contents. What I mentioned in the, as per the standards is at an air void content of 4% say one wants to test at a higher air void content as when the material or to simulate the material when it is laid and compacted, you can test it at say 7 or 8 percent air void content and see how the deformation happens. Or you can have a very low air void content and see how the shear deformation happens. So such possibilities are there to use in the rut field testing.

Now what is important is that this as I said, rutting is a very ductile phenomenon, which go through a primary stage a secondary stage and a tertiary stage. Now this evolution of rutting will be different for different materials and you should be able to capture this. But what we have observed in the sample data that I have shown you that even you have extended it for say 15,000 cycles, you were not able to see a definite primary secondary or tertiary kind of behavior. So this evolution over a period of time may not be visible in a simulative test like rut wheel testing.

Because the load and the conditions are simulated in such a way that you get an immediate result or you say that you are not prolonging the test for sufficiently long. So that you may not be able to see all these kind of stages. And the major important aspect is the confinement condition. So as I mentioned in the case of ASTM standards, see, the confinement that is happening on the material in the field is highly varying. This will depend upon the load that is applied at which point that you are trying to collect the information and for a viscoelastic material, which bituminous mixture is, this confinement will depend upon the rate of loading as well. So all these aspects are not incorporated or simulated in your wheel tracker test because the material is placed in a very rigid mould.

And the next aspect as I already mentioned is the three stage ductile behavior which is not covered. And another aspect is the effect of rest period okay. As you know that after the application of one wheel axle or axle load, there is certain time period for the next wheel load application or the next axle load application.

So during this rest period there could be recovery of deformation that can happen, but that recovery is not considered in this kind of test, especially when it is done in a bidirectional way. As you have seen that in the accelerated loading facility, the wheel is actually loading in one direction and in the second direction you have lifted up the wheel and the loading is not done in the other direction.

Whereas in the case of a simulative test using dry wheel tracker or wheel tracker, the loading is done in the to and fro motion. So there is no rest period being given to the specimen. So these are some of the aspects that are to be considered, while you use this as the indicative test for the rutting behavior of bituminous mixtures.

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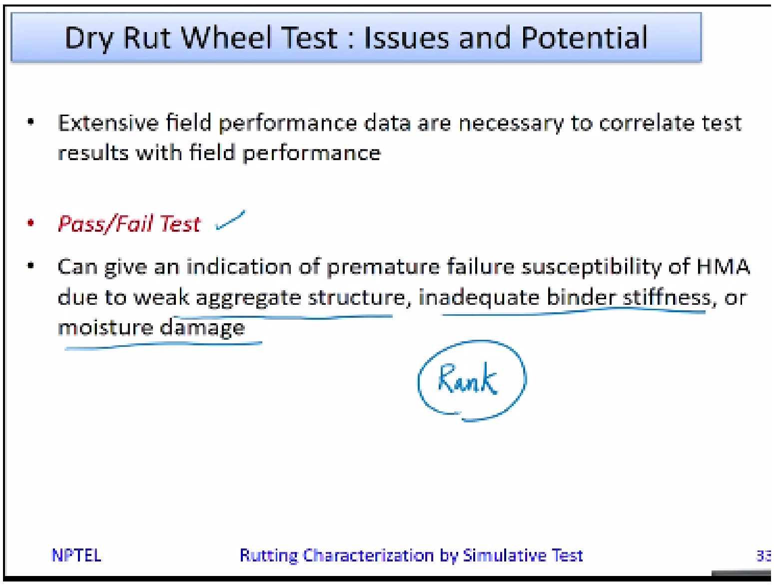

And another aspect is that you need extensive field performance data that is necessary to correlate this laboratory investigation to the field data. But the main advantage of using a simulative test like this is that it is essentially a pass fail test. And it can give you an indication of whether there is chances of any premature failure on this material due to various aspects such as a weak aggregate structure, inadequate binder stiffness or moisture damage.

So such information can be obtained and essentially it is a tool that can be used to rank different materials. We will be trying out different materials like polymer modified binders or unmodified binders. If you want to use, get a comparison between the performance of these materials or to rank the different mixtures, this definitely can be used as an effective technique.

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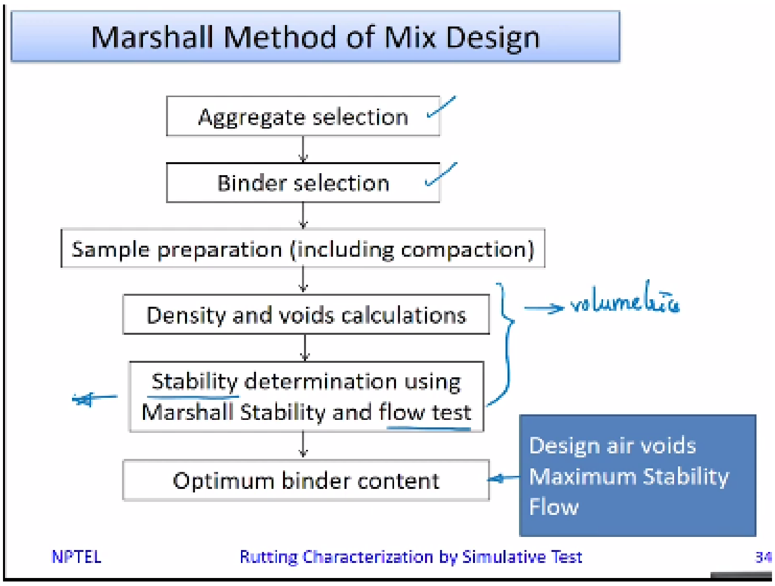

Now let me discuss a little bit about how this test has to be correlated to your next design procedure, okay. Now, we in India, follow the Marshall method of mixed design. As you all know this is the steps for Marshall method of mixed design. The first step is the aggregate selection and then comes the binder selection and you prepare the sample based on the compactive effort that is there in the field or based on the such correlations you compact the specimen and prepare the specimen and you do its volumetric analysis. You compute parameters such as density, voids in mineral aggregates, void with bitumen and so on. And then you determine two aspects, one is its stability and flow of the material using a Marshall stability test.

And finally, the optimum binder content is chosen based on a design air voids, say for example 4 percentage and then you check for this stability and flow whether it meets the required criteria. Now what is there in this whole aspect is that you have your volumetrics part and then you have a stability and flow part. But these two aspects are not correlated to the rutting behavior or it is not a strength parameter as such.

So no strength parameter is being used directly in this Marshall method of mix design. Whereas, one needs to correlate this kind of a testing wherein rutting phenomenon is simulated that has to come into the mix design so that before you choose your binder content or the mix as such.

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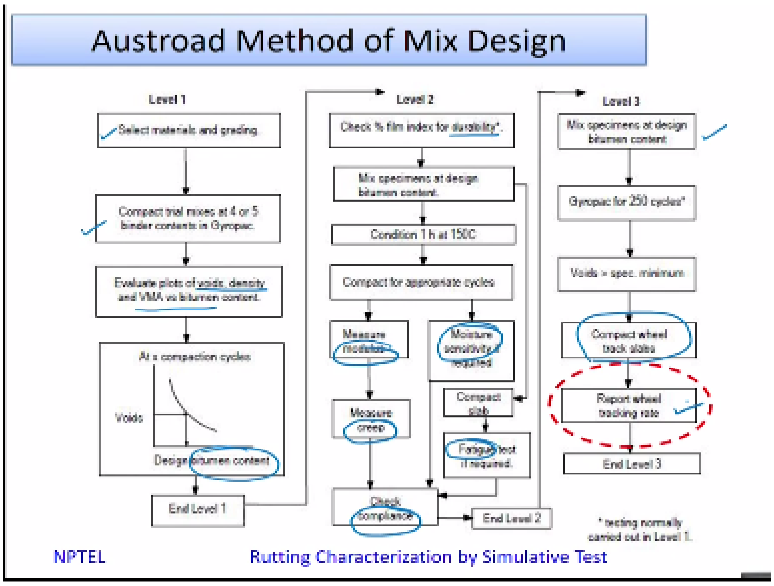

So you have seen many developments in different countries and this is a mix design strategy that is adopted in by Austroad or it is the Australian method of mix design. As you can see that it is divided into three levels, okay. So I am not going into the details of this test, but I will just introduce what is the three levels is. One is level 1, wherein you look into the volumetrics similar to your Marshall method.

So you have the selection of materials, then you compact the materials a different binder contents and you evaluate its voids, density, voids in mineral aggregates etc. and you arrive at the design bitumen content okay. So your bitumen content for that particular mix is determined based on the volumetrics. Then you go to the level 2 where in various aspect of the mixture such as durability, then the modulus of the material, then creep and creep compliance, fatigue resistance and moisture sensitivity.

So all these aspects of the mixture has to be considered in the level 2 of your mixture design and once approved through all these aspect only it goes to the third level okay. And in the third level, the material is again prepared or the mixture is again cast with the design binder content and then you do the wheel tracker test and the wheel tracking rate is reported. If this does not satisfy the requirement as per the standards, you have to redo your mix design.

So this is a whole procedure wherein which, you consider the volumetrics and in addition to the volumetrics, the various durability parameters, the strength parameters are also taken into account for designing the mixture okay. So with that I conclude this lecture. We will continue with the other bituminous mixture testing or the performance related testing like flow time and flow number test in the upcoming lecture.

Thank you.