Pavement Materials
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Lecture: 17
Aggregate Properties (Part-1)

Hello everyone. Welcome back. In the last lecture, if you remember, we were talking about the shape and texture properties of the aggregate.

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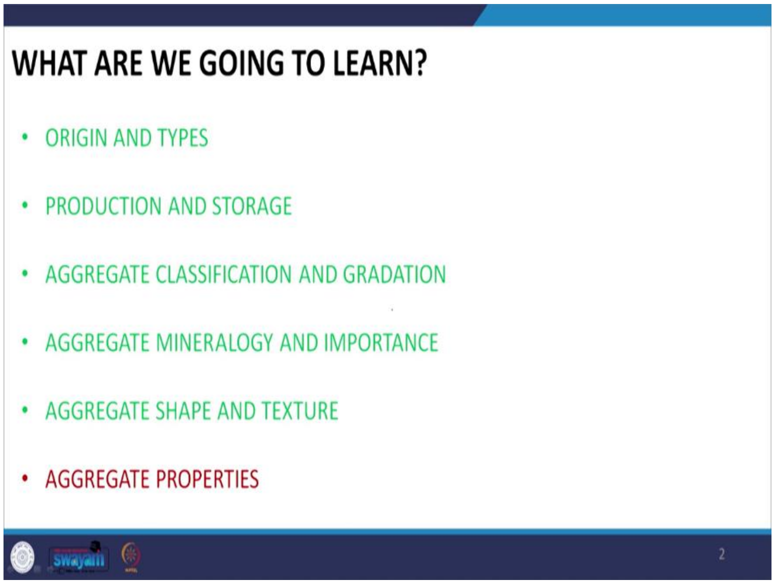

Before ending the last lecture, I discussed that there is one point which remains to be discussed under the topic of aggregate shape and texture and that we will discuss today and we will also start discussing about the aggregate properties which will be the last phase of our discussion on mineral aggregates.

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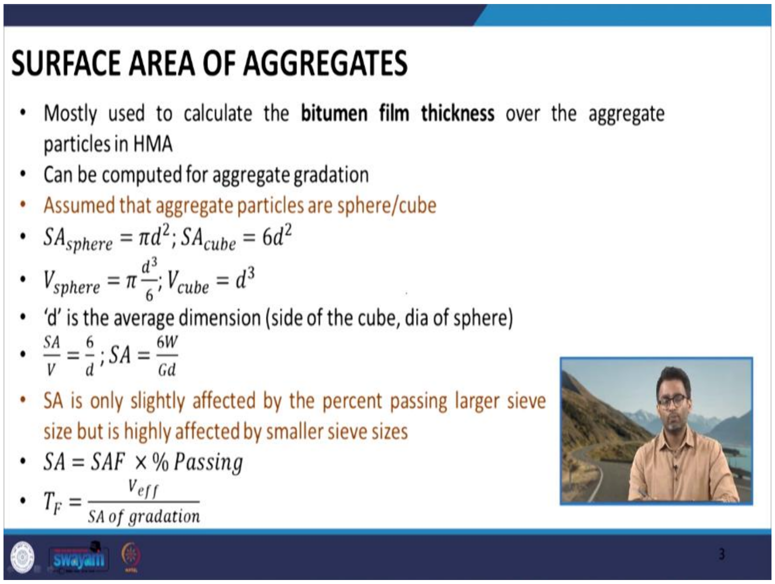

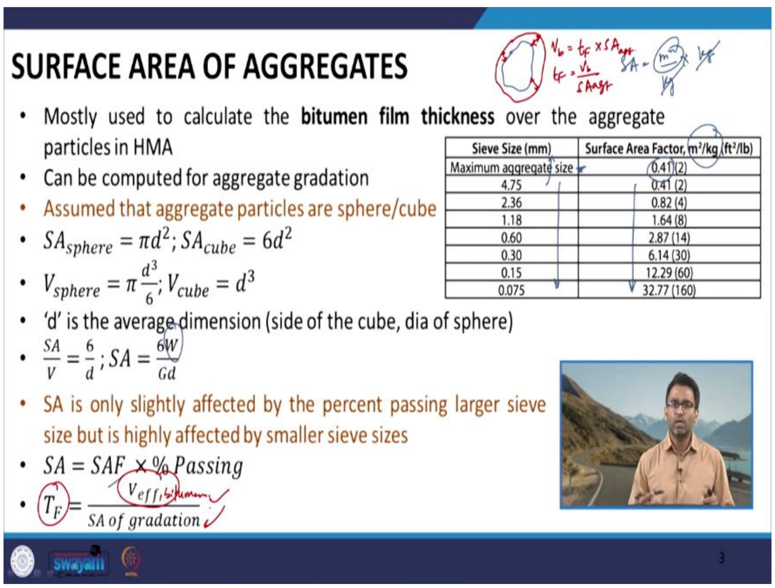

So, before I begin to discuss about the properties of mineral aggregates, let us discuss one additional point related to the shape and surface texture. And if you remember that before concluding, I told that there is a food for thought to try to figure out, how the surface area of an irregular object like aggregate can be mathematically calculated or can be experimentally measured. So, researchers have you know put a lot of effort in this direction to understand about this characteristic specially about surface area of irregular objects like aggregates and till date we still use approximate procedures specially for mineral aggregates to estimate its surface area.

In relation to pavement engineering, why is surface area of aggregates important to us? So, we will see later not in our discussion today on mineral aggregates, but later when we start discussing about hot mix asphalt or bituminous mixtures, we will see that in bituminous mixture the film thickness of the bitumen over the aggregate particle is very critical and is directly related to the durability of the mixtures.

So, it is of interest to know that in a given mix design process for a given aggregate gradation for the corresponding volumetrics of bituminous mixtures, what is the average or the apparent film thickness of the bitumen over the aggregate particles. So, researchers have concluded that there is a particular appropriate range in which this film thickness should lies and if other volumetric parameters are controlled in a proper way, then this range of film thickness will ensure the production of a durable bituminous mixture.

I am not discussing in detail today about the film thickness aspect, but today our main aim will be to understand the approximate calculation involved in estimating the surface area of aggregate and later when we discuss about the volumetrics of bituminous mixtures, we will use this concept which we learn today to calculate the apparent film thickness of the bitumen film over the aggregate particles in a bituminous mixture.

Actually the calculation of film thickness is a function of aggregate gradation, because this we have already discussed that be it a bituminous mixture, be it a concrete mixture, the aggregate particles are of different sizes and they are strategically designed to meet some design purpose or to satisfy some performance attributes. The calculation of surface area is also a function of aggregate gradation, because if we start varying the amount of aggregate particles and the type of aggregate particles within the mixture, it is very obvious that the average surface characteristic of the entire mixture will also keep on changing. To approximately have an estimate about the surface area of aggregates or to say aggregate gradation, it is usually assumed that aggregate particles are either spherical or cubical in nature.

Now, the question is why are we you know going for both this assumption, because very interestingly we will see that the ratio of surface area to volume for both sphere and cube is a constant. I mean in the sense that in some way we are defining the average size of aggregate particle, I will come into the calculation. So, this assumption of sphericity or cubicity of the particle which we are discussing here, this also ensures that we are not considering our aggregate particles to be entirely spherical or rounded in nature, because aggregates are usually crushed in nature. So, it also has cubical characteristics. So, it is more logical to you know consider the aggregate particle somewhere between a sphere and a cube.

So, let us see how the calculation for both the sphere and cube is done. So, if we see the surface area of sphere, it is πd^2 and surface area of cube it is $6d^2$, I mean what is d here. So, if it is a sphere, so d is representing the dia of the sphere, whereas if it is a cube, I am just drawing the two-dimensional picture of this cube of course, it is a 3D object. So, for the cube here d represents any of the side.

Now, the reason for assuming this is that we typically use sieves to quantify the size of the aggregates. So, if let us say it is a purely cubical aggregate or purely spherical aggregate and let us say the value of d here is 19 or let us say 18.5 mm, no not 18.5, let us say 19.5 mm, whereas the dia of this sphere is also 19.5 mm. In this case, you will agree that if we have a sieve of sieve opening size 19 mm, then both this particle will get retained on this sieve. So, that is why these particular dimensions are used to define the average dimension of either a sphere or a cube.

Now, moving on, so we know, now we know what is the surface area of sphere and cube, whereas the volume of sphere is $\frac{\pi d^3}{6}$ and the volume of cube is d^3. So, actually this is $\frac{4\pi r^3}{3}$. So, in terms of d or the diameter it is $\frac{\pi d^3}{6}$. So, here I have already mentioned that d is the average dimension, so side of the cube or the dia of the sphere.

Now, individually if we take the ratio of surface area to volume for both the sphere and the cube, what do we get? So, if we just divide this, this square gets cancelled here, this pi gets cancelled here, this 6 goes to the numerator, so it is $\frac{6}{d}$. So, the $\frac{SA}{V} = \frac{6}{d}$ and similarly for this it is very straightforward it is also $\frac{6}{d}$. So, the surface area per unit volume for both sphere and cube comes out to be $\frac{6}{d}$.

Now, volume can be represented in terms of mass and specific gravity. So, we know that specific gravity is equal to weight by volume. So, here volume becomes equal to weight by specific gravity. So, if we just put $V = \frac{W}{G}$ then $SA = \frac{6W}{Gd}$. Here you can see if you know the average size of the particle, if you know the weight of the particle and if you know the specific gravity of the particle, then very conveniently we can approximately calculate, you can say the apparent surface area of the aggregate particle.

Now, we will see in one of the calculations in the next slide, if you will see it is $\frac{6W}{Gd}$. So, when the dia of the particle increases, when the size of the particle increases the surface area will basically keep on reducing. So, of course, it is a function of other parameters like weight and specific gravity. So, I am just assuming that both of the weight and specific gravity is constant and I am seeing how things will change when the size of the aggregate will change. So, we will see later that surface area is only slightly affected by the percent passing larger sieve size, but is highly affected by smaller sieve sizes.

Now, here I am also trying to explain about the surface area not of individual aggregate particles, but of an aggregate gradation because that is of our interest because we have a mixture here in question be it a bituminous mixture, be it a concrete mixture. So, for me it is more logical to understand the surface area characteristic of the mix entirely rather than individual aggregate particles. So, that is why I am trying to shift my discussion from the surface area of individual aggregate particle to the actual you know the gradation of the mix which I am looking at.

If you see some of the available literatures which discusses about the concept of surface area. So, they typically say that $SA = SAF \times \%\ Passing$. So, well percent passing we understand because it is telling that let us say you want to find the surface area of aggregates which is passing 19 mm and let us say retained on 10 mm. So, here I am looking at the amount of particle also because here weight is one of the factor. So, I am interested to know that how much percent of a particular size is available in the mix. And, this is how the percent passing is coming in the calculation.

Talking about the surface area factor typically you will see a table of this form in most of the textbook or literature where for different sizes. So, they say that you know for maximum aggregate size it is 0.41 m^2/Kg, the surface area factor. And, you will see that above 4.75 they typically assume that the surface area factor is constant and it is 0.41. And, I will tell you why they consider this and for other sieve sizes down to 0.075 mm you will see that the surface area factor keeps on increasing. And, the unit is meter square per kg and therefore, that $SA = m^2/\text{Kg} \times \%\ Passing$ which will also be in kg in terms of weight. So, this gets cancelled and the answer which you get is in terms of meter square. This I will not discuss in detail today, that if you know the I will just try to explain the concept here.

So, you see if this is the aggregate particle and say this is the film of the bitumen. And, you are interested to find out the average film thickness of the bitumen about this aggregate. If I want to find out the entire volume. So, I can say that volume of this bitumen volume of this bitumen is equal to thickness of the film into the surface area of the not exactly the aggregate, but somewhere around the aggregate. Because, the film is very small that is why surface area of aggregate can be considered as the surface area for which I am trying to find out the volume of bitumen.

So, here therefore, film thickness becomes equal to volume of bitumen divided by surface area of aggregate and that is what is written here. So, because we are discussing in terms of gradation. So, the formula says that film thickness is equal to volume of it should be bitumen actually effective bitumen. We will discuss later about this terminology effective bitumen, but let us say this is volume of bitumen and surface area of the aggregate gradation. So, this is how you will calculate the film thickness, but not in our discussion today later, but today we are just trying to understand about the estimation of surface area of aggregates. So, with this understanding let us try to see or take an example and try to understand how the calculation will be done.

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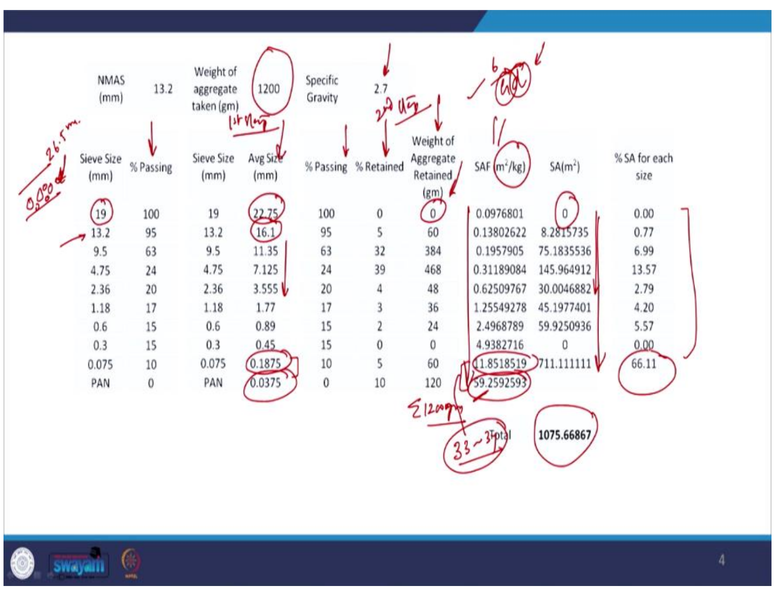

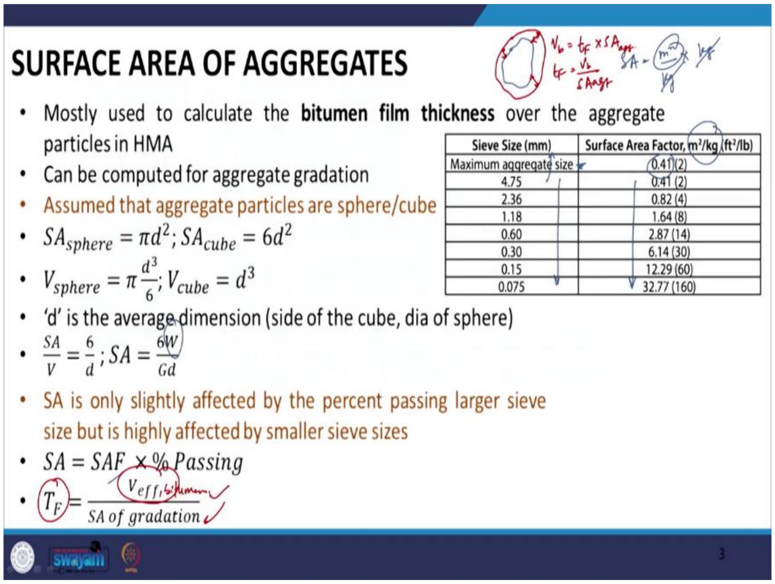

So, you can do the calculation using a simple excel sheet. Let us say that you have this gradation. So, this is a gradation for which you are interested to find out the surface area. So, if someone asked that this is the aggregate gradation and calculate the surface area for this aggregate gradation, how will you do that? So, for the calculation there are few inputs which will be required which you have to fix. So, let us say that we already know that the nominal maximum aggregate size of this gradation is 13.2 mm.

The let us say that we have taken 1200 gram of aggregates because weight is a parameter here. So, you will have to know how much aggregate you are actually taking in order to calculate the surface area corresponding to that particular gradation and then you will need the specific gravity G. Now, let us say that the G for this gradation is equal to 2.7 g/cm^3. So, for this aggregate gradation let us see how the calculations will be done.

First you have sieve size, this is the first step that for the given sieves you have to calculate the average size because you see 19 mm, any material which is retained on 19 mm is not necessarily 19 mm is not it, it will have other sizes also. One way is to consider that if aggregates are retained on 19 mm then this is the average size is 19 mm, but here in this example what we have taken that the next sieve to it is 26.5 mm. So, this average size is taken as $\frac{19+26.5}{2}$. So, whatever gets retained on 19 mm will have an average size of 22.75.

Now then the aggregates passes 19 mm and is retained on 13.2 mm. So, definitely again there is a range of aggregate particle sizes. One way is to take that the average size is 13.2 mm only or the other way which we have taken here is that we have taken the average size is $\frac{19+13.2}{2}$ here. This is how we have done the calculations here and similarly the calculations have been done for other sieve sizes as well.

So, the first step is to define the size either you can take the size of the sieve as it is or you can take the average size as I have shown you in this particular table. The second step is to calculate the amount of aggregates that will be retained on each sieve because the sieve size distribution is quantified in terms of percent passing, we need to know the amount of material corresponding to each sieve size. For example, what is the proportion of weight of total aggregate which is retained on 13.2 mm or retained on 9.5 mm and so on. This calculation we have already learned so I am not discussing.

So, using percent passing I can calculate percent retained and using percent retained I can calculate the weight of aggregate retained because I have the total weight of aggregates here. So, obviously, the summation should be 1200 grams. So, this is the second step. Now comes the third step which is very easy calculating the surface area factor and we know that the formula is $\frac{6}{Gd}$. We have G here which we are assuming as constant here for all the sizes and we have d here which we have taken from the first step. So, using this you can calculate in meter square per kg the surface area factors.

Now for example, you see the surface area factor in case of materials passing 75 micron here is 59.25 which does not match with our previous slide where it is 32.77. The reason being firstly, their consideration of specific gravity can be different probably they have taken a specific gravity of 2.65. The main difference lies in the consideration of size. Here they are considering 0.075 mm as the size for which 32.77 m^2/Kg is the surface area factor. But in our calculation you see the way we have defined the size this is not 75 micron this is 0.03. And for 0.03 the surface area factor is 59, whereas for 0.1875 the surface area factor is 11.8.

So, of course, if you do the interpolation for 0.075 which will be somewhere between 0.03 to 0.18 the value which you will get will be close to 33 or 34 which approximately matches with the surface area factor which I showed you in the previous slide. So, it all depends how we are considering the size of the aggregate and what is the value of specific gravity that we have chosen. But I mean this is the fundamental way of defining the surface area factor.

So, now, once we have the surface area factor you can very easily calculate the surface area because you have the respective weight. So, just multiply the surface area factor with the corresponding weight to calculate the surface area for different sizes. And for this entire gradation you just need to do the total of the surface area and as you can see the total comes out to be 1075.66 m^2. So, this is the way of calculating the surface area of any given aggregate gradation. So, I hope that this calculation is pretty much clear to you and you understand the concept for approximately calculating the surface area and using these values you can try to again understand more about the effect of sizes on the total surface area.

For example, if you see the percent distribution of surface area you will see that almost 66 percent of the surface area of the total gradation comes only from material which is passing 75 micron sieve. So, you know in this way you can have a fair idea about the effect of aggregate size on the distribution of surface area within the aggregate mixture. And in fact, this distribution is very important in relation to the performance, in relation to the bitumen film thickness because depending on the amount of fine aggregates, I mean more are the amount of fine aggregates more will be the requirement of bitumen to produce a mixture with some apparent or some standard range of film thickness. So, it becomes critical that way.

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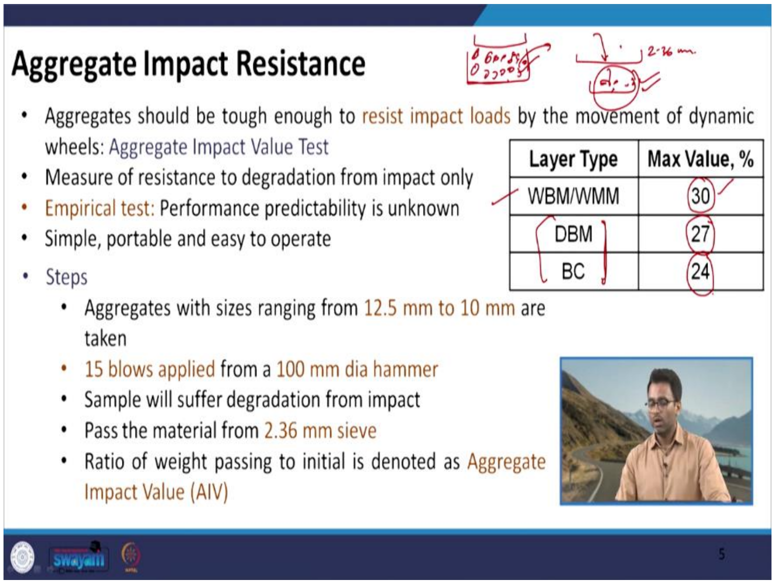

So, now, we will start discussing about the aggregate properties and the first property which we are going to discuss is related to the impact resistance of the aggregate. Now, before I begin discussing about the aggregate properties, I just want to make clear few things which should come in our mind when we are learning about these properties that ultimately whatever property we are going to study or we are going to measure in the lab let us say should have some relation to the performance of the actual mixture. Because ultimately the decision of how many test should be done and which critical should test, test should be done is very important.

So, let us say if we have to do 15 number of experiments for 15 different aggregate properties, but out of that 15 the purpose for which I am using the aggregates, let us say only 5 properties are sufficient to tell me about the performance of the entire structure for which I am going to use this aggregates, then we need not do those 13 or 15 set of experiments. We should only consider those 5 set of experiments which tells us about the performance of the final structure in which I am going to use this aggregate as a material.

Whenever we are trying to learn a concept a test method immediate question which should come to our mind is how important this test is. Has this test shown any correlation with the actual in field performance of the structure? If it has shown then of course, this test becomes very important for the selection of materials. If I have some limiting values for these aggregate properties, then definitely the next time when I am going to select a material I will just do this test and see whether it qualifies the minimum standard. If it does I can very confidently use this material for construction. So, this is the main purpose of learning about the aggregate properties and conducting different tests on aggregates.

So, as we move forward as we discuss about this property we will also discuss about the correlation which have been found by other researchers with performance in relation to these properties. Of course, why we are trying to find out the impact resistance because this is a measure of toughness of the aggregate. So, we want that our aggregate should be tough enough to resist the impact loads and from where these impact loads are coming it is assumed that it is coming from the movement of the dynamic wheels which may not be in the similar way in which we are applying the load in the laboratory.

Now, this is also a very important point that the way we are doing this test, the way we are quantifying the parameter in the laboratory should also have some relation to the way the load is appearing in the field. For example, if the load is dynamic it is better to do a dynamic test in the laboratory because that will have a better simulation to what is happening, but many a times to simplify the experiments to ease the procedure we take into consideration several assumptions and we also do experiments in a more convenient manner rather than in a more actual process in which the material is actually exposed in the field, anyway.

So, here it is assumed that the vehicles are applying dynamic load and this dynamic load causes impact on the aggregate particles and in specific locations there actually are some impact for example, when the vehicle is moving over the speed breaker. So, as it goes as it jumps on the other side of the speed breaker, let us say if the speed breaker is not designed very properly or the speed of the vehicle is higher then there can be an impact on the pavement and we have to ensure that under such condition the aggregate does not have the tendency to break down and this is the reason why we do an aggregate impact value test.

This test is used to see the resistance of the aggregate to degradation from impact only. So, here we are not considering any other effect. Of course, this is an empirical test and studies have not shown very promising correlation of performance of the actual pavement in forms of different distresses and the impact value of the aggregate. For example, studies have found that even aggregates with higher impact value or you know aggregates have showing more degradation under the impact test in the laboratory has given satisfactory performance in the field.

So, again it is a question that what is the actual need of this test in the laboratory, but this is a pass or fail kind of test which can be used to differentiate between different aggregate types and then gives us some indication about the choice of aggregate which we can make before doing the construction. One advantage of course, of this equipment is that it is simple, portable and it is easy to operate. So, this makes this equipment very handy in nature and any non-technical manpower can also be used to operate this equipment.

If we discuss about the steps then what we do here we take aggregates with size ranging from 12.5 mm to 10 mm which means this test is done on single sized coarse aggregate. Then we have a container here, this container is actually filled with the aggregate I will show you some of the images in the next slide. So, this container is filled with aggregate in a specific way this also I will discuss in the next slide and then we apply 15 blows using a specific type of hammer in a specific manner.

So, this is a 100 dia hammer and we apply 15 blows. So, once you apply 15 blow you can imagine that this aggregates will suffer degradation from the impact of the load and few aggregate particles will break down into smaller sizes. So, what we do after the test we take out this material which has suffered degradation. We take a 2.36 mm sieve and we just pass this material from this sieve and we see that how much material is collected here.

So, impact value is the ratio of weight of material which is passing divided by the initial weight. So, understand that if the aggregates are tough enough then the amount of degradation will be less. So, the amount of material passing 2.36 mm sieve will be less. So, the impact value will be lower which means more the material is passing higher will be the impact value.

So, specifications desire that for aggregates used in the different layers the impact value should not exceed a limiting value which has been decided empirically based on experience. So, of course, lower value will indicate tougher and more wear resistant mixture and this test can be done to select the appropriate type of aggregates to be used in construction.

You see that for this is what our ministry of road transport and highway specifies depending on layer type because WBM and WMM they are base layers used in flexible pavement construction. So, the maximum value limited here is 30 percent. Again the reason being these are layers placed at lower depths. So, the magnitude of stresses in these layers will be lower in comparison to layer which are placed at the top of the pavement.

So, that is why a maximum value is on the higher side. But for surface layers and binder courses like dense bituminous macadam and bituminous concrete. So, these are typical bituminous layers used in the construction of flexible pavement in India and you can see that DBM which is a binder course has a limiting value of 27 percent maximum whereas, a bituminous concrete which is typically placed as the wearing course or the surface layer has a limiting value of 24 percent.

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These are some pictures of the impact value machine. So, this is the complete machine you can see here. So, we have two vertical guides here. So, that this load can move up and down in this guide. If you can see this hammer, this is the hammer, this is actually 50 mm in depth and 100 mm in width 100 mm is the dia. Then we have a lifting handle here which is this one is shown here and this lifting handle has locking pin here as well as it has release pin. So, once the pin is released the load can be moved up and down. The height of fall is around 380 plus minus 5 mm this is also standard.

We have a sample measure here the sample measure is shown here. So, the sample measure is 75 mm in dia and it is 50 mm in height, but this sample measure is not directly put in the equipment. So, this sample measure is used to measure some amount of aggregates and this aggregate is then placed in the case hardened bottom cylinder. So, there is some difference. If you can see right now in my hand I have this sample measure which is basically 75 mm in height and 50 mm in dia and this is used to measure the aggregates.

So, what we will do, we will take single sized aggregates and fill this measuring cylinder in three layers and each layer we will compact with this standard tamping rod. This tamping rod is 10 mm in dia and the approximate height is 230 mm you fill this in three layers. So, after each layer we will give 25 random blows, and then we will place the next layer place give 25 random blows, and at the end the extra material which will be there we will just remove this material. And this will be directly transferred this entire material will be directly transferred to the case hardened bottom cylinder which is shown here, in this cylinder at one go.

Here we are not again filling it in layers, after filling it we will give 25 blows again just to compact it at place properly and the dia of the cylinder is approximately 102 mm because you see we have the hammer here which is 100 mm dia, this should completely have immersed within the case hardened bottom. So, that is why the dia is little higher and the height is basically 50 mm. These are some of the details of the equipment and the process in which the test is done.

With this we will stop here today by now we have discussed about the impact resistance of the aggregate and we have discussed about the aggregate impact value test and its procedure. So, in the next class we will continue discussing about other properties of the aggregates. And we will discuss about some additional experiments that are used to quantify various properties of the aggregates to be used in construction of pavements. And of course, we are also going to discuss about the importance of these experiments and the relation of these experiments with the performance of in service pavement. Thank you.