Pavement Materials
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Lecture: 35
Volumetrics in Mix Design (Part-1)

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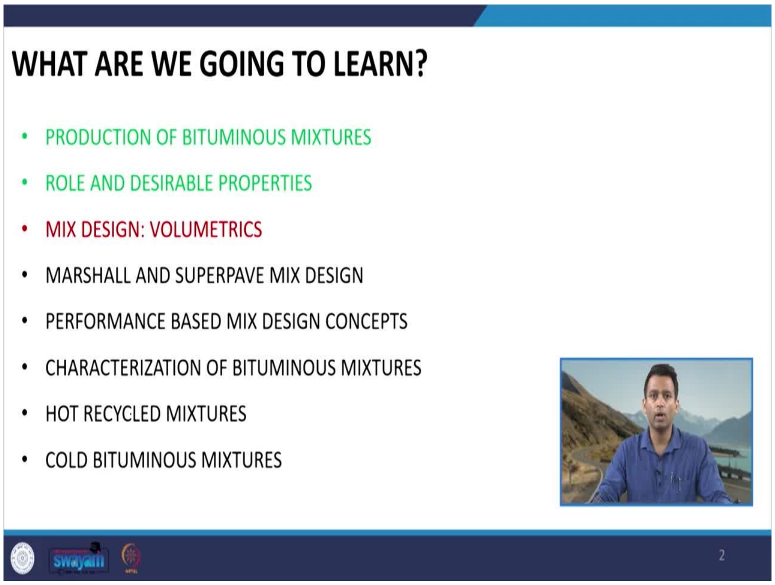

Hello everyone, if you remember in the last lecture, we started discussing about the properties related to asphalt mixtures. In the last lecture, we have discussed about various performance characteristics that are linked to the response of the asphalt mixture and that are desirable from the asphalt mixture. And then we discussed also about the development of mix design process from the historical perspective.

So, today we are going to discuss about the volumetrics of bituminous mixtures or asphalt mixtures from the perspective of mix design and this is the backbone of any mix design process. So, irrespective of whichever mix design process we are adopting for finding out the aggregate gradation and the optimum binder content, these concepts will always remain the same and will form the backbone of the mix design process.

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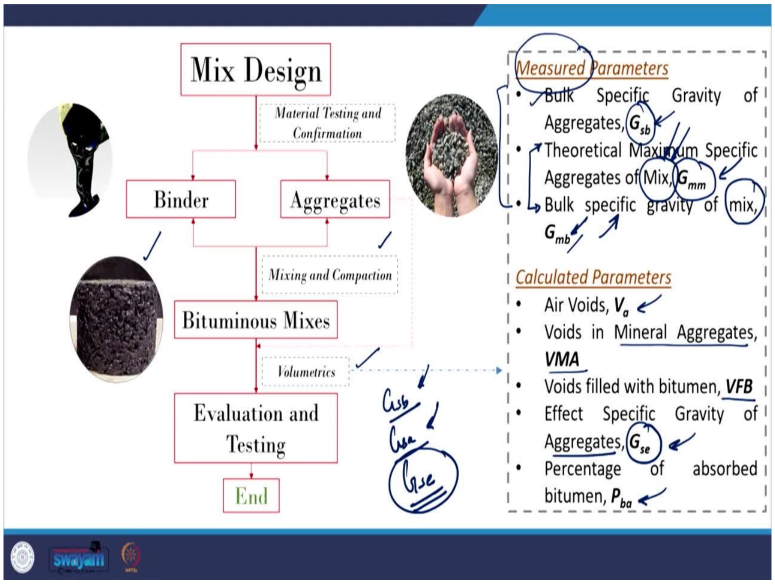

So, talking about the mix design process, the steps of which we will be discussing later when we will discuss about individual mix design such as Marshall mix design and Superpave mix design. The process is outlined in this simple flow diagram which you are seeing on the screen. So, in any mix design process, it starts with material testing and confirmation. So, you we have to check whether the binder which we are going to use is appropriate for the design and also the aggregate and the aggregate properties physical properties of aggregates and the aggregate gradation is within the desired range as specified by the highway agencies.

Once we confirm these materials, then of course, we have to mix the bitumen and the aggregate particles at elevated temperature and there is a specific condition for mixing and compaction which should be achieved in the plant in the laboratory and also in the plant and the field. So, we will discuss about that step today that why this mixing and compaction the step of mixing in compaction temperature is so important. Of course, once they are mixed, we will have our bituminous mixture using any compaction process about which we have discussed for example, it can be an impact compaction, it can be a gyratory compaction, or it can be kneading compaction.

So, we adopt some compaction process and finally, we will have our bituminous mixture which you are seeing here in the screen and I mean something in this form it can be of different dia and height depending on the compaction process we are adopting and also depending on the gradation, which we will discuss later. And then comes the analysis of the volumetrics of the asphalt mixtures, which will be our focus today and we will discuss about different volumetric critical volumetric parameters, which are directly related to the performance of the bituminous mixture.

Once the volumetrics have been analyzed, then we do some typical testing in the laboratory it can be different forms of mechanical testing on the compacted bituminous mixtures and finally, the volumetric data and the results of this mechanical tests they are analyzed to complete the mix design process. So, again the steps we will be discussing later when we will talk about the individual mix design process.

Well talking about the volumetrics, which will be our prime discussion today, we have to note down few important points. We have already discussed that for aggregates and I also told you that aggregate the specific gravity of aggregates is one such parameter which is directly used in the mix design. So, this can be measured in the lab we are measuring it using some process for example, weight in here, saturated surface dry weight and weight in water. So, Gsb is one parameter which can be measured in the lab.

Then what else we can measure? We can measure the theoretical maximum specific gravity of the mix. Now, this concept we have not discussed till now, and we will start discussing or we will talk about this particular specific gravity today. Just to note here that it says theoretical maximum specific gravity of mix. So, you have to remember that this specific gravity is not related to the specific gravity of the aggregates, this is related to the combination of bitumen and aggregate and we will talk about that particular specific gravity.

The next measured parameter is the bulk specific gravity again of the mix, which we have not discussed we will discuss today before we jump into the volumetrics and this is denoted as G_{mb}. Here again, we have to keep remembering these notations so that, it becomes simple for us to understand the process of the mix design, the process of the volumetric calculation, for example, G_{sb} denotes the bulk specific gravity of the aggregates, G_{mm} it denotes the theoretical maximum specific gravity of the mix. And bulk specific and G_{mb} it denotes the bulk specific gravity of the mixture. So, this Gmb is also a mixed property not only an aggregate property.

So, this is again one important point which we have to note because, confusion arises when we talk about multiple types of specific gravity specifically in the asphalt mix design process, there is one more specific gravity which we will be talking. So, there will be so many different terminologies related to specific gravity, which sometimes can be confusing for any student or for any practitioner who is doing the volumetric calculation. So, let us get comfortable with this notation and then let us try to also differentiate that which specific gravity relates to the aggregate and which specific gravity relates to the properties of the mix.

So, now, I have told you about two specific gravities which is related to the mixture property that is theoretical maximum specific gravity G_{mm} and bulk specific gravity G_{mb}. Now, these parameters can be measured in the laboratory, so we have control on it, if we have the material, we can do a set of we can do some form of testing and then we can get or calculate this parameter.

Then there are parameters which cannot be measured in the laboratory and these inputs, these inputs means the specific gravity which we have measured in the laboratory and the weights of the individual material which we have with us can be used in combination to derive other parameters such as air voids. So, we will discuss about these volumetric parameters.

So, how much what is the volume of voids in the bituminous mixture. So, this we cannot measure in the laboratory you have to remember net volume is something which is not directly measurable in the laboratory, we always indirectly measure it or calculate it you can say. So, air void the calculation of air void will also is also dependent on these measured properties, which we have discussed. The other critical parameter is voids in mineral aggregates again, this is a new terminology which we will have which we will define and then we will try to understand. So, voids in mineral aggregates. So, this is also a form of volume. So, this again will depend on these measured parameters.

The next critical parameter is VFB, which is voids filled with bitumen. So, this will also calculate using the measured parameters. Now, one most important I feel is the parameter that is Gse. that Gse is one such parameter, which because of which we do so, many calculations in the mix design process, the reason being Gse cannot be measured in the laboratory unlike Gsb and Gsa. So, what is a Gsb? Again, this is a bulk specific gravity of the aggregates and Gsa is the apparent specific gravity of the aggregates.

If you remember we have discussed that there are three types of specific gravity of aggregates which we are interested in, one is Gsb, Gsa and the third one is Gse which depends on the bitumen absorption. And since we cannot measure the bitumen absorption, we cannot measure Gse or calculate Gse from laboratory measurements, we calculate it indirectly using some form of calculative approach. So, we will discuss about that.

So, again effective specific gravity of aggregates. Now, this is the aggregate property Gse, so this also we will calculate. And finally, we will get we are interested to calculate the percentage of absorbed bitumen, because percentage of absorbed bitumen cannot be measured using any laboratory test procedure.

So, before we discuss about these volumetric properties, let us discuss about the first step here, which is the mixing and compaction process. So, as I told mixing and compaction process is also a very critical process and we have to be very careful in the laboratory and also in the mixing plant that at what temperature our materials are exposed to.

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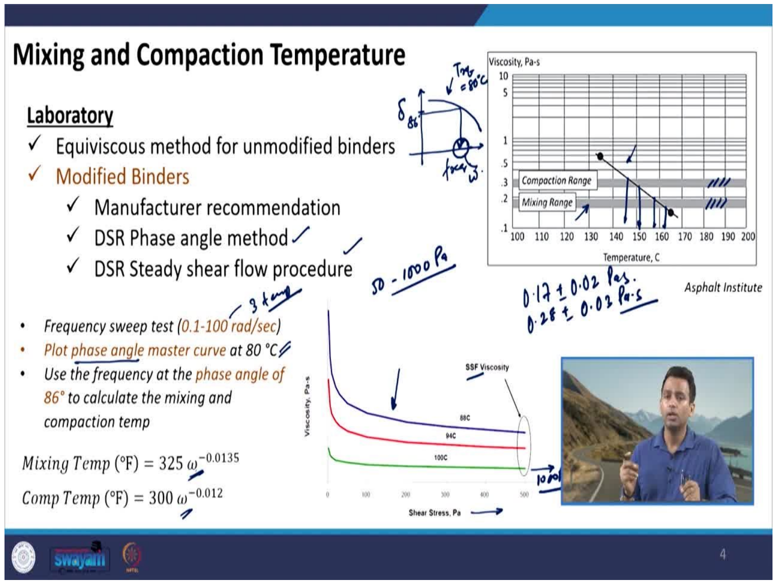

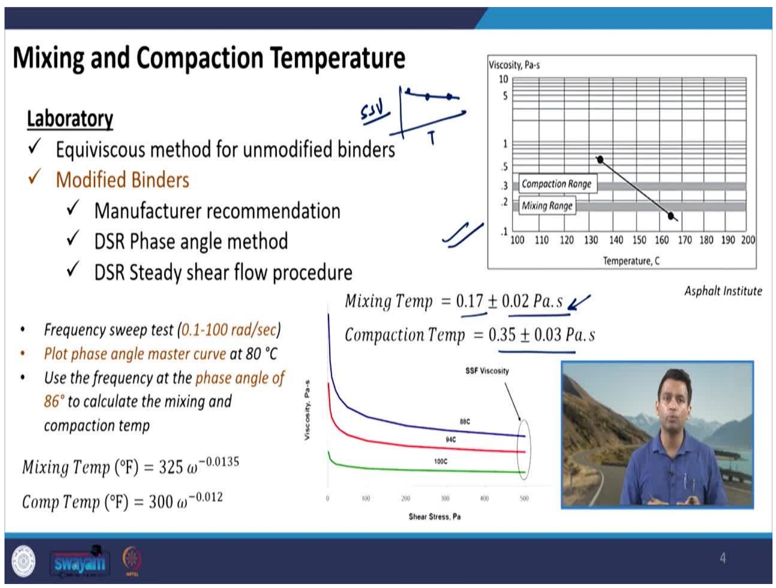

Let us first talk about laboratory. So, mixing and compaction, so, what are this temperature mixing temperature is the temperature at which the bitumen and the graded mineral aggregates are mixed in the plant inside the pug-mill. So, aggregates are dried, it is sent through elevated through hot elevators and then finally, it comes in contact with filler and bitumen and they are mixed together. So, this process at what temperature this mixing will take place that is the mixing temperature. And here again the target is that I should obtain a uniform coating of the bitumen over the aggregate particles.

And what is compaction? This is something which is happening in the field that I am transporting the loose bituminous mixture through trucks to the field and in the field using pavers and using rollers, I am finally compacting the mix. So, compaction temperature is that temperature at which the roller basically compacts the bituminous mixture or that range of temperature you can say. So, and this is what is happening in the field and then in the laboratory also we have to prepare bituminous mixture to do the mix design calculations.

So, in the laboratory, how do I determine at which temperature the bitumen should be mixed with the aggregate. Now, this concept for specially for unmodified bitumen is called as the equiviscous method and here our assumption is that the viscosity of the bitumen is related to the workability characteristic of the bituminous mixture. So, there is certain range of viscosity at which I can obtain appropriate coating of the bitumen over the aggregates. And again there is another range of temperature at which I can obtain appropriate compaction for the bituminous mixture and this already we have discussed in module 3, when we are talking about properties of bitumen.

So, in the previous method as we have discussed previously that we will do the Rotational Viscometer testing at two temperatures typically, let us say 135 and 165 degrees Celsius and we will plot the variation of viscosity with temperature in a semi logarithmic graph where the y axis is in the logarithmic scale and x axis is in the arithmetic scale, and the mixing range will be determined corresponding to the viscosity of 0.17 ± 0.02 Pascal seconds and the compaction temperature will be 0.28 ± 0.03 Pascal seconds therefore, we will mark this range which you are seeing here and corresponding to that we can determine the range of that temperature for mixing as well as for compaction.

So, this method is usually used for when we are dealing with unmodified binders, but as also we have discussed previously that modified binders even at higher temperature can show non-Newtonian behaviour and therefore, this equiviscous method might not give the correct value of the corresponding workability characteristics, corresponding value which will replicate the or which will identify the workability characteristics. So, for modified binders in fact a lot of studies have been done, few of the guidelines they say that manufacturer recommendation should be taken to determine the appropriate range of mixing and compaction temperature.

And then asphalt institute MS 2 from where I have taken most of the discussion related to mix design has identified two additional methods, one is the DSR phase angle method and the other is the DSR study shear flow procedure. As the name indicates mixing and compaction temperature using this procedure can be evaluated using a dynamic shear rheometer. So, what happens in a phase angle method that we will carry out frequencies we test on the binder at 0.1 to 100 radians per second and typically we will do this at three temperatures, so, we will do the frequency sweep tested minimum three temperatures.

And then what we will do because we have three temperatures, we will plot a master curve at 80 degrees Celsius. So, we will plot a phase angle master curve, and we have already discussed about the concept of master curve. So, we will plot a phase angle master curve at 80 degrees Celsius and then let us say if this is the frequency and this is the phase angle, if this is the master curve which we have obtained, so, what we will do it so, this is it at T reference of 80 degrees Celsius.

And then using this master curve, we will identify the frequency corresponding to the phase angle of 86 degrees. So, I will identify this frequency ω. And using this frequency I will use these formulas to calculate the mixing and compaction temperature and these are empirical formulas.

So, this mixing temperature this formula will give me the temperature in degree Fahrenheit so, we can convert it to degrees Celsius very easily. So, here ω is that frequency corresponding to the phase angle of 86 degrees. Another method which has been identified by asphalt institute is the DSR study shear flow procedure.

In this what we do, we do a shear stress sweep test. So, we will do a shear stress sweep test at a range of typically like 50 to 1000 Pascal's and then we will see the variation of the viscosity. So, it is expected that it vary after the particular shear stress the viscosity will become constant. So, usually the viscosity is taken as at 1000 Pascal's, so, at 1000 Pascal we will take these, so, this is the steady state viscosity.

So, again this test is also done at three different temperatures and at three different temperatures, we will note the steady state viscosity. And we will plot the variation of temperature versus steady state viscosity. So, this is steady state viscosity let us say this is SSV and we will have at this at three temperatures.

So, we will just see the variation and using this variation, we will we can find out the mixing temperature corresponding to the steady state viscosity range of 0.17 ± 0.02 Pascal second you see this is same as the equiviscous method, but the range of compaction temperature is a little different, it is 0.35 ± 0.03 Pascal seconds. So, corresponding to this range using the same process which we have seen here, we can determine the range of mixing and compaction temperature.

Here I would just like to mention that various researchers in the past have attended attempted to propose other procedures also, but these two additional procedures have been suggested by asphalt institute. So, this is what we will do it in the laboratory. Now, let us see what we have to do in the field that is in the plant and during the compaction process. So, here we have to understand that the laboratory mixing and compaction temperatures, they are not intended to represent the field mixing and compaction temperatures.

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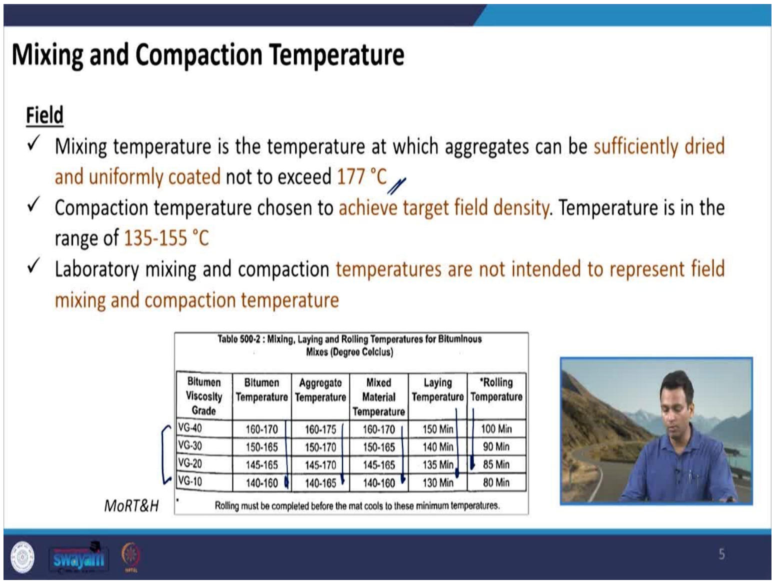

Table 500-2 : Mixing, Laying and Rolling Temperatures for Bituminous Mixes (Degree Celcius)

Bitumen Viscosity Grade	Bitumen Temperature	Aggregate Temperature	Mixed Material Temperature	Laying Temperature	*Rolling Temperature
VG-40	160-170	160-175	160-170	150 Min	100 Min
VG-30	150-165	150-170	150-165	140 Min	90 Min
VG-20	145-165	145-170	145-165	135 Min	85 Min
VG-10	140-160	140-165	140-160	130 Min	80 Min

* Rolling must be completed before the mat cools to these minimum temperatures.

So, in the plant, how we determine the mixing temperature that at this temperature the aggregate can be sufficiently dried so, that we can remove all the moisture from the aggregates and then it can be uniformly coated with the aggregates and this temperature should not exceed 177 degrees Celsius as suggested by asphalt institute. Also, the idea for compaction temperature is to achieve the target field density and this this range can be between 135 to 155 degrees Celsius.

If we look at the guidelines given by ministry of road transport and highways, we will you will see that this is the table which has been suggested for the mixing and compaction temperature and they have also suggested individual temperature for binder and the aggregate. So, you can see that that here depending on the type of bitumen, because of course, the workability characteristic is a function of the viscosity of bitumen, different bitumen temperature has been proposed, different aggregate temperature has been proposed, different mix the mixture temperature has been proposed. And then we have some minimum laying temperature and minimum rolling temperature.

So, laying temperature is that temperature at which we are basically spreading the mix and laying the mix in the field and then at rolling temperature we are finally using the rollers to compact the bituminous mixture at the desired density. So, these minimum temperatures has been suggested by MORTH. Since, the mixing and compaction temperature now we know, so, now at this temperature we have to mix the aggregate particles with the bitumen and we have to prepare the mixture.

So, here we are in the laboratory usually we select 3 to 5 trial binder contents, because one of the objective of mix design is to find the appropriate binder content. So, in order to find it binder content, I should have the variation of different volumetric parameters, different properties with respect to different binder content. So, I have to select 3 to 5 binder content at which I will prepare the mixture. So, usually based on experience the designer can select this range and usually they should be selected at a gap of around 0.5 percent

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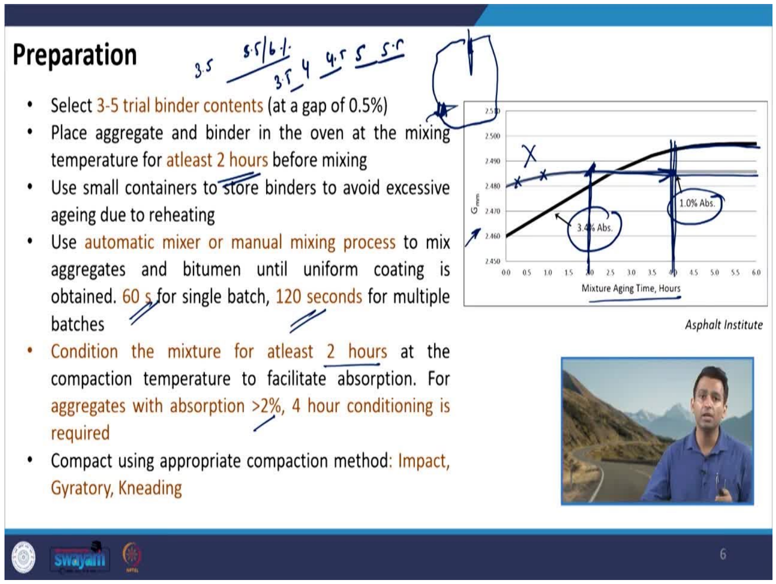

Then what we have to do once we decided what is the range let us say that the range is between somewhere between 3.5 to 5.5 or let us say 6 percent. So, this is the range at which we will be preparing and we have decided let us say to prepare at 3.5, 4, 4.5. So, this is 0.5 percent gap which we have decided to prepare for example.

Then we will place the aggregate, the measured aggregate for either one mix or a batch of mix and the measured binder in the oven at the mixing temperature for at least two hours before mixing. So, we should not excessively heat the aggregate in the binder to cause especially the binder to cause excessive ageing we should heat it to that particular period that uniform temperature can be arrived.

Then what we have to remember that the bitumen which we are using in the laboratory should ideally be stored in small containers rather than big containers. Because we have to prepare multiple mixtures and it is possible that we will hit the bitumen there will be reheating of bitumen at multiple times. So, in order to in order not to cause excessive ageing, it is important that bitumen is stored in small containers may be in multiple small containers.

So, now, when the aggregate and bitumen are sufficiently heated, we will take the measured quantity of aggregate and the measured quantity of bitumen and we will mix them either using a automatic mixer or we can also do manual mixing in the laboratory. And it is suggested that for single batch, if we are using an automatic mixer, the typical mixing time is around 1 minute that is 60 seconds.

And if you are using multiple batches at one go, it can be up to 2 minutes. So, in this period, the binder will sufficiently code the aggregate. And remember this mixing time is in laboratory not in the plant, in the plant, the mixing are typically around 10 to 15 seconds only. So, this process is only in the laboratory.

Then once the loose mixture is ready, then we will condition the mixture. So, we have to condition the mixture for at least two hours at the compaction temperature. So, before compaction, we have to allow the bitumen and the aggregate to stay together for some time and why this is important, because we have already discussed that the aggregates have pores. So, bitumen will get absorbed within this pores to a particular depth. So, this process takes time which means bitumen has to sufficiently stay with the aggregates and then only the appropriate absorption will take place.

Now, remember in the plant also bitumen and aggregates they are getting sufficient time before compaction, because it is either stored in the silos or it is when it is dumped in the trucks it during the transportation there is a sufficient period for appropriate absorption to take place. But in the laboratory many times we have a tendency because the marshal mix design which we adopt in India, it does not specify this conditioning period. So, we have a tendency that immediately after mixing we go for compaction which may not be correct.

And why this is critical? This is critical from the perspective of bitumen absorption, because if we do not give sufficient time for the bitumen to stay with the heated aggregates, the complete absorption will not take place. If the complete absorption does not take place, then the volumetric calculations especially the percentage absorbed bitumen, which is again related to effective specific gravity of aggregate, which is again related to theoretical maximum specific gravity of the mix, everything will change. So, therefore, it is very-very important that complete bitumen absorption should take place before we do the volumetric calculations or volumetric measurements.

So, asphalt Institute suggests that if the absorption of the aggregates with which we are making the mix is less than 2 percent, then at least two hours of conditioning should be is required before compaction, and if the absorption of the aggregate is more than 2 percent we can go up to 4 hour of conditioning. So, this is explained using this chart which you can see on the screen as I said the Gmm which is dependent on the effective binder content or the absorb bitumen, it changes depending on the mixture ageing time, which means the conditioning period.

So, if the absorption is 1 percent, then for some period the Gmm will increase, but after some time it becomes constant. So, we have to understand that, what is that time beyond which it should be constant. So, we should not try to compact here or here otherwise, this does not indicate complete absorption of the mix.

Similarly, if the absorption is more than 2 percent you can see that before a steady state is reached or a constant value of Gmm can be arrived, we need sufficient time for this to happen. So, depending on the absorption of the aggregate the conditioning period will also change. And this is a very-very important step which we have to remember.

Once, we have given sufficient time for the bitumen and the aggregate before compaction, so, that complete absorption take place then we have to finally compact the mixture the loose mixture. So, this compaction can be done using any compaction method depending on the mix design we are following it can be an impact compaction, if it is a Marshall mix design process it can be gyratory compaction, if it is a Superpave mix design process or it can be Kneading compaction if it is a heavy mix design process.

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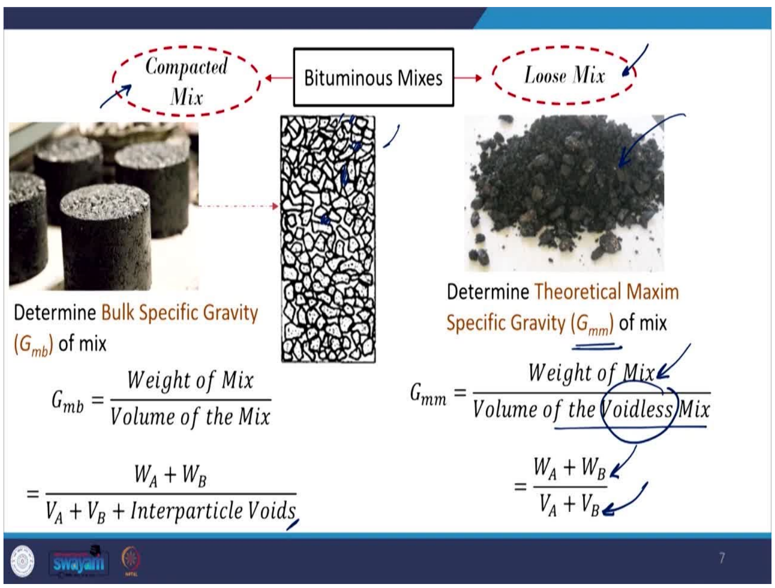

As I said that there are few measured parameters and then there are calculated parameters. So, before we look into the calculated parameters and the volumetric parameters, let us understand what additional measurement we have to do with the bituminous mixture. So, we have already tested the bitumen in the laboratory, we have confirmed bitumen, we have already tested all the physical properties of the aggregates in the laboratory.

Now, we have prepared the mix and, in this mix, we have to do two additional measurements in the laboratory related to the physical and volumetric properties of the mixture. So, these two measurements one measurement will be done on loose mixture and the other measurement will be done on a compacted mixture.

So, in the loose mixture, which will be something in this form, you we determine the theoretical maximum specific gravity of the mix. So, now, we are introducing or trying to understand a new parameter a new type of specific gravity, which is actually the specific gravity of the mixture and not for the aggregates.

So, this is a specific gravity of this loose mixture which we are. So, what is the definition of Gmm? Of course, it is weight per volume, but what is that volume, this is the volume of the voidless mix and this is the weight of the mix. So, weight of the total material divided by the volume of the voidless mix which means, I am not looking at or considering those voids which are between the individual particles, between the individual particles.

So, do not get confused here with the voids in the aggregate surface because that is now completely covered with bitumen and whatever bitumen absorption has to take place that has already taken place and we will see how to determine the bitumen absorption. But now, this voids which we are talking about is the voids between these individual bitumen coated particles. So, we are not taking that void into consideration, which means this is $\frac{\text{weight of aggregate+weight of binder}}{\text{volume of aggregate+ volume of binder}}$. In the subsequent slides we will see the procedure to determine this particular specific gravity.

And then we have compacted mixture with us and of course, I think you can imagine very easily that in the compacted mixture what will be the volume comprise of, this volume will be the volume of the bitumen, volume of the aggregate and there will be some inter particle voids, which is very clear here, these are the inter particle voids between these coated particles. So, here the bulk specific gravity of the mix which is denoted as Gmb is defined as $\frac{\text{weight of the mix}}{\text{volume of the total compacted mixture}}$, which means we are also including the inter particle voids in the calculation. So, VA + VB + inter particle voids.

Here, if you try to compare both the specific gravity just try to imagine that if we have a compaction process theoretically, which can reduce the air void of the mixture to 0 percent which means if I am able to compact the mixture such that there is no air void in the mixture, then Gmb and Gmm will be same, ideally, Gmb will be lower than Gmm in practical condition because we cannot compact the mixture ideally to 0 percent air voids. And again, just to again reiterate that Gmb and Gmm are mixtures specific gravities and not the specific gravity of aggregates.

So, let us stop here now, and then in the next presentation, we will continue discussing about the volumetrics. And we will first discuss about the laboratory procedure to measure the theoretical maximum specific gravity and the bulk specific gravity and then further, we will look at the will try to understand the calculated parameters and look at the derivations for the calculated parameters. We will continue this topic in the next presentation. Thank you.