Pavement Materials
Professor Nikhil Saboo
Department of Civil Engineering
Indian Institute of Technology, Roorkee
Lecture 36
Volumetrics in Mix Design (Part 2)

Hello friends, welcome back. And if you remember that in the last presentation we were talking about the volumetric aspect of our bituminous mixtures. And we discussed about two new specific gravities which is related to the bituminous mixture and that is the bulk specific gravity of the mixture, which was denoted by Gmb and the theoretical maximum specific gravity of the mix, which was denoted as Gmm.

So, just to review Gmm is the specific gravity of the mix corresponding to the void-less mixture, which means we do not consider the volume of the voids here. So this is the weight of the aggregate plus weight of bitumen divided by the volume of aggregate plus volume of bitumen. In contrast, Gmb, it represents the specific gravity of the compacted mixture.

And here we include the inter particle voids. And the definition or the calculation incorporates the $\frac{\text{weight of aggregate} + \text{weight of bitumen}}{\text{volume of aggregate} + \text{volume of bitumen} + \text{the inter particle voids}}$.

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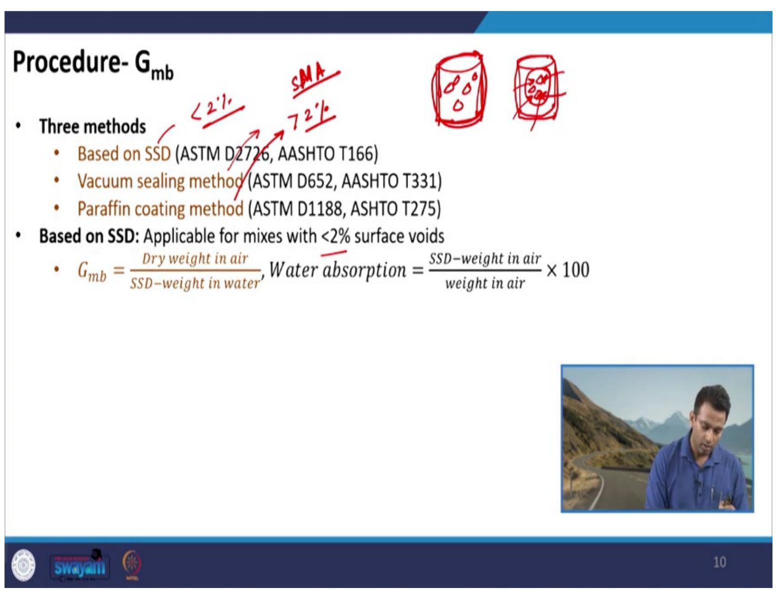

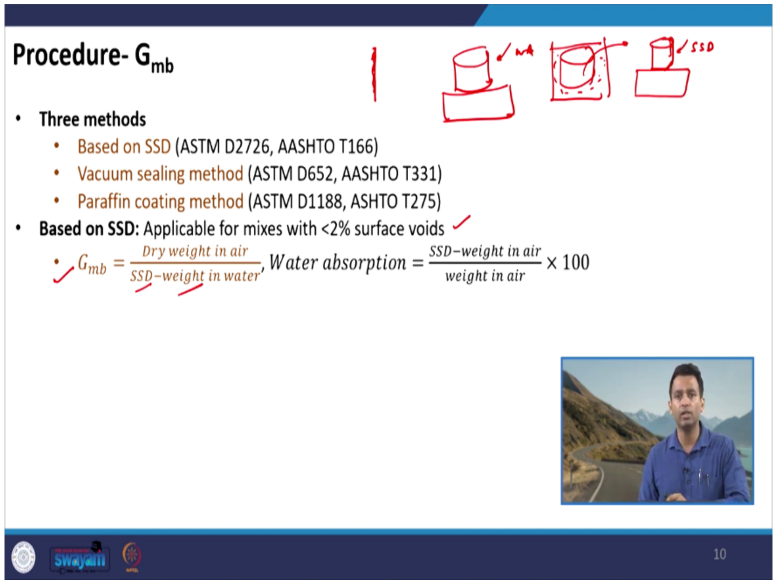

Today, we will start first by looking at the laboratory procedure to measure the bulk specific gravity of the mixture that is Gmb. So, there are three methods. The first method is basically for dense mixtures whose surface air void is less than 2 percent. So, and this is based on the saturated surface dry sample of the compacted bituminous mixture, then we have vacuum sealing method.

This vacuum sealing method can be adopted from for any mix for a dense graded mix even for an open graded or gap ridden mix. So, we will look at this method and then we have a paraffin coating method this is typically adopted when the surface voids of the mixture is more than 2 percent.

For example, let us say we have a stone mastic asphalt, or an open graded mixture, where the surface voids will be higher which can trap the moisture within the intra-particle voids. So, for that we use the paraffin coating. So, let us first discuss about the the specific gravity which is based on saturated surface dry specimens and as I said this is applicable for mixes with less than 2 percent void.

Now, before I move forward, let me try to explain you why we are talking about this surface voids here, because you see we are trying to have an indirect measure of this volume, this volume, the surface volume of the mixture and this volume comprises of everything is not, it comprises of the aggregate volume, the bitumen volume and also the inter particle voids volume.

So, we only need this surface, but if let us say the mixture is such that the surface voids are very high then what will happen it may it may happen that when we are conditioning the specimen inside water or taking the weight inside water some of the water particles will go inside because of high surface voids and it will occupy space.

Once it will occupy space it will change our weight, but this is not the volume I have to I want to represent I only want to represent the surface volume, the bulk volume. So, if water goes inside it will give it will give me a wrong weight inside water which I am doing to represent the volume, but the actual volume which I want is is not acquired in this manner.

So, therefore, for such mixture we have to ensure that I completely fill the surface voids so that water particles are not going inside the specimen. So, for dense graded mixture, usually the mixture is so dense that water particle usually will not get inside the mixture, so we do not have to worry about it.

So, here in the process what we do the process is similar to what we have done for aggregates. So we will first we will have the compacted specimen we will first take the dry weight in here so this is the weight in here. Then, we will take the weight inside water, we will take the weight inside water, and then and then we will take out the sample.

We will saturate surface dry the sample using a dry cloth and again we will take the weight of the SSD sample in the air and this process we have already discussed. So, once we do that using three these three weights I can determine the bulk specific gravity of the mix that is the $\frac{\text{dry weight in air}}{\text{SSD} - \text{weight in water}}$.

And similarly, I can also find out the water absorption at least how much absorption has taken place because the surface is not entirely smooth it is not, it has some roughness because of the presence of this aggregate particles. So, some voids will be occupied here. So, this to see how much water absorption has taken place I can do this calculation, similar to what we did for an aggregate particle,

$\frac{\text{SSD} - \text{weight in air}}{\text{weight in air}} \times 100.$

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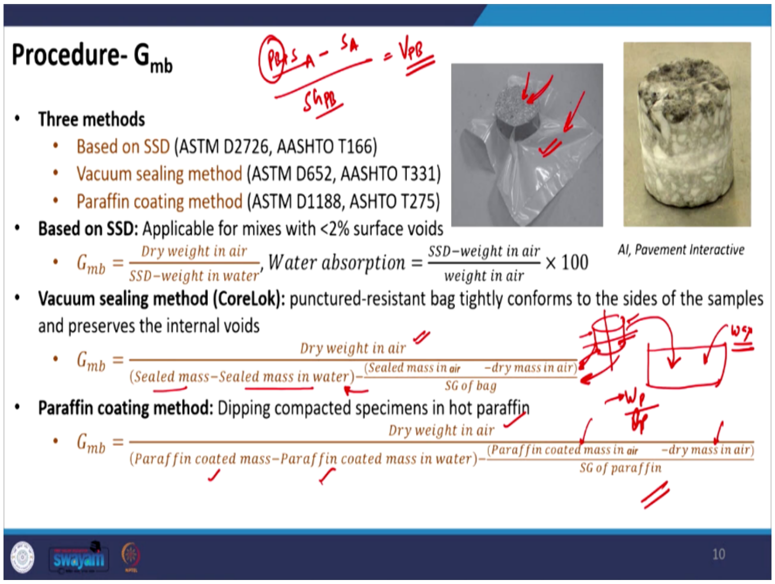

So, this was about the SSD method. In the vacuum sealing method this is usually done using a machine equipment which is which is called as CoreLok. So, this is a specific machine basically or an equipment. So, here what is done we will see our sample seal the compacted bituminous mixture in an airtight bag. So, this puncture resistant bag which tightly will hold the compacted specimen such that there is no voids inside the bag.

So, you see after I put the sample in the machine with the polyethylene bag, this specific bag, so it will, it will hold the specimen in such a way that there is no voids here, the voids will be completely sealed. And then, what we will do. And now, conceptually let us first discuss. So, the sealing has been done.

So, here the weights which are taken are, we will first take the weight of the sample in the air before the sealing has been done then we will put this entire specimen which is compacted specimen along with the seal bag inside water, along with the sealing bag and we will take the weight inside water and we will also take the weight of the sealed specimen in the air. So, the seal specimen in the air.

So, if we look at the fundamental calculation, so you see that here what I want only take the measurement corresponding to the bulk volume of the specimen. So, when I take a dry weight in air that is fine that is only for the specimen without the polythene bag, and then what I am doing in the denominator this is sealed minus, minus the sealed mass in water.

So this gives me a buoyant force corresponding to the volume, including the volume of the compacted specimen and the polythene bag. So, but since I am interested only in the bulk volume, I have to deduct the volume of the polythene bag from the calculation of this bulk volume. So, this is what I am doing here from this particular value I am deducting that particular volume.

So, how do I find the volume of the polythene bag for this I will have to know the specific gravity of the polythene bag. So, this is usually given by the supplier. So, I have the (weight of the polythene bag + the sample in air), so polythene bag +sample in air - weight of sample in air, dry sample in air, so this will give me the weight of the polythene bag.

So weight of the polythene bag divided by the specific gravity of the polythene bag is nothing but the volume of the polythene bag, so this is what I am doing here to remove that particular or to deduct that particular volume in the denominator so that I have the volume only for the bulk volume.

And then, the third method which is the paraffin coating method, what we do we take a container and we fill this with a wax paraffin wax a liquid paraffin wax will heat and we will fill it and for this wax paraffin also we have to know the specific gravity of the paraffin from the supplier or we have to do the measurements in the laboratory.

So, we will heat the wax will fill this with in a container, we will take the compacted mixture, which will be a mixture having a surface voids of more than 2 percent typically, and then we will dip this mixture into this particular the wax bath or the paraffin bath and this can be done. This can be done in I mean if, for example, if we are holding the sample from the top, so first we can dip the half of the sample.

Then we can rotate the sample we can dip the other half of the sample we can also dip the sample from this side and from this side so that a complete coating of the sample is done. And then the calculation is similar to what we did in the CoreLok method. First we will take the dry weight in air, then we will have the paraffin coated mass minus paraffin coated mass inside water and then we have to deduct the volume of the paraffin coating.

So, which means, I have to deduct weight of paraffin divided by volume of divided by specific gravity of paraffin. So, how do I know the weight of paraffin this will be the paraffin coated mass in air minus dry mass of the sample in air this will give me the weight of the paraffin coating divided by the specific gravity of the paraffin coating. So, these three methods are usually adopted to measure the value of Gmb in the laboratory.

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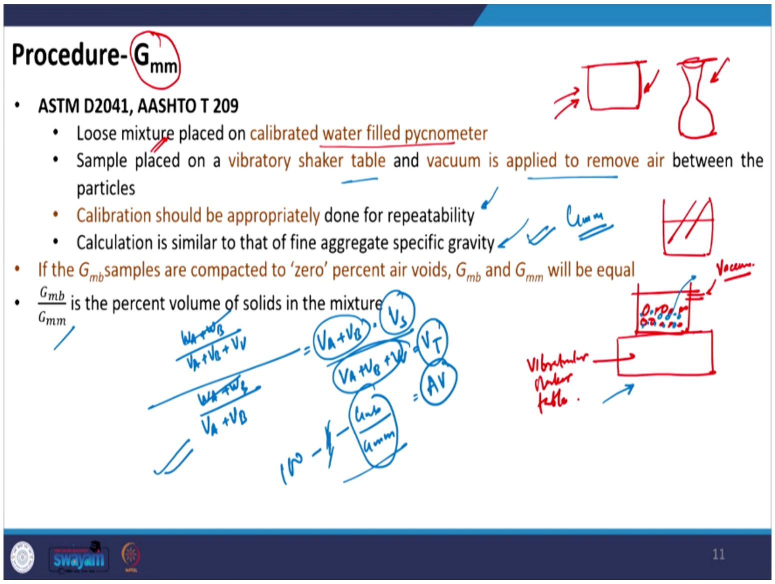

Then now, let us discuss about the procedure to determine the theoretical maximum specific gravity which is Gmm, so the corresponding AASHTO code and ASTM code has been mentioned in the presentation. So, usually what we do here first we will take the loose bituminous mixture, loose mixture of bitumen coated aggregate and we will place it on a calibrated water filled pycnometer.

So, we can we can have a pycnometer something like this, this depends on the equipment which we are using we can also have a pycnometer which looks something like this, and this pycnometer is should be calibrated what is calibration that we should know that what is the weight of the completely water filled pycnometer.

Now, sometimes because this this measurement especially Gmm has lots of variability in the lab and this variability arises mainly because that this calibration is sometimes not, sometimes not done properly, we have to remember that this particular weight, which I am saying that the calibration of the container, it depends also on the source of water, if you are using distilled water or water from different sources, then the weight will be different.

So every time you do the test using a specific source of water, the calibration should be done properly by filling this container completely with water and taking the weight of the water filled container, so coming to the procedure what we do here first we will take the container and then we will place our loose mixture here, and then what we will do we will cover this with water to a specific height and then we will put this on a vibratory shaker table.

And then we also apply a vacuum here, a vacuum is applied to remove the entrapped air between the mixture. So, what we do here, so there will be some air bubbles in the mixture when it is dipped inside the water. So, I have to remove these air bubbles because here I want the void less volume of the mix. So, I do not want any voids within the loose within the loose particle mixtures also.

So, I use the shaker table because the shaking will help to push the or to pull out the air bubbles inside and it will help the aggregate particles to settle or to orientate itself properly and then this vacuum is additionally applied so that we are forcefully pulling out the voids or the air bubbles between the aggregate particles. So, sample is placed in the vibratory shaker and vacuum is applied to remove the air between the particles as I said calibration should be done properly.

And the calculation then become very simple. So, similar to what we did for the in case of fine aggregate, calculation of fine aggregate specific gravity. The same calculation applies here that we will take the weight of the sample filled with pycnometer to the complete height and the weight of the pycnometer only with the water and then use the same calculation which we did for fine aggregate to determine the value of Gmm.

So Gmm can also be measured in the laboratory in this way. And as I mentioned previously, that if the Gmb samples are compacted to 0 percent air void, then theoretically Gmb will be equal to Gmm but this is usually practically this is not the case. Now, talking about their importance. The ratio of Gmb by Gmm is the percentage volume of solid in the mixture which is very obvious you can understand that this is Gmb is what?

$\frac{\frac{\text{Weight of aggregate+ weight of bitumen}}{\text{volume of aggregate+ volume of bitumen+ volume of voids}}}{\frac{\text{Weight of aggregate+ weight of bitumen}}{\text{volume of aggregate+ volume of bitumen}}}$. So, this gets cancelled. So, we have volume of aggregate plus volume of bitumen. So, this is basically the $\frac{VA+VB}{VA+VB+VV} = \frac{VS}{VT}$.

So, you see, this tells me that this ratio tells me that this is equal to the total percent volume of solid in the mixture which means if I just subtract $1 - \frac{G_{mb}}{G_{mm}}$, so this will give me what, air voids, is not it. So, the remaining voids is occupied by the air. So, 1 minus this value will give me or if this is in percentage, then 100 minus this value will give me the volume of the air voids in the mixture. So, I hope again that this is clear to you.

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Procedure- G_{mm}

- **ASTM D2041, AASHTO T 209**
  - Loose mixture placed on calibrated water filled pycnometer
  - Sample placed on a vibratory shaker table and vacuum is applied to remove air between the particles
  - Calibration should be appropriately done for repeatability
  - Calculation is similar to that of fine aggregate specific gravity
- If the G_{mb} samples are compacted to 'zero' percent air voids, G_{mb} and G_{mm} will be equal
- $\frac{G_{mb}}{G_{mm}}$ is the percent volume of solids in the mixture
- **Effect of binder content**
  - G_{mb}: At low binder content, aggregates are lubricated, which facilitates increase in density, and reduction in volume. Therefore G_{mb} increases. Once the voids are filled, additional binder increases the volume, G_{mb} reduces

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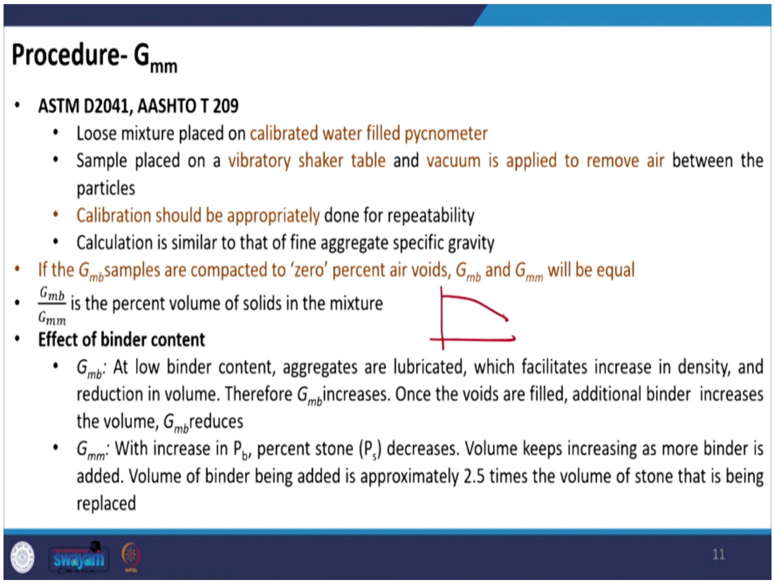
  - G_{mm}: With increase in P_b, percent stone (P_s) decreases. Volume keeps increasing as more binder is added. Volume of binder being added is approximately 2.5 times the volume of stone that is being replaced



Now, we will also talk about the effect of binder content on both these parameters that what happens if binder content changes what happened, what happens to Gmb because we are measuring in it in the laboratory and what will happen to Gmm. So, if you talk about Gmb, what happens that it lower binder content, we have to imagine this that when we start adding binder in the mixture and we start compacting it.

So, initially the binder is providing lubrication in the mix, it helps the aggregate particles to easily pass slide each other easily to orient itself in a much more denser mass. So, initially the binder content as we keep on increasing it provides lubrication which facilitates increase in density which means Gmb will initially increase with increasing binder content, because the volume is reducing but once the voids are completely filled, let us say you have this mixture you have the aggregate particles coated with bitumen.

And once these intra-particle voids are completely filled with bitumen that any additional binder which will add, it will basically increase the volume of the mix, and therefore, Gmb will actually reduce. So, the variation of Gmb with binder content is something like this, that it increases and then it decreases.

We have just discussed the reason now, but Gmm is not very similar to Gmb because it is in Gmm, we are not concerned about the air voids. So, if you see the definition, this is weight of aggregate plus weight of bitumen divided by volume of aggregate plus volume of bitumen. So, what happens with increasing Pb here, Pb represent the percentage of binder.

So, with increase, of course, if you see the total volume, the more you increase Pb the percentage stone will reduce if I am considering that Pb plus Ps is basically 100 percent. So, if I keep on increasing the percentage of binder, the relative percentage of stone will start reducing. And here, the volume keeps increasing as more binder is added.

So, if we keep on increasing the bitumen content, of course, you have more material in the mix. So, the volume will increase, but here you have to note that this volume replacement of the bitumen is almost 2.5 times of the volume of the stone that is being replaced. And, why I say that? Let us say you have a bitumen it is typical specific gravities 1.02.

And aggregate can have a specific gravity let us say of around 2.5, 2.6 or something like that, for same weight of aggregate and bitumen if the weight are same, this volume because if I say that G is equal to weight by volume, so $G_b = \frac{W_b}{V_b}$ and $G_a = \frac{W_a}{V}$. So, which means if I take the ratio Gb by or if I take the ratio of the aggregate versus bitumen,

So, $\frac{G_a}{G_b} = \frac{\frac{W_a}{V}}{\frac{W_b}{V_b}}$ if the weights are same, this will get cancelled. So, this is approximately equal to let us say 2.5. So, this is volume of bitumen by volume of aggregate and so you see volume of bitumen is equal to almost 2.5 times the volume of aggregate.

So, if you are adding more and more bitumen which means we are reducing almost 2.5 times of the volume of the aggregates, and that is why the more binder we add the Gmm keep on reducing because the extent of volume keeps on increasing and therefore, the Gmm will have continuously decreased with the increase in the binder content. So, I hope this is also clear that how the variation take place.

So, with this, let us now start discussing about the concepts of volumetrics. And here we will try to stick to the fundamental concepts and we will not try to memorize different formulas which we will be discussing rather we will try to derive them and we will try to understand about the derivation process. So, in order to understand that, we have to first understand how the different components are distributed in a compacted bituminous mixture.

So, if this is the compacted bituminous mixture, so what are the different proportions or what are the components of the volume of this particular mixture.

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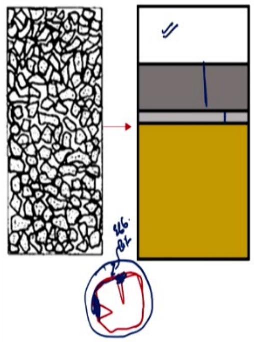
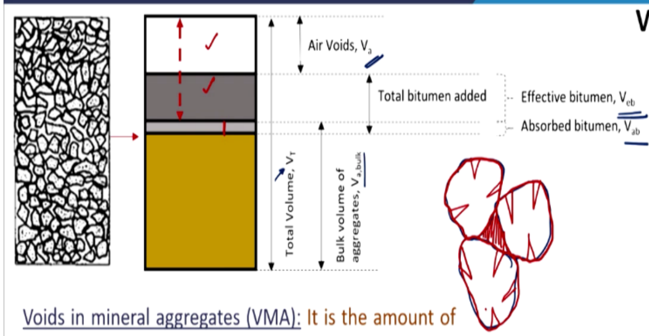
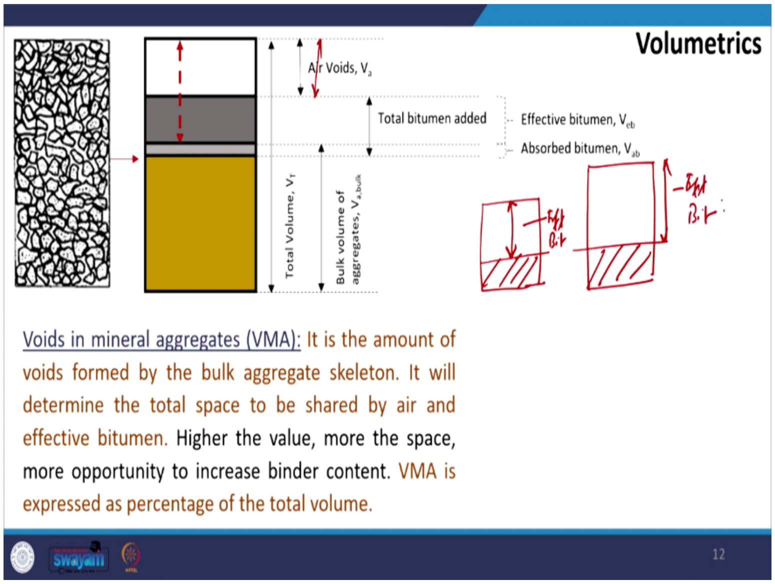
Volumetrics



Volumetrics



Voids in mineral aggregates (VMA): It is the amount of voids formed by the bulk aggregate skeleton. It will determine the total space to be shared by air and effective bitumen. Higher the value, more the space, more opportunity to increase binder content. VMA is expressed as percentage of the total volume.



So, in this mixture, we have the volume of solids, so you have the aggregate particles and I am just drawing one aggregate particle here because the next thing which I am going to show you will require this understanding, you have this aggregate particle and this volume which I have shown you is the bulk volume of the aggregate.

So, bulk volume of the aggregate and then we have the bitumen, but a part of the bitumen is within this aggregate particle. So, a part of the bitumen is absorbed and whatever remains is the effective bitumen. So, if you see here that within the bulk volume of the aggregate a part is the absorb bitumen and then whatever remains is the effective bitumen and then you have some space available that is the air void.

If I want to represent this volume using different terminologies, then how will I do that, for in our discussion, we will say that V_T is the volume of the total mix, so I am denoting it as V_T. So, this is the bulk volume of the mixture as just a volume of the aggregates as I just explained. So, this is the bulk volume of the aggregate.

And I am representing it as $V_{a,bulk}$, then we have the total bitumen, this is the total bitumen which I have added but a part of the bitumen is absorbed and we call it as absorbed bitumen and whatever remains is called as the effective bitumen on it. So, this is V_{eb} and V_{ab} and then the remaining part is the air voids, V_a.

The first parameter which we will discuss, which we will discuss today is voids is in mineral aggregates, VMA. So, what is the definition of VMA? It is the amount of voids formed by the bulk aggregate skeleton. So, as the definition says we are packing the aggregate particles and the inter particle voids between the bulk of aggregate particles.

what do I mean by bulk of aggregate particles let us say that you have this this aggregate, this aggregate, this aggregate and remember these aggregates already have some voids, So, I am looking only at the bulk of the aggregate I am not looking at these voids. So, the space formed between the bulk of these aggregates and this is not yet coated by bitumen, only aggregate.

So, the space formed by bulk of aggregate is basically the voids in mineral aggregates. And now, you can understand that this will comprise of what because this absorbed bitumen is inside the bulk. So, which means, what is the volume, (the volume is the volume of air + volume of effective bitumen). So, this represents the voids in mineral aggregate.

So, in fact voids in mineral aggregate it will determine the total space to be shared by air and the effective bitumen. So, higher the value more is the space more opportunity to increase the binder content. So, and it is expressed as the total volume and in fact when I say that higher the volume or the space, which means this does this also depends on the aggregate gradation for example, gab graded mix has higher VMA in comparison to dense graded mixture.

And therefore, as you can imagine for a fixed air void content, the gap, we have more opportunity to add binder in the gap graded mix in comparison to dense grade. So, let us say in dense graded, mix this is the space available, let us say that the air void content I am fixing that this is the air void which is permissible.

So, you see here you have this much space available for effective bitumen. So, this shows that the more VMA will be the more space and will the opportunity to increase the binder content.

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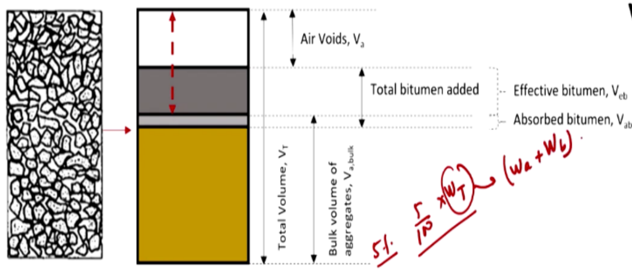
Volumetrics



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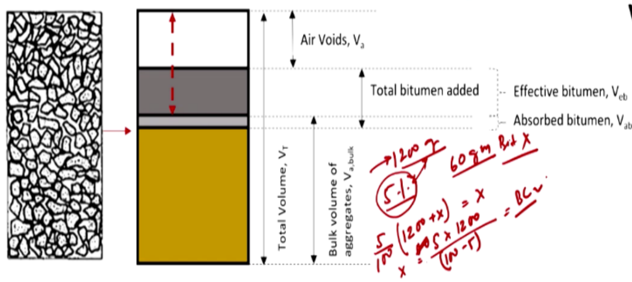
$$VMA = \left(\frac{V_V + V_{eb}}{V_T}\right) \times 100$$

$$VMA = \left[1 - \left(\frac{G_{mb}}{G_{sb}}\right)(1 - p_b)\right] \times 100$$

Volumetrics



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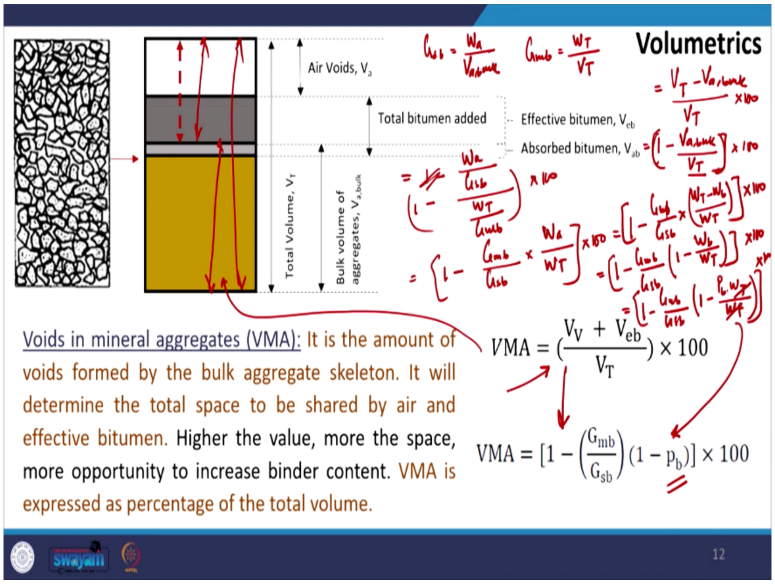

And, VMA is in fact one of the very-very critical parameters and also one of the very underrated parameters, which is many times ignored during the calculation. So, we will also have a special discussion on the importance of VMA. So, here before we discuss about the, maybe that I will discuss in the next slide that how the size of the aggregate particles also affects the value of the VMA. So, that I will discuss in the next slide.

So, before that since we have defined VMA. So, in terms of volume this can be written as $VMA = \frac{\text{equal to volume of voids+volume of effective bitumen}}{\text{total volume}} \times 100$. So, this is the fundamental definition which you have to remember. But now, if you look at this definition in the numerator and in the denominator we have volumes, but as I said we cannot measure the volume in the laboratory, we can only measure the specific gravity or we can measure the weight which means using only this definition in terms of volume is not sufficient to calculate the VMA.

So, we have to express this definition in terms of measurable parameters. And if you see most of the textbooks or different provisions, you will find this formula that

$VMA = [1 - \left(\frac{G_{mb}}{G_{sb}}\right) \times (1 - P_b)]$, where Gmb is the bulk specific gravity of the mix, Gsb is the specific gravity of the aggregates Pb is the percentage of binder just again to add here because we will be discussing in the derivation percentage of binder is expressed with respect to the weight of the total mix.

So, if I say 5 percent binder, it means $\frac{5}{100} \times W_T$. So, this you have to remember and weight of the total mix means, weight of aggregate plus weight of bitumen. So, this again this is also sometimes a confusion to many people, let us say you are using a 1200 gram aggregate to make a bituminous mixture and I say add 5 percent bitumen in the mixture.

So, many times what I have seen that there is a tendency to add only 60 grams, which means 0.05 ×260 grams bitumen, but this is wrong why because this binder content is by percentage of the total mix. So, what you have to do this is $\frac{5}{100}$ let us say the weight of the bitumen is X, weight of the aggregate is 1200 gram.0 So, $\frac{5}{100} \times (1200 + X) = X$. So, this is the equation which you have to solve.

So, ultimately X is equal to 5 × 1200. So, this is 0.05 ×12 or you can say $\frac{5\times1200}{100-5}$. So, this is the calculation which you have to do to calculate the actual binder content. So, this is just for your information. We will discuss this again, when we will discuss about some of, we will talk about an example on mix design. So, Pb is the percentage of binary in the mix.

Now, the question is that how do I come from here to here. So, we will look at the derivation by referring to this diagram which I have drawn here so that we can understand each step which we are discussing. So, you see in the numerator we have $V_V + V_{eb}$. So, I am just starting here.

So, in the numerator you have $V_V + V_{eb}$. So, this like I can write as $V_T - V_{a,bulk}$, I hope it is fine because this $\frac{V_T - V_{a,bulk}}{V_T} \times 100$. So, this again, $1 - \frac{V_{a,bulk}}{V_T} \times 100$. So here, I am starting my calculation here.

So, $(1 - V_{A,\ bulk})$ now, a bulk specific gravity of aggregate is equal to weight of aggregate by volume of aggregate bulk. So, I hope this is clear to everyone by now. So, $1 - \frac{V_{a,bulk}}{V_T} = 1 - (\frac{\frac{W_a}{G_{sb}}}{\frac{W_T}{G_{mb}}}) \times 100$.

So, $1 - (\frac{\frac{W_a}{G_{sb}}}{\frac{W_T}{G_{mb}}}) \times 100$. So here I can just, I am just rearranging it this is $1 - \left(\frac{G_{mb}}{G_{sb}} \times \frac{W_a}{W_T}\right) \times 100$. This I am again trying to add something here, this is $1 - \left(\frac{G_{mb}}{G_{sb}} \times \frac{W_T - W_b}{W_T}\right) \times 100$.

So this can further be written as $[1 - \frac{G_{mb}}{G_{sb}} \times \left(1 - \frac{W_b}{W_T}\right)] \times 100 = [1 - \frac{G_{mb}}{G_{sb}} \times \left(1 - \frac{P_b \times W_T}{W_T}\right)] \times 100$.

$$= [1 - \frac{G_{mb}}{G_{sb}} \times (1 - P_b)] \times 100$$

So, here this gets cancelled and this is what is written is actually equal to this if you see, so you see from the fundamental definition of VMA or the definition based on volume of VMA, we can very easily derive the actual formula for the calculation of VMA using the measurable parameters, so I hope that this calculation, this derivation is clear to you and similarly, we are going to look at other derivations related to other volumetric parameters.

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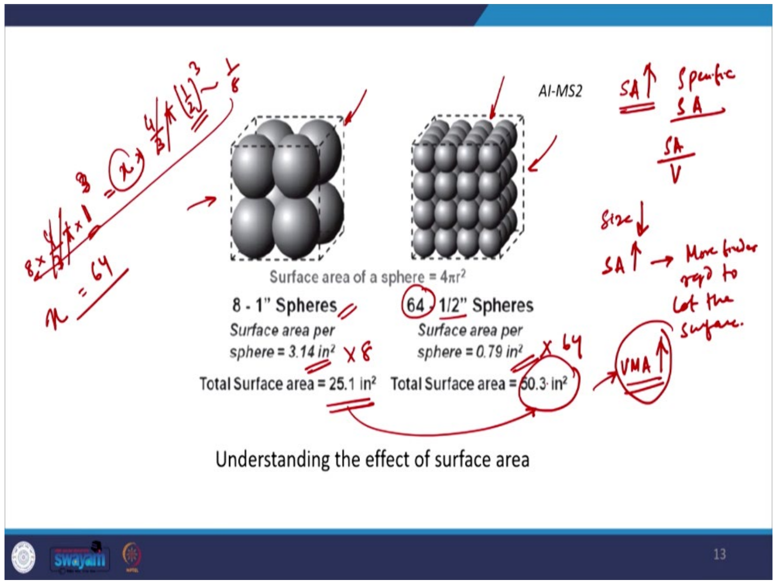

But before that, as I said that the VMA is also a function of the size of the aggregate particles. So, here you have to remember that as the nominal maximum aggregate size in the aggregate gradation decreases, the surface area increases. So, many times people say that surface area increases.

So, try to remember it in this form that the specific surface area increases and specific surface area is the surface area per unit volume. And therefore, more binder is required to sufficiently code the aggregate particles. So, if the surface area increases, because, here it is saying that if the size of the aggregate is small, the surface area will increase if the surface area increase which means more binder is required to coat the surface, to coat the surface.

And as in the mix usually the air void criteria is fixed, which means that the VMA should increase, VMA should increase to accommodate this higher binder content. So, in dense graded mixture with lower nominal maximum aggregate size, the requirement of minimum VMA should be higher, why it should be higher because in that mix we will have aggregates with smaller sizes.

Which means more surface area, which means that more binder will be required to appropriately coat these smaller size aggregates and this also can be understood using this example which is shown in the slide. And here you see that we have a constant volume of a cube and inside this we are fixing some spherical we are adding some spherical, spherical particles.

So, what is happening here, that let us say that in the first cube, we can add just 8 spherical particles. So, let us say we have 8 spherical particles of approximately 1 inch dia. So, if you calculate the surface area per sphere, so the surface area is basically equal to $\frac{4}{3} \times \pi r^3$. So, if you do the calculation of $\frac{4}{5} \times \pi r^3$, you will get 3.14 inches square and if you multiply this with 8 you will get 25.1 inches square.

So, in the same volume if I had to add spheres of smaller dia, let us say we are just reducing the dia by half of the initial one which means half inches sphere, if I want to add, it is 64. The question is, why it is 64? So, you can do this calculation very easily if you are adding 8 spheres into the volume which is $\frac{4}{3}\pi$ let us say it is a unit πr^3 cube then the question is how many spheres can be added in in the same one with a half the dia.

So, this is 1 because we are taking 1 inch dia here. So, this is half inches dia. So, if you do this calculation the value of x will come out to be 64. So, you can see that very easily this gets cancelled completely. So, this is this becomes equal to $\frac{1}{8}$ and x becomes equal to 8×8 which is 64. So, you see 64 half inches spheres can be combined can be put in this volume and per, per sphere it is again $\frac{4}{3} \times \pi r^3$.

So, this is 0.79 inches square and the total surface area is 0.79×64 which is 50.3. So, you can see that almost the surface area doubles here, if you reduce the size of the particles. So, which means that if the surface area is more than again you have to add more binder to completely coat this particular surface.

So, I hope the importance of VMA and its relation to surface area is clear here. And now we will stop here and then we will continue our discussion on other volumetric parameters. We will look at various other derivations which are very important to understand the volume metrics and then to complete the mix design process. Thank you.