**Pavement Materials**
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**Lecture 43**
**Hot Recycled Mixtures (Part 2)**

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Hello friends. In the last class we were discussing about the mixed design concepts related to recycled or reclaimed asphalt pavement materials and we discussed about the concepts related to determination or use of bulk specific gravity, basically, determination of bulk specific gravity and also we discussed that which properties are required depending on the percentage of RAP which we are intending to use or reuse in the production of new recycled or hot recycle mixtures. So, let us continue our discussion from where we left in the last class.

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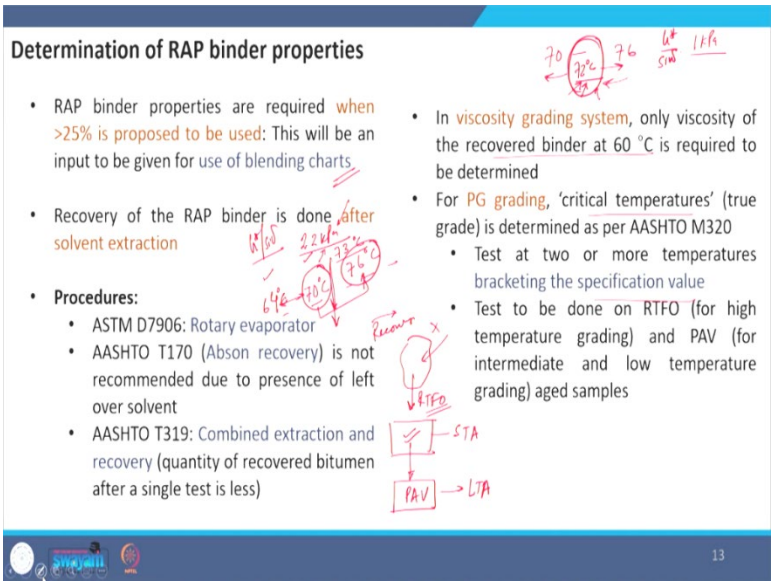


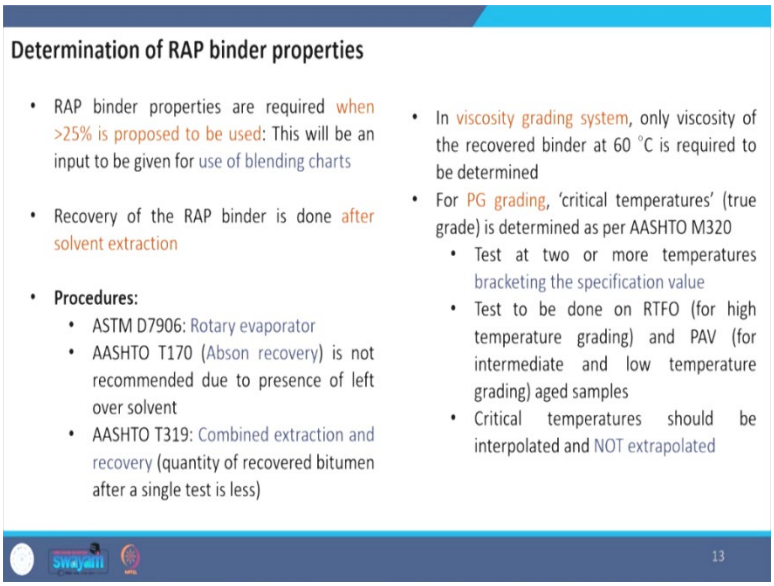


Moving forward the next concept which will be looking at is determination of RAP binder properties. If you remember, in the initial slides I told that the properties that which properties of RAP we are going to determine it will depend on the percentage of RAP to be used.

Now, for RAP percentage less than 25 percent, we usually do not determine the properties of the RAP binder. But when the RAP percentage is more than 25 percent then in addition to the gradation of aggregate, determining the bulk specific gravity of the RAP aggregates and determining the residual binder content in the RAP, we also have to determine the properties of the RAP binder.

Let us see that which properties typically are determined for the RAP binder. So, as I mentioned RAP binder properties are required when greater than 25 percent of RAP is proposed to be used. And why do we need

the properties of RAP? We will discuss further that these properties will be used in the blending charts. We will talk about blending charts or linear blending today.

The next question is in order to determine the property of RAP binder we need to have the RAP binder. And from where do we get the RAP binder? We have to extract it from the RAP source. So, using the solvent extraction method we can remove the RAP binder from the aggregate surface but in the solvent extraction method, after extraction, the RAP binder is dissolved or is basically mixed with the solvent.

So, in order to extract that particular RAP binder from the mixture of RAP binder and solvent we have to go for a recovery process. So, recovery of RAP binder is done after solvent extraction and there are several procedures to do that. Some of the popular procedures include the use of a rotary evaporator and the procedure to do that is outlined in ASTM D 7906.

So, we use a rotary evaporator machine. We put in this solvent and then the machine is subjected to a different level of temperature, heating and cooling and then subsequently we can remove the solvent from the mixture of solvent and RAP binder. Another method to recover the RAP binder is Abson recovery but is not generally recommended to be used.

The reason is in the Abson recovery method the recovered binder can also have good percentage of solvent. And when results are compared with of Abson recovery with other available procedure, it is found that Abson recovery method does not give accurate results in comparison to other methods. So, though Abson recovery method is there but in general it is not recommended to be used.

We also have another procedure as per AASHTO T 319 which is basically a combined extraction and recovery process which means both the extraction and recovery will take place subsequently using the same machine or a parallel system of testing. But the problem with this method is that the amount of RAP which can be used aT1 go is to be limited to 1 kg only.

So, if you say that there is 5 percent of residual binder in the RAP source then at 1 go you get only 50 grams of binder which can be very less. So, though the 50 gram of binder is sufficient to carry out a certain binder testing but more number of testings or cannot be done using this particular recovery method at least after one go.

So, you we can do multiple extraction and recovery and then we will have the sufficient amount of binder to do further testing. The first part was to tell you how to do the recovery. Now, we know how to do the recovery. Now, let us see once we have the recovered binder which tests are we going to do. The test which we are going to do will basically depend on the binder grading system we are adopting.

For example, in India we adopt a viscosity grading system. So, if we are adopting a viscosity grading system, the only property which we are interested in is the viscosity of the recovered binder at 60 degree celsius. So, we have to subject the recovered binder to viscosity testing at 60 degree celsius and this property will then be used in the blending chart to complete the mix design process.

If it is a PG grading system then the task is more cumbersome in comparison to the viscosity grading system. So, in PG grading system we have to do a series of testing including the high PG analysis or measurement, intermediate temperature measurement and then low PG temperature measurement.

And in this process what we are trying to find out is the critical temperature. So, critical temperature is also called as true grade. So, if you remember in the PG grading system, the grading is at, for example, the high PG grading is done at a gap of 6 degree celsius. So, if there is something called PG 70 then the next grade is PG 76. But let us say we are looking at the original binder grading which is 1 KPa $G^*/\sin\delta$.

So, if the temperature at which the value of 1, at which the value becomes less than 1 KPa is let us say 72 degree celsius. So, this is basically the actual failed temperature of the specimen at which the value of G star by sin delta becomes lower than 1 KPa. But if it fails at 72 degree celsius we cannot call this a binder as PG 76, we still call it as PG 70.

So, when we are doing the PG grading of the RAP binder, we intend to basically calculate or to evaluate the critical temperature or the true temperature in addition to the final PG temperature. So, once we know the true temperature, we can obviously determine the PG temperature. So, this will be called as the critical temperature during our discussion on RAP binder.

So, for PG grading critical temperature is determined as per AASHTO M320 and this critical temperature will be determined both for high temperature category, intermediate temperature category and also for low temperature category. For a given extracted binder, each test will be done. I mean each evaluation will be done at 2 or more temperatures bracketing the specification value. Why we say bracketing the specification value?

For example, we are trying to find out the actual failed temperature corresponding to 2.2 KPa which we do after RTFO aging that is $G^*/\sin\delta$. And presently we do not know that at which temperature the RAP binder will have this particular value. So, the actual value is supposed to be say 73 degree celsius.

So, we will do the testing at 70 degree Celsius, maybe we will start at 64 degree Celsius. Because we do not know that it is 73 degree Celsius. We will keep on seeing the value and keep on increasing the temperature. Next we will do at 76 degree Celsius. And then once we find that at 76 degree Celsius, it is failing, we will stop. Which means our bracket is here. This is the bracket.

And then we will interpolate the value based on the value at 70 degree celsius and 76 degree Celsius. But you cannot extrapolate the value just by looking at 64 at 70 degree Celsius. Because your material is not failing in between this temperature. So, it is suggested that you bracket at 2 temperatures such that the failed temperature or critical temperature is interpolated and not extrapolated.

So, extrapolated will give you more inaccurate result and therefore interpolation is recommended. So, for the RAP binder, extracted binder which we get, we do not test the binder in its original form which means after recovery you get the binder. But in PG grading you do not test this binder. You will subject this binder to RTFO aging and you will get the short-term aged binder.

Then you will further subject the short-term aged binder to PAV aging. And you will get the long-term aged binder. Now, sometimes a question is asked that the RAP binder is already aged already oxidized, why we need to further subject it to short term and long term aging?

So, as per the suggestions or recommendations of MS2, they say that after the recovery there is a possibility that some of the solvent will still remain in the residual binder. So, doing RTFO will ensure that, that residual solvent gets evaporated and you have a complete binder after short term aging.

And then once you reuse this bitumen in a new mix, it is again going to be subjected to short term aging and long term aging. And therefore determining the properties after short-term aging and long-term aging is more logical rather than doing the original binder grading.

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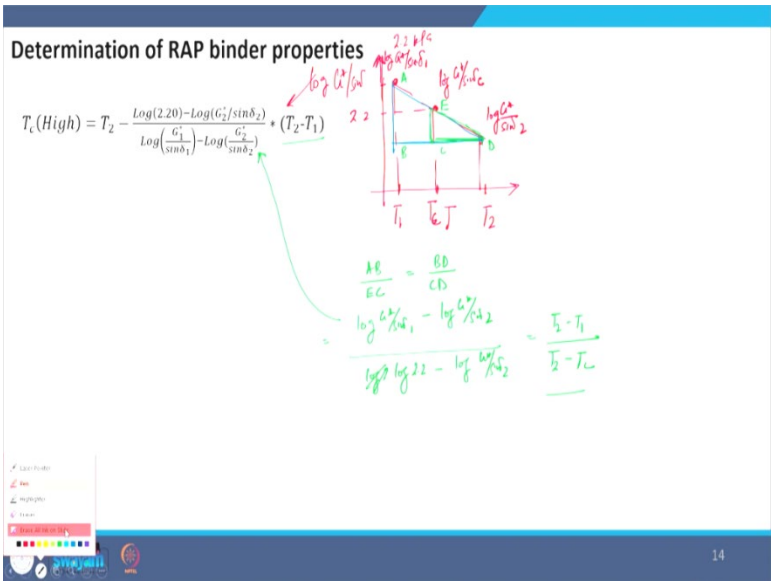


Now, critical temperatures as I said should be interpolated and not extrapolated. Now, this is an important point to remember here. Now, let us see how do we do that and we will see that using an example. But before that let us see the how the calculation is done. You see the calculation is done using a simple interpolation and I will tell you how this formula is arrived at. So, say we are looking at high PG after RTFO.

So, our target is 2.2 KPa. So, this is G*/sinδ. This is temperature and this is log of G*. So, this is a log scale. So, let us say we have a temperature T1, we have a temperature T2 and our temperature is somewhere here TC, the critical temperature we are trying to determine.

So, for T1, let us say this is the value which we get, G*/sinδ log of G*/sinδ 1. This is at as we increase the temperature G*/sinδ will decrease. So, G*/sinδ 2. And our value is somewhere here log of G*/sinδ critical and as I said that this value is equal to 2.2 KPa.

So, we will just do a linear interpolation here. And I hope that everyone knows how to do a linear interpolation. So, you can take this particular triangle, the one with blue and then you can take this particular triangle. So, if I say A B C D E then here you see that A B by if you see triangle ABD and ECD then A B by E C should be equal to B D by C D. And this is what I am going to use. So, A B is Log G*/sinδ1 - G*/sinδ2. EC=Log2.2 -Log G*/sinδ2. BD =T2 -T1, if you see.

And then CD = T2 -TC. And you just need to use this formula, break it up and then you get what is written here. So, $T_C = T_2 - \frac{\text{Log } 2.2 - \text{Log } G*\frac{}{\sin\delta}2}{Log\left(\frac{G*}{\sin\delta 1}\right) - Log\left(\frac{G*}{\sin\delta 2}\right)} \times (T2 - T1)$ So, this is how we can do the, find out the critical, high critical temperature.

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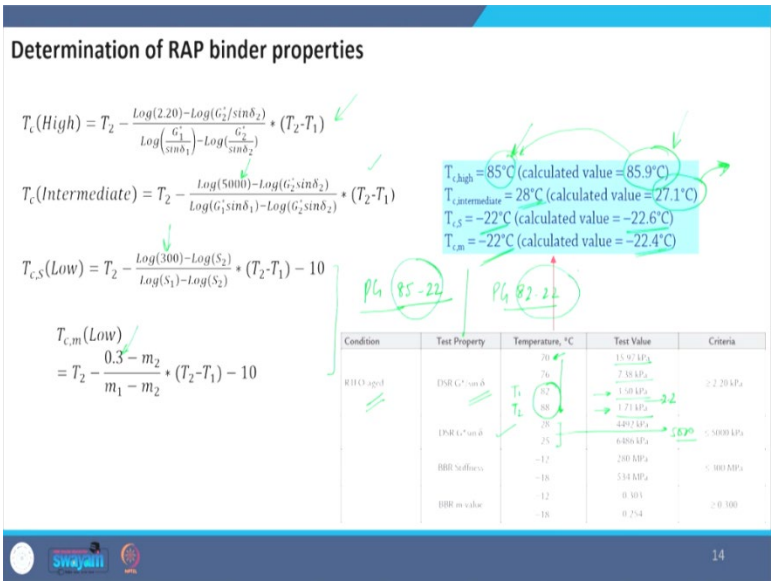


Similarly, for intermediate temperature we are targeting 5000 KPa, we will use the same interpolation procedure. For low temperature after PAV aging we usually conduct two tests. One is the creep stiffness, I mean we find the creep stiffness and the other we find is the value of m. So, the both can be used. And we use the same formula corresponding to 300 MPa corresponding to slope of 0.3. And they both will be analyzed together. So, if you just take an example given in MS2.

So, let us say that you you have a RTFO binder, you evaluated the value of G*/sinδ corresponding to 2.2, you started with 70 degree celsius at which you got this value. You kept on increasing the temperature and you see you got 7.38. So, you increase the temperature by 6 degree. 3.5. You further increase the temperature by 6 degrees. 1.71. And finally you stopped here because the value of 2.2 is somewhere between these values.

So, we will use 82 and 88 degree Celsius. Which means T2 = 82, T1 = 88. Sorry. T2 = 88, T1 = 82, G*/sinδ 1 = 3.5 and G*/sinδ2 = 1.71. You plug in this formula and you calculate what is the value of TC. So, if you do this calculation the value of TC which you get is 85.9 degree celsius.

Now, for high PG, we just round down the value to 85 degree celsius to be on the conservative side. And why it is done? Just try to understand it in this form that if the binder satisfies the criteria of G*/sinδ = 2.2 KPa at 85.9 degree Celsius. Then at a lower temperature it will definitely satisfy these criteria. The value will be obviously higher than 2.2. And that is why it is rounded down here.

Similarly, you calculate the intermediate temperature corresponding to 5000 KPa using the second formula. And in this particular example which we have taken, if you do the calculation, you will get the value as 27.1. And here you will round up. Why you will round up?

Because if the value of G*.sinδ is less than 5000 KPa at 27.1 then at higher temperature the stiffness will reduce and therefore the value will obviously be lower than 5000 KPa. So, you round down to 28 degree Celsius. Similarly, for low temperature also will round down.

So, if it is minus 22.6 then we will take it as minus 22. If it is minus 22.4 we have taken as minus 22. So, what does it mean? That the actual critical grade of this particular example is 85 minus 22. So, this is 85 minus 22. I hope that this is clear that how we are determining the critical temperature.

So, this is PG 85-22 and as per the PG grading system it will be actually PG 82-22. This is critical this is actual. So, I hope that this is clear to you. Let us move further.

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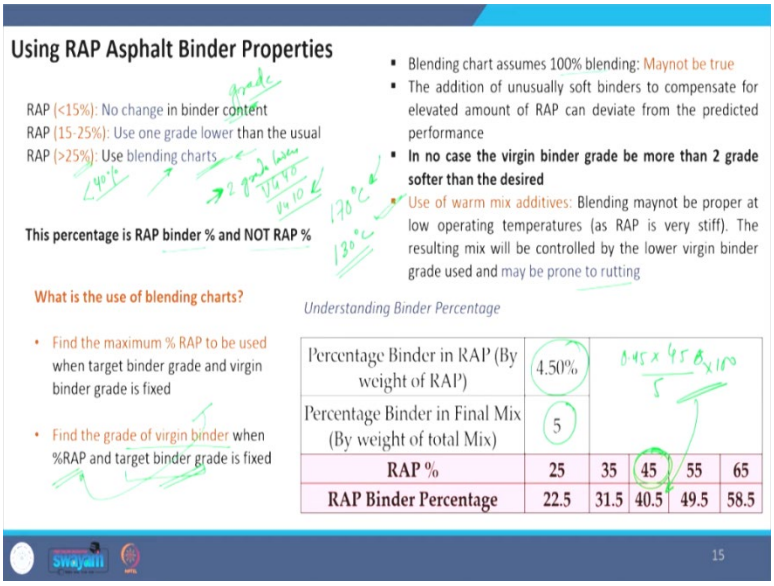


Once we know how to determine the properties of the RAP binder which has been finally recovered, let us see how we use the properties of the RAP binder. So, when the RAP binder is less than 15 percent then the new mix which we are going to make using 15 percent or lower RAP binder, we do not change the binder grade. Because you see, ultimately, what we are trying to do in the mix design when we are using RAP?

We have to find that when we are using RAP in the new mix, what will be the grade of the binder, virgin binder we should use. Because using RAP binder, we are increasing the stiffness of the mix because the RAP binder is already oxidized. So, if the virgin binder is also of higher stiffness then the total stiffness of the mix will be very high which can lead to distresses such as fatigue cracking.

And therefore in order to reduce the chances of occurrence of these distresses, the choice of the virgin binder which we are going to use is very important. So, this exercise we have to do and as per Asphalt Institute, if the RAP we are going to use in the new mix is kept to a very lower amount, let us say less than 15 percent then we do not need to change the binder grade.

If in a conventional mix design, we are using a VG40 binder then we keep using VG40 binder, if the percentage of RAP is less than 15 percent. If the percentage of RAP is between 15 to 25 percent then the specifications suggest that we use one grade lower than the usual. So, in case you are using VG40 for conventional construction and you are trying to make a mix having let us say 20 percent RAP then it is suggested that instead of VG40 you use VG30. Because the stiffness of the mix by this 20 percent RAP will this 20 percent RAP which we are going to use will increase the stiffness of the mix.

And therefore you are trying to balance this stiffness by reducing the grade of the virgin binder. So, a VG30 binder with 80 virgin aggregates along with 20 percent RAP binder, let us say 20 percent RAP will basically probably will maintain the stiffness similar to VG40. And that is why we are going for one grade lower.

If we are using the RAP binder more than 25 percent then we use blending charts. Then we have to determine looking at the properties of the RAP binder that what grade of virgin binder will be suitable. But we have to remember that this percentage of RAP binder which we have discussing that is 15 percent 15 to 25 or more than 25, it refers to the RAP binder percentage and not the RAP percentage.

And we have already discussed about this calculation. So, I am not repeating this. Just take one example that corresponding to let us say 45 percent of RAP. So, if the binder percentage is RAP is 4.5 percent, the percentage of binder in the final mix is 5 percent and the RAP percentage we are going to use is 45 percent. Then the percentage of RAP binder will be equal to how much? $0.45 \times \frac{4.5}{5} \times 100$.

So, if you do this calculation you will get as 40.5 percent. So, though 45 percent RAP we are using but the RAP binder actually is 40.5 percent. Here additional one point which I have to make that the MS2 guidelines also says that though you will use blending chart and you will evaluate the grade of the virgin binder but in no case the virgin binder grade should be two grades lower.

Even if you are using the blending chart, you cannot go more than two grades lower. Because in blending chart we assume that the RAP binder and the virgin binder get completely blended with each other. But it may not happen because 100 percent blending does not happen. This is just an assumption.

In that case, if the RAP binder is very stiff in the RAP source we are using and we go two grades lower. Let us say we are using VG40 normal construction and now the blending chart says that you use VG10 then

this may produce excessively soft bituminous mixture which may be prone to occurrence of rotting in the field.

And MS2 also suggests that typically the percentage of RAP should be kept lower than 40 percent. Because, if you are going beyond 40 percent then the blending charts does not work well. It can give us erroneous results and therefore MS2 suggest that we have to incorporate some additional performance testing.

For example, testing related to permanent deformation or testing related to fatigue cracking, to ensure that the mix which we are producing is not prone to or subjected to these critical distresses. Talking about the blending chart, what is the use of blending chart? One use we have already discussed that you have to find the grade of the virgin binder when the percentage of RAP and the target binder grade is fixed. So, like two things are fixed and one we vary. So, what are these three parameters?

One is the grade of virgin binder, one is the percentage of RAP and one is the the target grade of the binder. So, two of these should be fixed and one will keep on vary, depending on the objective. So, one objective can be that I have already decided, what is the percentage of RAP.

I also know that the final mix which I produce, what will should be the target binder grade in the mix. And then for this I have to determine what should be the grade of virgin binder which I have to use. Which means virgin binder when added to the RAP binder should produce the target binder grade.

Another utility of blending chart is that I have not decided what percentage of RAP I have to use but I know that what is the target binder grade and I also know that which version binder I am going to use. Let us say I will only use VG30 in the new mix. Then I have to determine, if I am restricting my choice to VG30 then what can be the maximum percentage of RAP to be allowed in that particular mix design process.

These are some important points and we have already discussed them. I will just quickly go through them that blending charts assume 100 percent blending. It may not be true. Therefore we have to be very cautious while executing or using the blending chart. The addition of unusually soft binders to compensate for elevated amount of RAP can deviate from the predicted performance.

And therefore in no case the virgin binder grade should be more than two grades softer than the desired. One more important point, this is specially related to a use of warm mix additive is that, that blending may not be, because in warm mix asphalt we are subjected the mix to a lower temperature in comparison to hot mix asphalt.

Let us say the hot mix asphalt is prepared at 170 degree celsius or 160 degree celsius and the warm mix asphalt is prepared at 130 degree Celsius. So, when we increase the temperature, we are allowing more opportunity for the virgin binder to blend with the RAP aggregate.

So, the blending will be to a higher degree but when we are subjecting the mix to a lower temperature then the blending between the RAP and the binder may not be proper and this may result in rutting because of the presence of a lower grade of virgin binder. So, for warm mix additives, MS2 suggest that we should use performance testings in addition to using blending chart and doing other calculations.

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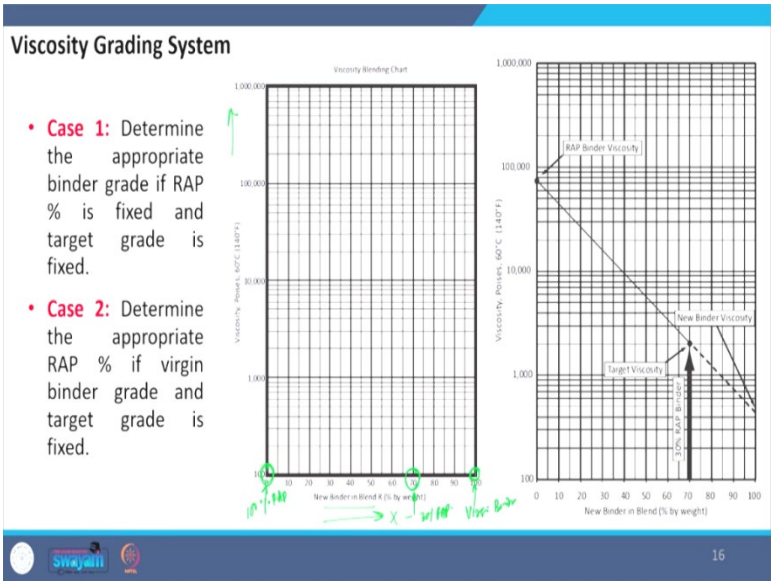


Now, we will quickly discuss about the utility of the blending chart and how to do the blending using two examples. You will use a viscosity grading system that is more simpler in nature because we are only measuring the viscosity of the binder at 60 degree celsius and then we will also discuss about the performance grading system.

So, you need to have a chart. You can also do hand calculation if you do not have a chart. So, this is a semi log chart, log of viscosity on the y-axis and new binder in the blend percent by weight in the x-axis. So, try to understand the x-axis because this is something which is always confusing to the students. It says new binder in the blend.

When the new binder in the blend is 0 percent this means this is 100 percent RAP. When the new binder in the blend is 100 percent, this means this is the virgin binder we are getting. And somewhere in between let us say 70 percent new binder which means this is 30 percent RAP. So, just for clarity.

We will use this chart for two cases, determining the appropriate binder grade, if RAP percentage is fixed and target grade of the binder is fixed. And the second case is determine the appropriate RAP percentage, if virgin binder grade is fixed and target grade is also fixed.

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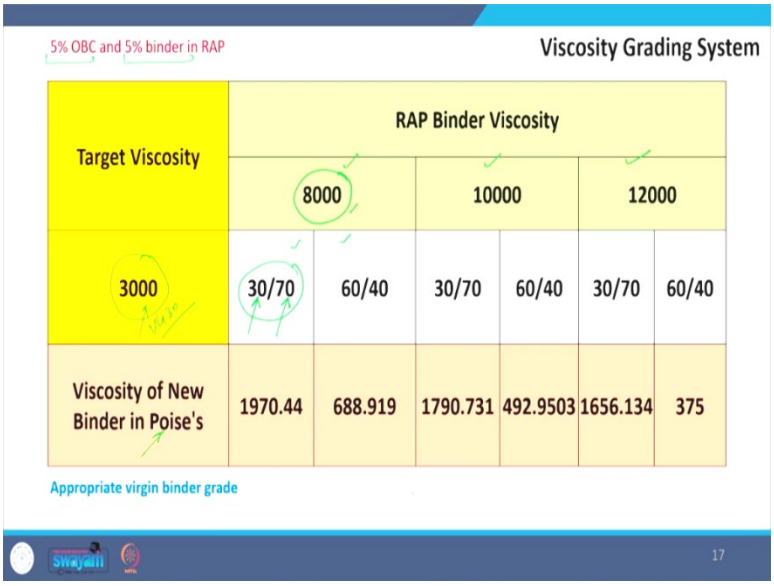


So, let us take this example. So, say in this example, we are looking at a mix which has 5 percent optimum binder content and the residual binder in the RAP is 5 percent. So, we have taken several cases here. Let us say there are three sources of RAP. We will just look at one source so that other calculations are very straightforward, will be similar.

Let us say we have a RAP source whose the viscosity of the residual binder of which is 8000 poises at 60 degree Celsius. We are trying to target a viscosity of 3000 poises which means we are targeting for VG30, let us say. Under each case, I have taken two sub cases. The first case is I am using 30 percent RAP and 70 percent virgin aggregate. Then the question is what is the viscosity of the new binder which I am trying to use?

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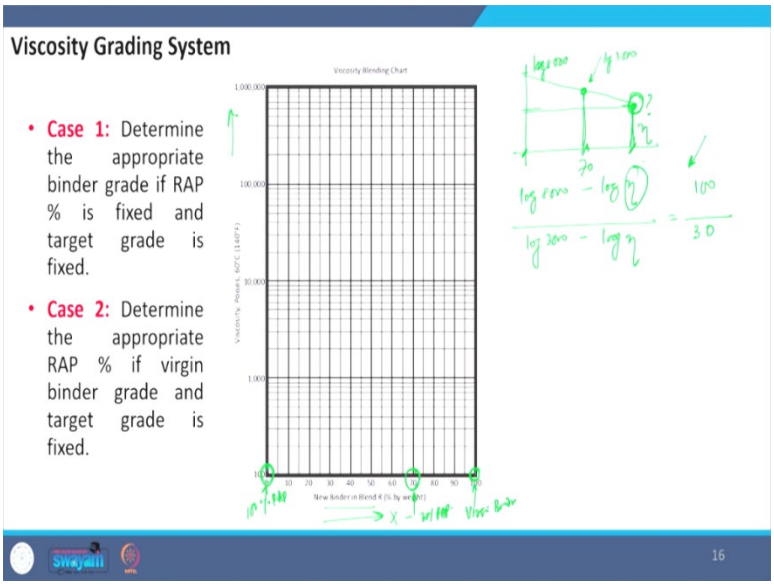


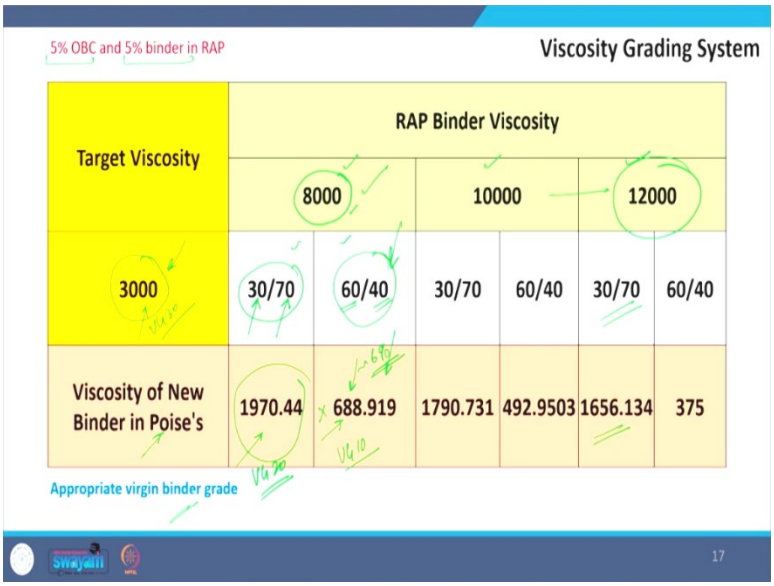


So, this is very simple basically, just use the blending chart. So, I am just using the blending chart. So, this is ln8000. Let us say log8000. This is because a 100 percent RAP. Virgin binder grade I do not know, I have to determine this point. I am using 30 percent. So, this is 70. So, 30 percent RAP has a along with the virgin binder should have a grade of 30000. So, this is log 3000. I am just doing is linear interpolation now. So, I have to find out this point.

So, how do I find this point? I just use the similar triangle concept. So, I can write (log8000 -log η) which I am trying to determine. Let us say this is $\frac{\eta}{\log 3000 - \log \eta}$ is equal to this is percentage. So, this is $\frac{100}{100-70}$. So, this is 30. So, this is what we will do and we will find out the value of η.

So, if you do the calculation, you will get that the value of neta is 1970.44. So, which means that this is something like a VG20 binder which we have to use. Now, what interesting I want to show you here. For the same case, if you use 60 percent RAP and 40 percent virgin aggregate then you will have to use something like VG7 or let us say VG10 here.

Because, the viscosity which you are targeting is somewhere around 690 poises, 690 poises. Maybe not even VG10, it is like a VG7 or VG8 here, but which means that we cannot use this because this is more than 2 grades lower than the target grade which is VG30, which means we cannot use this case. So, what does that mean? It means that we have to restrict the percentage of RAP here. We cannot use 60 percent RAP.

Similarly, when you increase the viscosity to let us say 2000, even in the first case you see you have to use a lower grade of somewhere around VG15 here. So, you see the choice of the virgin binder is dependent both on the percentage of RAP we are using and the properties of the RAP binder we are looking at. So, I hope this example is clear that how we use the blending chart to determine the appropriate virgin binder grade.

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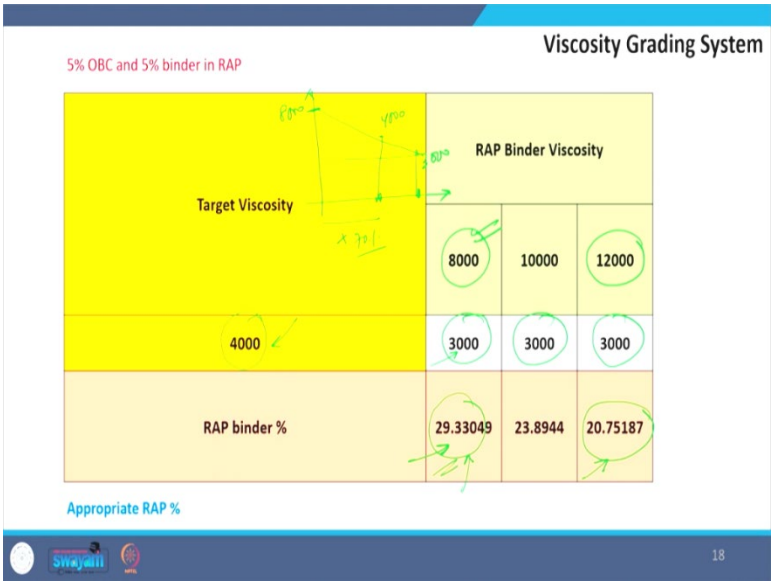


Now, we will look at another the second example where we are trying to find out the RAP percentage. So, here what is fixed? Here, we are fixing the target viscosity to 4000 and we are trying to use VG30. So, the binder grade is also fixed, the virgin binder grade is also fixed. So, if you see the viscosity blending chart.

So, this value is for this case is 8000, log 8000 here, 100 percent, the target is 3000. This value, this x, I do not know. This should be around 4000. So, here, I am trying to find the value of x. Here I am trying to find

the value of x. So, if you just do this interpolation, you try to find the value of x. You get the value of x as; I mean 100 – ( x as 30 percent) .

So, this you will get as around 70 percent. So, therefore the RAP binder is 30 percent here. So, with 30 percent RAP, having a viscosity of 8000 poises, you can make a virgin, a new hot recycle mixture having a virgin bitumen grade of VG30 such that the final mix, the final binder, the final mixture of the binder will have a viscosity corresponding to VG40.

Similarly, if you keep on increasing the viscosity of the RAP binder of higher viscosity, this percentage reduces, which means, here, you will have to restrict only to 20 percent and in this case you can go up to 30 percent.

So, I hope again that this example is clear to you. I was expecting that we should have completed our discussion on mix design of RAP today. But I think one more class will be required to complete the further concepts and discussions related to the mix design of RAP. So, let us stop here today and we will continue our discussion from here in the next class. Thank you.