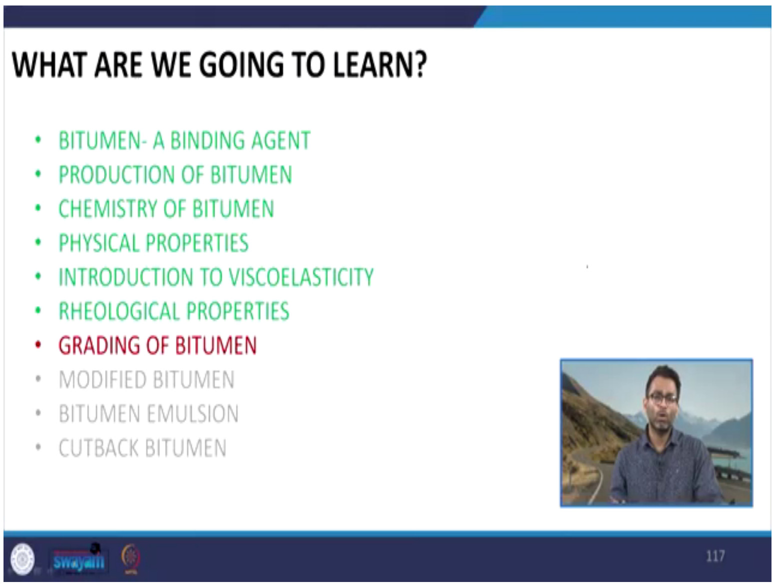
Pavement Materials
Professor Nikhil Saboo
Department of Civil Engineering
Indian Institute of Technology, Roorkee
Lecture: 29
Grading of Bitumen (Part-1)

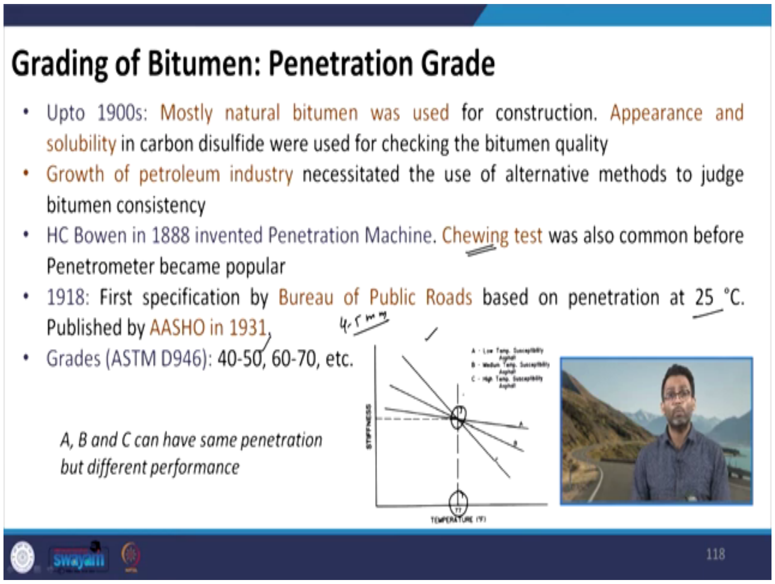
Hello everyone, welcome back. By now we have discussed about various chemical, physical and rheological properties of bitumen.

(Refer Slide Time: 0:40)



Today, we will start discussing about the grading of bitumen which is basically done to differentiate between the bitumen samples which we get from different crude sources. Also this grading system is used to select the bitumen for construction purposes and this grading system is essentially related to these physical and rheological properties which we have discussed in our previous lectures.

(Refer Slide Time: 1:07)



Starting with the grading of bitumen, during the initial period when that is up to 1900s, most of the bitumen were not from the conventional refinery process which we use today. As we have discussed previously that before 1900s, before the crude refining became common, mostly natural bitumen was used for the construction of pavement.

And during that time, there were only few sources of this natural deposit, for example, Trinidad Lake bitumen was one of them. So, simple process such as appearance of the bitumen sample and its solubility in carbon disulfide because if you remember this natural bitumen had high content of other mineral matters. So, the solubility in carbon disulfide, these were used for checking the bitumen quality.

Later after the manufacturing of bitumen started, there was a necessity to develop alternate methods so that bitumen with different consistency can be differentiated with each other. Different crude sources will produce different types of bitumen and the selection of bitumen required more or you can say rational or better process for selection or for grading.

During that time around 1888, H.C. Bowen, he invented the penetration machine or the penetrometer which we commonly call today. Various modifications were made to this penetration machine. The one which we use today it has the initial penetrometer had undergone various changes which were done by ASTM and Federal Highway Administration that was called as Bureau of Public Roads during that time.

So, they made several changes before adopting it in the specification. During the similar period, another crude method which was used was the chewing test. So, this is a very interesting test where an asphalt specialist used to take a sample of bitumen and by the amount of pressure he required to apply to chew the bitumen between his teeths, he used to predict by this pressure he used to tell about the consistency of bitumen.

In 1918, the first specification by Bureau of Public Roads was developed which was based on penetration of bitumen at 25 degree Celsius. And this we have discussed why this 25 degree Celsius was specially chosen. This was because this represented the average service temperature of the pavement especially in US. And this was published by AASHO which is the American Association of State Highway Officials in 1931.

Various grades of bitumen as per the penetration value were defined. For example, there were grades such as 40, 50, 60, 70 etcetera. Just to remind you again, what do you understand by the grade 40, 50? By the grade 40, 50 we understand that the penetration of the needle under standard condition will range from 4 to 5mm in the penetrometer when we penetrate the needle in the bitumen sample.

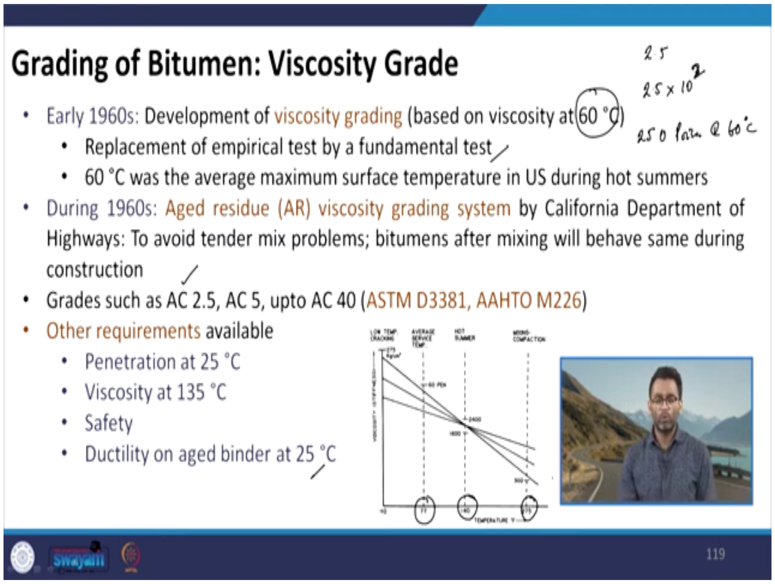
So, this is basically a bitumen which will be graded as 40, 50. Similarly 60, 70 indicates a bitumen where the penetration of the needle will be somewhere between 6 to 7mm and so on. So, based on this penetration value, different grades of bitumen or the consistency of the bitumen can be defined. Let us talk about some of the advantages and disadvantages of this penetration grade bitumen.

One of the advantages of penetration grade bitumen is that it is simple to use. The equipment is cheaper, it can be handled by a normal manpower. You do not need a specially technical staff to handle this equipment and it is also portable. It can be taken to different places, to different sites for testing the bitumen sample. If we talk about the disadvantages of penetration test or penetration grading, one disadvantage is that this is an empirical test.

We are not testing any fundamental property of the material here. Another disadvantage is, if you remember we have discussed about this that here the bitumen sample is subjected to a very high and non-uniform shear rate, which depends actually on the consistency of bitumen during the test. Also it is possible because we are testing the bitumen at one particular temperature and the penetration value at that particular temperature is used to grade the bitumen or define the consistency of bitumen.

So, this example shows that we can have bitumen samples, three different bitumen samples having the same penetration at 25 degree Celsius, but they can behave very much differently from each other if you compare a range of temperature, which means that the temperature susceptibility of the bitumen can be very different from each other. But if we talk only about the consistency at 25 degree Celsius, then all the bitumen will be graded as the same binder which may not be rational.

(Refer Slide Time: 6:48)



So, then further, around 1960s researchers and agencies, they thought that they needed some more fundamental property to grade the bitumen samples and therefore, they selected the viscosity of the bitumen at 60 degree Celsius as the basis for grading or defining the consistency of bitumen.

And there were several reasons why the viscosity was chosen, one is that viscosity is a fundamental property of the material, so it does not depend on the testing system. So, this is a property of the or the fundamental property of the material. Also the choice of 60 degree Celsius will ensure that we are testing the performance of the binder with respect to its rutting resistance.

Similar to this when penetration grade came to 25 degree Celsius was also chosen, so that the results can be compared with the occurrence of fatigue cracking or low temperature cracking. Likewise in the viscosity grading system the temperature 60 degree Celsius is important because at this temperature the permanent deformation characteristics of the binder can be related.

As I said this is a fundamental test in comparison to the penetration test and also the reason of choosing 60 degree Celsius during that development was because this was the average maximum surface temperature in the US during hot summers. Parallelly, during 1960s again the California Department of Highways, they were developing similar specification which required measuring the viscosity of the binder.

But they did this on the short term residue or the aged residue. And this was done because they found that some of the binders when in the unaged condition they have the same consistency after aging, after undergoing mixing with the aggregates, few of these binders becomes or yields tender mixes. So, they do not compact properly under the rollers.

In order to differentiate this bitumens or to solve the problem of tender mixes they found it more logical that bitumen should be graded after undergoing the short term aging because only after short term aging this is used in the field and this will also ensure that asphalt binders after mixing they will behave similarly during the construction process.

In the viscosity grading several viscosity grades were defined by the ASTM standard and the AASHTO standard. So, this is AC 2.5, AC 5 and we have grades up to AC 40. So, this 2.5 AC 2.5 or AC 5 what does it mean? AC 2.5 indicates that the viscosity in poises at 60 degree Celsius will be 2.5 into 10 is to power 3 which is 250 poises at 60 degree Celsius.

Similarly, for example, AC 40 means that the viscosity will be 4000 plus minus something of or if this is a minimum or a one side specification it can be minimum 4000 poises at 60 degree Celsius. In addition, in this grading system in addition to the viscosity of the binder there are several other tests which are conducted or which were conducted such as penetration at 25 degree Celsius.

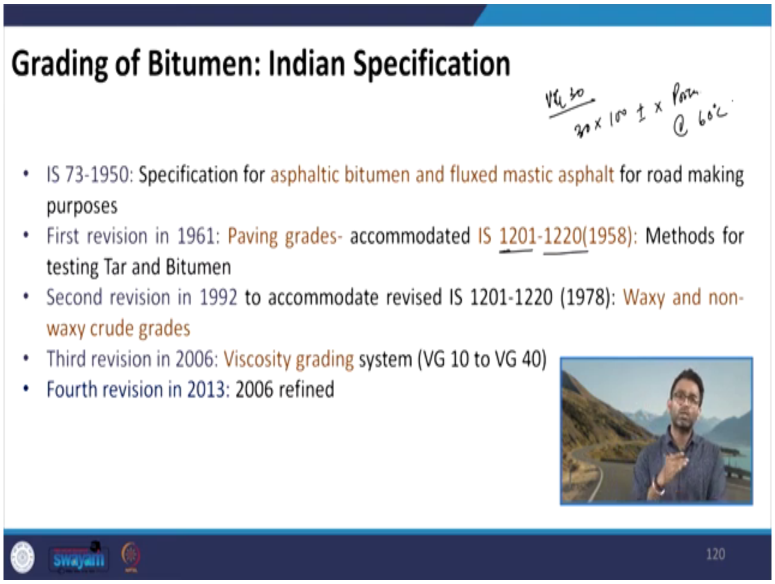
So, this can control the consistency at the intermediate temperature range. 60 degree Celsius can control the consistency at the average maximum temperature range, whereas viscosity at 135 degree Celsius will control the consistency at higher temperatures. So, since three temperatures are used to control the consistency we have more control over the temperature susceptibility of different bitumen samples.

Additionally safety test which is the, we have also learned about the Cleveland open cup apparatus where flash and fire point test is done. So, this test was also included and they also had a provision of doing the ductility test on short term aged binder at 25 degree Celsius. So, this were the requirements of the viscosity grading system. So, this figure it shows that how different temperature ranges are controlled here.

Different temperature ranges talking about the average service temperature, mixing compaction temperature and hot summers temperatures. Talking about the advantages and disadvantages of the viscosity test if we talk about the advantages viscosity test measures one of the fundamental properties. It can control the rutting resistance during hot summers.

Since consistency is measured at three temperatures we have more control over the temperature susceptibility and if we talk about the disadvantages one disadvantage is which may not be truly a disadvantage, but yes, in comparison to the penetration test the viscosity apparatus is more costly. And using the viscosity value we are not able to predict or understand about the intermediate and low temperature properties of the bitumen sample.

(Refer Slide Time: 12:17)



Since we have talked about the development or of the penetration grade and the viscosity grade let us see that how and when in India we adopted different specification. So, the first specification for grading of bitumen it came in 1950 which was titled as specification for asphaltic bitumen and fluxed mastic asphalt for road making purposes.

Later on they removed the criteria for fluxed mastic so that only paving grade can be considered. So, this first revision included only the paving grade bitumen and it also accommodated parallelly the test methods on the bitumens, different tests which are required to be done on bitumen and this test can be done using the specification IS 12012-1220 which was developed in 1958. So, this is methods for testing tar and bitumen.

In the second revision which came in 1992 few changes were made because IS 12012-1220 which was initially developed in 1958 also underwent some revision in 1978. So, in order to incorporate those revised standards the standard of grading the bitumen was also revised. And during those times, because the process in the refinery were not highly controlled as we have today. So, there were waxy and non-waxy crude bitumens.

So, it was found that bitumen with heavy high wax content at low temperatures they are more susceptible to thermal cracking because they become very stiff and at high temperatures they become excessively soft. Though these different bitumens the non-waxy and waxy bitumens can have the same consistency at intermediate temperature, but at very low temperature and very high temperature they showed very very different behaviors.

So, that is why two different tables were produced which I will be showing you in the next slide to grade the bitumen under the waxy and non-waxy crude grades. And this specification up to 1992 was based on the penetration value. So, we adopted the penetration grade which was similar to the penetration grade developed in US.

The third revision came very late around 2006. Here we started using the viscosity grading system and in India we define the viscosity grading system or the viscosity grade as VGX where VG denote the viscosity grade and X is a number again which represents the viscosity of the binder at 60 degree Celsius similar to the AC grades which we have talked about in the previous slide.

So, here for example, if you talk about VG30, so this is a binder whose viscosity is $30 \times (100 \pm x)$ at 60 degree Celsius. This value of x it will change from grade to grade which I will show you in the subsequent slides. Further the 2006 specification was refined in 2013 with some additional provisions which we will see the table and we will try to see that - what was the major difference in the specification given in 2006 and 2013?

(Refer Slide Time: 15:49)

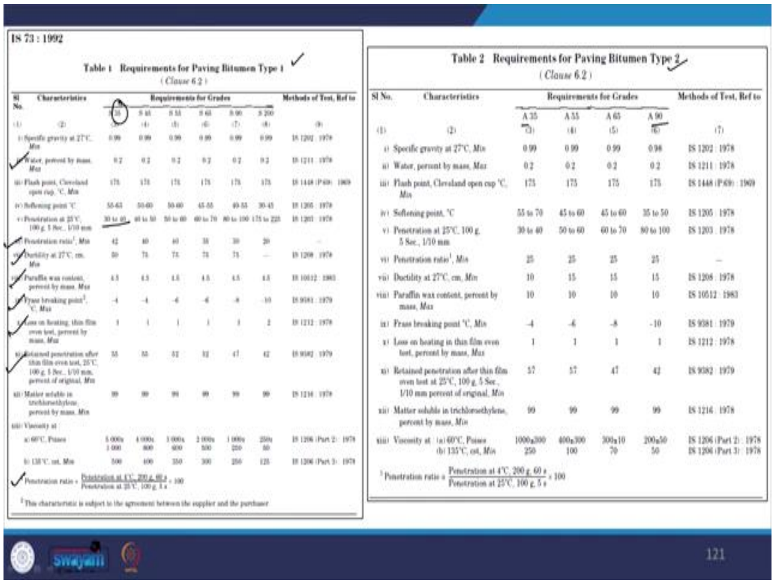

IS 73 : 1992

Table 1 Requirements for Paving Bitumen Type 1
(Clause 6.2)

Sl No.	Characteristics	S 35	S 45	S 55	S 65	S 90	S 200	Methods of Test, Ref to
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
i)	Specific gravity at 27°C, Min	0.99	0.99	0.99	0.99	0.99	0.99	IS 1202 : 1978
ii)	Water, percent by mass, Max	0.2	0.2	0.2	0.2	0.2	0.2	IS 1211 : 1978
iii)	Flash point, Cleveland open cup, °C, Min	175	175	175	175	175	175	IS 1448 (P:69) : 1969
iv)	Softening point °C	55-63	50-60	50-60	45-55	40-55	30-45	IS 1205 : 1978
v)	Penetration at 25°C, 100 g, 5 Sec., 1/10 mm	30 to 40	40 to 50	50 to 60	60 to 70	80 to 100	175 to 225	IS 1203 : 1978
vi)	Penetration ratio[1], Min	42	40	40	35	30	20	—
vii)	Ductility at 27°C, cm, Min	50	75	75	75	75	—	IS 1208 : 1978
viii)	Paraffin wax content, percent by mass, Max	4.5	4.5	4.5	4.5	4.5	4.5	IS 10512 : 1983
ix)	Fraas breaking point[1], °C, Max	-4	-4	-6	-6	-8	-10	IS 9381 : 1979
x)	Loss on heating, thin film oven test, percent by mass, Max	1	1	1	1	1	2	IS 1212 : 1978
xi)	Retained penetration after thin film oven test, 25°C, 100 g, 5 Sec., 1/10 mm, percent of original, Min	55	55	52	52	47	42	IS 9382 : 1979
xii)	Matter soluble in trichloroethylene, percent by mass, Min	99	99	99	99	99	99	IS 1216 : 1978
xiii)	Viscosity at							
	a) 60°C, Poises	5 000± 1 000	4 000± 800	3 000± 600	2 000± 500	1 000± 200	250± 50	IS 1206 (Part 2) : 1978
	b) 135°C, cst, Min	500	400	350	300	250	125	IS 1206 (Part 3) : 1978

Penetration ratio = $\frac{\text{Penetration at } 4^\circ C, 200 g, 60 s}{\text{Penetration at } 25^\circ C, 100 g, 5 s} \times 100$

[1] This characteristic is subject to the agreement between the supplier and the purchaser

Table 2 Requirements for Paving Bitumen Type 2
(Clause 6.2)

Sl No.	Characteristics	A 35	A 55	A 65	A 90	Methods of Test, Ref to
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	Specific gravity at 27°C, Min	0.99	0.99	0.99	0.98	IS 1202 : 1978
ii)	Water, percent by mass, Max	0.2	0.2	0.2	0.2	IS 1211 : 1978
iii)	Flash point, Cleveland open cup °C, Min	175	175	175	175	IS 1448 (P:69) : 1969
iv)	Softening point, °C	55 to 70	45 to 60	45 to 60	35 to 50	IS 1205 : 1978
v)	Penetration at 25°C, 100 g, 5 Sec., 1/10 mm	30 to 40	50 to 60	60 to 70	80 to 100	IS 1203 : 1978
vi)	Penetration ratio[1], Min	25	25	25	25	—
vii)	Ductility at 27°C, cm, Min	10	15	15	15	IS 1208 : 1978
viii)	Paraffin wax content, percent by mass, Max	10	10	10	10	IS 10512 : 1983
ix)	Fraas breaking point °C, Min	-4	-6	-8	-10	IS 9381 : 1979
x)	Loss on heating in thin film oven test, percent by mass, Max	1	1	1	1	IS 1212 : 1978
xi)	Retained penetration after thin film oven test at 25°C, 100 g, 5 Sec., 1/10 mm percent of original, Min	57	57	47	42	IS 9382 : 1979
xii)	Matter soluble in trichloroethylene, percent by mass, Min	99	99	99	99	IS 1216 : 1978
xiii)	Viscosity at (a) 60°C, Poises	1000±300	400±300	300±10	200±50	IS 1206 (Part 2) : 1978
	(b) 135°C, cst, Min	250	100	70	50	IS 1206 (Part 3) : 1978

[1] Penetration ratio = $\frac{\text{Penetration at } 4^\circ C, 200 g, 60 s}{\text{Penetration at } 25^\circ C, 100 g, 5 s} \times 100$

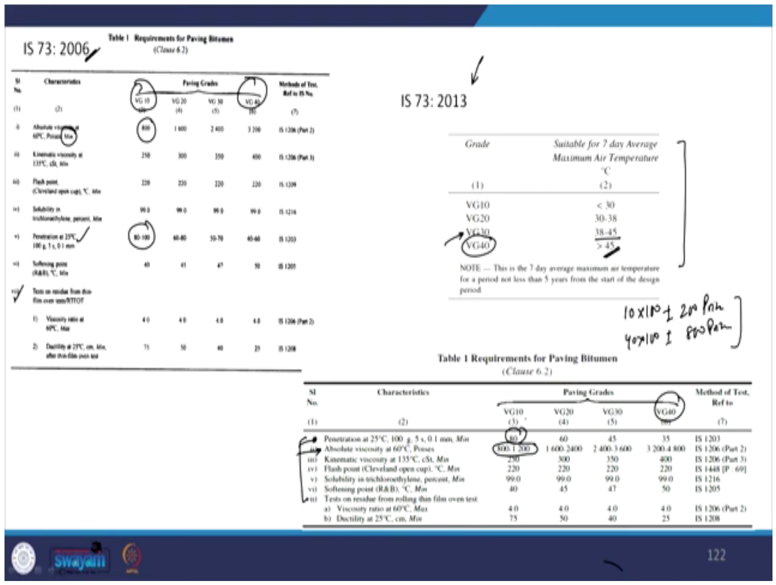
So, well this is just a snapshot taken from the code IS 73:1992 and you can see that you have two tables here for bitumen type 1 for waxy and non-waxy grades. And here one important point to note is that there are 13 different tests which are required to be done in order to grade the bitumen. And this was a penetration grade where 35 indicated the penetration, average penetration value you see, therefore, the penetration is between 30 to 40.

And similarly we have grades up to S200 whereas, in type 2 we have grades from A35 to A90. So, you can see that some of the interesting things to note down here is that during that time we used to do penetration ratio where penetration ratio was defined as the ratio of penetration at 4 degree Celsius to the ratio of penetration at 25 degree Celsius.

Why I am highlighting this is because today we no longer use the penetration value at 4 degree Celsius or we do not conduct the test. Paraffin wax content test again we do not do it today. Ductility test was done on unaged binder and today we do it on short term aged binder or thin film oven or RTFO aged binder.

Then that time we used to determine water percent by mass, we no longer do this test today. That time we used to carry out the low temperature test, I find this test to be important, but since we are in a tropical climate we do not no longer use this test in our specification now. Similarly retained penetration we no longer measure and we also do not measure the loss on heating. So, there are several tests which were done during that time and now the number of tests have reduced considerably.

(Refer Slide Time: 17:54)



So, this is again taken from the further revisions. So, 2006 you can see, so here we started using the viscosity grading system and therefore, you see that we have like VG10 to VG40 here. Before that let us see the requirement of the number of test, you can see only 7 tests are required in comparison to the previous revision.

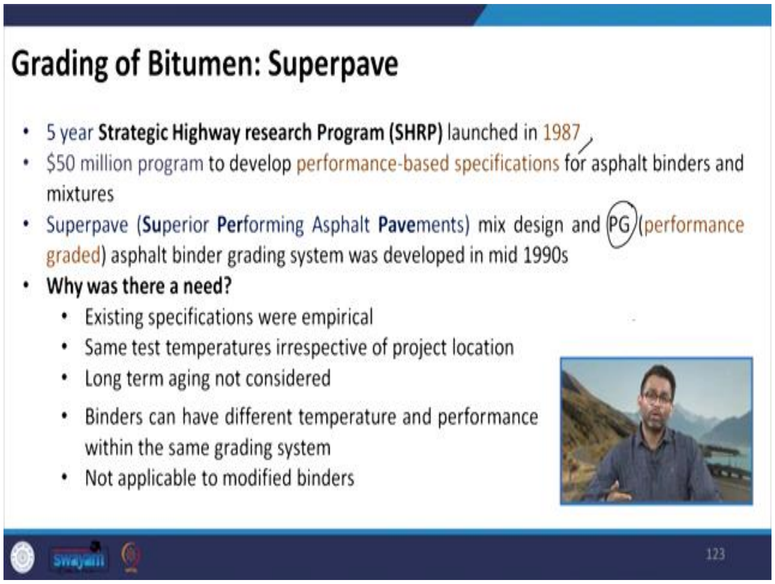
In 2013 they gave additionally this table where based on the 7 day average maximum air temperature of the location where we are doing the construction you can choose the appropriate binder. For example, if 7 day average maximum air temperature is more than 45 degree Celsius then you have to use VG40, if it is between 38 to 45 VG30 and so on.

So, this is something which was new and again if you see we have only 7 tests to be done as per the 2013 revision, but let us compare the 2006 and 2013 because they both are the viscosity grading system. In 2006 if you see the requirement of absolute viscosity is based on the minimum criteria. So, VG10 means that the viscosity minimum should be 800 poises at 60 degree Celsius, whereas here the requirement of absolute viscosity is provided in a range.

So, this is, if it is VG10 so as I said $10 \times 100 \pm 200$ poises, if it is VG40 $40 \times 100 \pm 800$ poises. So, in this way the viscosity is given in a range rather than a minimum value. Similarly the penetration value at 25 degree Celsius is given in a range in the 2006 version whereas, here if you see that the penetration is given as a minimum criteria.

Now, I really recommend this and if you can do all these experiments it might be enough to get the best results. Well, these are the two prominent changes which were done in the 2013 revision in comparison to the 2006 revision. Having discussed about the penetration grade and viscosity grading of bitumen, let us now talk about the superpave grading system and which uses the rheological parameters in contrast to the physical properties such as penetration and viscosity to classify or grade different bitumen samples.

(Refer Slide Time: 20:31)



The superpave criteria was developed through the strategic highway research program which was a 5 year research program and launched in 1987. This was actually a 150 million dollar project, but out of the entire amount 50 million dollars were used or were invested to develop the performance based specification for asphalt binders.

And mixtures which resulted in the development of superpave mix design criteria where superpave stands for superior performing asphalt pavements and it also resulted in the development of the performance graded asphalt binder grading system which we also call as the PG grading system. And this was developed somewhere around mid-1990s. Now the important question is that why was there a need to develop the superpave grading system?

What were the issues in the viscosity graded system due to which the researchers started working towards you know another grading system which is the superpave grading system? One of the main reasons where that the existing specifications were mostly empirical in nature. Most of the consistency tests which were required to be done on bitumen to classify them to assess the consistency or the behavior were empirical in nature.

Another problem was irrespective of the location where we are going to use this binder. Let us say if you talk about India, we can have a variety of temperature conditions. In the extreme northern side we can have during the summers we can have very very high temperatures and the pavement temperature can be as high as 70 degree Celsius.

On the other hand in locations extreme locations such as north eastern regions or Himalayan regions we have extremely low temperatures. Since bitumen is a viscoelastic material by now we understand that the response of the bitumen to the loading condition will definitely be a function of temperature and loading condition or the frequency of load.

So, therefore, doing or carrying out tests on bitumen for its classification based on a single temperature or only one temperature seems to be irrational and this was also one of the reason which was highlighted, which prompted the researchers to work on a better grading system. Earlier we used to carry out the test at the same test temperatures irrespective of the project locations.

If we see the specifications of the viscosity grading system and penetration grading system you will see that there was a requirement to do the ductility test after short term aging of the binder which or viscosity ratio after short term aging of the binder which means that only short term aging of the binder was done to assess the durability characteristics.

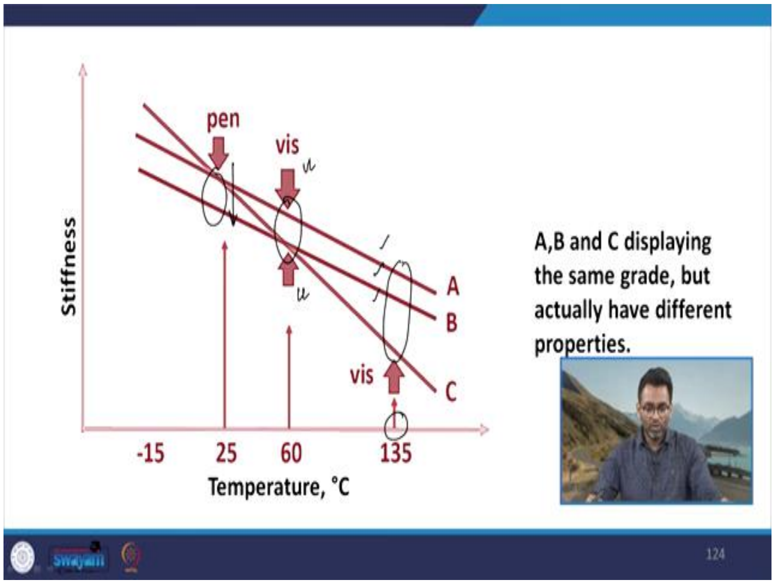
However, we have discussed in detail that durability is also a function of the long term behavior of the binder when the binder is exposed to the average temperature conditions during its entire service life which is just after opening to the traffic to the end of its service life it undergoes a lot of temperature changes.

However, long term aging was not considered in the previous specifications. It was also observed in the, that in the viscosity grading system which was the earlier specification binders can have different temperatures susceptibility and different performance characteristic even though they fall under the same grading system with respect to the viscosity grading system.

This I will show you in the next slide through a graph. Another point which was noted was that that the previous specifications were mostly applicable for unmodified binder. For example, if you talk about the experimentation we have discussed that if polymer modified binders or crumb rubber modified binders, they are used in a capillary tube it can choke the tube, it can give you unrealistic results.

So, these issues were identified which required, which necessitated to develop better grading system and which resulted basically in the superpave grading system.

(Refer Slide Time: 25:11)



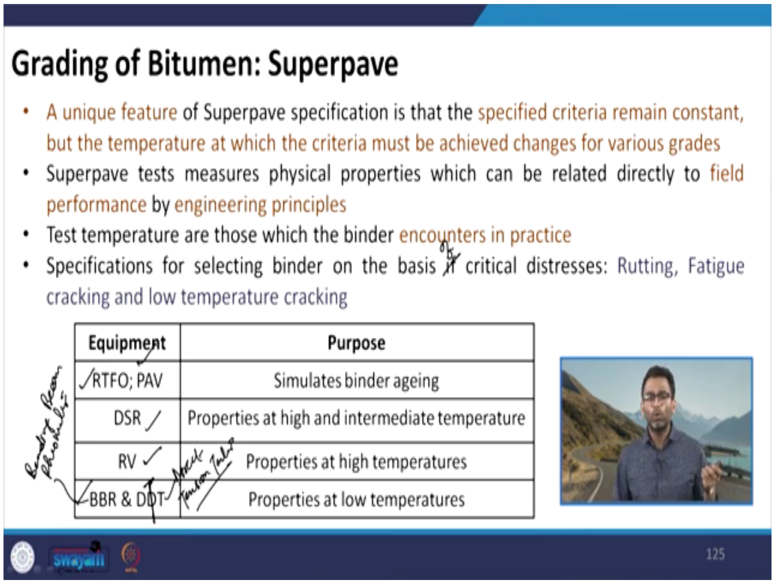
This graph shows that you can have three binders and let us see what are the specifications here? Let us say we have the specification for a range of viscosity at 60 degree Celsius. So, you see between A, B and C they all have the same range of stiffness at 60 degree Celsius and let us say this is the upper limit and this is the lower limit as per the specification. The viscosity grading system requires a minimum penetration value at 25 degree Celsius.

So, if this is 25 degree Celsius then all these three bitumens has the minimum penetration value at 25 degree Celsius. Similarly at high temperature or 135 degree Celsius there is a requirement that there should be a minimum viscosity or you can say maximum viscosity of the bitumen sample for pumping criteria. So, here all the three bitumens satisfy that criteria.

If we are given this three bitumen A, B and C and we are asked to grade this bitumen we will actually end up grading this bitumen under the same grade. However, you can see that the variation of stiffness with respect to temperature is very much different for all the three binders which means when these binders are exposed to actual field conditions at different locations and these locations can have very different rate of change of temperature with time.

So, this bitumen will behave completely differently. So, this is again one of the reason which required the development of a better specification system for bitumen.

(Refer Slide Time: 26:54)



So, one of the unique feature of superpave grading system which we will be discussing is that the specified criteria it remains constant, but the temperature at which the criteria must be achieved it changes for various grades. Now, let us again try to understand this statement, it might appear to be confusing at the first time. So, we will try to understand in reference to what we do in the usual specification.

So, in the usual specification as we have discussed if it is a viscosity grading system we will carry out the viscosity graded 60 degree Celsius and we will report the value. So, this value is variable depends on the consistency of bitumen, but the temperature at which I am carrying out the test is constant 60 degree Celsius irrespective of wherever I am going to use this bitumen.

Now, in the superpave grading system what they have done that the specified criteria remains constant. So, here with reference to viscosity I will say that the value of viscosity will be constant, but the temperature at which this value of viscosity is reached by different bitumens or the temperature at which this criteria must be achieved will vary from grade to grade, from project to project.

So, let us say we have identified that if a bitumen has a viscosity of 4000 poises, let us say. So, if a bitumen has a minimum viscosity of 4000 poises this can give you a satisfactory performance with respect to rutting at locations where the temperature is 60 degree Celsius, let us say. So, that means, that I am fixing this 4000 poises.

Now I will select the bitumen for this location where the average pavement temperature, maximum pavement temperature is 60 degree Celsius ensuring that the viscosity of the bitumen which I am going to use is minimum 4000 poises. So, this is what is different in the superpave specification that the parameter will, the value of the parameter will remain constant, but the temperature at which this parameter should be met or will be met by a binder will change from grade to grade.

In superpave we are measuring parameters or properties of the binder which can directly be related to the field performance and through engineering principles which means we are here testing more fundamental properties of the binder and these are not empirical in nature. We test the binders at a range of temperature which means that we are not restricting our test for one temperature for a particular test.

A single test can be run at different temperatures and these test temperatures are chosen such that or these temperatures will tell us about the range of temperature which the bitumen will encounter in the actual practice or in service. Specifications for selecting the binder on the basis of critical distress. So, here the target is to select a binder, so that this binder is able to resist the critical distresses.

And this critical distresses are permanent deformation or rutting which occurs at higher temperature or higher average maximum temperature of the pavement in service, fatigue cracking which takes place usually at intermediate temperature ranges and low temperature cracking which is a non-load associated cracking or you can say thermal cracking.

So, since these are the three critical distresses we are going to test the binder to see if the binder can resist these three failure criteria at the location where we are going to use it. Here in this presentation we are not going to discuss again about the test process, all the tests we have already covered in our previous presentation, but let us see that in superpave grading criteria what are the tests which are required to be done.

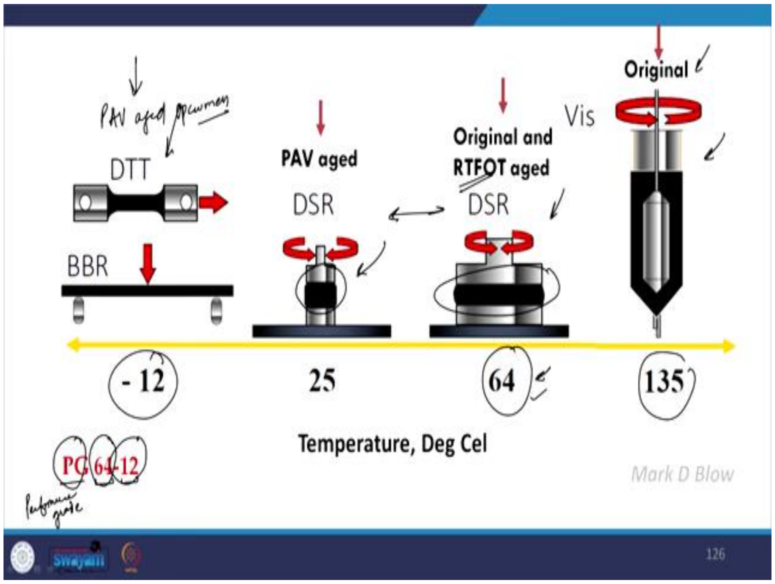
So, here we will use RTFO and PAV, by now we understand what an RTFO is and what PAV is. So, they are used to simulate the aging of the binder and since they are used to simulate the aging of the binder they basically measure or are used to assess the resistance of the binder to aging or to assess the durability characteristics of the binder during construction and also in service life.

So, if we are interested during construction we will be looking at the short term aged samples, if you are interested in in service condition we will be looking at the PAV aged samples. Then we use dynamic shear rheometer, dynamic shear rheometer will measure the properties at high and intermediate temperature, not at extremely low temperature, which means DSR is essentially used to assess the rutting and fatigue characteristics of the bitumen.

Then we have rotational viscometer which is usually done on samples in unaged condition and here we are assessing the properties of the binder at higher temperatures which is used to assess the handling and pumping characteristics of the bitumen in the mixing plant. Then we have bending beam rheometer, this is maybe a new term for us now.

This should be direct tension tester so, this is direct tension tester and they are used to assess the performance at lower temperature and to evaluate the resistance of the bitumen to thermal cracking.

(Refer Slide Time: 33:01)



This is a typical grade, of course, we will be discussing about how this grading system is actually done. So, the grade is written as PG one number another number. So, PG indicates a performance grade, this first term it represents the 7 day average maximum temperature of the location or of the pavement where we are going to do the construction using this bitumen and -12 it represents the lowest temperature of the location where we are going to do the construction or which place or which project we are going to select the bitumen sample.

And this slide it shows you the range of temperatures which is covered during the DSR testing, this is just a revision, at higher temperature we are doing rotational viscometer test to assess the pumping and handling characteristics and this is done on the original binder or the unaged bitumen. Then after doing the RTFOT, after doing the short term aging and also on the unaged condition we will do DSR and this is typically done at the 7 day average maximum temperature of the pavement.

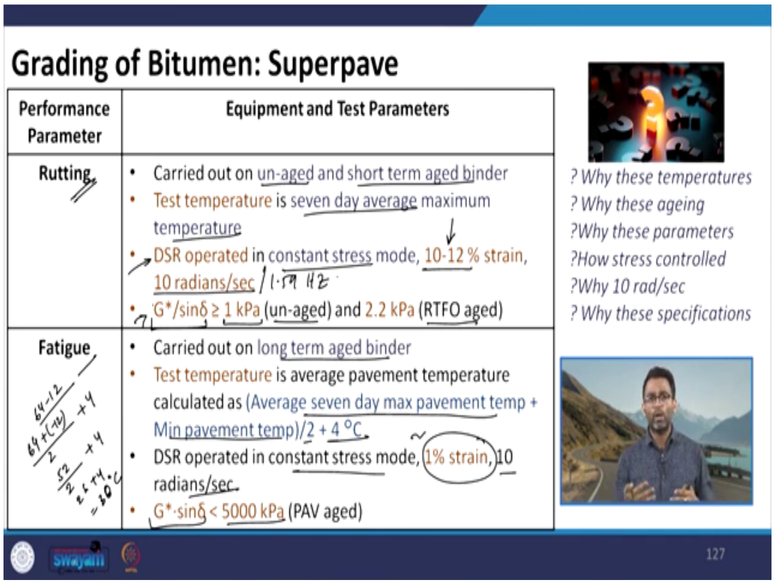
So, for example, this is 64 degree Celsius here. So, since the project requirement is 64 degree Celsius we are doing the testing at 64 degree Celsius and we will ensure that the bitumen samples which are tested in unaged condition at 64 degree Celsius and RTFOT aged condition at 64 degree Celsius are able to satisfy some standard criteria. We will again do the DSR test at 25 degree Celsius.

But here we will be using the long term aged specimen because we are trying to assess the fatigue cracking related characteristics and fatigue cracking is a phenomenon which occurs when the binder has become stiff and also at the intermediate temperature range. So, binder will become stiff only after long term aging. So, we are using the PAV aged samples here.

And if you remember from our discussion on rheology that in DSR we have different spindle geometries depending on the stiffness of the binder. If the stiffness of the binder is high we use 8 mm dia and 2 mm gap. If the stiffness of the bitumen is less we use 25 mm spindle with 1 mm gap. So, therefore, the geometry is different, but the test is DSR.

And at lower temperature we are going to assess the low temperature characteristics using direct tension tester and bending beam rheometer and just to tell you that here also we will use PAV aged specimen because low temperature cracking also depends on the stiffness of the bitumen. So, the binder will be more susceptible when the bitumen is highly stiff and therefore, we are taking the PAV aged specimens to do the testing here.

(Refer Slide Time: 36:23)



Now let us talk about some of the parameters which are used during the superpave grading system. So, let us take them one by one. So, for example, let us look at how the testing on or how the rutting parameter is controlled. So, here for the rutting parameter the test is carried out as we have discussed in the previous slide in unaged and short term aged condition. At which temperature you will do the test?

You will do the test at 7 day average maximum temperature of the location for which you are selecting the bitumen. Here we are going to use dynamic shear rheometer which will be operated in constant stress mode and we have to ensure that the binder is or we are applying a stress or strain within the linear viscoelastic region.

So, here as per the specification the strain should be in the range of 10 to 12 percent and we do the test at a fixed frequency of 10 radians per second or 1.59 hertz. Then the specification or the criteria is that the value of G*/sinδ if you again remember we have discussed that G*/sinδ represents the rutting resistance of the viscoelastic material when it is tested in the DSR this represents the amount of dissipated energy.

So, this should be greater than 1 kPa if the bitumen is in unaged condition and 2.2 kPa when the bitumen is in short term aged condition or RTFO aged condition. So, this is the entire requirement for rutting characteristics. Now talking about the fatigue characteristics this is carried out on long term aged binder which means PAV aged samples. What is the test temperature?

This is the average pavement temperature which is calculated as $\frac{\text{average 7 day maximum pavement temperature+ minimum pavement temperature}}{2} + 4$ degree celsius. And for example, if it is let us say in the previous slide it was 64-12. So, if 64-12 is the grade we are targeting for then the fatigue will be analyzed or fatigue characteristics will be measured at a temperature of $\frac{64+(-12)}{2} + 4$.

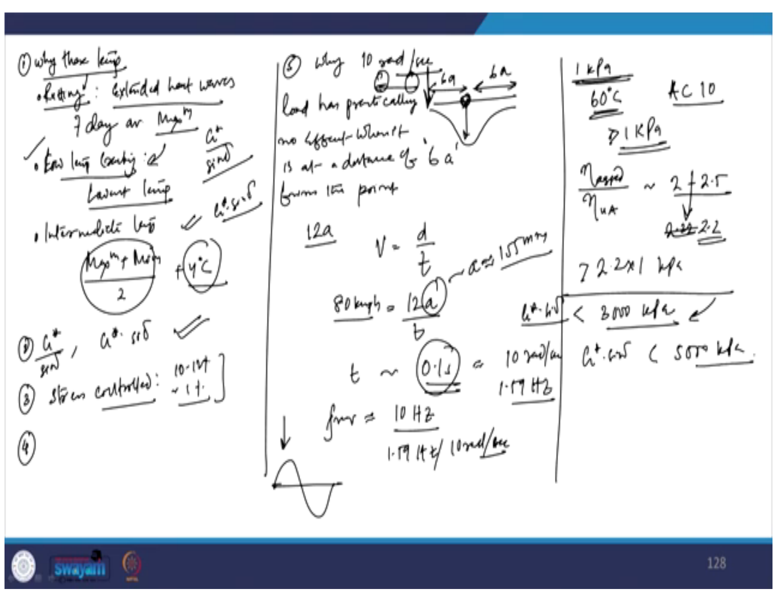
So, this is $\frac{52}{2} + 4$. So, this is 26 + 4, this is 30 degree Celsius. So, this will be chosen as the test temperature. Since again this is the PG grading system, the DSR is operated in a constant stress mode and here at low temperature for intermediate or the fatigue characteristic the strain should be kept low about 1 percent strain here it is 10 to 12 percent strain and here also the test is done at 10 radians per second.

And the criteria is that G*sinδ which we discussed in the previous presentation is a representation of fatigue characteristics of the bitumen should be less than 5000 kPa because lower is the value of G*sinδ more will be the resistance to fatigue cracking. So there is a maximum limit here, whereas for G*/sinδ it is a minimum limit because higher is the value of G*/sinδ more will be the resistance to rutting.

Now, you must be wondering that that what we have discussed now and there can be many questions which fundamentally we have to answer before we accept that, yes, this is the right way to do it. These questions can be that why these temperatures are chosen, why these aging conditions are chosen, why these parameters have been considered.

How the DSR is stress controlled when we are saying that we are targeting for the… we are having some target strain values? Why 10 radians per second is used and not any other frequency to do the test? And why these specifications have been laid down as 1 kPa, 2.2 kPa or 5000 kPa. So, let us answer these questions one by one.

(Refer Slide Time: 41:03)



The first question was that why these temperatures. Let us try to understand it in this way that rutting is a phenomena which will occur during the extended heat waves, during the extended heat waves in hot summer and it will, it is not a phenomena which will occur only at a single temperature. So, the binder will become soft gradually, so therefore, the pavement has to be exposed to this extended heat wave or extended high temperature for some period of time.

And therefore, the 7 day average maximum temperature has been chosen and not only one single because one single maximum temperature can be too conservative and the 7 day average maximum temperature while developing in US, they assessed the 7 day average maximum temperature based on the weather data of about 20 years.

So, 20 years weather data was taken to define several average maximum temperature ranges or values at which the specifications have been basically developed. Talking about the low temperature cracking, this is basically carried out only at the lowest temperature not any average low temperature. So, why lowest temperature is chosen because let us understand how low temperature cracking will occur.

When the temperature will reduce the top layer or the HMA will try to contract and therefore, a tensile stress will be developed between the HMA layer and the base course. If this stress which is developed between these two layers, it exceeds the tensile strength of the HMA layer, the HMA layer will crack. So, which means that even a single low temperature is sufficient to induce the cracking or the thermal cracking in the mixture.

So, of course, there are also chances that cycles of low temperature, if let us say the low temperature is not as low to exceed the tensile strength of the HMA, this will not crack. So, at that time we will see that how many cycles are required of low temperature are required to induce the thermal cracking in the HMA mixture.

But if let us say there is a drop in temperature to such a level that only one cycle is sufficient to induce thermal cracking in the pavement, so that temperature also becomes a critical concern and therefore, low temperature cracking is taken. Talking about the intermediate temperature, I showed you a formula. It is $\frac{\text{maximum}+\text{minimum}}{2} + 4$ degree Celsius.

Now this is something which was which came into specification through experience. So, during the SHRP program there was a task group which was involved in developing this specification and that time Dr. Dave Anderson he found that the average temperatures is not only the average of the maximum and minimum, but is little higher than this average and that little higher is around 4 degree Celsius.

Therefore, they chose or added this 4 degree Celsius to the average to calculate the temperature at which the fatigue cracking should be estimated or should be assessed. So, this is the reason why these temperatures are chosen. Also if you want to understand or if you want to understand about the aging conditions at which these criteria have been developed.

So, you see rutting in the hot mix asphalt will typically occur during the first few months or let us say a year of construction, because as time progresses the mix will become stiffer. As mix becomes stiffer the resistance to rutting increases. So, therefore, we will, if there is a problem in the HMA mixture and not beneath or not in any other layers of the pavement construction…

So, if there is a problem in the bituminous mixture typically the occurrence of crack or occurrence of rutting, it will be during the first few months of or after the first few months of construction. Therefore, and during this period the binder is exposed only to short term aging or maybe the binder initially is in the unaged condition.

Therefore, the unaged binder and RTFO aged binder are used to see the value of G*/sinδ. Whereas, the fatigue cracking is a phenomenon which will occur at intermediate temperature range and on stiff binders. So, binder becomes stiff only after long term aging. So, therefore, assessing G*sinδ. we are using the long term aged specimen and similarly for low temperature cracking also stiffness is one of the critical parameter and therefore, PAV aged samples are used.

Talking about the parameters why G*/sinδ. and why G*sinδ., this we have already covered in our previous presentation. So, I am not discussing it here that how they are related to rutting and fatigue respectively. Talking about the stress controlled testing. So, DSR for PG grading is done under a stress control mode.

So, what is done here in order to achieve the target range of 10 to 12 percent or 1 percent the DSR will do an initial adjustment to the torque. So, it will set the stress levels at which this strain can be achieved and it will maintain that stress level and therefore, this is a stress control test. Now, I will just do it here. Now the question is why 10 radians per second. So, I will give you two form of explanations here one form says that if you see one point and the stress in this particular point, so studies have shown that load has practically no effect when it is at a distance of 6a from the point.

So, if this is at a distance of 6a and this is our point of concern, so beyond this point, if the load is here this will have no effect, only when the load comes here which is at a distance of 6a from the point a deflection ball will start appearing for this particular point. So, similarly there also this side also it should be 6 a. So, the total deflection ball becomes equal to 12 a.

So, if we say that $V = \frac{D}{T}$ where D is 12a and V let us say we are trying to see a condition which is 80 kmph for which is an average speed of the vehicle in a highway and we are trying to find T this will be around 0.1 second if you do the calculation here you can assume that a is approximately equal to 155 mm. So, you will get that T is equal to 0.1 second, but this tells us that the frequency should be actually 10 hertz.

So, the question is that why SHRP took 1.59 hertz and or 10 radians per second instead of 10 hertz and not 1.59 hertz. So, well, I could not find any specific explanation to this in different literatures, but what few literature states that since we are using a sinusoidal loading in the DSR. So, under the sinusoidal loading 0.1 second is approximately equal to 10 radians per second or 1.59 hertz.

So, this can be, but I am not sure about the derivation at this point that how sinusoidal loading will produce an equivalent frequency of, if the time is 0.1 second how will it will produce a frequency of 10 radians per second, but this is the typical explanation in few of the literatures as cited. Now, talking about the specifications. So, let us talk about 1 kilo Pascal specification.

So, as I told you that for the development of the SHRP specification a special task group was formed by FHWA and the specifications limit were decided based on consensus by the expert task group. So, it is very interesting to note that even this specification has been derived from the viscosity grading system. They found that in US if the, for moderate climates when the average pavement temperature is 60 degree Celsius typically an AC 10 bitumen is used.

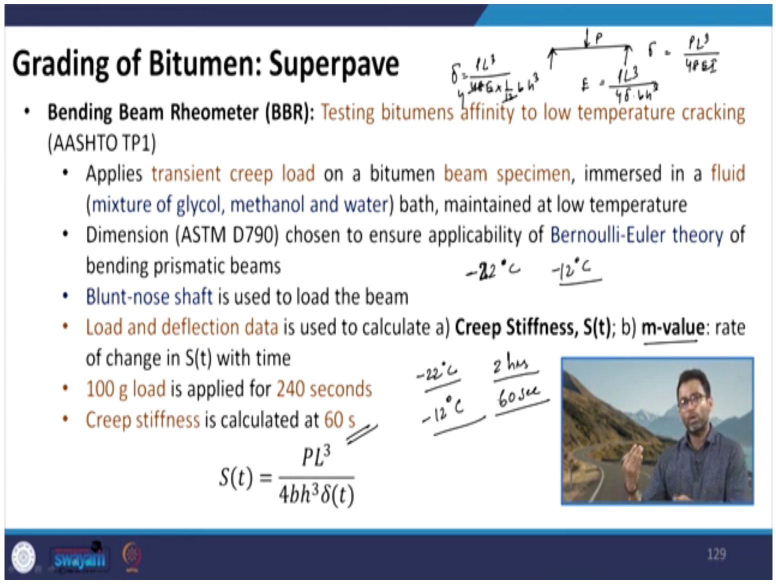
So, several AC 10 bitumens which gave satisfactory performance in US, when they were tested in the DSR at 10 radians per second to evaluate the $G^*/\sin\delta$. value. So, it was found that the value is around 1 kPa or greater than 1 kPa. So, therefore, 1 kPa was developed as the specification. Now talking about the short term aging condition it is 2.2 kPa. So, for this what they did, they evaluated the aging index of these binders.

So, aging index was calculated as ratio of viscosity of aged and unaged binder and they found that the ratio of or the viscosity ratio for these binders, they typically range from around 2 to 2.5. So, they finally took an average value of 2.2 and therefore, the specification of 2.2 into 1 kPa came in which is 2.2 kPa. So, this was the reasons for selecting 1 kPa and 2.2 kPa for $G^*/\sin\delta$..

Talking about the fatigue racking again for these binders which were found to be satisfactory initially they proposed a value of 3000 kPa as the standard, initially. So, they say that the value should be less, $G^*\sin\delta$ should be less than 3000 kPa. So, when they gave this specification many of the binders which were further tested they failed to meet this conservative specification.

Later on they saw that what should be the value at which at least 85 percent of the sample should pass. So, they found at $G^*\sin\delta$. if the limit is set to 5000 kPa should be satisfactory. So, 5000 kPa was thus put as the specification.

(Refer Slide Time: 52:58)



Moving further, well, so, this was about the high temperature and intermediate temperature performance criteria as per superpave grading system. Now, let us talk about the low temperature criteria. So, before I show you any table with these specifications let us try to understand the test methods. So, we have two different tests here which are required to be done one is bending beam rheometer and the other is direct tension tester.

So, in the bending beam rheometer what we are trying to do, we are trying to test the affinity of the bitumen sample to low temperature cracking. What we do in the bending beam rheometer test? We apply a transient creep load on a bitumen beam specimen. So, there is a beam specimen of the bitumen which is prepared and this beam specimen it is immersed in a fluid. Now, since we are trying to do the test at a very low temperature, definitely water bath cannot be used.

So, we use a mixture of chemicals such as glycol, methanol and water. So, we make this mixture or we make this fluid ready, we set the temperature at the temperature at which we are interested to do the test and we will just put this beam specimen inside the bath where the test has to be done and it is maintained at that particular low temperature.

Now, the dimension of this beam which is taken, because this is a very small beam which is taken. This is chosen to ensure that the Bernoulli-Euler theory of bending prismatic beams can be applied while doing the calculations. So, as per this theory it states that if the section is plane before deformation it will remain plane after deformation and perpendicular after deformation.

So, based or to satisfy this criteria the dimension of the beam specimen is chosen, then we will use a blunt nose shaft to load this specimen. So, this is like a three point bending test, we are holding the specimen like this and at the center we are applying the load using a blunt nose shaft. And once we are applying a load of course, you can imagine that this, if this is a beam it will start deflect.

It will deflect, if you keep on, if it is a transient load which means it is increasing with time, so, definitely the deflection will also keep on increasing with time. So, load versus deflection data is continuously monitored in the test and using this data we determine two parameters, one is the creep stiffness.

So, if you remember from the simple concept of mechanics of solids that if this is a three point bending test, if this is the load P, then a $\delta = \frac{PL^3}{48EI}$, I mean this is the conventional formula. So, here $\delta = \frac{PL^3}{48EI}$, E is the stiffness or the elastic modulus you can say, $I = \frac{1}{12}bh^3$ because this is a rectangular specimen. So, here this becomes 4.

So, if I am interested to find E this becomes as $E = \frac{PL^3}{4\,\delta bh^3}$. So, this formula is used to calculate the creep stiffness of the beam specimen and also since we are getting the or we are monitoring the variation of deflection with time we try to see that how the slope or the rate of change of stiffness with time is monitored based on the deflection data and we define a slope at a particular point which is considered as the m value.

So, let us see that at what point we are finding it out. So, here we are using a 100 gram load, again here why 100 gram load was selected to ensure that the response of the sample remains in the linear viscoelastic regime. So, therefore, a 100 gram of load was chosen and this load is applied for 240 seconds or you can say 4 minutes and the creep stiffness is calculated at 60 seconds.

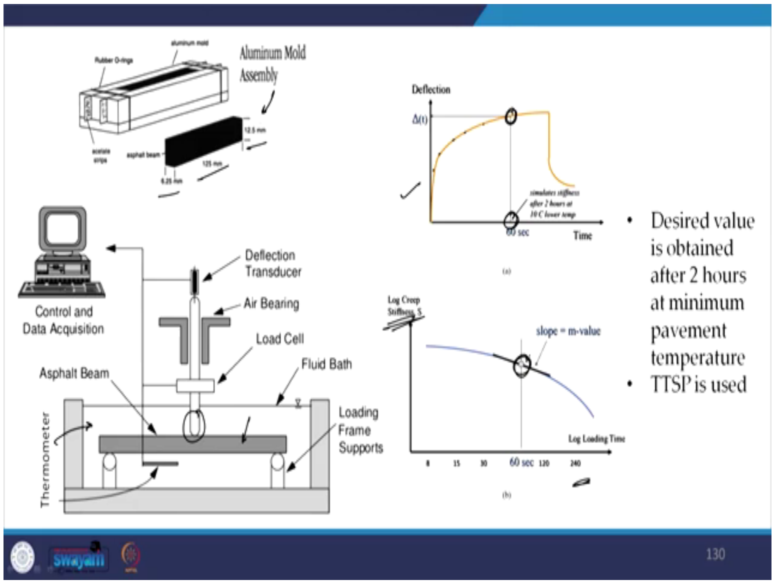
Now, when initially they wanted to correlate the thermal cracking with the stiffness value. So, what literature says that you have to carry out the test for a very long period of time and the value at which you are targeting is after 2 hours, after 2 hours, but you can understand that 2 hours can be a very long duration for the test to be done.

So, in order to reduce the timing of the test what they did they use the time temperature superposition principle and if the target temperature is minus 22 degree Celsius you will do actually the test at 10 degree Celsius higher than this temperature. So, you will actually do the test at minus 12 degree Celsius. So, how time temperature superposition is used? So, you see you are interested at minus 22 degree Celsius and you are interested at the value after 2 hours.

So, if you want to get the response at lower loading time, then of course, you have to increase the temperature which means the response of a viscoelastic material at low temperature and higher loading time is equal to the stiffness of the viscoelastic material at higher temperature and lower loading time. So, I hope you can understand or correlate this with the concepts of time temperature superposition principle which we have learned in the previous classes.

So, this was used, so therefore, this test is done usually at 10 degree Celsius higher temperature than the anticipated lowest temperature and this formula as we discussed is used to calculate the creep stiffness.

(Refer Slide Time: 59:05)



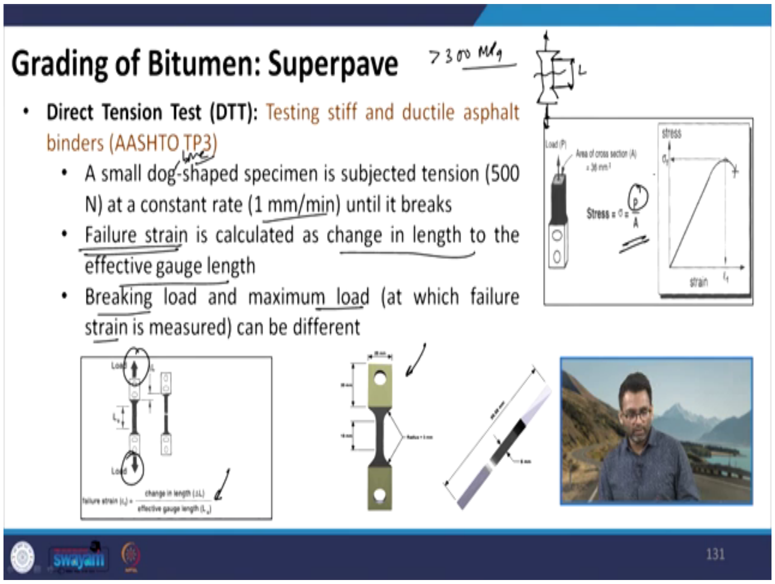
So, these are some pictures of the test experimental process. So, you see you have a beam specimen of a specified dimension 6.25 into 125 into 12.5 mm. We have a control and data acquisition system. This is the bath which is maintained at that particular temperature at which we are doing the test. This is the beam specimen, this is the notch using which we are applying the load and then we are monitoring the deflection versus time data.

And we are basically taking the deflection value at 60 second and using it in the formula which we have discussed to calculate the stiffness. And since we are also monitoring we can, at using deflection at different points we can find out the stiffness and we can plot the creep stiffness versus time and at 60 degree Celsius we see what is the slope here.

So, try to understand it in this way that if I want my bitumen to be resistant to thermal cracking, what should I aim for? I should aim for a lower value of creep stiffness because higher is the stiffness more will be the affinity to cracking. Here during the test what is happening that the bitumen sample is being loaded and it is deforming, is not it? So, there is an energy dissipation which is occurring and there is a relaxation which is occurring.

So, the faster my sample will relax, the higher will be its resistance to the loss of energy. So, therefore, I want the M value to be as high as possible because higher is the M value it will indicate that the change in stiffness is higher which means it is able to relax at a much faster rate. So, we will see the specification probably in the next slide. Before that let us discuss about our next test which is the direct tension test.

(Refer Slide Time: 61:06)



So, here what was found that in the BBR test you see if the stiffness of the bitumen is high which means it will have more chances to thermal cracking. And of course, the strain tolerance of this binder will be low because it will crack, but for some of the binders such as polymer modified binders it may happen that even at low temperatures the binder has very high stiffness, but also has very high strain tolerance.

Which means there will be much higher resistance to thermal cracking for these bitumens. Therefore, an alternate method that is direct tension test was developed to assess these stiff binders which are ductile in nature even at very low temperatures, even when the stiffness of the bitumen is greater than 300 MPa. For these binders the direct tension test was developed and can be done.

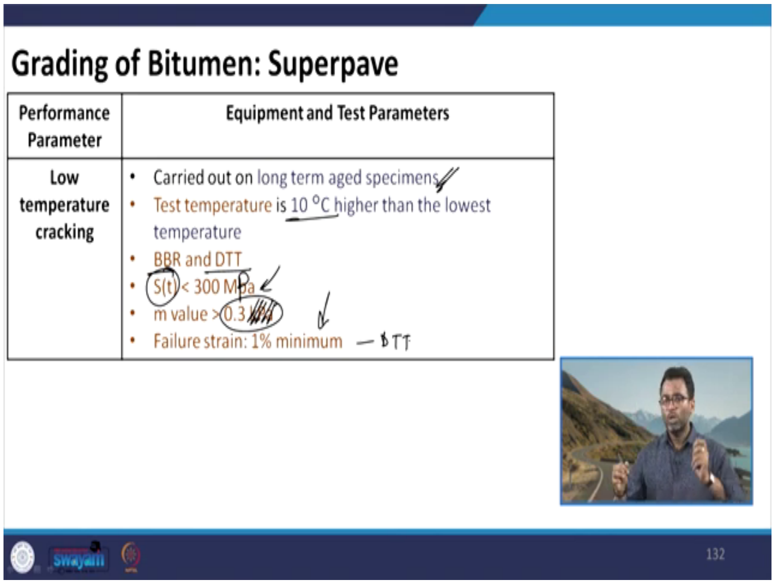
So, here what we do? We use a small dog bone shaped specimen. So, it is a dog bone shaped specimen which we use here and which is subjected to tension at a constant rate and this rate is 1 mm per minute and we apply a load of 500 Newton and we apply the load until the sample will break. So, you can imagine it to be like this. So, if it is a dog bone shaped specimen it will be something like this.

We are applying a load and we are applying a load till the sample will break from the middle and we will monitor how much the length is changing before failure. So, we calculate failure strain which is defined as the change in length to the effective gauge length. Now, what is gauge length or effective gauge length? This is from neck to neck, from here to here. So, this is the effective gauge length L.

It has to be again noted that here we are for we are trying to see the maximum stress in the material at which we are basically measuring the failure strain. So, this maximum load may not be similar to the actual breaking load. So, the breaking load may be higher than the load at which this stress is maximum. So, these again are few pictures you can see you have a standard specimen. This specimen is being pulled from both the sides.

We are trying to calculate the failure strain which is change in length to the effective gauge length here. And the $Stress\ (\sigma) = \frac{P}{A}$ where P is actually the maximum load or the load at which this stress is maximum, not necessarily the breaking load.

(Refer Slide Time: 63:52)



So, if we now see the criteria given in the superpave grading system, so for low temperature cracking it is carried out on long term aged specimen as we discussed. Test temperature is 10 degree Celsius higher than the lowest temperature. We are basically using a BBR and DTT to do the test. In BBR the criteria is that the creep stiffness should be less than 300 MPa.

So, M value should be greater than 0.3 and the minimum strain or the failure strain should be at least 1 percent in the DTT test. So, these are the criterias which should be satisfied for the selection of the appropriate binder in the superpave grading system. So, today we will stop here and in the next presentation we will continue from where we have left and we will try to see that based on these criterias how a PG grading is actually defined.

And again some of the additional important points related to the PG grading system and also we will discuss about the PG plus specifications which presently is very popular specially for polymer modified binders for which the normal specifications or the normal superpave grade specification fails to meet the desired criteria. Thank you.