Pavement Materials
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Lecture: 16
Aggregates Shape and Surface Texture

Hello everyone, welcome back. In the last lecture, we have discussed about the mineralogical aspects of aggregate and we have tried to see the importance of mineralogy, from two perspectives, that is adhesion characteristics and skid resistance properties.

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Today, we are going to discuss about another important property of aggregates that is not very well understood, that is shape and surface texture. If you try to imagine an aggregate, you will agree that the aggregates do not have any uniform or defined shape, they are irregular objects, and they can have various degrees of shape attributes or parameters influencing the shape and these attributes of shape they are directly related to the performance of the final mixture, because they dictate how the aggregate particle is going to orient itself inside the mixture, be it a concrete mixture, be it a asphalt mixture. So, let us try to understand about the shape characteristics, discuss about the methodologies that are commonly used to quantify these shape characteristics.

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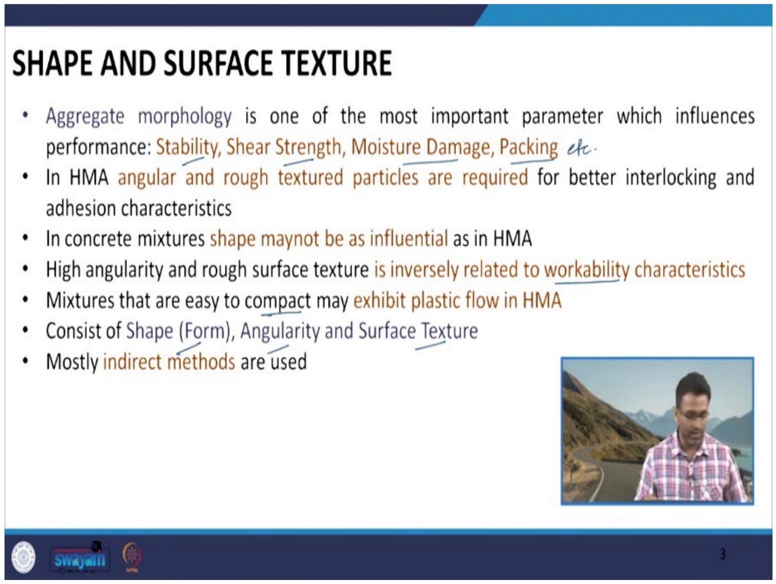

Aggregate morphology or the shape characteristics. Now, when I say morphology, it is not only the shape, but also other factors related to the appearance of the aggregates. So, it can be the shape of the aggregate or the form of the aggregate, it can be the angularity characteristics of the aggregate, it can be the surface texture properties of the aggregates. So, morphology basically is an overall definition of the surface related attributes of the aggregates. So, aggregate morphology is one of the important parameters which influences the properties or influences the performance of the mixtures.

Now, it has been found that the morphology of the aggregate has relation to various performance parameters for example, stability of the mixture, it is related to the shear strength within the mixture, it is related to the extent of moisture damage in the mixture, it is related to the packing characteristics of the aggregates in the mixture. And actually, there are various other parameters or performance indices that gets affected because of these shape characteristics or in general the morphology of the aggregate.

If you talk about hot mix asphalt, here the shape characteristics play a more dominant role. Ideally, what we desire in HMA are Angular and rough textured particles and why do we desire that, because Angular particle will have better interlocking properties, because Angular particles when several and angular particles are locked inside a matrix, they will create more internal friction and therefore, better stability of the mixture. And when we talk about texture, it is related to the bond between the aggregate surface and the bitumen.

So, on rough surface bitumen will have more stronger hold over the aggregate surface in comparison to when the aggregate surface is smooth in nature, where the aggregate where the bitumen will have a tendency to peel off much easily in comparison to the forces required to peel off the bitumen film from a rough textured aggregate particle. On the other hand, in concrete mixture shape of the aggregates do not specifically influence its performance as it does in hot mix asphalt.

Now, on one hand, we say that better angularity characteristics more angular particles and rough textured aggregate particles have better interlocking properties and as a result of which its resistance to deformation increases. But on the other hand, if the angularity of the aggregates are too high or the surface is too rough, it can also create some problems related to workability characteristics.

Because Angular and rough textured particles are more difficult to work with, more forces are required to move these particles, and in fact more force or more amount of energy will be required to mix the bitumen or any other type of binding agent with highly Angular and rough textured, surface textured particles. So, therefore, we have discussed two things on one hand, Angular and rough textured particles improves the stability and on the other hand, if the angular rate is too high, and the surface is too rough, it can also lead to reduction in workability characteristics of the mix.

Also, though we see that the workability characteristics get affected, but, we cannot consider workability characteristic as the major phenomena or major parameter of consideration. Because, if we try to reduce the angularity of the aggregates, if we tend to make it more rounded in nature, then definitely the workability gets better, but these mixtures with rounded particles, they have you know higher tendency to compact which means, they get compacted easily.

So, once the rollers compact the mix and it is open to traffic, if the particles are more rounded, there can be more densification there can be much higher degree of secondary densification and because of which the mix can show plastic flow or will show a permanent deformation appearing on the surface which is not desirable.

Therefore, we have to ensure that our aggregates are properly Angular in nature and has good amount of roughness in the texture, so that we are not compromising the strength properties of the mix. If we try to define the morphology as I was discussing initially, it consists of various attributes for example, shape angularity and surface texture is another attribute.

Now, these morphological characteristics, the question is how to quantify them because if we see an aggregate let us say I have an aggregate here. So, you can see that this aggregate is Angular in nature, it is rough surface structure, but there is no predict I mean no definite shape here.

So, if someone gives me an aggregate or gives you an aggregate and if they desired it, that quantify the shape or the morphology, it becomes difficult just to do some tests and define the morphology because it is so, irregular there are so many discontinuity in the shape. And therefore, mostly indirect methods are used in the laboratory to understand or to quantify these shape attributes.

Now, some of the very common tests which we are going to discuss includes the flakiness and elongation properties and there are different tests to test the flakiness and elongation properties we will discuss about them, then we have test which quantifies the angularity of fine and coarse aggregate and the test is called as fine aggregate angularity or coarse aggregate angularity depending on the size of the aggregate in question.

For coarse aggregates, we have another separate Angular number, angularity number, which is different from the definition of coarse aggregate angularity. So, we are going to discuss about that, then, there is another test which is particle index test using which we will calculate the particle index value which also is a parameter that can quantify the combined effect of shape and surface texture. So, we will discuss about that also.

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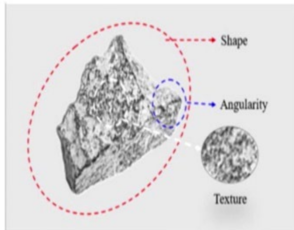

F. Gong, Y. Liu, Z. You, X. Zhou, Characterization and evaluation of morphological features for aggregate in asphalt mixture: a review
Constr. Build. Mater., 273 (2021), Article 121989.

- Particle shape and surface texture of fine aggregates has more influence on performance of dense asphalt mixtures than coarse aggregates shape
- For open graded and gap graded structures shape and surface texture of CA is very important
- **Visual:** *More than 90% of the CA should have atleast 1 fractured face, while more than 60% should have atleast 2 fractured faces*
- **Imaging techniques** have been developed for better quantification of shape and surface texture

Now, this has been taken from the literature from one of the paper which reviews the shape characteristics or the morphological characteristics of the aggregates, you can see that how the shape is defined. So, shape or the form it tells about the macro structure of the aggregates the overall way the aggregate looks like, then we have more micro aspects for example, angularity is one of that it tells us how the edges are distributed over the aggregate particles, then we have textured it is also about the micro characteristics that how the surface roughness varies in the aggregate particle.

Now, if you talk about the importance of the shape attributes. So, particle shape and surface texture of fine aggregates has more influence in performance of dense asphalt mixture. Now, this is again, strongly proven in the literature than that when we talk about hot mix asphalt. So, based on the aggregate gradation, we can have different types of hot mixes filed we have dense graded hot mix asphalt, we have gap graded hot mix asphalt, we can have an open graded hot mix asphalt.

So, in dense graded hot mix asphalt studies have shown that the shape attributes of the fine aggregates are more dominant, when we discuss about the performance characteristics in comparison to the shape of the coarse aggregates. So, there are studies that have shown that if you make an asphalt mixture having let us say not so, Angular or let us say I am writing it not so, Angular, coarse aggregate and highly Angular fine aggregate and we have another asphalt mixture of same gradation and here we have used let us say highly Angular coarse aggregate and rounded or less angular fine aggregate and if you try to judge the performance of this mixtures in terms of resistance to rutting or resistance to any other form of deformation. So, studies have shown that this makes will perform inferior in comparison to this mix.

So, this means that in a dense graded matrix of aggregate particles, if the angularity in the fine aggregate is more critical in describing the development of internal friction within the mix in comparison to the coarse aggregates. Whereas, when we talk about an open or gap graded structures, where the amount of fine aggregates are very less, so, it is very obvious that since the coarse aggregates controls most of the point of contact in the aggregate skeleton.

So, angularity of coarse aggregates becomes much important here in comparison to the you know properties of the fine aggregate which anyways is less in volume, in usual practice, we have again various specifications to describe the shape attributes like one of the visual process which is used for coarse aggregates is that we will take some aggregate particles from the quarry using which we are going to produce the mixture. And we will just visually inspect a number of coarse aggregate particle and we will try to see the amount of angularity in it or amount of fractured faces in the aggregate particle.

So, some of the specifications for example, suggests or specifies that there should be more than 90 percent of the coarse aggregate with at least one fractured face, while more than 60 percent of the coarse aggregate should have at least two fractured faces. So, again this is one specification which tells how the coarse aggregate looks like, but this is more of subjective in nature, because we have to visually see the coarse aggregates and tell about the fractured faces.

Also, one more point here is to note that in India, because we were discussing that fine aggregate angularity is more critical for dense graded mixture, but you will see that in India, presently, we do not have any specification to quantify the shape properties of the fine aggregate, which is again in need of the hour, because, if we see a Superpave mix design consideration, they have fine again aggregate angularity, which of course, is an indirect method to judge the angularity of the fine aggregate, but, again a one of one of the good ways of doing it in the laboratory.

So, they have a mandatory check, where they have to ensure that the fine aggregates that are used has appropriate angularity in the mixture. So, but presently in India, we only measure the angularity or the shape properties of the coarse aggregates. Well, further discussing about the shape properties, though we will be discussing about the tests which are typically used in the laboratory or simple methods that are used to indirectly define the morphology of the aggregate in terms of shape or surface texture, a lot of researches have been done and there are various methods and equipment's data that have evolved over a period of time, which mostly uses imaging technique and different forms form.

So, now, it is very much possible to define the three-dimensional shape of the aggregate using various you know indices of shape, which can be calculated based on imaging techniques. So, imaging techniques have been developed for better quantification of shaping such restriction, but the usual specification which is used by highway agencies, they do not employ these imaging techniques. So, these imaging techniques are more used for research presently, rather than employing it in actual practice, when we do the construction.

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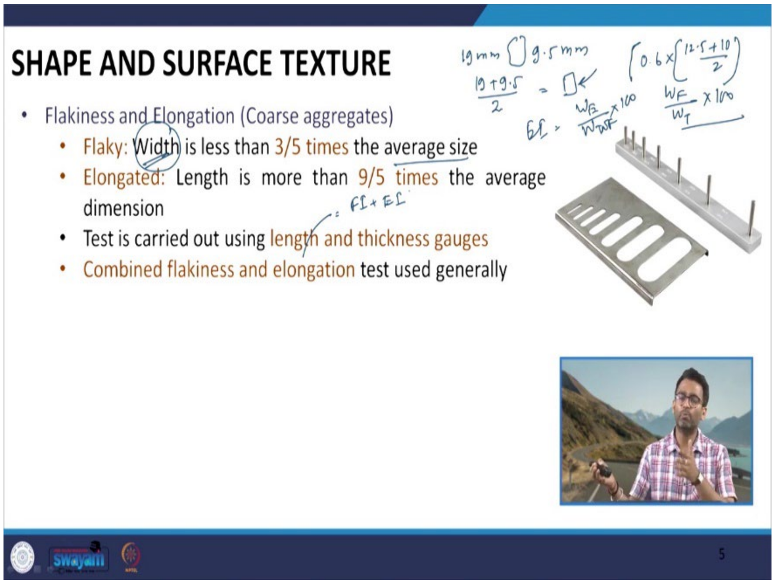

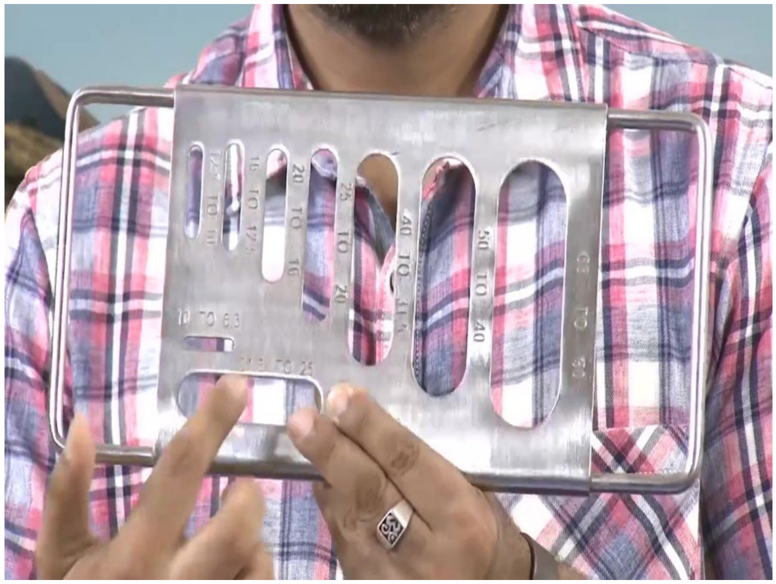

Now, let us start discussing about various tests which we do in the laboratory. So, first let us discuss about flakiness and elongation properties and these flakiness and elongation properties, they are mostly measured for coarse aggregates mostly aggregates that are larger than 4.75 mm or 6.3 mm sieves. So, first let me tell you the definition of flakiness. So, how do you define a flaky particle? A flaky particle is the one in which the width of the particle or you can say the average width of the particle is less than 0.6 times the average size.

So, what is this average size here? Let us say you have an aggregate that passes 19 mm and is retained on 9.5 mm, let us say, so, the average size of this aggregate which will be here in between is taken as $\frac{19+9.5}{2}$. So, this is the average size and flaky particle is that, who's width, so, let me show you I have a flaky particle here. So, this is a flaky particle, alright, if you are able to see it, so, you see, the width of this particle is really small in comparison to the average dimension in comparison to this average dimension. So, this width is small, so, this is a flaky particle. So, this width is less than 0.6 times the average size and this is how you define a flaky particle.

Let us try to understand that the problems with flat and elongated particles are that they get logged up very easily now, and they do not tend to reorient themselves. Now, since they will get logged up in the mix rather than orienting, so the interlocking cannot will not be achieved. So, this will just live flat and then there will be some other aggregates around it and it is not filling the voids or locking inside between the aggregates.

The other problem with such type of aggregates is that when they lie flat and let us say there are two more aggregates holding it and when you apply a pressure on it, this tends to break because the width is small, it has more less resistance to break in this direction. So, it tends to break and once it breaks the size will reduce and the entire gradation of the aggregate will get disturbed. Once the gradation gets disturb the entire volume metrics of the mixture get disturbed and all the calculations which will do will lead to the production of a mix which will be very different than our theoretical calculations. So, that is the problem with such type of particle. So, I hope the definition of flakiness is clear to all of you.

Then let us try to understand what are elongated particles? Elongated particles are those whose length is more than 9 by 5 times or you see 1.8 times the average dimension. So, I have a elongated particle here I hope you are able to see these elongated particles. So, this is the length and you see the this is the this is the average dimension here.

So, this length of the particle is 1.8 times more than the average dimension and this is how you define an elongated particle. The same the elongated particle also have the same problem that it does not orient itself it has poor interlocking properties and again it tends to break when forces are applied which leads to change in the gradation.

Now, how do you quantify because in the mix, which I am making, I do not want the accumulation of too much of flaky and elongated particles. So, I have to do a test so that I can ensure that the gradation or the aggregate quarry that I have selected or the stockpile that have selected does not have higher percentage of flat and elongated particles, this test is called as the flakiness and elongation test and we mostly do the combined flakiness though you can separately measure flakiness index and elongation index, but in practice, we do we calculate the combined flakiness and elongation to quantify the shape of the coarse aggregates.

So, this test is done on aggregates that are larger than 6.3 mm and we use a length and thickness gauges here. So, we have a length gauge here. So, you can see this this is a length gauge and then you have a thickness gauge here. So, this is the thickness gauge which is used. Now, one important thing here to note because like this gauge is used for finding out the flakiness index. So, there are some gaps here is not it, there are some apertures here through which we have to pass the aggregate particle.

Now, you see, we have defined flakiness index as the weight the particles for which the weight is less than 3 by 5 times or 0.6 times the average size. Now, if you see this gauge very closely there are numbers written so, there are numbers written like 12.5 to 10 mm. So, which means this opening has a size which is I mean the dimension of this opening is equal to 0.6 multiplied by the average size. So, the average size for this is 12.5 plus 10 divided by 2. So, the size opening will be 0.6 times of this average size.

So, similarly, we have several other sizes for example, this is 63 mm to 50, then we have 50 to 40, 40 to 31.5, and so on, we have this gauge. So, what we do here we select approximately 200 coarse aggregate particles and then we usually do the measurement by weight, so you weigh these aggregate particles and then based on the size of the aggregate particle you just pass it corresponding to the respective slot. And if it is a non-flaky particle, then of course, this will not pass it will get retained. So, once you separate the flaky particles and separate the non-flaky particles.

So, first you calculate the flakiness index, which is the amount of flakiness particle which means, $\frac{\text{weight of flaky particle}}{\text{total weight}} \times 100$, so this will give you the flakiness index and then you take the non-flaky particle. On the non-flaky particle we will do the elongation index test. So, we will use the length gauge here, the same thing applies to this gauge.

So, this gauge has some numbers written here, for example, we have 20 mm to 25 mm which means that this dimension will be equal to $1.8 \times \frac{(25+20)}{2}$, the average size, so that is this gap. And we have to ensure that in the non-flaky particles, we do not have much of elongated particles. So, we are measuring the elongation here.

So, again we will take each non-flaky particle pass it through this gauge and then we will try to see how many elongated particles are there. So, if we have more number of elongated particles, elongated particles will not pass through the slot alright. So, if you try to pass this through this corresponding slot, it will not pass we will again calculate the elongation index. So, $\frac{\text{amount of weight of elongated particle}}{\text{the total weight we have taken for in consideration of a non-flaky particles}} \times 100$.

And then we will just sum the elongation index and flakiness index, the combined flakiness and elongation index is actually flakiness index plus elongation index. And then depending on the layer where we are using these aggregates, we have specifications which tells us that to what maximum percentage I can use flaky and elongated particles.

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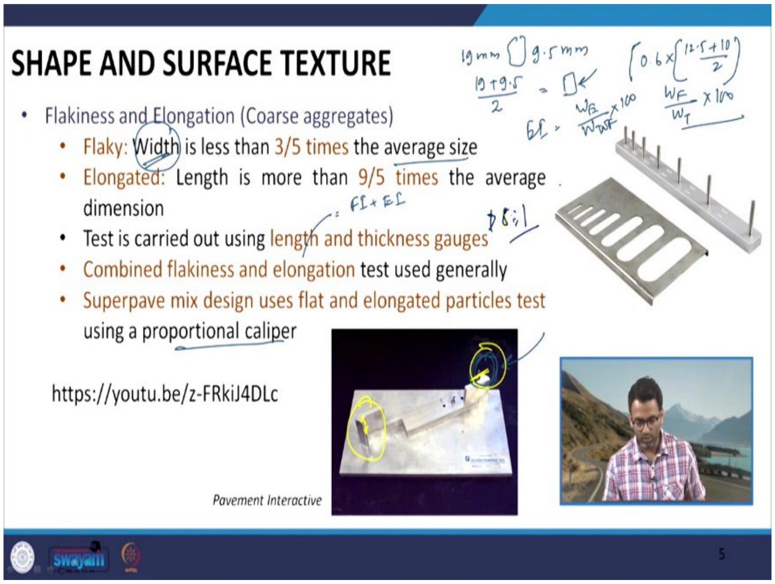

On the other hand, in the Superpave mix design, we have again the provision of measuring the flatness and elongation, but we use a proportional caliper here, we will use a proportional caliper to assess the amount of flat and elongated particles. So, the proportional caliper looks something like this. Since in India we typically do not use a proportional caliper, so I do not have it with me here, but this is how it looks like I have taken it from an internet source.

Here you see we have two slots, so, we have one slot this size and one slot this size. So, we usually first set this larger size and then pass the aggregate from this smaller size. Now, the question is how do we set it, so, we set it to ensure that the ratio of length to width is not you know more than 5:1. Typically, not because the Superpave specification uses the ratio of 5:1 so, I am saying 5 :1 is should not be greater than 5:1, I will tell you about this test method in the next slide.

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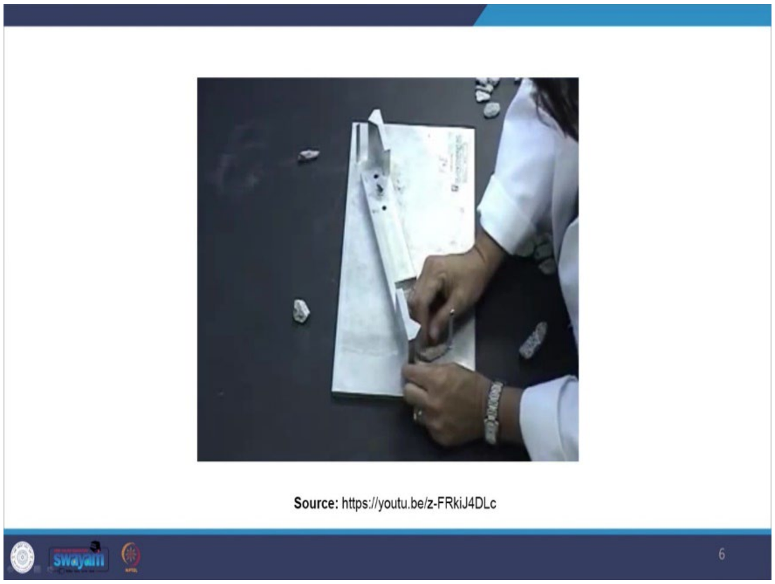

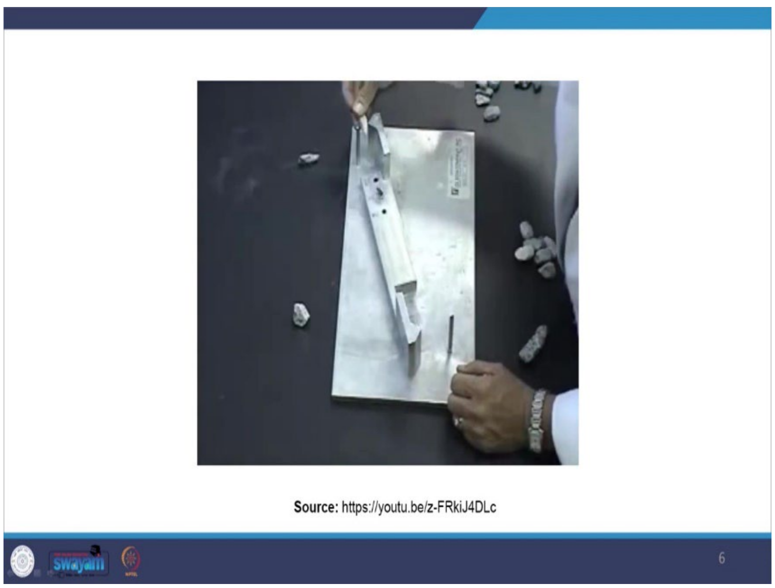

I have a link here you can see that how the larger size is fixed first. So, this is how we keep the aggregate and fix the larger size and then we pass it from the smaller size and then we separate it. Likewise, for each aggregate particle which we select we have to first fix the larger size and then pass the material from the smaller size, and then we will see that how many aggregates has a flatness and elongation depending on how we do it.

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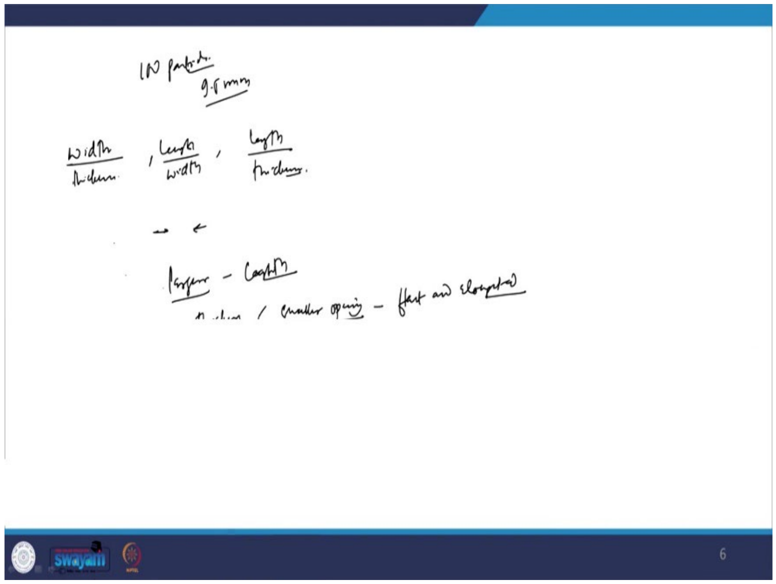

So, I hope that this video was clear, let me tell you the process because now once the specified ratio is set alright on the caliber and then we take as you have seen in the video we take about too many particles. So, typically we take about 100 particles here which are coarser in nature, so we take 9.5 mm typically and for each specified sieve size we do the test. So, for individual aggregate particles of this sieve size, specific sieve size, they are tested here for the ratio of width to thickness. So, we can fix or we can try to see the ratio of width to thickness, length to width, or length to thickness, using the caliper.

So, if we see the testing for flatness, what we do we set the larger opening of the proportional caliper equal to the particle width. So, this to width will be fixed in the caliper we will set the larger opening of the proportional caliper equal to the particle width and the particle is considered flat if the thickness it fits the smaller opening, which was shown in the video which we just played.

On the other hand, if we have to see the elongation, then again, the larger opening of the proportional caliper is first set to the length of the particle and you have seen that in the video that the length was being fixed and the particle is considered elongated if the width it fits in this smaller opening. So, you can also measure the combined effect of flatness and elongation.

So, here what we do, we will set the larger opening of the caliper. So, the larger opening of the caliper will be set equal to the length of the particle and the particle is considered flat and elongated if the particle when we oriented to measure it thickness can pass completely through the smaller opening of the caliper.

So, if the thickness is smaller than the smaller opening then we consider this part is this particle is flat and elongated. After we test all the particles, then we will determine the proportion of the sample in each group, either by counting or by mass, as I mentioned that the Superpave specification, which we will be discussing later, it uses the ratio of 5:1 for determining flat and elongated particles and as per this Superpave specification, it should be limited to less than 10 percent, it should be limited to less than 10 percent. I hope that again this process was clear to you.

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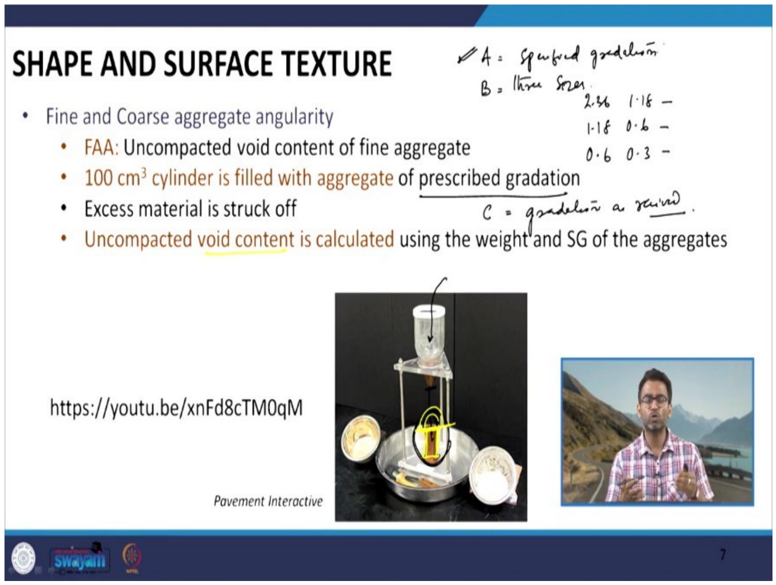

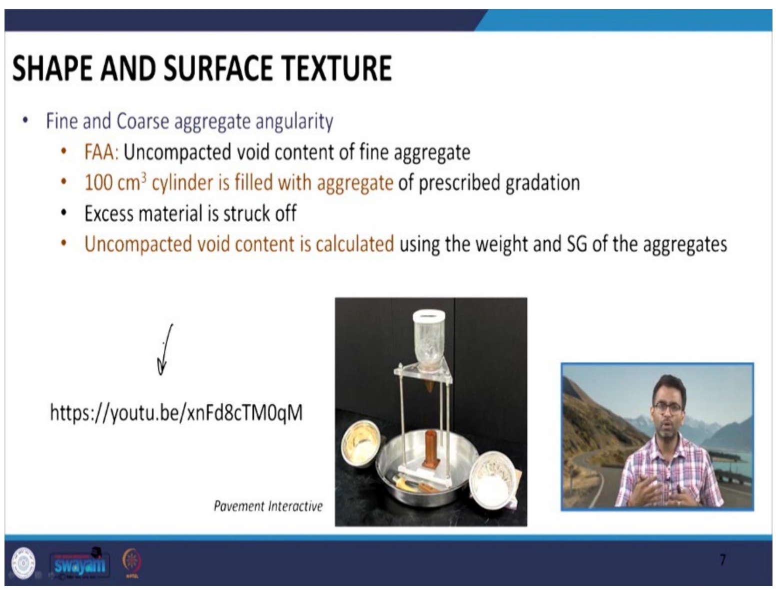

Now, we move forward to understand the fine and coarse aggregate angularity test here. So, now, as I mentioned that in India we do not have a separate test to measure the shape properties of fine aggregate, but in Superpave specification, they have a requirement and we use every simple equipment to measure the fine aggregate angularity which is measured through uncompacted void content of fine aggregate. And I think that in future in India also we can adopt similar specification, because the shape attributes of fine aggregates are very critical specifically for dense graded asphalt mixtures.

So, you see, we have a very simple equipment here. So, we take 100-centimeter cube cylinder which is shown here and it is filled with aggregates of prescribed gradation. So, first we will put the aggregates here we will close this conical opening and once the aggregates have been filled, then we will just open it and we will allow the fine aggregate to fall freely here within the 100-centimeter cube cylinder.

There are three ways of describing the gradation of the aggregates or selecting the fine aggregates. So, one is that we take a specified gradation. So, this process is used by Superpave that they have a specific gradation of fine aggregate which you have to use to test the angularity, the other way is that we will use three sizes. So, these sizes are 2.36 to 1.18 mm, we have 1.18 mm to 0.6 mm and we have 0.6 mm to 0.3 mm.

And then what we will do after conducting the test after finding the uncompacted void content for all three sizes, we will take the mean of this value and this mean we will compare with the specification and we will report the mean as the fine aggregate angularity. And in the method C we will use gradation as received for the stockpile, which we are considering as the fine aggregate stockpile. So, but as I mentioned that A is used in the Superpave specification.

So, after filling the material once the entire material is filled, there will be some overflow in the material, I hope you are able to imagine it that there will be some overflow in the material. So, this overflow will be struck off first, and then we will determine the uncompacted void content by using the weight and the specific gravity of the aggregate.

So, we know the volume of the cylinder, we know how much weight has come within the volume of the cylinder how much fine aggregate and separately if you have the value of specific gravity of the fine aggregate, you can calculate that in this volume what is the volume of solid and how much voids has been created. So, that void content is used to quantify the fine aggregate angularity.

I hope you can understand here that more will be the angularity which means more will be the void content because rounded particles they will tend to have lower void content in the cylinder. So, I hope that again, this process is clear on how we do this test I have another video, which basically shows the process of filling the cylinder, but this video is applicable for coarse aggregate angularity. Since the process is same, I hope by looking at the video we at least will be able to understand visually that are how aggregates are filled in the cylinder and how the process is done to struck off the aggregate.

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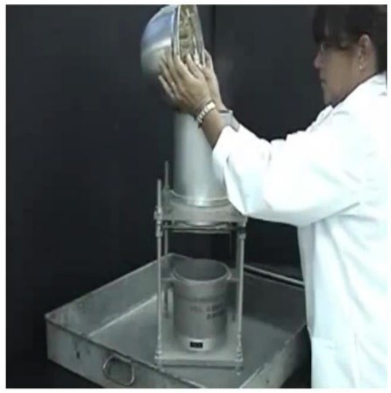

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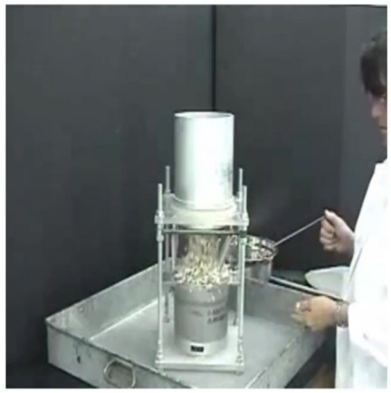

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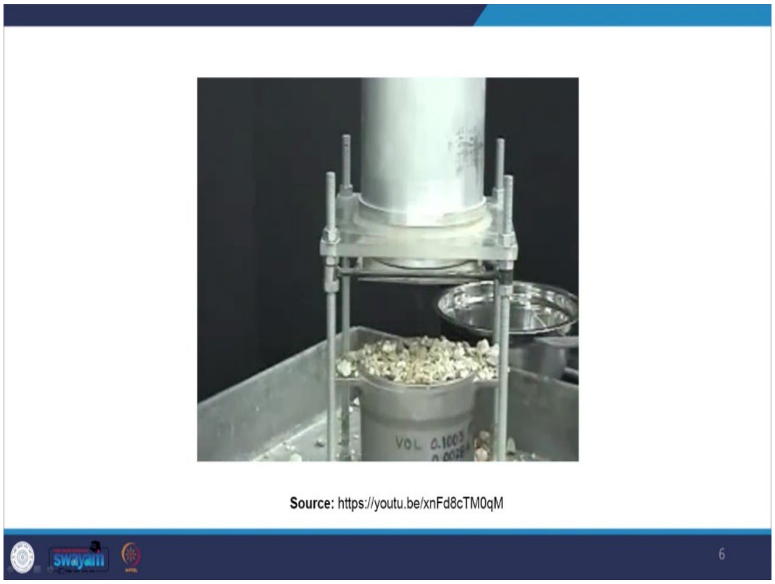

So, let us see this video very quickly it is a very short video. So, you see how for coarse aggregate angularity first the upper cylinder is filled it is closed. Now, it does not allow aggregates to pass because first we have to fill the cylinder in prescribed amount. So, after doing that, we will open the lower part and then we will allow the aggregates to fall in this way.

And then the additional materials which is collected is struck off and then again, we will weight the cylinder we already have the volume of the cylinder we can measure the specific gravity of the aggregate separately and using these values we can calculate the amount of voids and amount of solids in this cylinder. And this void will give us an indirect measure of the angularity of the aggregate particle.

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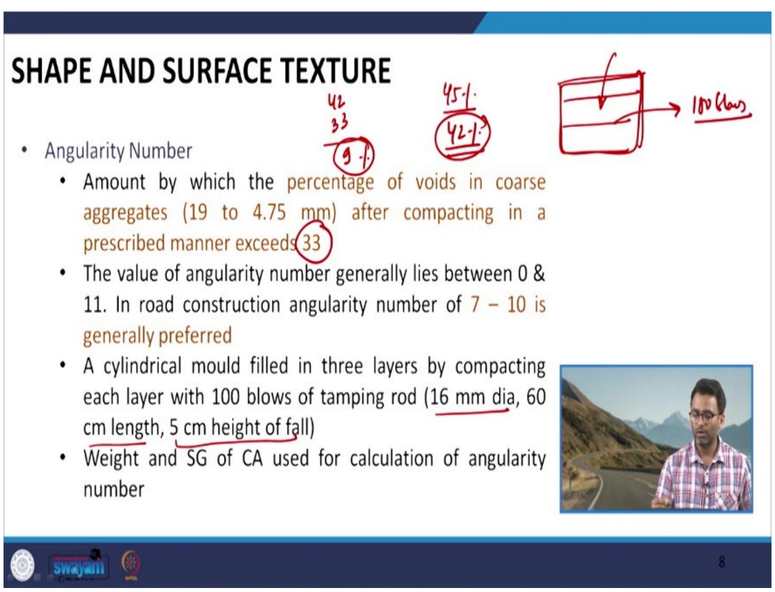

Now, we move on to the another attribute of the coarse aggregate which is the angularity number. This test is based on the concept that if we have spherical particles or rounded particles, they will tend to have an approximate void of 33 percent. So, here what we try to find? We try to find the amount by which the percentage of voids in coarse aggregates here also we take good segregates typically 19 mm to 4.75 mm, after compacting.

Now, here we are not only measuring the free flow volume, we are compacting the aggregate in a prescribed form, because as I said the theory says that if there is a spherical particles and if they are compacted in a cylinder then the amount of voids which will be created will be approximately 33 percent. So, if we have angular particles instead of spherical particles, so, the amount of voids will increase it will be higher than 33. So, we want to see that how much angularity is present in those aggregate particles above the roundness, above dispersity.

Therefore, whatever is the value let us say that we find that the volume of void is say 45 percent or 42 percent which means, these aggregate particle has created a void which is 42 minus 33 which is 9 percent more than the void which will be created by purely rounded particles. So, here the value 9 it represents the angularity number of the coarse aggregate. So, typically the value of angularity ranges from somewhere between 0 to 11, more it is towards the 11 higher is the angularity, I hope it is very clear now. So, in road construction and angularity number of typically 7 to 10 is generally preferred.

So, as I said what we do here this is again a simple test you take a cylindrical mold fill the cylindrical mold in 3 layers, each layer you compact with 100 blows using a standard tamping rod which is 60 mm in diameter, 60 centimeters in length and the height of fall is 5 centimeter. And once a stroke of the extra material and we do the same calculation as we have learned in the previous slide, we use the specific gravity value we know the volume of the cylinder, we know the weight of the aggregates filled in the cylinder, using these three values we can calculate the amount of voids that are created and we will compare it relative to the value 33.

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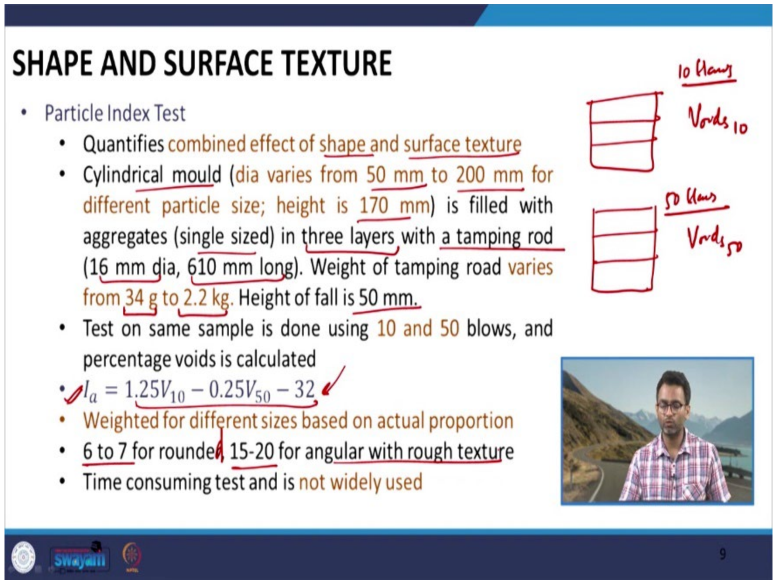

Now, we have another test as I was mentioning, which is the particle index test and this is used to quantify the combined effect of shape and surface texture. Here, what we do again we have a cylindrical mold. Now, this is a long test actually. So, here are four different sizes we have different types of cylindrical molds, and the diameter of the cylindrical mold varies as the size of the aggregate varies. So, the dia varies from 50 mm for smaller sized aggregate to 200 mm for larger size particle and the height of the cylinder is approximately 170 mm. So, this is filled with aggregate single sized.

So, every time you are testing an aggregate, the next time you test another size aggregate you have to use a different cylinder. So, it is filled with single sized aggregate in three layers with a tamping rod here. So, this tamping rod is 16 mm in dia 610 mm long and very importantly here also the weight of the tamping rod also changes, depending on the size of aggregate your testing. So, for smaller sized aggregate, we use approximately 34 gram of tamping rod, for larger sizes, it goes up to 2.2 kg weight of the tamping rod and the height of fall is constant, which is 50 mm.

So, once we have compacted the specimen, now, here the compaction will be done using two different blowing method the same sample first you will compact in three layers using 10 blows measure the amount of voids. Again, using the same aggregate and using the same mold you compact it in 3 layers, but now use 50 blows, again measure the voids. So, I call it $Voids_{50}$. And then we will measure the particle index value which is I_a using this empirical formula. And by using this empirical formula the value which we get we can understand whether we have a rough textured angular particles or we have smooth and rounded particles.

Typically, for rounded particles the value will be between 6 to 7 and it will be between 15 to 20 for Angular particle with rough texture. We can understand this that this is a time consuming test we have to do it for different sizes 2 times 3 or 3 layers and we are giving two different number of blows each time. Therefore, this test is not widely used, but why we have discussed this test because this is one of the tests which can quantify both the effect of shape and surface texture.

So, let us stop here today and today, just to recall that we have discussed about various shape attributes the importance of aggregate morphology and then we have discussed about test methods that can quantify the shape and surface texture properties. As I mentioned that presently, there are various more advanced techniques based on image analysis, that can be used to have more information about the aggregate morphology, but most of these tests are not used, I mean these imaging techniques, they are not used for regular testing of the aggregates in the laboratory or using the values as specification for selection of aggregate.

In the next class, I will continue from the same discussion here and I will start by touching upon an important property, which is somewhere related to the shape of the aggregate and calculation of surface area of aggregates. And I just leave this discussion today and this can be a fruitful thought if you can find an aggregate particle somewhere outside your house, just try to see and just try to ponder that, how is it possible to mathematically or using some method to measure or to calculate the surface area of this aggregate particle and this will be our discussion in the next class. Thank you.