Concrete Technology
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Lecture - 6
Aggregates (Size, Shape)

Welcome to concrete technology module 2. Module 2 deals with aggregates module 2 deals with aggregates; and today in the lecture one, we shall be looking into requirements of aggregates, petrographic classification, the size, shape and texture

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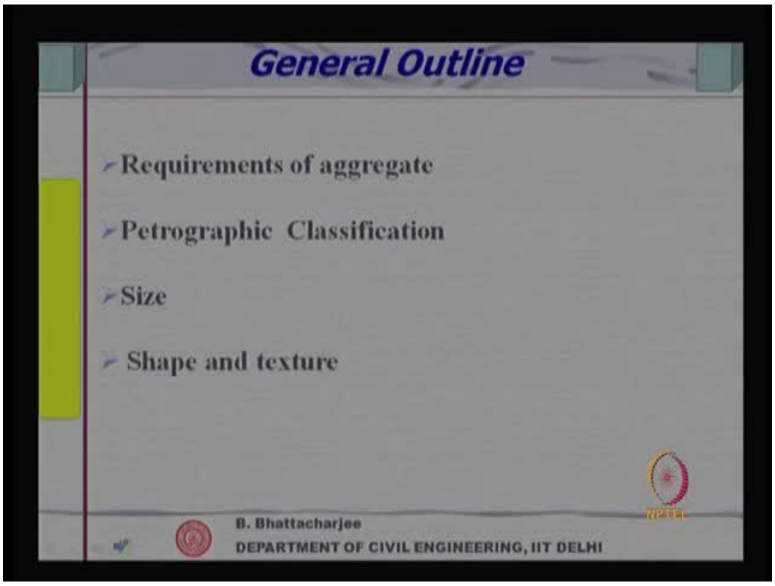

So, let us see what is requirements of aggregates, basically if you recall, when you look at concrete. Concrete consist of cement paste matrix if I may so, say so. With aggregate particles embedded in the cement paste matrix. And in normal concrete the aggregate which actually forms a skeleton is about 65 to 70 percent and paste is a rest of it. So, this 65 to 70 percent is a, you know large quantity it occupies the major volume of concrete in normal concrete, right. Therefore, why you call it aggregate, because aggregation of solid particles other than paste.

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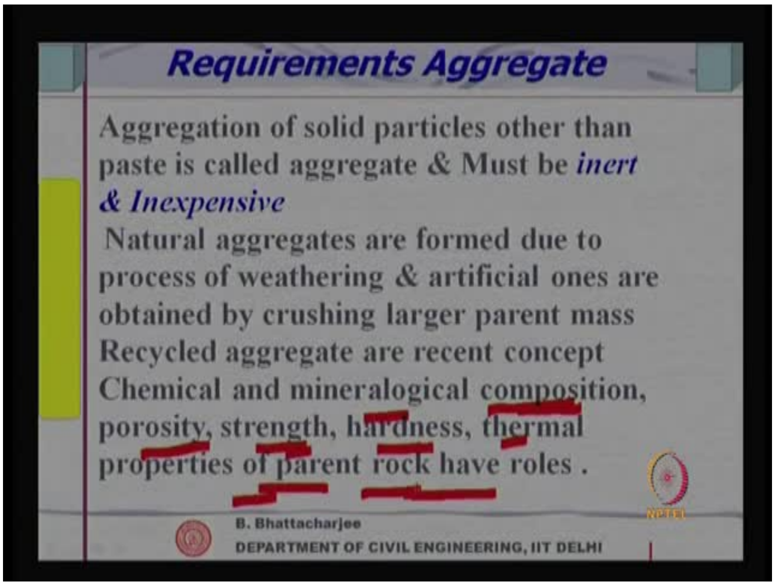

So, aggregation of solid particle other than paste and that is what we call as the aggregates. This is essentially aggregation of solid particles and that is what we call as aggregate. And one major important property is that it must be inert and obviously since large quantity is used it must be inexpensive, it must be inexpensive. Natural aggregates are formed due to process of weathering and artificial once are obtained by crushing larger parent mass. Well, I would not call it, I mean this I will call crushed aggregation actually, second one.

So, you can have natural aggregates that means natural gravels or a natural sand, those forms are natural aggregates as they are available and they are form by the weathering action on rocks, parent rocks, you know and then the other source of aggregate other than natural once, naturally available once are the crushed aggregates. Now, artificial aggregates can be produced from some materials like (( )) these artificial aggregates have courses separate class of material use for specific purpose, but lastly what we use in normal concrete normal strength concrete and when in high strength in concrete they are either the, they are obtain by crushing rocks or they are naturally available material like pebbles, gravels, I mean gravel, sand etcetera.

Recycled aggregates of course is a recent concept because of, you see the aggregates sources are not infinite, aggregates resource are not infinite more and more aggregates are consumed in the concrete. The resources is getting reduced so there is now a thought process of utilizing recycled aggregates. There is another aspect also, there is you know significant amount of demolition of existing structure, concrete structure may occur in future, you know. So, when you demolish a structure you get the demolition a waste similarly, construction waste. So, can they be reprocessed in some manner, reprocessed and recycle them for use in concrete again, this is been looked into and therefore, recycle concrete aggregate is a recent concept.

Chemical and mineralogical composition are important, porosity, strength, hardness thermal properties all have their origin in the parent rock. So, the chemical and mineralogical composition, porosity, strength, hardness, thermal properties it all depends upon the parent rock itself, parent rock itself parent rock itself.

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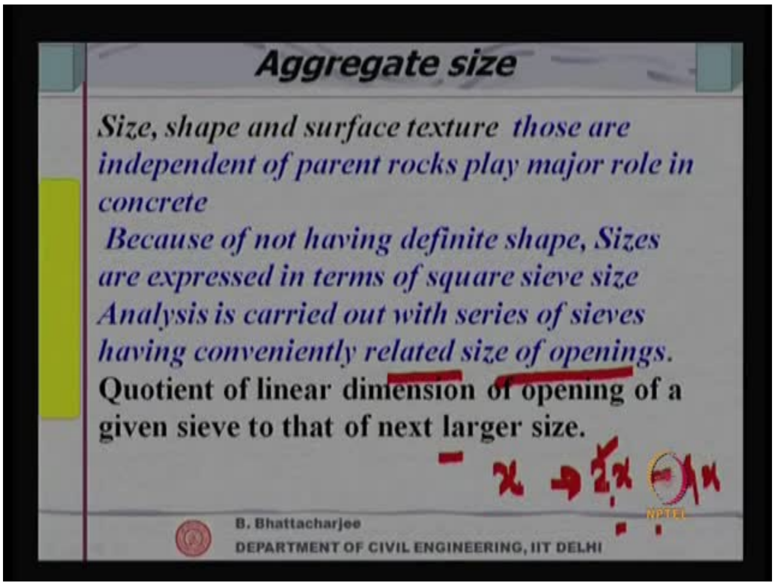

Size, shape and surface texture these are independent of parent rock, but play major role in concrete. Size, shape and surface texture. So, thermal properties of concrete the porosity, chemical composition, mineralogical composition they are, they you know, they there will be same as the original parent rock itself, but once you make them, get them into appropriate size after crushing or if it is natural. So, in itself the shape and the size they have very strong role and surface texture of course, a very strong role in concrete. Well, they do not have definite shape and sizes are expressed in terms of square sieve size, you do not have definite shapes. So, you talk in terms of some source of qualitative or linguistic terms such as rounded etcetera, etcetera.

They do not have geometrical, definite geometrical shape. Size also varies so their sizes define in terms of square sieve sizes. So, you have sieve, square sieve and this sizes are what we talk about, you the square sieve side length. So, sieve size we talk about so sieve size is related to sieve size. So, basically we sieve the do, what is called sieve analysis, allow it to pass through square meshes or sieve and series of them, normally a series of sieve should be there and they are conveniently, then the aggregate size is conveniently described in terms of size of the openings.

So, we do sieve analysis and conveniently relate the size of the aggregate, the size of the aggregates to the size of the mesh square mesh or sieve size, as you call it. Quotient of linear dimension of opening of a given sieve to that of next larger size, actually this is the sieve sizes. Many things in nature actually vary, do not vary linearly. For example, sizes of this particles, if you talk in terms of some sort of equivalent diameter or through the sieve analysis, you find out the size. You will find that the sizes varies over large range for example, might vary from something like 75, 0.75 millimeter 0.07 millimeter, there is a 75 micron size to 40 mm or 100 mm or 150 mm or let us say, let say in given concrete it might vary 75 micron to something like 25, 20 millimeter.

Now, the range is micron is 10 to the power of minus 6 meter, millimeter is 10 to the power minus 3 meter. So, you can see the variation, the size varies or the range of size is more than a 1000 or nearly 1000, 1000 or more such a large range it is convenient to express in terms of log, log sizes. So, the case of frequency, let us say mechanical waves or many waves frequency of waves there are also we express them in terms of logarithmic scale. So, here the sieves we express them in logarithmic scale in geometric progression rather than in arithmetic progression because the range is large it is convenient to express them in geometric progression that is if I have a size x next size will be 2 x next to next size will be so it is x, 2 x, 4 x etcetera, etcetera, right 4 x, 8 x and so on. Well, this 2, the question there are for this 2.

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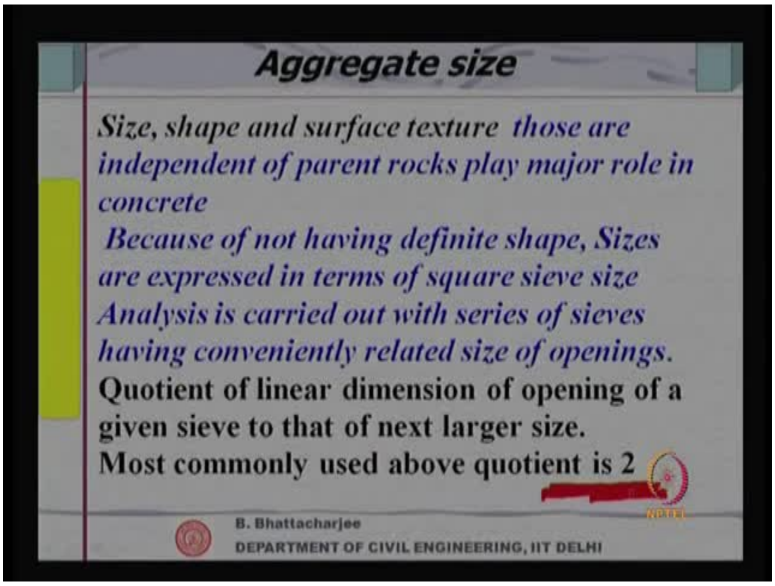

So, quotient of linear dimension of opening of a given sieve to the next larger size, this quotient of linear dimension this actually we keep constant and most often most often we use this quotient is 2. So, it is convenient to express the size of particles or aggregates, aggregate particles in terms in geometric progression and the quotient size quotient is generally used is 2. Although it could have been anything else, but this is most conveniently use and that is what we have been using.

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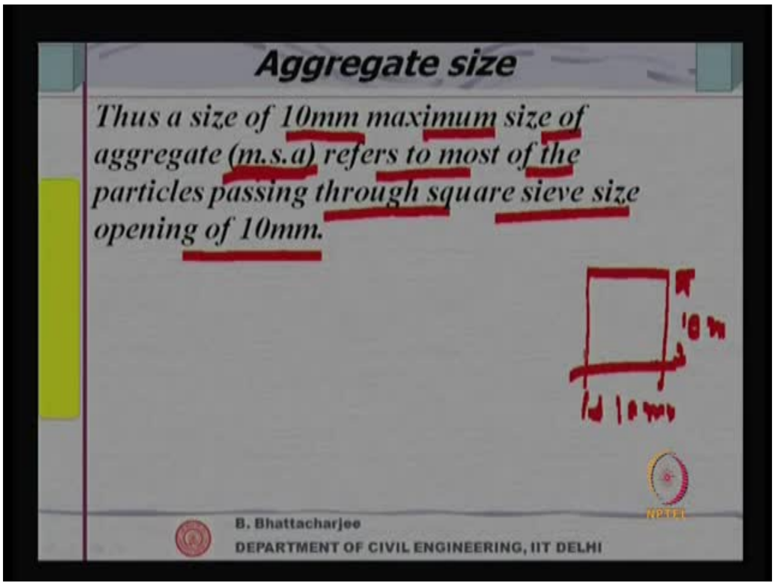

Well therefore, if I have a 10 millimeter maximum size of aggregate, nominal maximum size of aggregate means majority of the aggregate will be passing through a 10 millimeter, 10 millimeter size mesh, so square mesh so 10 mm, 10 mm, 10 mm. So, when I say that nominal maximum size of aggregate is m s a aggregate is 10 millimeter or aggregate is m s a, m s a maximum size of aggregate as 10 millimeter. Now, on wards I will be talking of m s a and may not be stating this maximum size of aggregate all the time.

So if we understand this is m s a is equal to ten millimeter it refers that the most of the particles passing through the square sieve size opening of 10 millimeter, most of it a few small percentage might be retained and this has come from practice how much percentage can be retain, is it comes from practice or are given in codes as we understand.

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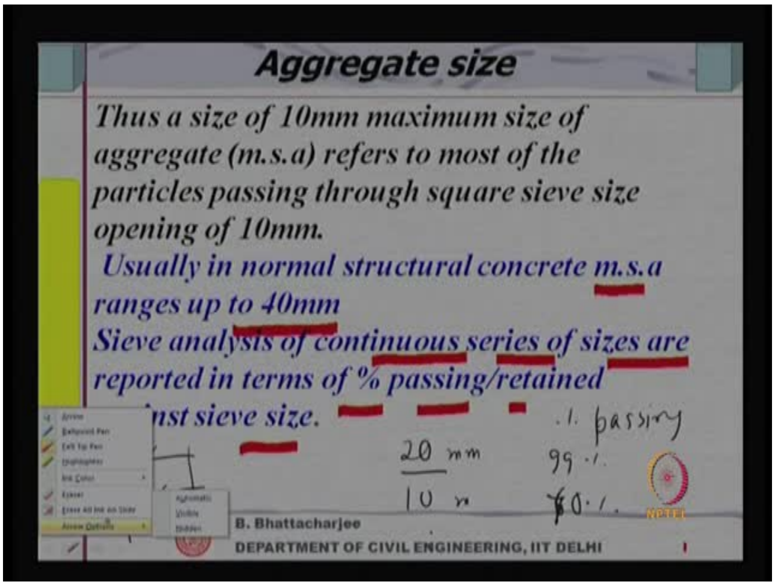

Usually in normal structural concrete m s a ranges up to 40 millimeters. So, in normal structural concrete m s a ranges up to 40 millimeter mostly 20 millimeters and will see of course, what it depends on, the choice of m s a depends on. Now, there we carry out sieve analysis in continuous series of sieves and they are reported in terms of percentage passing or retained against sieve size. So, it is in the tabular form usually it is in a tabular form usually, you know for example, 20 mm size, 10 mm etcetera, etcetera and percentage passing. So, may be 99 percent passing through, this is the m. s. a is 20 mm may be 50 percent or 60 or 70 percent passing through this etcetera.

So, this is how we express, so we do sieve analysis. Sieves are place one over another, series of them, sieves are placed one or the another series of them put the material up and then shake it so that the particles finer than the sieve size will pass downward to the next sieve and some amount will be retain here. So, I can then measure the weights, the masses retain from a known mass. So, percentage retain over passing etcetera again find out and sieve analyses is done and results are expressing this form.

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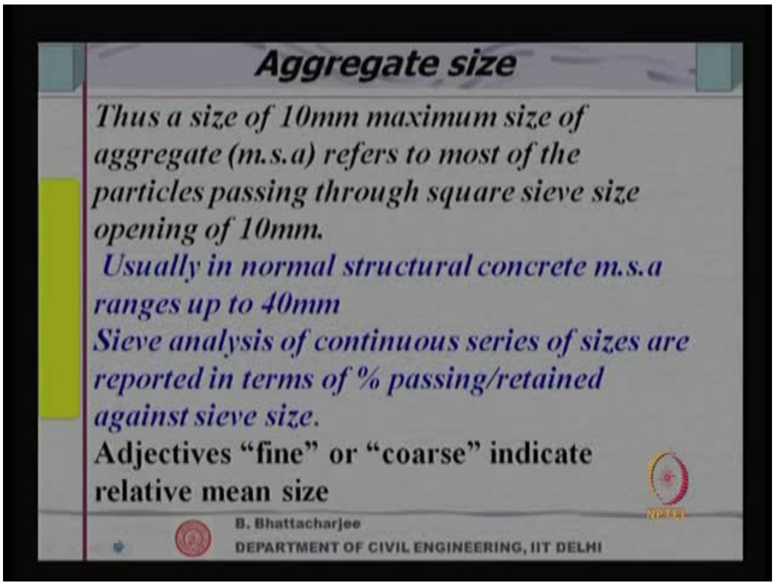

Adjectives such as fine or coarse aggregate indicate relative mean size. Fine aggregates has got a smaller relative mean size, smaller relative mean size right smaller relative mean size.

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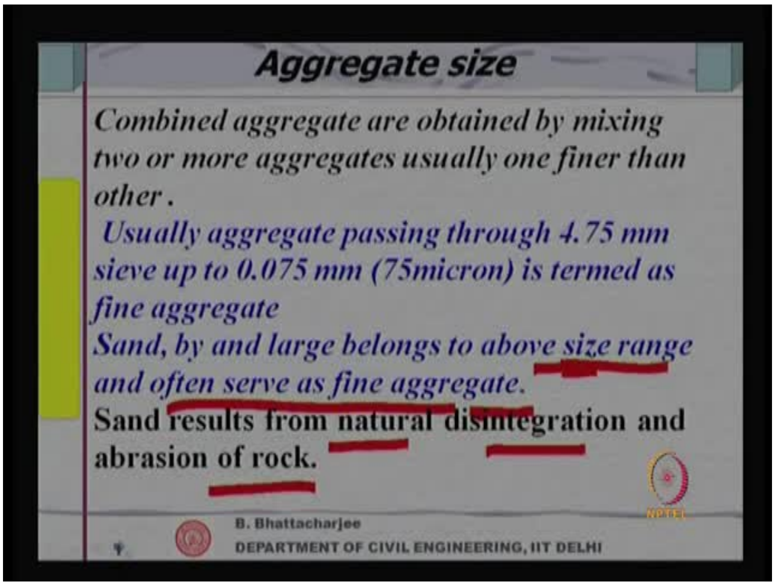

Combined aggregate obtain by mixing two or more aggregate, usually one finer than other. So, we combine example fine aggregate, course aggregate, both are mixed together. When we mix them together we get combined aggregate and then combined aggregate, you know is obtained by mixing in definite portion, usually one fine one is the course. Well, the aggregate passing through 4.75 mm sieve size is important and up to 0.075 millimeter that is 75 micron, we call this as fine aggregate we call this as fine aggregate we call this as fine aggregate and aggregate retained on 4.75 sizes higher, larger than that we call them course aggregate. Sand by a large belongs to above size range, you know normal sands normal sand normal sand.

Sand belongs to this size that is natural sand that is available belongs to this size and it often serve as fine aggregate. Natural sand belongs to the size greater than 0.075 millimeter up to 0.75 mm and it serves as fine aggregate. Clay, you know silt and clay are finer than this size as you know and sand of course results from natural disintegration and abrasion of rocks. Sand results from disintegration, natural disintegration by wind, rain etcetera etcetera and abrasion of rock.

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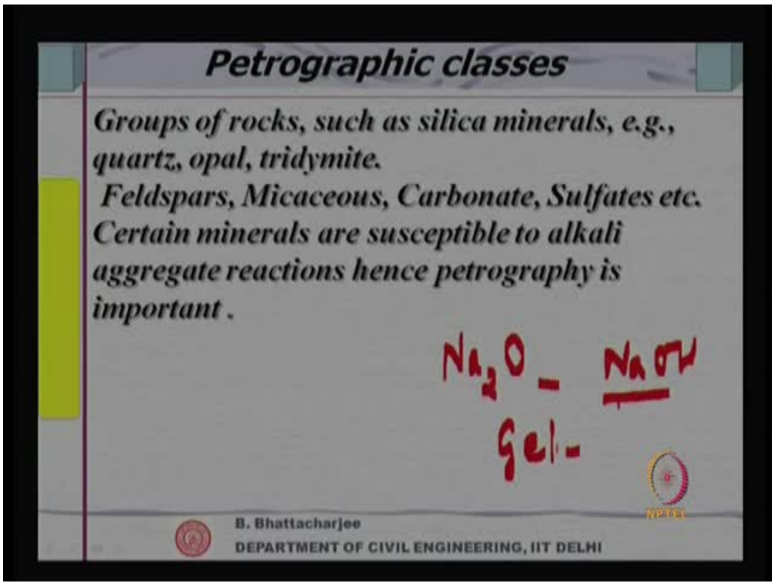

Groups of rocks such as silica minerals, quartz, opal, tridymite etcetera etcetera these are the groups. So, classification on the basis of petro graphic that is mineralogical classification. So, petro graphic classification can be in terms, you know minerals for example, quartz, opal, feldspars, micaceous, carbonate sulfates, etcetera etcetera. So, you can classify them in this kind of terms.

Now, certain minerals have a little bit of problem that is their susceptible to what is known as alkali aggregate reaction hence petrography is important because of the durably issue petrography is important when an aggregate is use for the first time. If it is proven aggregate it is used in many structures for I mean, did not exhibit sign of any deterioration or alkali aggregate reaction over many many years. Then of course, we are sure of it, but if an aggregate is used for the first time, not used before then it, you know its petrography must be or its mineralogical composition must be looked into because some aggregates are susceptible able to what is called alkali aggregate reaction. Recall, I in the first slide itself said that aggregate must be inert it should not react.

Now, certain types of silica like this is one of them, certain types of silica such as opal they can react with sodium, you know or sodium hydroxide. Finally, of course, in presence of water and can form a kind of gel form a kind of gel. This gel absorbs water and increases in volume, this gel absorbs water and increases in volume and this expanses in harden concrete can cause cracking.

We will look into this issue of alkali aggregate reaction in detail when you talk about durable concrete. So, certain aggregate are prone to such durability problem and cause deterioration of concrete structure. So petrography analyses is very important because you can then identify the mineralogical composition and the mineral if present in the aggregate can make the concrete susceptible to alkali aggregate reaction.

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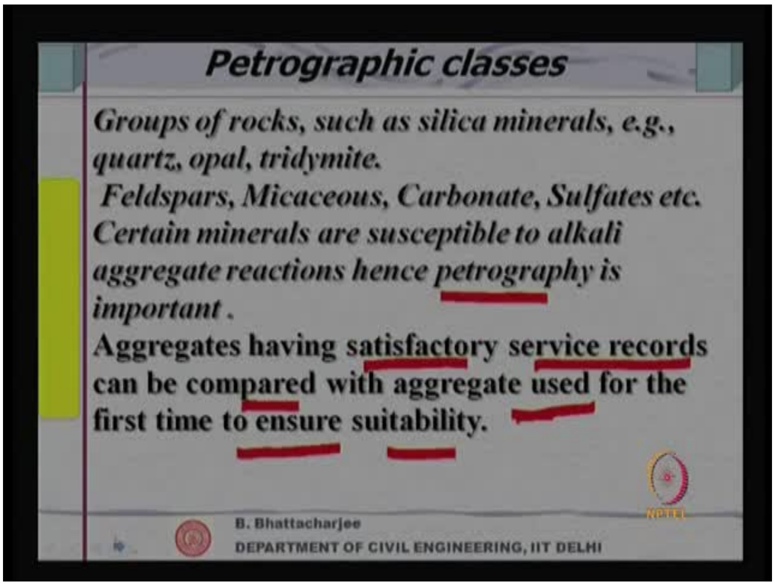

So, you can see that aggregate having satisfactory services records can be compared with aggregate used for the first time, to ensure suitability. If you are using it for first time that is where you got to look into the suitability, the one which you have been used for long long period of time, one need not bother about it. So, petrography is done in order to find out the mineralogical composition, type of minerals present and to identify weather a potentially alkali aggregates reactive minerals are present or no.

Classification, petrography classification are based on the mineralogical composition, like I said you know dolomite, may be lime stone (( )) or you know that kind of that kind of nomenclature. So, they are important from alkali aggregate reaction point of view, if you know a particular type of mineral which is prone to alkali aggregate reaction then that should be, you know that particular aggregation should be tested more and possibly may be may be isolated not used in concrete construction

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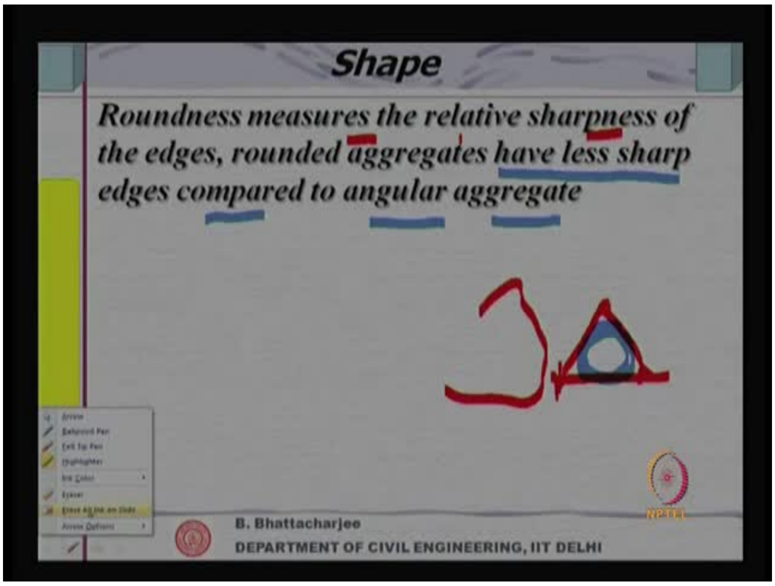

Shape is very, very important. Roundness measure the relative sharpness of the edges, you know relative sharpness of edges. So, if I have something like this this has got fixed edges, sharp edges. So, roundness measures the relative sharpness of edges. Rounded aggregate has less sharp, rounded aggregate has got less sharp edge. For example, this is round edge of the sharp edge would vanish so this will be a round aggregate.

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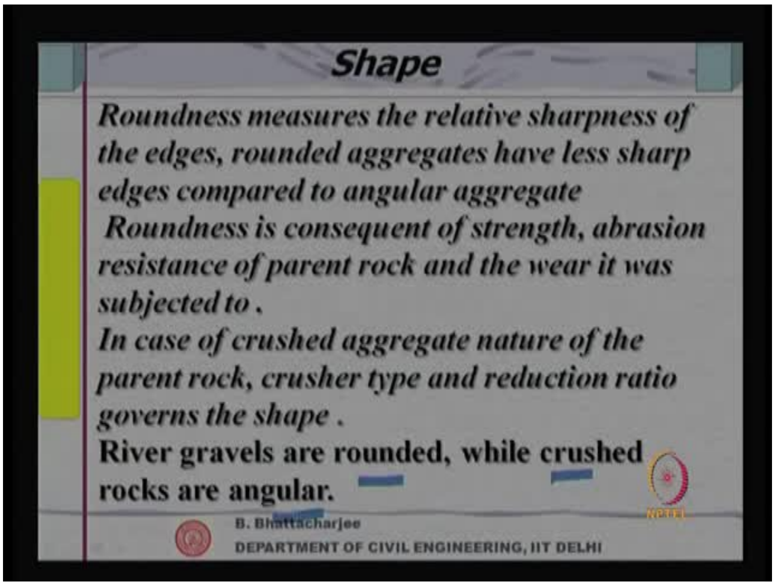

Normally natural aggregate will have tendency due to abbreviation and weathering action this sharp edges will vanish. So, other side the part, initial one was angular shape.

So, rounded aggregate have less shape edges compared to angular abbreviation so initially it was angular aggregate rounded aggregate will have less sharp edges.

Roundness is consequent of you know, strength abbreviation resistance of parent rock and where it was subjected to. If it is a strong aggregate it is like to just round because it may not get you know, its edges may not, may still be there and abbreviation resistance is very important because the edges are rounded through abbreviation action and wear and tear. Therefore, how much wear it is under gone it will depend upon that and the crushed aggregate obviously will have a tendency to remain angular, if you have crushed it, it will have a tendency to remain angular right. Rounded aggregate, natural aggregate through abbreviation and wear and tear it might lose its edges and therefore it may be rounded. In case of crushed aggregation natural of the parent rock crusher type and reduction ratio governs the shape.

So, it the crusher type parent aggregate of course, parent rock, crusher type and reduction type ratio, how much what size your reducing to all this will govern the shape. River gravels of course are rounded, while crush rocks are angular. So, this is what we must understand large crush, crush drop will be angular and river ravels will be rounded. Naturally available river sand is also rounded whereas crush stone powder, if I use stone dust they will be they will like to be angular because while crushing if you fail on the possible failure plane and it is unlikely that it will have a rounded shape.

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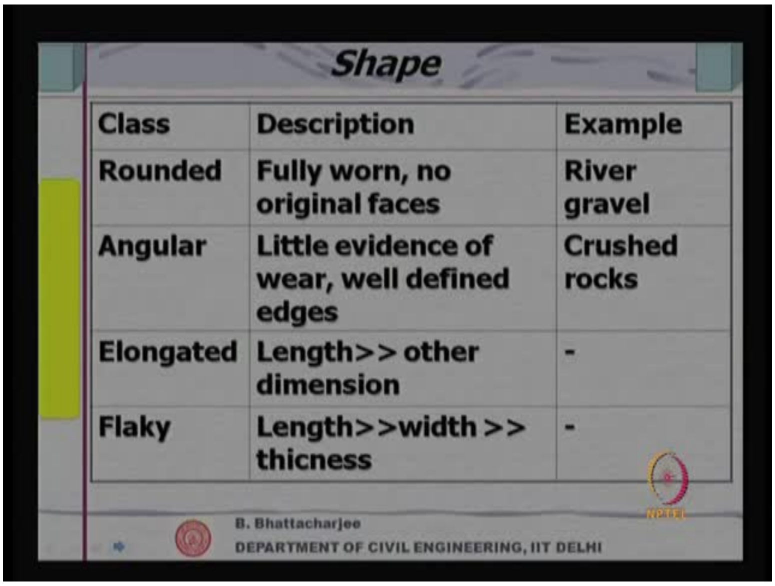

Class	Description	Example
Rounded	Fully worn, no original faces	River gravel
Angular	Little evidence of wear, well defined edges	Crushed rocks
Elongated	Length>> other dimension	-
Flaky	Length>>width >> thicness	-

We will crush at jaws between the crusher, this cross between crusher jaws. So, this you know, it is unlikely that will be rounded crush rocks are generally angular, crush adjoins are angular right.

So, shape wise will look at the classification rounded, this one of the classification, fully worn no original faces that we call it as rounded. River gravels for example, it will fully worn all wear out, no original faces. Angular, little evidence of wear, well defined edges, we get from crush rocks. Now there are, in between there are various shapes classification, but we have listed down a few here.

Elongated once which is got length much greater than other dimension. For example, this is an elongated aggregate, length greater than any other dimension, any other dimension. Flaky, length is greater than width alright, length is greater than width, but it is very large compare to, compare to thickness compare to thickness. So, shape wise some classification we can do very broad classification there may be any more in between sharp angular etcetera etcetera.

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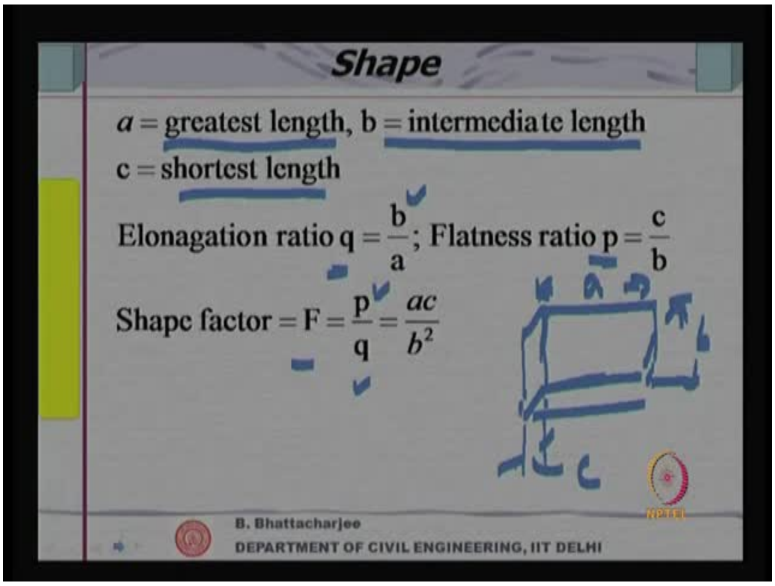

Now, numerically if we want to express some of the aspect related shape. Let us say a is the greatest length, maximum length, b is intermediate length and c is the shortest length. So, we define elongation ratio q as b by a, you know elongated is this. So, this my a, b is a intermediate could be when slightly bigger than this, so let us say b is b is something like this, alright b is something of this kind alright b is something of this kind, alright b is something like this. So, b is b is this and c is the thickness, c is this c is this

Then, elongation ratio is b by a, flatness ratio is c by b, flatness ratio is c by b right. Shape factor one can talk in terms of p by q that is flatness ratio divided by elongation ratio and a c by b square a c by b square. Now, if it is elongated b by a, if this is small that means this is elongated, if this is you know, if this is c is small compare to b then it is flat it is flat alright, this is flat. So, elongation ratio to flatness ratio gives you shape factor, gives you shape factor this is one of the way for quantifying shape.

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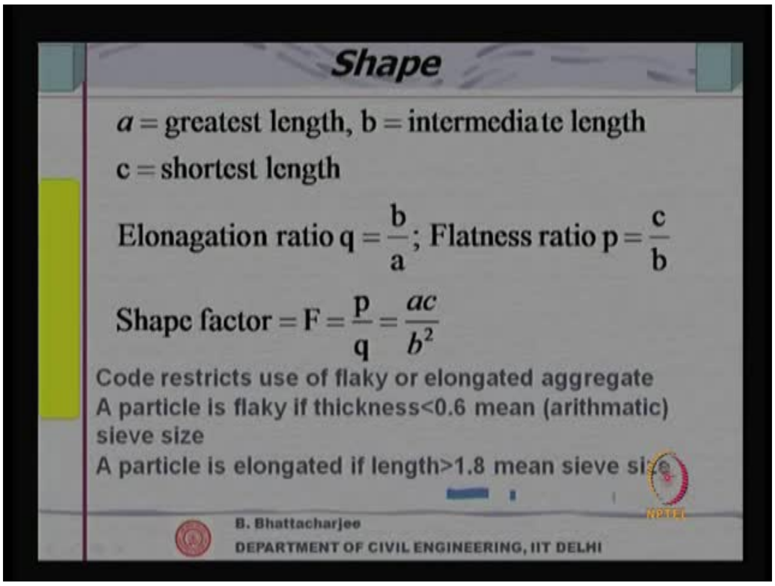

Codes, basically all codes will restricts use of flaky or elongated aggregate so codes actually restricts the use of flaky and elongated aggregate because they are, they would you know, they would normally create planes of weakness when you put them together. So, flaky aggregates, if you put them together set of flaky, one plate over another, one plate over another, they will tell to create weak joints in between right. We want in fact random, the aggregate should be embedded in paste. Now, here they might be aggregate they might be over aggregate weak planes should be created. So, this flaky or elongated aggregates are not desirable, they are not desirable.

A particle is flaky if thickness is 0.6 of mean arithmetic sieve size, if a particle is flaky if thickness is less than 0.6 of its mean arithmetic sieve size, mean sieve size, arithmetic mean sieve size you know mean is calculated on the base of arithmetic sieve size so just sieve size, is less than 0.6 of the mean sieve size then is we call it flaky. If it is elongated if it is elongated, if the length is 1.8 times the mean sieve size. So, you allow it to pass through some sieve and find out its length longest dimension, compare to the sieve size and if it is more than 1.8 because it can still pass through as a vertical, simple you know it vertically it can just pass through the sieve, through the sieve size.

So, if the length is more than 1.8 times then we call it elongated. Flaky is if it thickness its smaller than 0.6 of the sieve size then. So, you measure the smaller size dimension should not be less than 0.6 of the sieve size through which as pass through, through which it has pass through so that is what its flaky and it is the code restricts their use.

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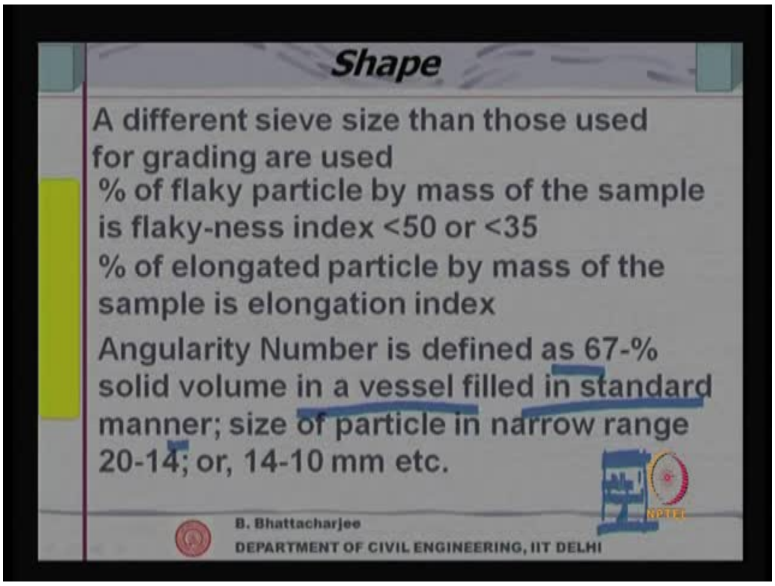

Shape, a different sieve size than those used for grading. Well, shape of course is define in terms of you know, you have a different sieves then which for grading or sieves analyses. The sieve analyses that the sieve used for shaking and finding out how much percentage is flaky we use at different sieve than those used for ratings. Percentage flaky particles by mass of the sample is flakiness index. So, if I have percentage of flaky particle in the material expressed as the percentage mass of the sample then we call it, that is, what is flakiness index. So, flakiness index is define as the percentage of flaky particle by mass of the total sample.

If it is less than 50 then, you know it should be 50 or less than 35 or depending upon the usage, should be less than 50 or less than 35 depending upon the usage code gives you this restriction. Percentage of elongation particle by mass of the sample is elongation index. So, flakiness index should be less than 50 or 35 depending upon the usage codes tell you that way. Similarly, elongated particle, mass of elongated particle divided by total mass expressed as percentage we call it elongation index and that also restricted by code.

Angularity number is defined as 67 percent minus solid volume in a vessel filed in standard manner. This is another definition trying to define the shape, you fill a container in three layer, pack it up in three layer right. Fill this container with aggregate in three layer and original volume is known by, volume of the vessel is known by filling water by you know. This is measured by filling water then you find out the solid volume in the vessel. So, if the solid volume is known because you know the mass aggregation that is gone in, divided by the specific gravity of the aggregate that will give you the solid volume. 67 minus the solid volume is angularity number because rounded aggregate packs better. So, the 67 has come from there actually.

It is expected that rounded aggregates will give you a packing, quality of 67 when you choose a specific sizes. So, these sizes are specified in the code and this specifics, when you use specific size and packet in a standard manner, you find out what is the volume of solid after packing and that volume 67 minus that volume will give you angularity number.

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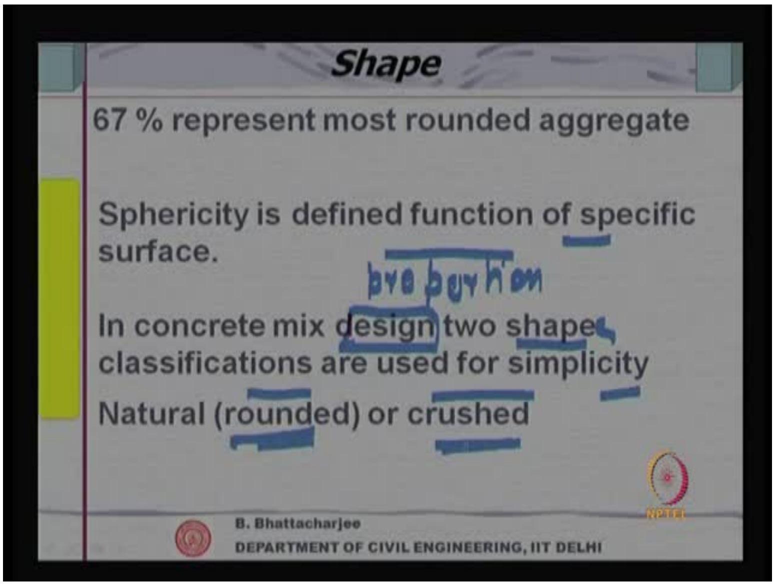

The size is generally in the narrow range of 20 to 14 mm or 14 to 10 mm etcetera depending upon the code, you know so and purpose. So, various codes uses this, ACI codes for example, ACI (( )) uses this angularity number. This is what the idea is 67 percent of the most rounded aggregate and that why the 67 percent was used.

Sphericity is defined as a function of specific surface, sphericity is defined as (( )) function of specific surface. Now, let us see how it is define, well I will come to this definition little bit later, but for practical usage in concrete mix proportioning, in concrete mix proportion when I want to determine the concrete mix proportion, two shapes, shape classification are used for simplicity.

These are simply natural rounded or crushed well new, of course some other course use more than that, but some course use simply two classification as rounded or crushed. So, from shape point of view quality we can talk in terms of simply rounded and crushed or then they are many other classification in between sub-angular, angular you know etcetera etcetera, but quantification is possible in terms of volume diameter.

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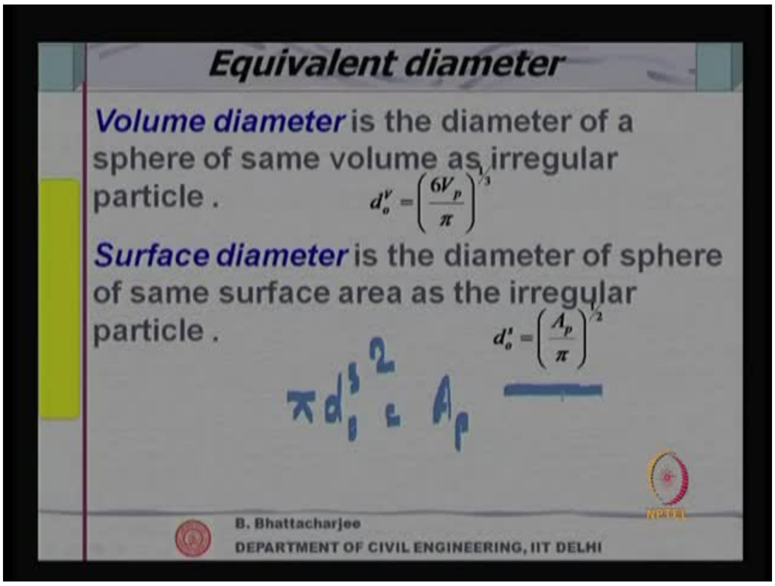

For example, volume diameter is a diameter of a sphere having same volume as irregular particle. So, volume diameter of a particle of an aggregate is a diameter of a sphere having same volume. Now if V p is the volume of a single particle and if I assume that I have sphere having the same volume then one by 6 pi d cube or d 0 v cube as we have define here will be equals to V p and therefore, volume diameter is given by this expression, this is V stands for volume. So, volume diameter is given by this expression.

Surface diameter is the diameter of the sphere of same surfaces area as a irregular particle. Now, surface area of sphere is pie by d 0 s, square. Pie d square is the surface area of a sphere. So, that must be equal to area surface area of the particle therefore, surface diameter is defined in this manner. So, if you have any regular shape particle if you know its surface area, surface area divided by pie and if you take root over of it that gives you surface diameter.

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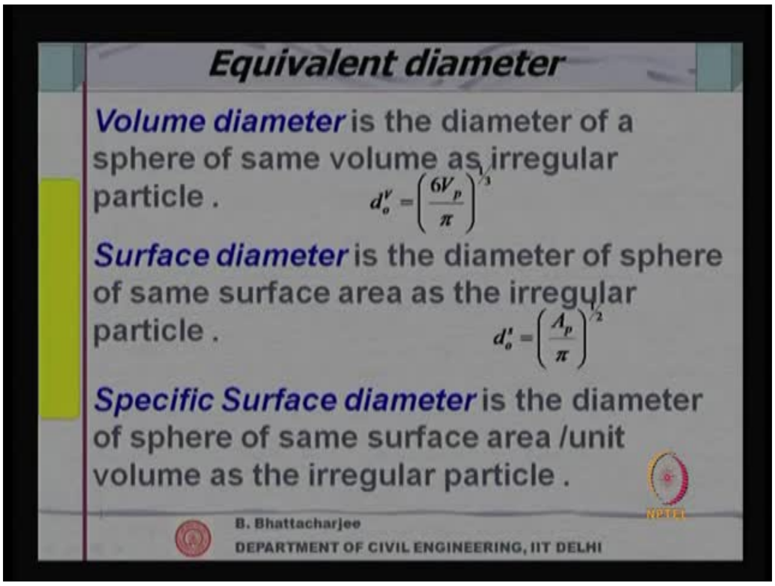

So, you can define diameter diameters in this manner, surface diameter and volume diameter and then specific surface diameter is a diameter is sphere of same surface area of a surface volume and the irregular particle. So, this is called specific, specific surface area diameter. Now, if you talk about specific surface earlier in connection with cement and we are talking and mentioning that surface area per unit mass or per unit volume is used as specific surface. In the contest of aggregate, will be talking in terms of surface area per unit volume as the specific. So, specific surface so specific surface here we define in the terms of surface area per unit volume. So, now you consider specific surface diameter, it is the diameter of sphere of same surface area per unit volume as the irregular particle.

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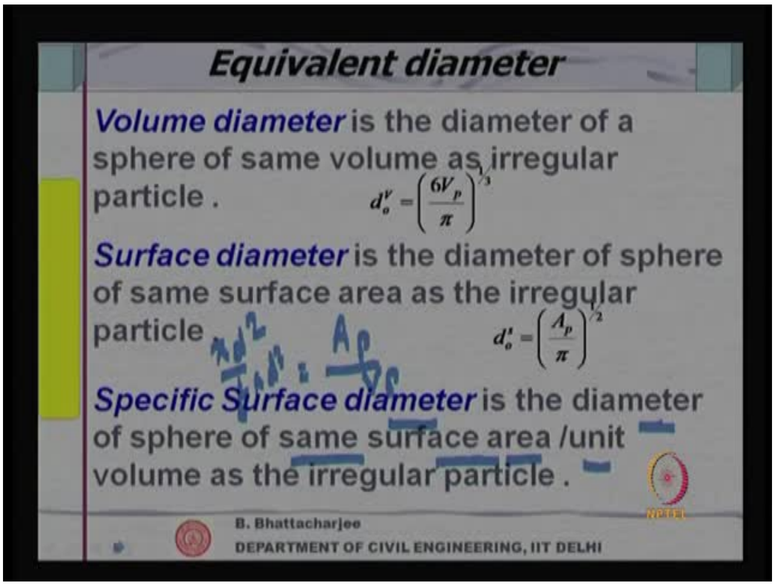

So, what you got to do is, you got to know A p and V p. So, that is the specific surface. Now, this must be equals to, for a sphere the, this is pie d square divided by volume 1 by 6 pie d cube. So you find that 6 by d cube… I think that it is there in the next slide it is there in the next slide so just look at it.

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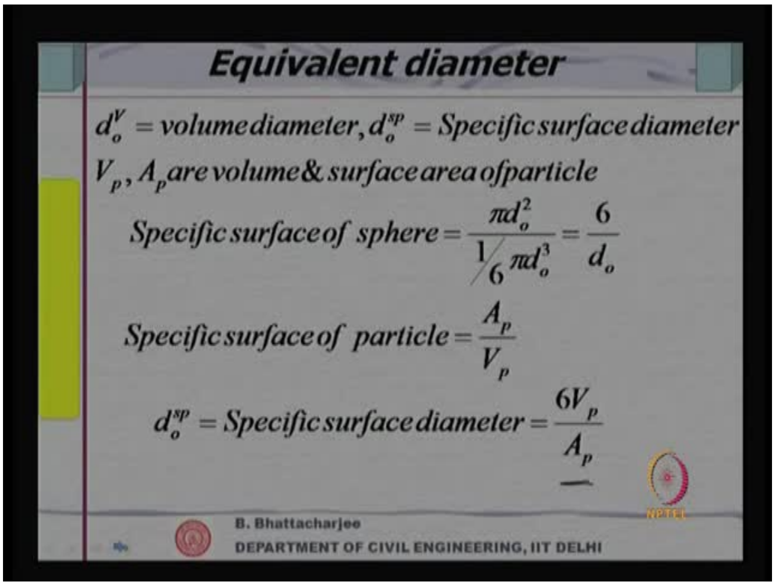

It will be V p V p V p by A p by V p and specific surface of a sphere would be pie d square divided by 1 6 pie d cube. So, is equals to simply 6 by d. So, this d will be equals to 6 V p by A p, right. Now, specific surface volume diameter was, what was volume diameter, volume diameter, specific surface diameter, volume and surface area of particle. There you see this same derivation is available here straight away. So, 6 by d 0 is a specific surface of the spear and specific surface of particle is this and if you equate this, specific surface diameter will be 6 V p by A p, 6 V p by A p, right. So, this is how we can find out various diameters and through this we defines sphericity factor so that is related to the shape.

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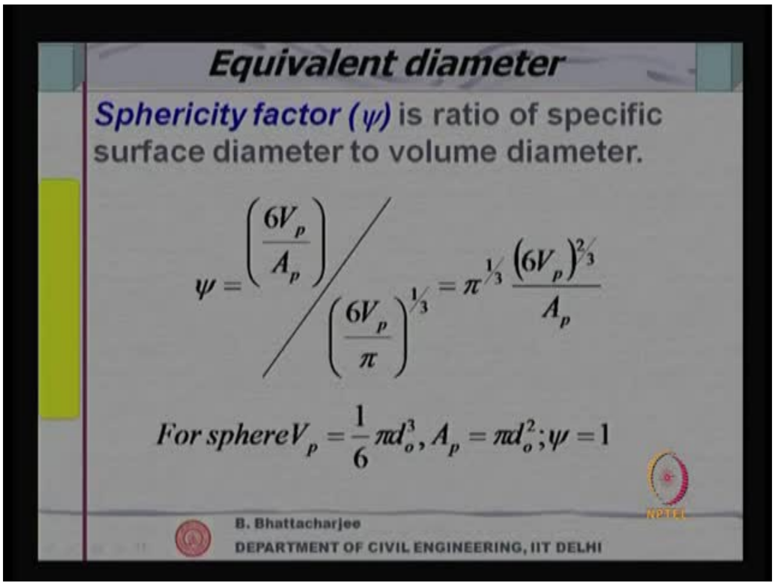

So, it is a ratio of sphere specific surface diameter to volume diameter. So, this is the ratio of specific surface diameter to volume diameter that is idea. It is the ratio of specific surface diameter to volume diameter, right. So, we have seen how it defines volume diameter therefore this is given by this formula this is the specific surface diameter and this is the volume diameter, right and 6 V p by A p and 6 V p by pie.

So, this will be pie to the power one third and 6 V p, this is one third, this was one minus one third so this will be two-third, here also 6 V p divided by A p. For sphere V p is equals to one by 6pie d 0 cube, A p is equals to pie d square, right. So, put these values here pie d 0 square and put this value here of V p 1 by 6 pie d 0 cube, this will come 1. So, sphericity factor you know, psi is the ratio specific diameter to volume diameter and is 1 for sphere.

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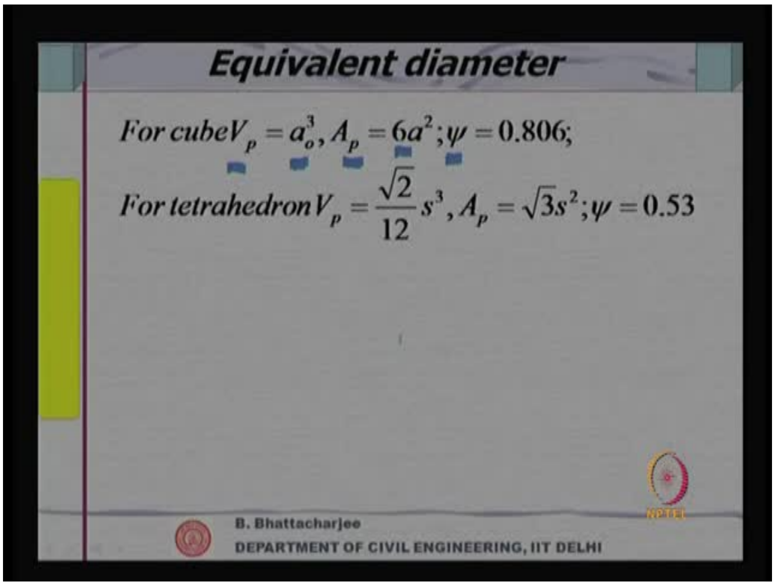

Let us see what happens if I have larger sizes I mean more angular sizes. For angular particle, for cube of course yes, if you see for cube volume is V p is a 0, cube A p is 6, a square and this will turn out to be 0.806, because if we go back to the formula if you go back to the formula.

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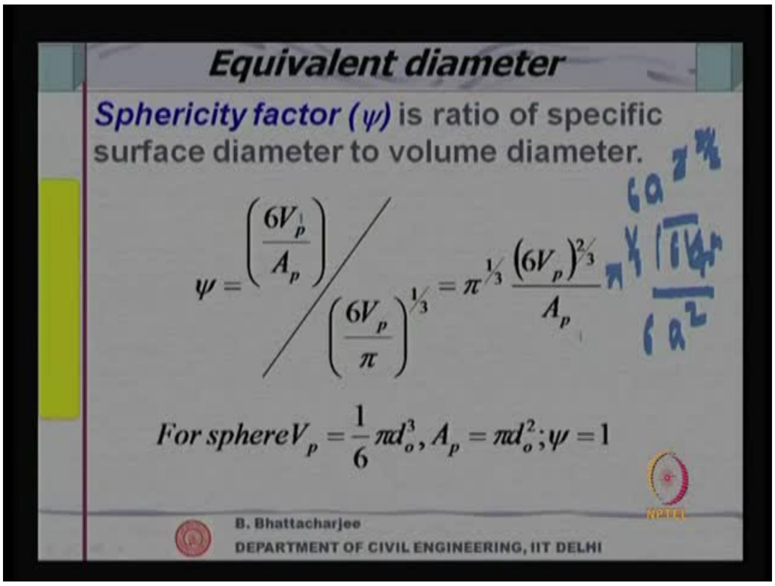

You know, V p by A p so this was a cube for the cubes 6 a cube, for 6 a cube to the power 3 by 2. So, it will be 6 under root 6 V p, pie to the power of 1 by 2 V p and area is V p and V p is attempt to A q, you know 6 under root 6 A and here A will be 6 A square and if you finally calculate out this stands out to be 0.806, velocity factor will come out to the 806, 0.806.

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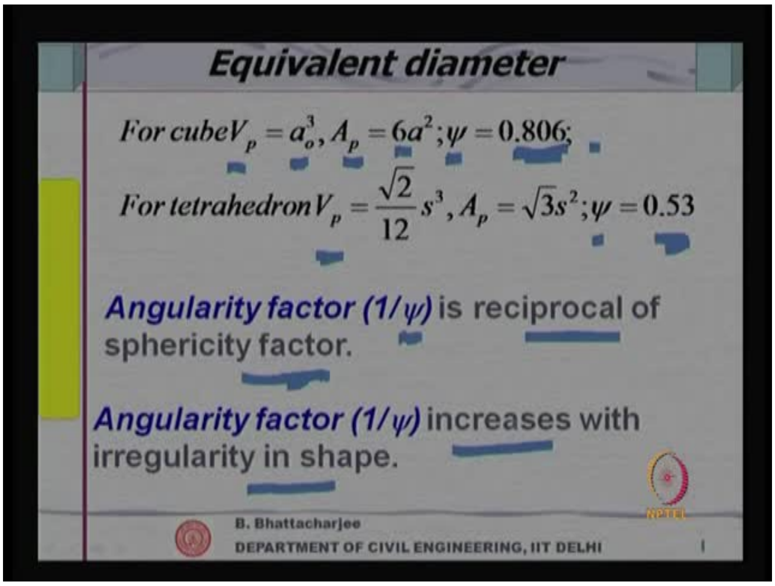

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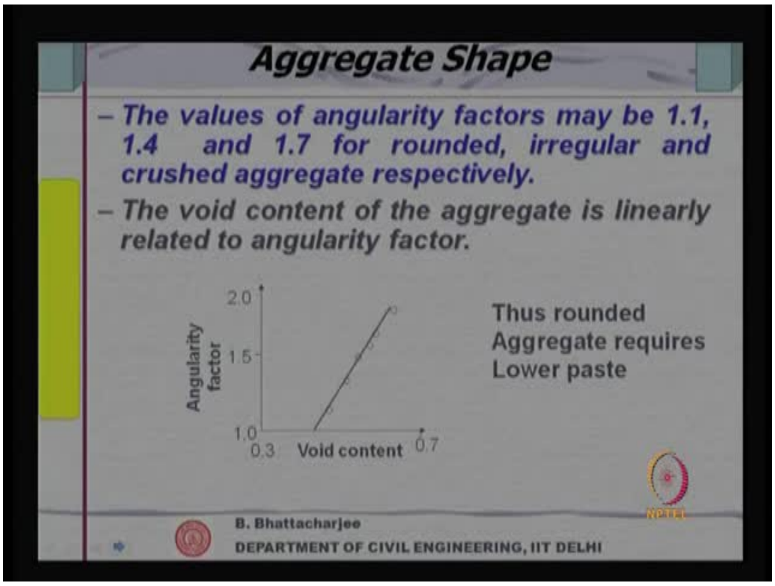

For tetrahedron this value is 0.53 you can show it similarly, for tetrahedron this value is 0.53. So, angularity factor is 1 by psi is a reciprocal of sphericity factor. So you define another term, this is how we can quantify in some manner. Angularity factor is a reciprocal of sphericity factor, right. It is reciprocal of sphericity factor and this increases with irregularity in shape or angular shapes. This is highly angular, this is highly angular, this is still angular. So as the angularity increases psi reduces therefore 1 by psi will increase. For sphere this value is 1 for angular shape this value is more than 1. Angularity factor is more than 1, angularity factor is more than 1.

This is important because more angular shape is, its packing density is poor. Means when you pack this particles together there will be large void left in them and thus it results in more paste that we use in the concrete filling those balls. So, that is why this is important, this will be very clear as we go further. The values of angularity factor may be 1.1, values of angularity factor will be 1.1, 1.1 for you know, rounded aggregate. Rounded aggregate it could be 1.1 for rounded aggregate it could be, rounded aggregate it could be 1.1, right.

So, it could be rounded for rounded aggregate may be 1.1 and for irregular 1.4 and crushed aggregate 1.7, for crushed aggregate it is 1.7. The main important issue is the, what content of aggregate is linear related to angularity factor, this is the most important issue that, you know this is linearly related to angularity factor and if plot you this graph it is been observed that void content increases, void content increases with aggregate void content increases with aggregate void content increase with aggregate and it is like this void content increases with aggregate.

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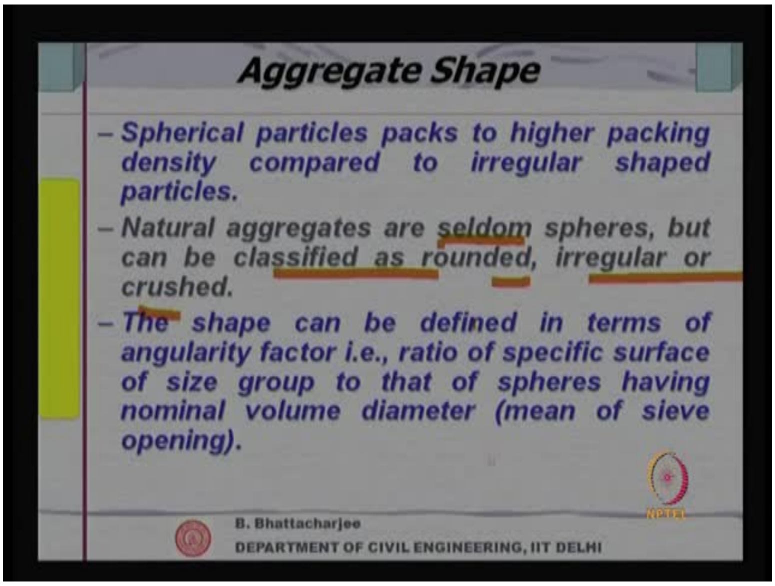

So, angularity factor angularity factor increases that means it is now more angular in shape and voids content increases as the angularity factor increases. So that is why the shape is important, now more the voids more would be the paste required, to fill in the voids. So that is why the shape is very important in case of concrete, in case of concrete and that is why you looking at the shape.

The size as got a role also we shall check that role of the size, you know, size also we look into so size has got a role size has got a role. Spherical particles expects to higher packing density compare to irregular shapes, right irregular shape particles and natural aggregate are seldom sphere, they are not sphere essentially they are seldom sphere, they are you know seldom spheres, but they can classified as rounded, irregular or crushed, as we have seen.

Natural aggregation are not spheres so other altogether aggregates can be classified rounded irregular or crushed rounded irregular or crushed, right. The shape can be defined in terms of angularity factor that is ratio of specific surface of size group spheres having minimum volume diameter that is mean of sieve opening, alright mean of sieve opening.

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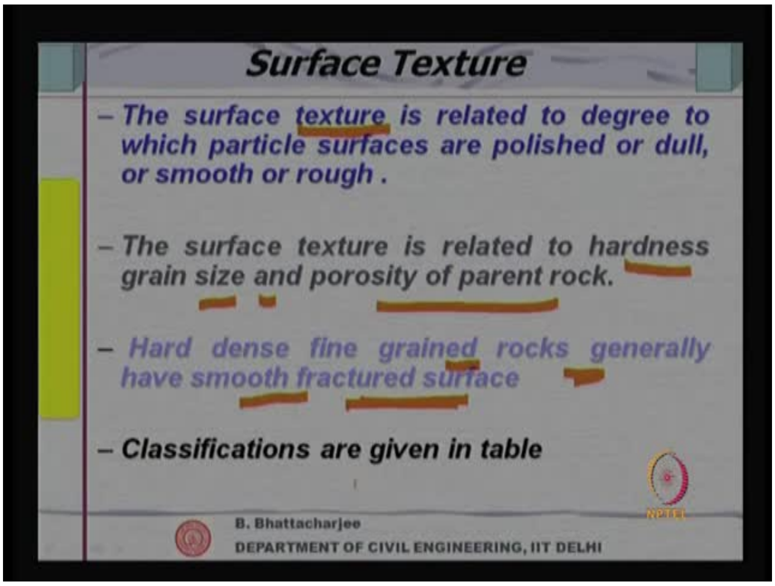

Let us see what this is. So, shape as we have seen, the shape and we have also observed that, we have just noted that shape has got an important role because packing depends upon the shape and quantifying the shape we have seen. You might be using the concepts some time later on right.

So, shape is an important issue and angularity factor, angularity factor can use define quantifying shapes higher than angularity factor more is void, for sphere the angularity factor is 1. Now, let us look at surface texture, surface texture is related to degree to which particle surface are polished, dull or smooth or rough. Now, this also important again because if it is if it is you know important, surface texture the bond of the cement paste will aggregate depends upon this surface texture. The bond of the aggregate bond of the aggregate with, with the cement paste depends upon the surface texture that is why surface texture is important, alright. Now, it depends upon actually hardness of the grain and the size of the grain and porosity of the parent rock.

A porous rock always will have honeycomb surface structure, hard dense fine grained rocks generally have smooth fractured surface, hard dense fine grained rocks. So, it is dependent upon the rock type usually hard rock and fine grain generally have smooth fractured surface because fine grain will go away, but if it is hard not many can go away. Therefore, you may likely to have generally smooth surfaces the classification related to these is something like this.

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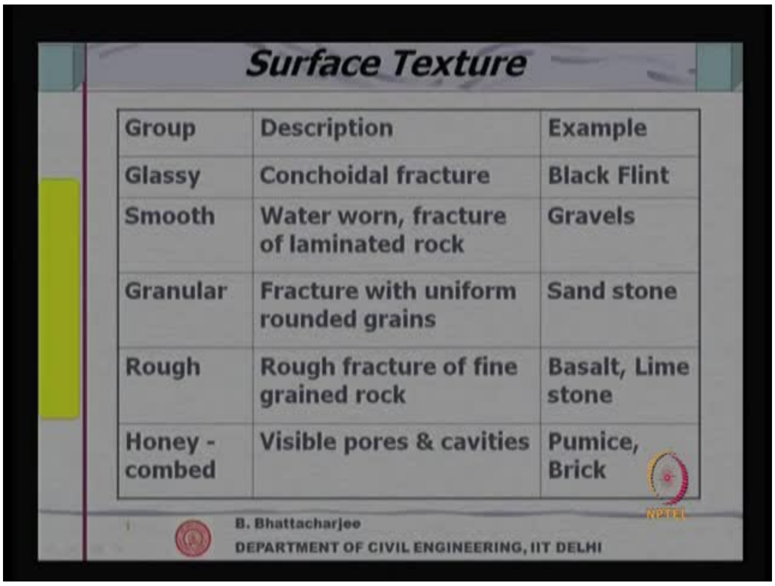

Group	Description	Example
Glassy	Conchoidal fracture	Black Flint
Smooth	Water worn, fracture of laminated rock	Gravels
Granular	Fracture with uniform rounded grains	Sand stone
Rough	Rough fracture of fine grained rock	Basalt, Lime stone
Honey - combed	Visible pores & cavities	Pumice, Brick

For example, glassy is conchoidal fracture, black flint is an example. Smooth is water worn fracture of laminated rocks that results in water worn so this gravels are like that. Granular fracture with granular surface structure we are talking about that means grains will be protruding out, fracture with uniform rounded grains, sand stone. Rough fracture of fine grained rock basalt, lime stone excreta and honey combed structure honey combed, honey combed surface texture comes from pores rocks such as if you take brick for example, so visible pores and cavities will be there. So, this is surface structure an important property related to concrete. So size, shape and surface texture, this is important properties so that is what we have looked into today.

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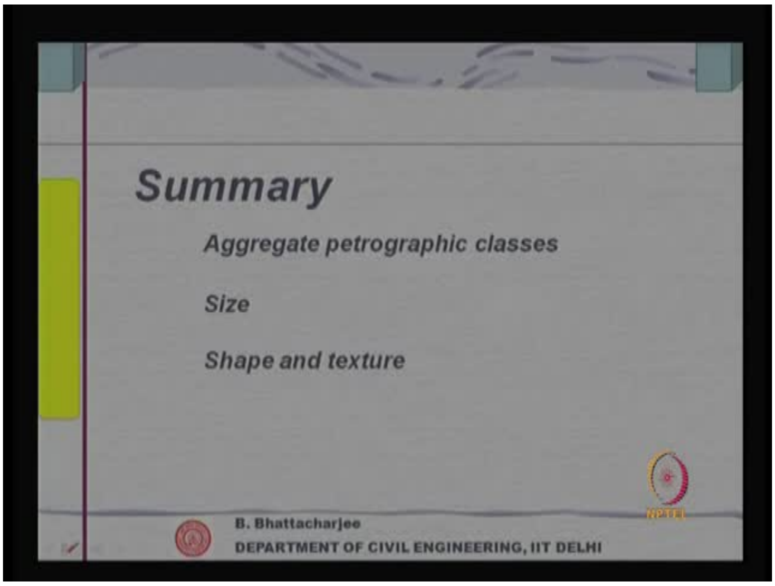

The size, shape and surface structure that is what we looked into today. Now packing characteristics packing characteristics depends on both size and both and both depends on size and shape. This is what we will look into next class. Size, if you have a single size particle they will always, you know create some amount of void, you cannot reduce it behind a point and the quantity amount of voids is a function of, amount of void is a function of amount of avoid is a function of the packing characteristics.

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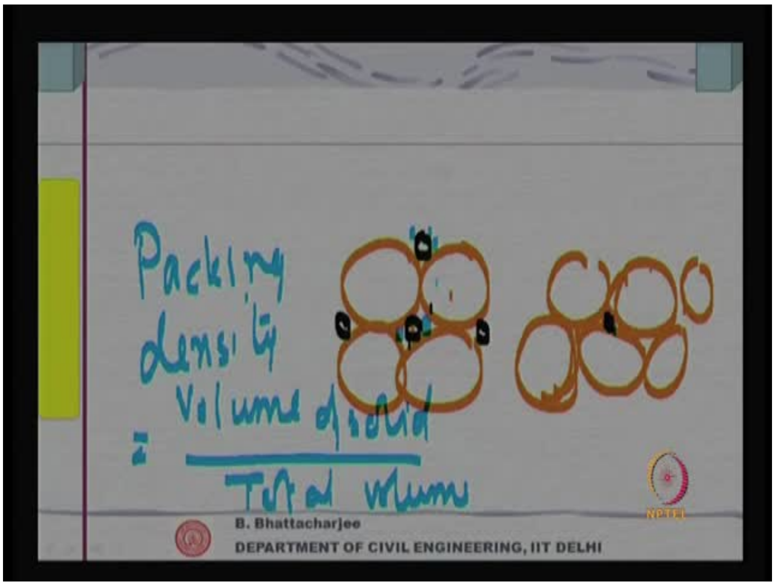

For example, if we consider simple cubic packing, if we consider simple cubic packing then the voids here will depend upon the packing, but I can assume a second kind of packing, let us say and you can see depending upon the packing, another particle coming here, voids have reduced voids have reduced, this is the two dimensional picture and you have to extend this idea to three dimension.

So, packing depends, governs the void contact, and in fact if I have a single sized particle, the maximum packing that I will obtain or maximum packing density that I will obtain, will define the maximum density later on. Maximum packing density is that I will obtain will depend upon the nature of packing. This is of course, for spherical particle; if you take angular particles so particles all other particles remaining constant, let us say. Void in the aggregate is the function; void in the aggregate is a function of the packing characteristic. For example, this is simple cubic packing I have larger void compared to this sort of packing, right.

So, we have different kinds of packing like body centered, face centered etcetera etcetera, we will discuss about them so it depends upon packing. So, if I want to reduce this void then if I want to reduce this void and what shall I do is, I put a small aggregate here and small aggregate here and smaller aggregates can, smaller size small size aggregate can reduce this void. Single sized particle, the amount of void you know the amount of void reduction that is possible is limited, you cannot reduce the void beyond the point it depends upon packing.

Only when we have different sizes particle or at least two different size particle, the void content would reduce. Even to reduce the void further even to reduce the void further let us say then you use maybe a third final particle. If you put final particle they go into the interstices of this particle itself, this particle itself and reduce the void. Therefore what contents depend upon packing characteristics, shape of course is a function, but for given shape given type of packing number of particles or size distribution of the particle governs the packing characteristics.

So individual sizes we define in terms of sieves of course we have seen, but we did not talk of different sizes mixed together, right. So, when you mix only, when you mix different sizes together then only there is a possibility of reducing down the voids. So, we define a term called packing density packing density packing density and it is the volume of solid divided by total volume, total volume, volume of solid by total volume so it is the volume fraction.

So, packing density is volume of solid by total volume and this packing density increases with (( )) larger size distribution, packing density increases with larger size distribution and this is what we will look into in the next class. The issue of packing density, how particles packs, we have seen how shape governs. So, to summarize everything today we have looked into petrographic classes, we do, we really did not go by any code or anything, but petrographic classes are essentially the classes based on mineralogical composition.

Their importance lies in the fact that some of those aggregates may not be inert, based on their mineralogical composition of course, mineralogical composition or parent rock type governs also the shape because rounded aggregates it depends up on grain structure and of course hardness of the parent rock. So, petrographic classes are important form that point of view. Then we have looked into the size, how do you define them, but the influence of the size. How it is important in concrete that we did not look into and what are the shape and texture that we looked into. So, the next class we will look into the, we will look into the… You know how they are relevant, shape of course we have already mentioned that packing would be better with rounded shape and we will look into the issue of size and their relevance in concrete.

One important thing is it is relevant in concrete, because better the packing less paste I will require. So, rounded aggregates is required to aggregate less paste. Shape is important, structure you know texture is important from bond with the cement paste. Surface structure is important from the point of view of bond with the cement paste. So, shape is important, petrography is important and size distribution is important which we will look into next class, and I think with that we can summarize this lecture.

Thank you very much for being present, thanks.