Pavement Materials
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Lecture: 30
Grading of Bitumen (Part-2)

Hello everyone, welcome back. If you remember, we were discussing about the grading of bitumen and here we have discussed about various grading system such as penetration grade, viscosity grade and in the last presentation we were discussing about the superpave grading system. We discussed that what are the equipments that are required to complete the superpave grading system and how the rheological properties are used to differentiate between different bitumen specimens.

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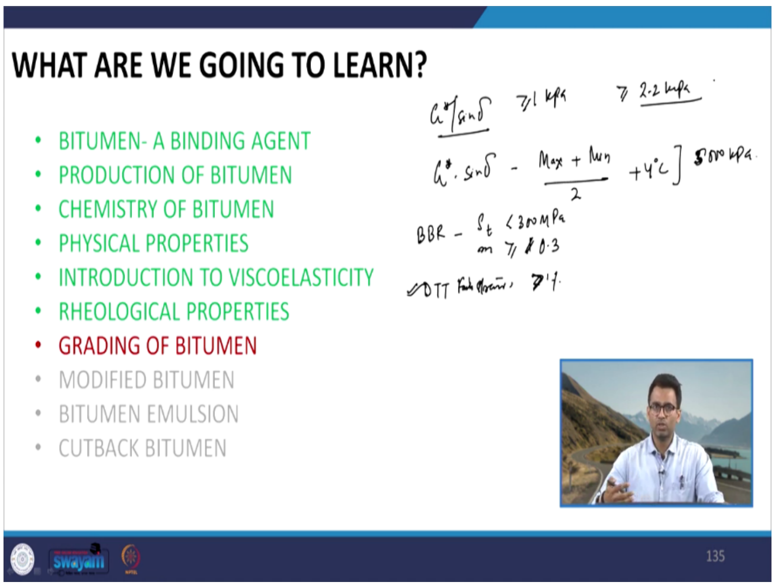

We also discussed that in the superpave grading system, one of the very important point is that here the test temperature does not remain constant. So, the parameter which we are testing or which is used as a performance indicator that remains constant and the temperature at which this parameter is satisfied or is reached is noted down and is used to grade the bitumen. Here the bitumen is graded using two numbers. The first number indicates the average 7 day maximum pavement temperature, whereas the second number it indicates the lowest pavement temperature of the location for where we are going to use that particular bitumen.

We discussed that these parameters to quantify the performance indicators that is or performance parameters such as rutting, fatigue and low temperature cracking are quantified using G*/sinδ. So, G*/sinδ if you remember is measured using a dynamic shear rheometer and we do this measurement in the unaged and short term aged condition of the bitumen sample. Then the fatigue characteristic is that is G*sinδ. This is measured at the average pavement temperature which if you remember is the $\frac{\text{maximum temperature+ the minimum temperature}}{2}$ + 4 degree Celsius.

And the low temperatures acceptability is quantified using tests such as bending beam rheometer where we use the parameter creep stiffness and the slope creeps or the slope of the stiffness versus time graph at 60 seconds and using direct tension tester. So, this is used specifically for very stiff binders which also have ductile properties for example, a polymer modified binder and we here use the train that should be greater than the failure strain that should be greater than 1 percent. Whereas, the creep stiffness should be less than 300 MPa and the m-value should be greater than 0.3 at 60 seconds.

Coming back to the fatigue parameter the limiting value is 5000 kPa whereas, for G* it is by sin delta in the unaged condition the limiting value is 1 kPa it should be greater than 1 kPa or 2.2 kPa if it is a short term aged sample. So, having done this revision let us now see that how the grading actually looks like and how different grades can be assessed using this system.

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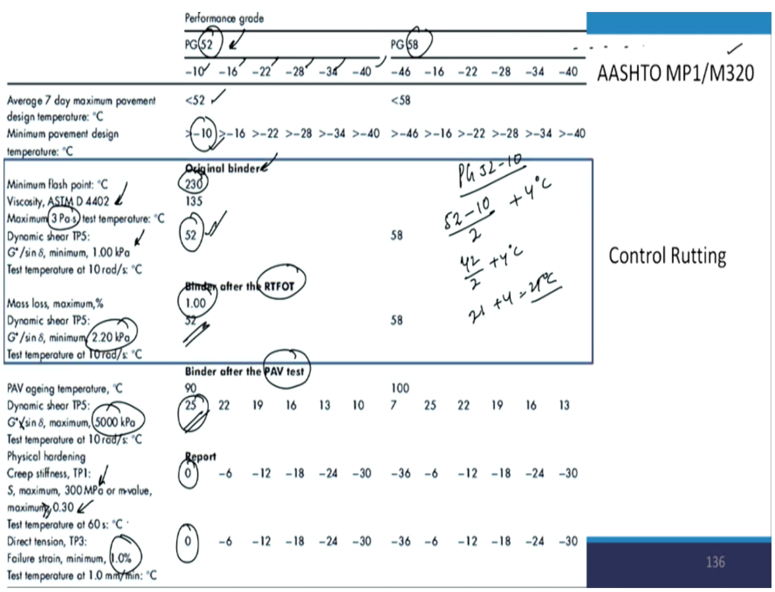

So, the code is AASHTO MP1 which is now converted to AASHTO M320 and this is just a partial image from the grading chart. Here I have shown only PG 52 and PG 58 likewise there are various other grades and we will discuss about those grades in the next slide. In this slide just we will try to have a look upon how to read this chart for grading. So, let us say that we are interested to see PG 52. So, 52 here indicates the 7 day average maximum temperature of the pavement. With this high temperature grading we have several options for low temperature grading. So, we can have PG-10, PG-16, -22, -28, -34, -40.

So, we have a bitumen which can be graded as PG 52-10, where -10 indicates the lowest pavement temperature of the particular location of a particular area. Similarly PG 52 -22 indicates that the binder, this binder will be suitable for a location where the average 7 day maximum temperature is less than equal to 52 degree Celsius and the minimum pavement temperature is -22 degree Celsius or higher. So, which you can see here and in the first two rows.

Now let us see what other rows indicate. So, you see there are some conditions on original binder which means binder in the unaged condition. So, the first criteria in the superpave grading system is that the minimum flash point. So, this is for safety same for all the grades the minimum flash point should be 230 degree Celsius and we have already learned about the flash point test. The viscosity using rotational viscometer at 135 degree Celsius should be maximum 3 Pascal second. So, this criteria also we have discussed previously which is for pumping of the binder in the mixing plant.

Now, we come to the performance indicator. The first performance indicator is G*/sinδ and the minimum value is 1 kPa and for this particular grade that is PG 52 it should satisfy at 52 degree Celsius or of course at lower temperatures it will satisfy or you can say that 52 degree Celsius is the failed temperature beyond which the value of G star by sin delta will be higher than 1 kPa. So, therefore, this particular bitumen will be graded as PG 52.

Similarly at 52 degree Celsius in the RTFO aged condition the value of G*/sinδ should be at least 2.2 kPa which you can see here and here the mass loss, maximum mass loss allowed after short term aging is 1 percent. So, we are done with an unaged binder and short term aged binder. Now on the long term aged binder which we get after the pressure aging vessel test, the value of G*sinδ is of interest G*sinδ and its maximum 5000 kpa you can see and this is the average temperature.

Now, let us have a look. Since we discussed that the average temperature is the average + 4 degree Celsius. So, here why it is 25? It is 25 because we are looking at a binder with PG grade PG 52-10. So, according to our discussion it should be $\frac{52+(-10)}{2} + 4$ degree Celsius. So, you can see this is $\frac{42}{2} + 4$ Celsius this is 21 + 4 which is 25 degree Celsius. So, therefore, this is 25 degree Celsius.

So, if you do calculation similarly for all the other grades you will be able to get the same value as indicated in this particular chart. Then talking about the low temperature property again we discussed that during the superpave grading system what they did? They increased the test temperature by 10 degree Celsius. So, that they can get the desired value after 2 hours in 60 seconds.

So, the PG grading is minus 10, but we are doing the test at 10 degree Celsius higher temperature which means it will be 0 degree Celsius in this case. So, at 0 degree Celsius we have to ensure that the creep stiffness is less than 300 MPa and the value of m is greater than equal to 0.3. Similarly if we are using a direct tension test for highly stiff binders in that case the failure strain at least should be 1 percent at that particular temperature. So, I hope that this the reading of this chart is clear that how these different grades looks like.

Now, here I have marked that which rows corresponds to different performance criteria. So, this row which you can see is marked in blue is to control rutting that is G*/sinδ, this is for fatigue G*sinδ and finally, we have a row to control thermal cracking or low temperature cracking based on the BBR and DTT test parameters.

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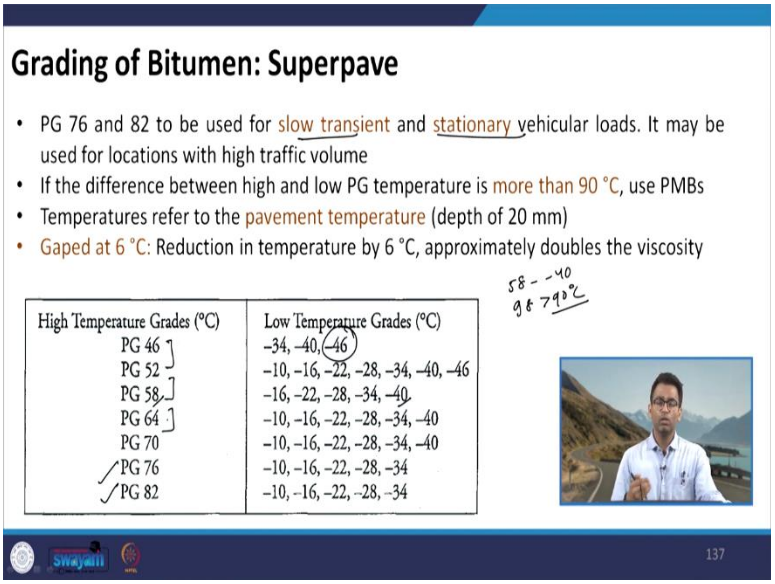

So, some of the other salient features to discuss here about the PG grading system. So, these are the different grades which you can see on the table on the left hand side we have the high temperature grades and the corresponding low temperature grades on the right hand side. So, you see here in all these grading systems PG 76 and 72 they are on the higher side which typically you would not expect at all the locations is not it.

So, PG 76 and 82 are actually used for slow transient and stationary vehicular loads. So, we have to remember that the superpave grading system is based on tests done in dynamic shear rheometer at 10 rad/sec which we discussed corresponds to a speed of around 80 to 90 kmph of the traffic. But it may happen that at some locations for example, near toll plazas we have stationary traffic, near traffic signals we can have stationary traffic.

So, sometimes we can have stationary and very slow moving traffic if the volume of traffic is very high in some location. So, in those cases because more is the loading time, softer the bitumen will behave, is not it. Because higher is the speed stiffer the bitumen will behave. So, the 80 to 90 kmph actually indicates a particular stiffness of the binder at that particular frequency. But if you are talking about a lower frequency which means more loading time, then the same binder is subjected to a frequency where it will behave in a different manner it will have more viscous response in comparison to the frequency of 10 rad/sec.

So, therefore, when the speed of the vehicle is less in order to have more resistance towards rutting failure PG 76 and 82 can be used. Another important point to discuss here is that if the difference between high and low PG temperature is more than 90 degree Celsius, in that case we have to use PMBs. So, suppose if you are talking about 58 and -40 let us say. So, 58 –(-40) it is 98 which is more than 90 degree Celsius.

So, if this is our desired grading which we want which means we have a location where the temperature difference the temperature difference between extreme high and extreme low is very wide. In that case it is preferable to go with polymer modified binders which have lower temperature susceptibility in comparison to the unmodified binders. Another point to note here is that when we are talking about these temperatures we say 46 degree Celsius we say minus 34 degree Celsius. So, you have to remember that in the PG grading system the high pavement temperature or the high PG temperature, it corresponds to the pavement temperature taken at a depth of 20 mm.

So, if you remember that we discussed that when the SHRP was developing this, they had a storehouse of a of from the weather stations of lot of temperature data and then they did study how to correlate the air temperature data with the pavement temperature data and for developing the high temperature specifications they use the pavement temperature at a depth of 20 mm.

On the other hand for low temperature while developing the code initially, at the low temperature for example, let us say -46 degree Celsius. So, this corresponds to the surface temperature of the pavement lowest surface temperature of the pavement and we will discuss that this -46 degree Celsius was taken as the air temperature.

So, towards the low temperature grade, the low temperature value is equal to the air temperature or the lowest air temperature and here the lowest air temperature is taken equal to the lowest pavement temperature. Whereas, on the high temperature side based on the air temperature they have developed a correlation of the pavement temperature. So, they have taken that the pavement temperature is higher than the air temperature here.

Another important point to note here is that that if you see closely see this the specification you will see that the values are gapped at 6 degree Celsius. So, there can be a question that why they specifically selected grades at 6 degree Celsius why not say there is a grade like PG 47 or PG 48 or PG 50. So, why there is a gap of 6 degree Celsius? Because they found that it is not really very practical or convenient to grade the bitumen at every 1 degree Celsius because there may be significant overlapping between the binders and they found that if there is a reduction in temperature by 6 degree Celsius the viscosity of the binder is approximately 2 times.

So, it is very easy to differentiate between one grade to the different grade. So, therefore, a 6 degree gap was chosen to develop this specification.

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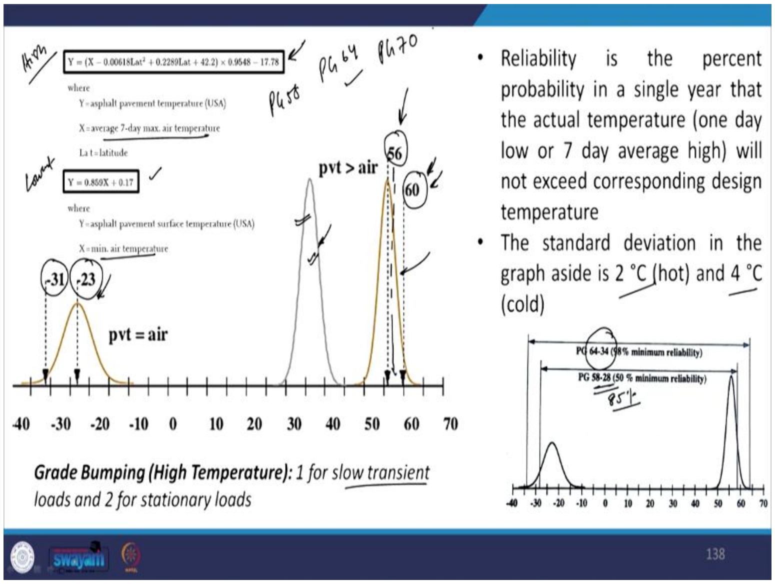

So, the superpave grading system also gives us an opportunity to select the binder based on the target reliability. So, here you can see that this shows the distribution because temperature of course, at a location cannot be constant even if we see the low temperature the daily variation of the lowest temperature there will be a variation there will be a distribution. So, here we have two extremes for a particular location in US.

So, here it shows that this brown dumbbell curve or normal distribution this indicates the pavement temperature which you see is more than the, so this is the fluctuation of air temperature variation in the air temperature and there are models available one of the model is written here which you can see that we can find the asphalt pavement temperature based on the latitude values and the value of the average 7 day maximum air temperature.

So, if you have the latitude of the location and the average 7 day maximum air temperature you can calculate the asphalt pavement temperature. Of course, this is a location specific model. So, there can be various models in various countries even in India we can develop one such model considering various locations in the country and similarly on this shows the a correlation between the air temperature and the pavement temperature when we are trying to calculate the low temperature.

So, this is just two models taken from literature which shows that what will be the pavement temperature if we have the minimum air temperature and if we have the average 7 day maximum air temperature. So, this is the lowest temperature and this is the high pavement temperature. So, anyway, so therefore you see here on the right hand side we have two normal distribution one is for air which is shown here and based on the correlation the brown one or the brown normal distribution is the variation of the temperature of the pavement. And on the left hand side we have only one curve because as I said pavement temperature was taken equal to the air temperature.

So, whatever is the variation in air temperature will also be taken as the variation of pavement temperature. So, here see how do you define reliability for in the grading system. So, reliability it is the percent probability in a single year that the actual temperature. For example, 1 day low or 7 day average high will not exceed the corresponding design temperature. So, this is the reliability which means that if you take 56 which is the mean which means there is a 50 percent chance that in 1 year this pavement temperature will be exceeded.

And if you take let us say the 98 percent value based on the standard deviation obviously. So, here in this graph which is shown the standard deviation of the 7 day high pavement temperature is 2 degree Celsius and on the low pavement temperature standard deviation is 4 degree Celsius. So, let us say you take 60 degree Celsius which here is the 98 percent percentile value. So, if you take 60 as your design which means there is only 2 percent chance that in 1 year the pavement temperature or the 7 day average maximum temperature will exceed 60 degree Celsius which means you can get a higher reliability by selecting 60 degree Celsius as your design temperature.

Similarly, on the on this side if you see, on the left side -23 is again at the 50 percent reliability. If you want to go to 98 percent reliability you have to choose -31 which means your design grade for this location should be PG 60-31 in order to get 98 percent reliability. At 50 percent reliability is PG 56-23, but again you have to remember here that it is possible that there is no grade as PG 56.

So, of course, let us say there is a grade like PG 58 which means by default you will be on the right hand side of the curve and though you are doing it for the mean, but you are selecting a grade which is PG 58. So, this will increase your reliability level automatically. So, in this way using this chart we can select any reliability we want to and we can choose the appropriate binder. This chart again shows the same example where you see they have taken PG 58-28, why because there is nothing called PG 56-23.

Now, here if you would have chosen PG 56-23, it would have given the design reliability of 50 percent as we discussed. Now, since we have a grade PG-28 and not a grade which is PG-23, I mean the nearest grade to this value is PG 58-28. So, if we do the actual calculation, we will find that this is actually 85 percent on at the 85 percent reliability level. Similarly, the 98 percent, the minimum 98 percent reliability is if I want to choose 68 and -31, but since there is no grade as PG 60, so I am choosing PG 64-34.

So, the minimum reliability will be 98 percent, but the actual reliability will be very close to 100 percent. So, this is how we can choose the appropriate binder based on the reliability consideration. One additional point here is that the PG grading system also suggest to do grade bumping. What is grade bumping? That you go one grade higher.

Now, this was done because of the same reason we discussed in the previous slide that the system was developed corresponding to a speed of 80 to 90 kmph, but during hot weather when we have a stationary traffic, very high volume or heavy traffic that will cause higher development of permanent deformation or you can say susceptibility to permanent deformation will be higher. So, in order to accommodate that condition, what superpave grading system suggest that, if the traffic is slow transient, you go for one grade bumping.

For example, if the design grade is PG 58 corresponding to a speed of 80 to 90 kmph, you choose a PG of 64. Similarly, if the traffic is stationary, it is almost in a stop condition, instead of PG 64, you choose PG 70. Of course, the low temperature choice is not affected by this condition because at low at lower temperature it is not very significant. If you remember that at lower temperature, the bitumen achieves an asymptotic value of the stiffness.

So, the stiffness, the change in stiffness is not time dependent at low temperature conditions, but at high temperature since it is more time dependent, we have to do grade bumping on the higher side. So, this is how grade bumping is done.

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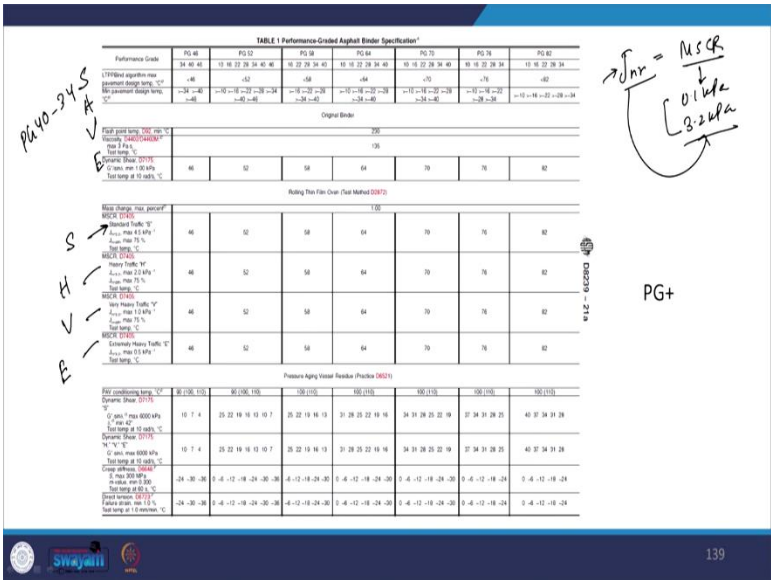

Well, this is all about the PG grading system. Now, this chart which has been taken from an ASTM code, I just wanted to place it here to discuss few advanced specifications which have been developed after the superpave grading system. So, if you remember, we have discussed about the multiple stress creep and recovery test. So, what was found by various researchers after this PG system developed, there were lot of studies done with different binders, different mixes to see whether these parameters like G star by sin delta or G star dot sin delta is really useful in quantifying the rutting and fatigue properties of the asphalt mixtures or the hot mix asphalt.

So, many studies indicated that when we have bitumen, modified bitumen such as polymer modified bitumen, the correlation between the occurrence of rut depth and G*/sinδ is not very good which means there is a poor correlation. One of the reason is because these polymer modified binders, they have very high delayed elastic response which is not captured by the stiffness parameter which is G*/sinδ.

And therefore, they developed the multiple stress creep and recovery test to bring in the effect of non-linear viscoelastic response of the binders. So, based on the multiple stress creep and recovery, they developed PG+ specification which is being used and applied specially for polymer modified binders and there are certain criterias under that which has to be met. So, this is just a snapshot of that particular criteria.

The chart is almost similar to what we saw for the superpave gridding system in the previous slides with few changes and differences. For example, here the rutting is quantified using the non-recoverable creep compliance J_{nr} and naught G*/sinδ in the short term aged condition. In the unaged condition, they still use G*/sinδ as the critical parameter. Here based on J_{nr}, so J_{nr} is the unrecoverable creep compliance which you get from MSCR test which is usually Jnr at two stress level 0.1 kPa and 3.2 kPa. And then we carry out 10 cycles for 0.1 kPa, 10 cycles for 3.2 kPa and we do a set of calculations to arrive at the value of J_{nr} which is basically taken.

And in this specification, they take basically Jnr with respect to 3.2 kPa not 0.1 kPa. So, 0.1 kPa is basically used to calculate a parameter which is called as J_{nr} difference which is a stress susceptibility parameter under the MSCR test. So, here using the value of Jnr and Jnr difference, they have segregated the same grade for different levels of traffic. So, we have a traffic which is standard, it is designated as S grade. We have a traffic which is heavy, they have designated as H grade. We have a traffic which is very heavy, they have designated it as V grade and extremely heavy traffic is indicated or is denoted as E grade.

So, you can have a binder whose grading can be for example, PG 46-34 S or H or V or E. So, the same grade can have four different grades based on the anticipated traffic level. So, of course, if you see in this particular slide, it may not appear to be readable.

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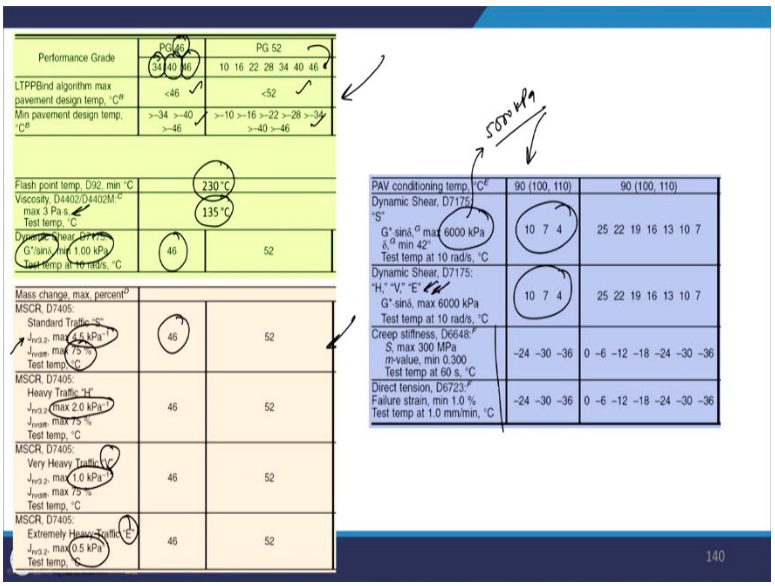

So, I have just taken here an example of PG 46 and 52. I have just you know magnified the image and here I hope you will be able to see. So, you see we have PG 46 -34 -40 -46, let us say. Under 52, you have more number of low temperature grades. So, I hope we understand what does these mean the same which we saw in the previous chart. Here also the safety indicator is same. The flash point should be minimum 230 degree Celsius. The value of viscosity remains same at 135 degree Celsius maximum 3 Pascal seconds, in the unaged condition.

So this green chart is for the criteria required in unaged condition. In the unaged condition, we have the same criteria G*sinδ should be at least 1 kPa at the grading temperature that is 46 degree Celsius. This the second color is for short term aged condition. So, after doing the RTFO aging, you will test the binder if it is a PG 46 grade. So, at 46 degree Celsius, if the traffic is under the S category or the standard category, then the value of J_{nr} at 3.2 kPa should be maximum 4.5 kPa^{-1}. And Jnr difference should be maximum 75 percent. So, this is the criteria for S grade.

For the same PG 46, when we do the test at 46 degree Celsius, but we are looking for a traffic which falls under H category, then the value of Jnr at 3.2 kPa should be maximum 2 kPa^{-1}. If you are looking at a very heavy traffic, then the maximum value of Jnr permissible is 1 kPa^{-1} and for extremely heavy, it is 0.5 kPa^{-1}.

Now, the value of Jnr difference remains same in all the criteria for Jnr difference remains same in all the cases that is maximum 75 percent up to the V traffic level. At the extremely heavy traffic level, there is no criteria for J_{nr} difference. Now, let us see the requirement at low temperature, I mean after the PAVA aging condition long term. So, under long term aging condition, one criteria is for fatigue.

Now, here in contrast to the previous value of 5000 kPa, they have increased the value as 6000 kPa. 6000 kPa for S category and similarly for H, V and E category. Now, in AASHTO, this is this is taken from the ASTM specification. In the AASHTO specification, for the S grade, they still have 5000 kPa and only for the H, V and E grade, they have 6000 kPa as the requirement. The temperature calculation remains same as we have seen previously.

The there is no change in the creep stiffness requirement, it remains same just like as the usual PG specification. This is clear how PG specification is used and what additional criterias are taken or are used to grade under the PG+ specification.

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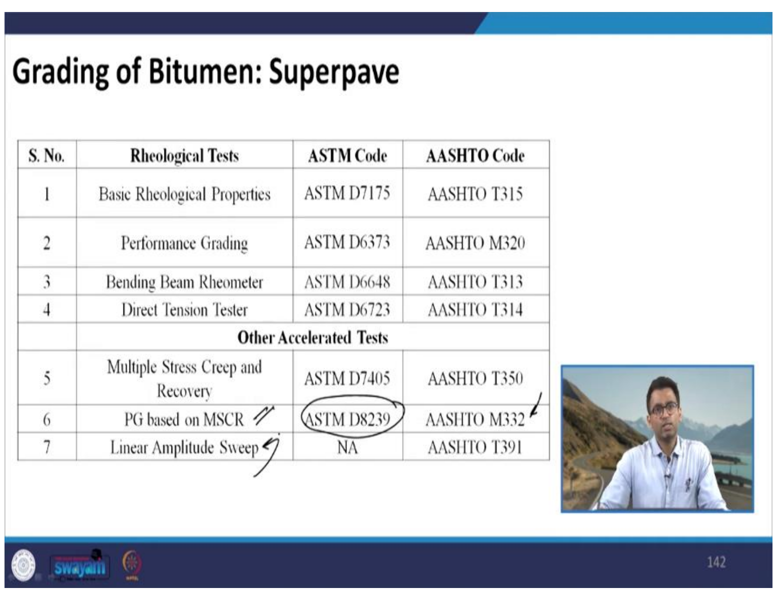

S. No.	Rheological Tests	ASTM Code	AASHTO Code
1	Basic Rheological Properties	ASTM D7175	AASHTO T315
2	Performance Grading	ASTM D6373	AASHTO M320
3	Bending Beam Rheometer	ASTM D6648	AASHTO T313
4	Direct Tension Tester	ASTM D6723	AASHTO T314
	Other Accelerated Tests		
5	Multiple Stress Creep and Recovery	ASTM D7405	AASHTO T350
6	PG based on MSCR	ASTM D8239	AASHTO M332
7	Linear Amplitude Sweep	NA	AASHTO T391

Just like I did for the physical testing, this table shows different ASTM, we do not have any specific IS code as of now because in India, we still follow viscosity grading system and the use of rheometer is limited for few specifications. So, therefore, we mostly have ASTM and AASHTO codes and these specifications can be looked for example, for basic rheological properties, we have ASTM D 7175 and AASHTO T 315. For performance grading again, we have an ASTM code and again M 320 of the AASHTO specification.

Similarly, for PG specification based on MSCR or PG+ specification, this is the one whose which we were looking now in the previous slide and again we have AASHTO M 332 which is for PG specification or PG grading based on MSCR test. Additionally, we have there is a popular test which is evolving slowly and about which we have discussed previously that is linear amplitude sweep test. Well, we do not have any specification for grading the binder based on linear amplitude sweep test, but this is being popularly used as a replacement of G star dot sin delta to quantify the fatigue resistance of the binder.

With this, let us end here and we have now completed our discussion on PG grading system. So, in the next class, we will start discussing about modified binders, emulsion and cutback bitumen and after completing these topics, we will complete module 3. Thank you.