Hydration, Porosity and Strength of Cementitious Materials
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Lecture – 23 & 24
Mineral Admixtures

Hi. Good morning to one and all. I am K. V. Harish, Assistant Professor Department of Civil Engineering, IIT Kanpur.

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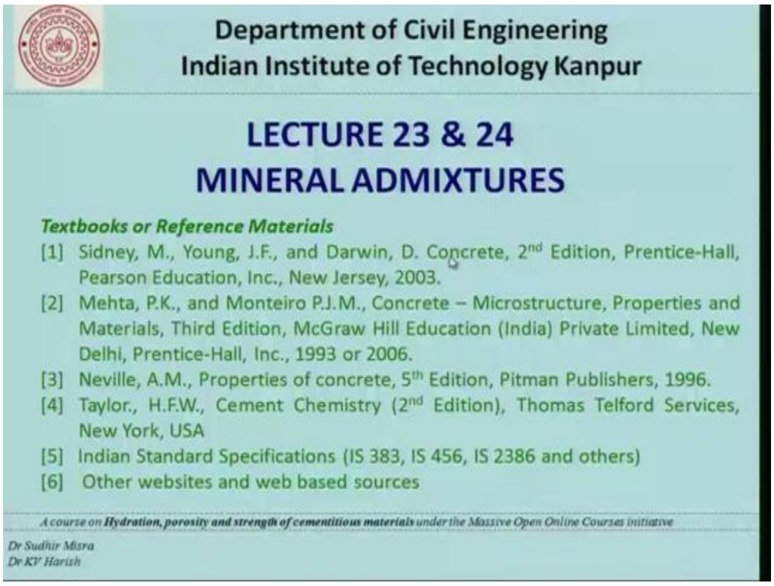

You are watching MOOC lecture course on Hydration, Porosity and Strength of Cementitious Materials. Today we will see lecture 23 and 24 mineral admixtures. Remember that in the last two lectures 21 and 22. We have seen a sustainability of concrete how to incorporate sustainability in concrete and again what are the different things and sustainability like sustainable development sustainable design and how to incorporate strategies of sustainability in concrete.

So, in this lecture we will see an introduction to mineral admixture and head on to fly ash as a very important mineral admixture in concrete. The text books and reference materials are shown here.

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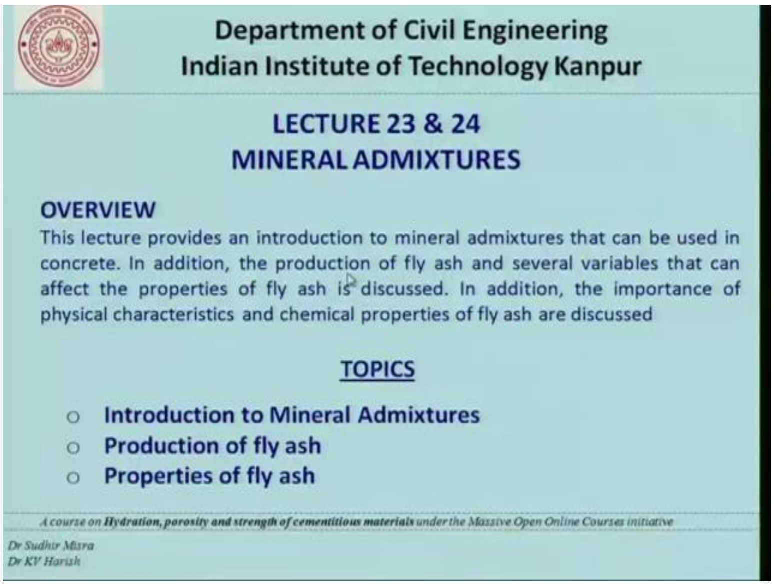

The overview of the lecturers 23 and 24 is provided. This lecture provides an introduction to mineral admixtures that can be used in concrete. The in addition the production of fly ash and several variables that can affect the properties of fly ash is also discussed. In addition, the importance of physical and chemical properties of fly ash is discussed. Especially, particularly how these properties affect the properties of concrete the topics? That we will see in these 2 lectures or introduction to mineral admixtures production of fly ash properties of fly ash.

Now, introduction to mineral admixtures: generally, we may be aware that mineral admixture is actually a forth entry to the common ingredients that we have seen in concrete mix design. So, the common ingredients include cement fine aggregate course aggregate water. And in addition to these 4 we can add chemical admixtures and mineral admixtures depending upon the requirement. And chemical admixtures are largely added primarily from the fresh property stand point, but in, but there are some exceptions or exceptional cases where we add chemical admixtures for long term properties also. In the case of mineral admixtures largely it should be seen from the angle of sustainability. So, mineral admixtures are usually added from the standpoint of long term. So, to achieve long term properties and durability mineral admixtures are generally added.

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Now, mineral admixtures many times or called in different names. For example, one of the commonly used name is supplementary cementing material or supplementary cementitious material. And sometimes mineral admixtures are also called in the name of pozzolans. There is some slight difference between of the terminologies used. Supplementary cementing material is primarily used to indicate that that particular admixture is hydraulic in nature; that means, it can set under water. Examples of supplementary cementing material is primary fly ash and slag, but if you take the definition of a pozzolan, it is usually non hydraulic in nature that is it be does not set and react with water directly, but many times in many text books the supplementary cementing material and pozzolans are not substantially differentiated, but there is a slight change in the meaning, for example, supplementary cementing material is hydraulic many times and likewise pozzolans are non hydraulic.

Now, likewise whenever we refer to admixtures usually in the industry admixtures largely refers to chemical admixtures. And we generally should not use a word admixture alone to indicate mineral admixture, because admixtures in the industry largely indicate chemical admixtures and not mineral admixtures.

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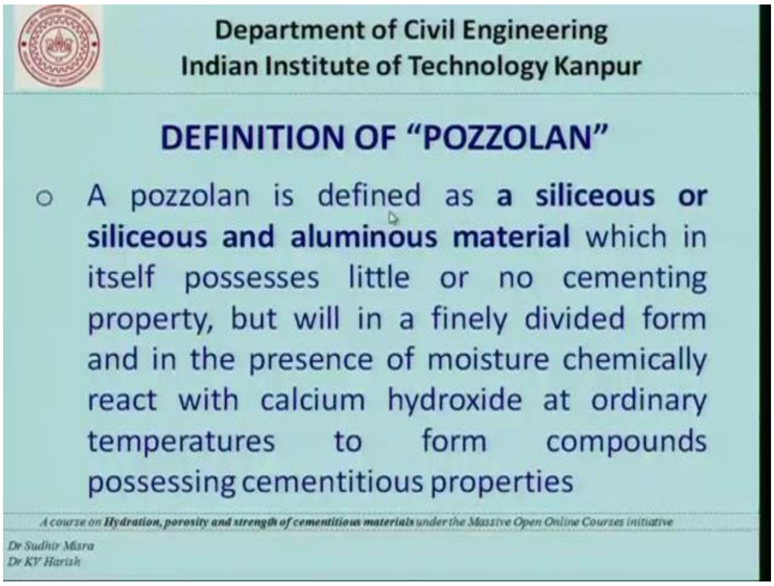

How do we define a pozzolan the standard definition of a pozzolan is shown here? Pozzolan is defined as siliceous or siliceous and aluminous material. Remember the pozzolan is largely by definition should contain either a siliceous compound or alumino siliceous material or a combination of these 2. And which in itself possesses little or no cementing property that is very important a pozzolans is basically defined as a material that has no cementing property directly, when it is added to water, but it will react in a, but it should react in a finely divided form, and in the presence of water or moisture it should chemically react with the calcium hydroxide. Remember that calcium hydroxide is an important compound in the hydration of cement in addition to calcium silicate hydrate gels. Calcium silicate hydrogen gel is a most important compound which provides the binding nature to the binder and calcium hydroxide is also formed in addition to calcium silicate hydrate gel.

So, the calcium hydroxide is usually is not a strength giving face. So, by definition of a pozzolan even though it is it does not have any cementing property, it should have the capacity to react with calcium hydroxide in the presence of moisture. And remember this is at ordinary temperature to form compounds processing cementitious property. Lastly what we will see in the later subsequence slides is that basically siliceous or aluminous siliceous materials react with the calcium hydroxide in the presence of moisture to form calcium silicate hydrate gel.

So, basically the calcium hydroxide which is not a strength giving face is converted to a calcium silicate hydrate gel which is strength giving face, because of the use of a pozzolan. So, that provides concrete or Portland cement based systems totally different property. And of course, it is a of course, improved properties. So, we will see all those things at a later stage. So, I am just again going through this definition because of the importance of it a pozzolan is defined as a siliceous or alumino siliceous material or siliceous and aluminous material which in itself poses possesses little or no cementing properties, but will in a finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

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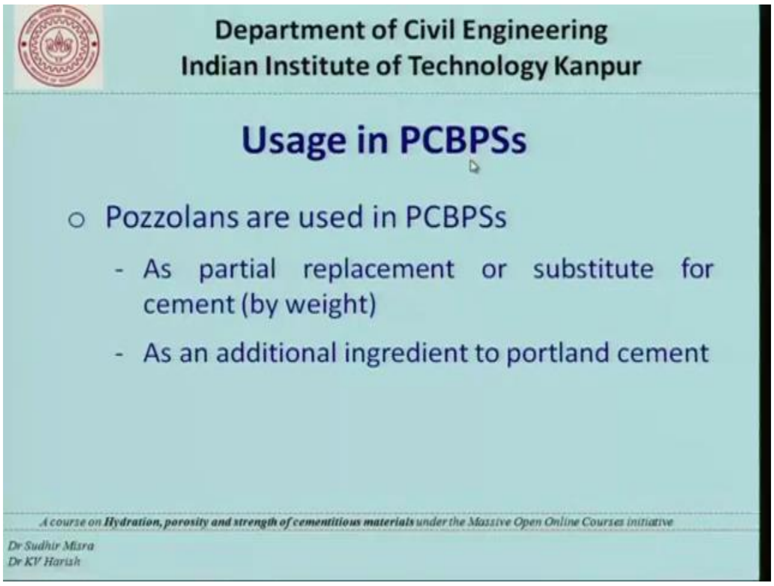

Now, how do we use pozzolans or supplementary cementing materials or mineral admixtures in Portland cement based phase systems? Basically 2 approaches are followed one is that the pozzolans, can be used as a partial replacement or a partial substitute for cement. So, if you get back to the volume proportion we typically have 10 to 12 15 percentage of cement that is being used by volume in Portland cement based phase systems, and of that volume a portion of it will be pozzolans. So, so when it is used as a partial replacement, it is evaluated on the basis of replacement by weight which means a portion of cement it could be 5 percent 10 percent 15 percent it could go up to 40 or 45 percent depending upon the performance of the pozzolan and depending upon the performance of pozzolan in the Portland cement based phase system.

Of course, the optimum amount of each of the pozzolan is extremely important, but the point here is that a portion of it is getting replaced by this pozzolan, when the remaining portion will be typical Portland cement. In addition to being it used as a partial replacement it can also be used as additional ingredient to Portland cement, which means that you do not want to change the minimum amount of cement content in the concrete. If you actually get back to the mix design lecture, what we have seen is that a Indian standard code has specified certain minimum amount of Portland cement to be present in concrete.

So, considering those tables and if you want to use pozzolans for improved properties durability properties at a later stage considering sustainability and long term pozzolans can be used in 2 ways either as a partial replacement. So, when you used as a partial replacement what happens is many times the amount of cement gets reduced. So, again having the mix design table in mind where the minimum cement content is specified by Indian standard we cannot go ahead sometimes with partial replacement. So, in that case we can fix the amount of Portland cement that is minimum Portland cement that is specified by IS and can still use pozzalan pozzolan as a additional ingredient to the system.

So, there are 2 ways which are typically followed. The first way goes ahead if the cement content is substantially higher than the minimum cement content that is specified in IS, but if you want to stick on to the minimum cement content that is specified in IS we can still use pozzolan as a additional ingredient.

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Now, what are the different types of pozzolans available or many times also called as categories, categories types basically or same terminologies or the terminologies used for classification. So, there are primarily 2 types one is natural pozzolans the other one is artificial pozzolans and many times it is also nowadays classified as industrial by products. Now natural pozzolans may include volcanic gases volcanic tuffs, diatomaceous earth, calcined clays or shales. And these are primarily obtained from natural sources as defined by the terminology used here natural.

So, these all are primarily obtained from natural sources. In the case of industrial by products or artificial pozzolans, the primary has fly ash silica fume slag. In addition to that we have rice husk ash metakaolin and several others. And primary in our course between say lectures 21 to 30, largely we will be covering fly ash silica fume and slag. So, the natural pozzolans is generally not required for this course, but probably for a research oriented things these things are important. So, what this course we will not get into the natural pozzolans, but at least you should know from audience stand point you should know at least some types of natural pozzolans.

Now in industrial by products we have this fly ash silica fume slag and remember that fly ash is again a industrial by product waste from coal production. Likewise, silica fume is from production of silicon or Ferro silicon alloys and slag is actually primary from the production of steel or copper metal. So, we will see all about these in the subsequent lectures, but in this lecture we will have some focus on fly ash.

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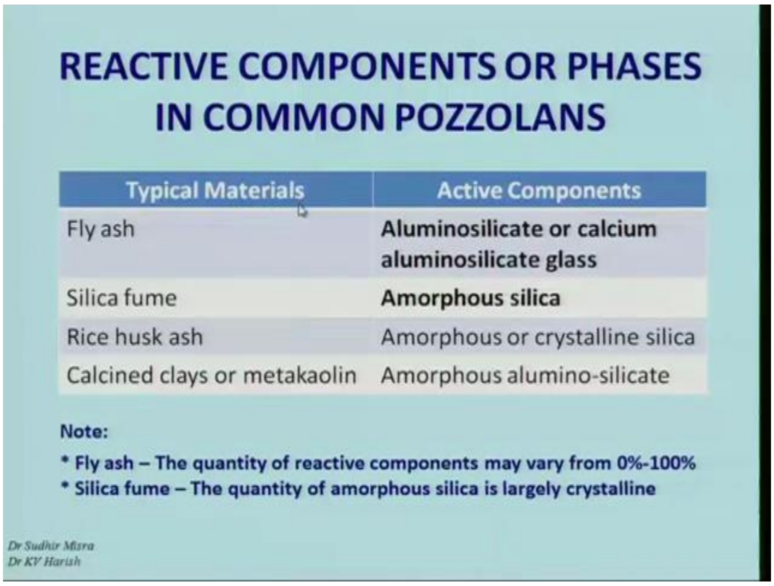

Now, when we move to the different pozzolans that are available, what is important is what is the reactive component or phases that are present in these pozzolans. Now so in this table what is presented is you have the different pozzolans like fly ash silica fume rice husk ash and calcined clays or metakaolin. And in the other column you have what is the active component or reactive phases. So, in the case of fly ash the active or reactive component is primarily aluminosilicate or calcium aluminosilicate glass. So, this is very important because this is; what is the component that actually reacts when we actually get back to the definition of a pozzolans. So, this is what actually reacts with the calcium hydroxide to form compounds which have cementitious property.

So, here what is listed is for the different pozzolans what are the reactive components or active components. In the case of fly ash, you have aluminosilicate or calcium aluminosilicate glass. In the case of silica fume you have near amorphous silica. In the case of rice husk ash, you may have amorphous or crystalline silica depending upon the temperature and (Refer Time: 14:39) condition during the production of rice husk ash likewise for calcined clay or metakaolin you have amorphous aluminosilicate. So, from a quiz stand point or from an examination or assignments stand point, it is important to know each of the reactive components present in different pozzolans. Remember that we are covering only the industrial by products or the artificial pozzolans. And primarily we will see only fly ash silica fume and slag, but some information about rice husk ash and metakaolin may also be of significance.

So, in this case rice husk ash some components of rice husk ash and metakaolin are shown primarily the reactive components. And the viewer should also have one more thing in mind which is given as a note here. For fly ash the note that is provided is the quantity of these reactive components may vary from 0 percentage to 100 percentage it is a very important point because the audience should not come to immediate conclusion after seeing this slide. Here that all the particles and fly ash or aluminosilicate or calcium aluminosilicate that is wrong. What audience should keep in mind is that some portion of fly ash contains this part reactive or active component. Remaining part contains crystalline compounds, which we will currently not deal with it at a later stage we will only list what are some crystalline compounds are minerals that are present.

So, out of say 100 percentage of fly ash some portion of it usually say if it is going to be fly ash it could vary from 0 to some 30 40 percentages. That will be active components. In other cases, like silica fume or others it could be substantially higher the amount of amorphous silica could be as high as say 70 to 100 percentage. In the case of fly ash, it is much lower 0 to 20 30 40 50 percentage and in the case of rice husk ash again it depends on the (Refer Time: 17:09) condition that is used during the production of rice husk ash.

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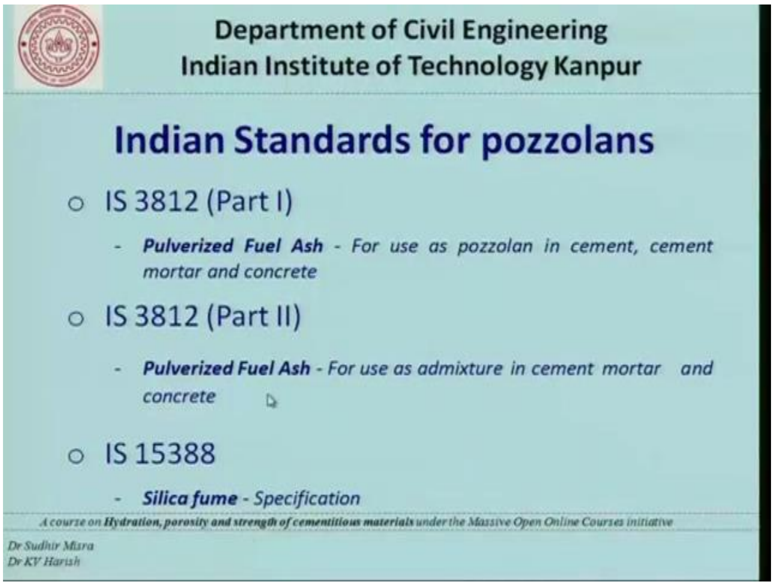

Now, what are the Indian standard codes available for pozzolans? We have several standards available. So, let us get into brief information about what are the codes and what it basically provides. In the case of fly ash we have IS 3812 part 1, IS 3812 part 2. And a part 1 deal with part 1 and 2 basically deals with pulverized fuel ash. And here what it covers is how to use pulverized fly ash as a pozzolan in cement mortar and concrete. So, that is covered in part 1. In part 2 how the pulverized fly ash can be used as an admixture in cement mortar and concrete.

So, remember the first one is in cement mortar and concrete. And the second one is in cement mortar and concrete not in cement and so that is these are the primary codes for fly ash. And when you come to silica fume you have IS 15388 which provides specifications for silica fume.

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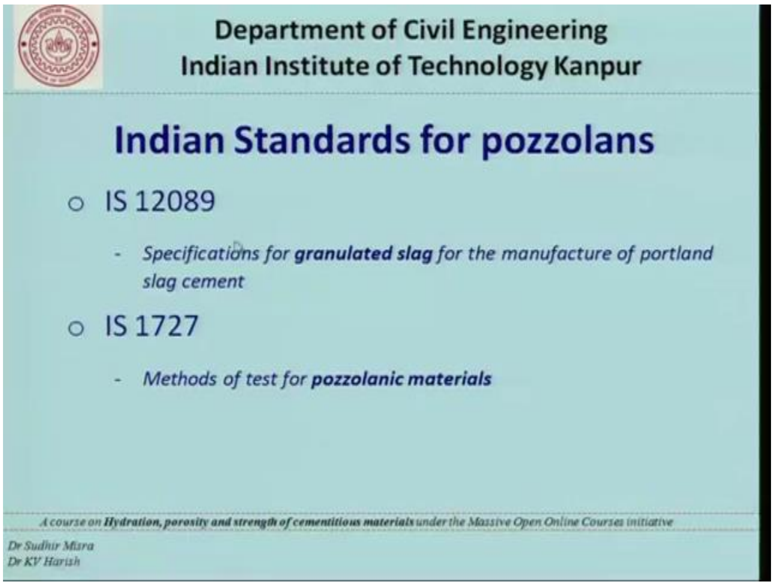

And likewise you have IS 12089 which provides specification for granulated slag. And generally the testing information of pulverized fly ash silica fume and granulated slag or all present in IS 1727. So, it basically covers method of testing for pozzolanic materials.

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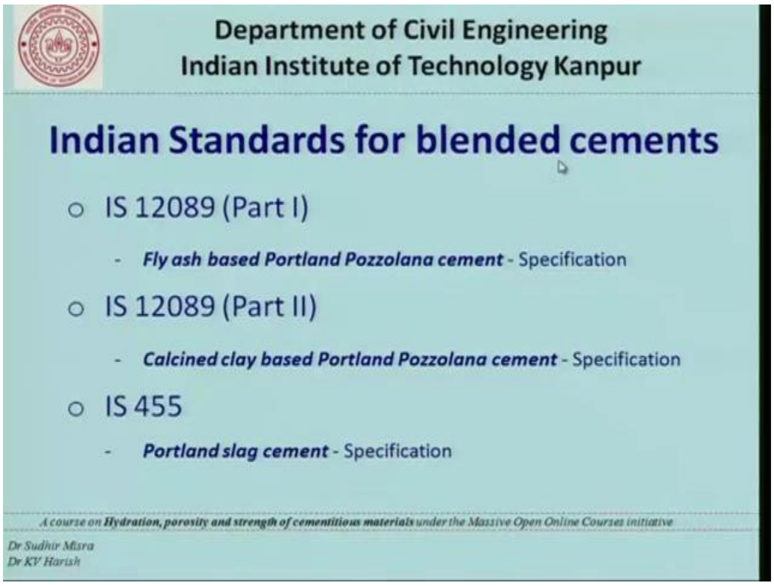

Now, in addition to these standards we also have standards for blended cement. The terminology blended cement is used under the heading mineral admixtures primarily to indicate that these pozzolans are already blended to cement at the plant level itself. I mean Indian standards for blended cement here primarily indicates that there are some standards that have to be maintained whenever these materials are used in cement as a replacement material at the plant level.

So, the codes available here are IS 12089 part 1 IS 12089 part 2, remember part 1 covers fly ash based Portland pozzolana cement and provide specification for that. And part 2 covers calcined clay based Portland pozzolana cement and again it provides specification for that. So, the different primary between this and this is that in this case you will have Portland cement and fly ash as the additional component and in this case you will have Portland cement with calcined clay as a additional component.

Now, we also have IS 455 which is for Portland slag cement, where slag is added as a entity to ordinary Portland cement. So, that specification is provided in IS 455 and with regard to silica fume currently there is no IS code, but general information and guidelines are present in IS 15388. And at the plant level silica fume is not usually blended with normal cements, where as in the case of fly ash calcined clay and slag they are blended at the plant level.

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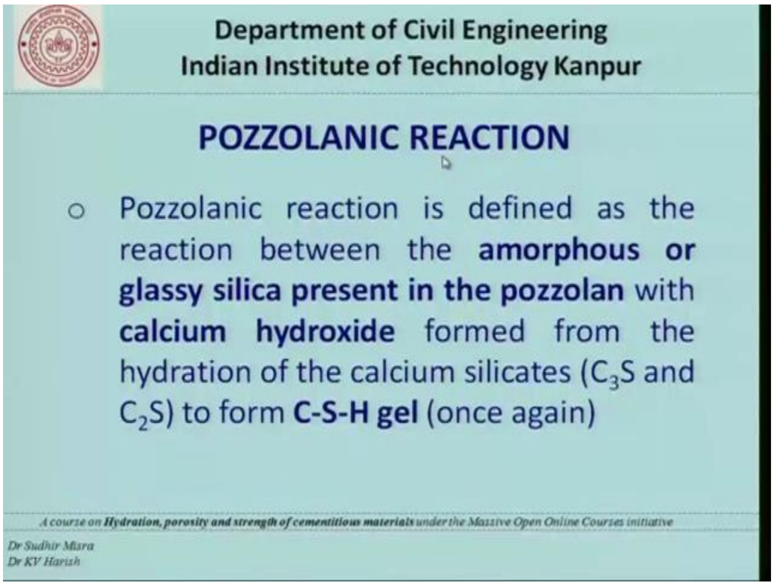

Now, coming onto pozzolanic reaction we have already seen; what is a pozzolan by definition to form calcium silicate hydrate gel or tobermorite gel and remember this is the important word once again.

So, in order to differentiate this calcium silicate hydrate gel from the calcium silicate hydrate gel that is produced from the hydration of calcium silicates. Usually this calcium silicate hydrate gel is referred as secondary calcium silicate hydrate gel. While the primary one is the hydration of calcium silicates. So, this this can be even though this gives calcium silicate hydrate gel the nature of this gel is very different from the nature of the gel that is formed from the hydration of calcium silicate. So, many times this calcium silicate hydrate gel is referred as secondary tobermorite gel while the calcium silicate hydrate gel formed from the hydration of calcium silicate is called as primary calcium silicate hydrate gel.

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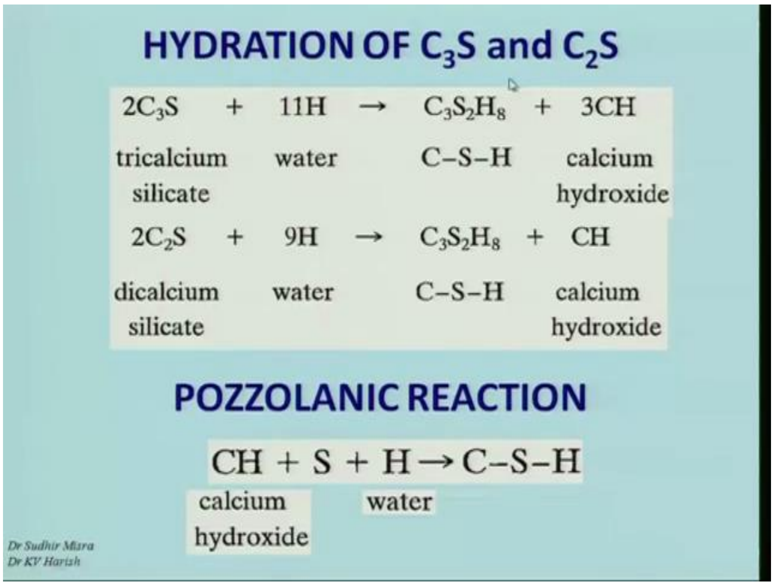

Now just revisiting the reactions of tricalcium, silicate and dicalcium silicate: so we have already seen that C 3 S plus water gives calcium silicate hydrate get plus calcium hydroxide, likewise C 2 S plus water gives calcium silicate hydrate gel plus calcium hydroxide and remember that the difference between these 2 equation is largely in the amount of calcium silicate hydrate gel and in the amount of calcium hydroxide produce for C 3 S the calcium silicate hydrate gel produces less compared to the C S gel produced from dicalcium silicate. Likewise, the calcium hydroxide produced by C 3 S is much higher compared to that of C 2 S. So, this calcium hydroxide quantity is much more compare to this.

And remember that at the early periods right from say one day to about say 7 days or 14 days primarily it is the tricalcium silicate which is actively involved in the reaction. So, in the Portland cement based phase system we typically have larger amounts of calcium hydroxide parallelly with calcium silicate hydrate gel and this calcium hydroxide is what which actually reacts with silica that is present from the pozzolan in the presence of water to form calcium silicate hydrate gel which is called as a secondary calcium silicate hydrate gel.

Now, this is some information about mineral admixtures and others. And let us get into fly ash which is very important mineral admixture in concrete. Now let us first go to the production process to understand what are the steps involved in that and what Ares what are the production parameters which can affect the sum of the physical and chemical properties. And then we will get into the details of what are the specific physical and chemical properties that are relevant with regard to concrete.

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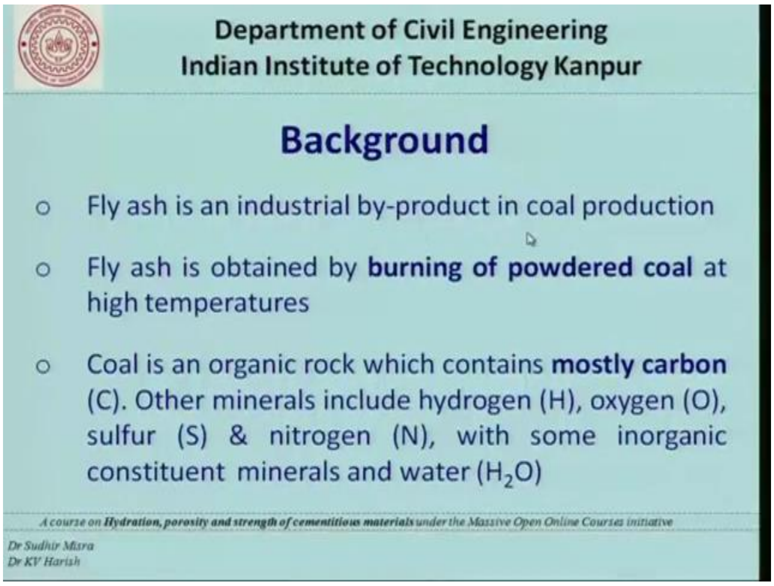

So, first is production of fly ash and a small background for that fly ash is an industrial by product in coal production. So, for audience who are completely new to what fly ash is they have to understand that it is an industrial by product in the production of coal. So, coal is basically the raw material. Fly ash is obtained by burning of powdered coal at very high temperatures. So, remember that the main objective in the production of coal is not a fly ash, because the main objective in the production of coal is primarily power generation. So, fly ash is only a byproduct or a product that is formed because of the heating of coal to get energy out of it.

So, important point that is mentioned here is that very high temperatures are used when you are burning coal. Coal again for people who are completely new and do not know what coal contains it is important the third point is important. Coal is an inorganic rock which contains mostly carbon close to 90 95 percentage is carbon other minerals may include hydrogen oxygen sulfur nitrogen etcetera, and it can also have some inorganic constituent including water.

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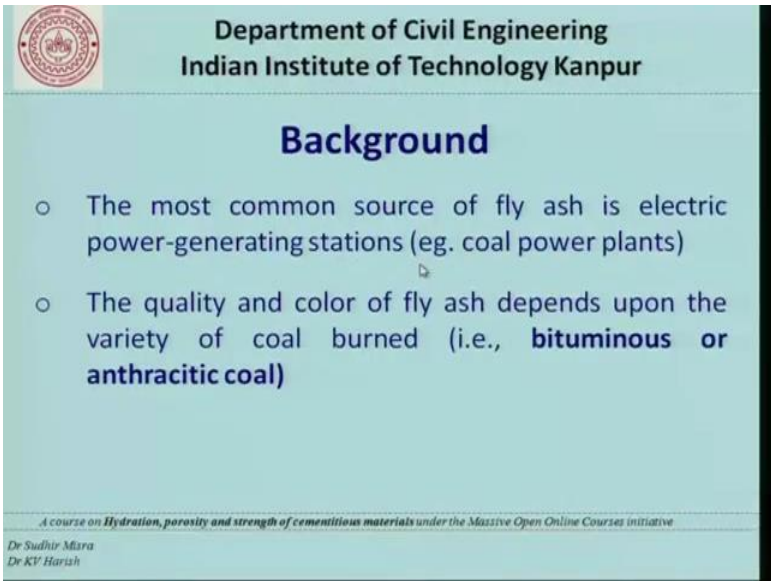

The most common source of fly ash is electric power generation. Primarily because power generation requires huge amount of energy and primary coal has a very high calorific value. And hence coal is used primarily in the power plants for energy generation. So, since fly ash is a byproduct primarily you see that substantial amount of fly ash is available in power generation stations, the quality and color of fly ash. Remember color is a physical properties quality is a relatively chemical property, but also some change in physical properties can improve the quality of fly ash. The quality and color of fly ash depends upon the variety of coal burnt.

So, basically cool is available in 2 different forms depending upon the source. One is bituminous coal the other one is anthracitic coal. So, depending upon the variety of coal are the constituent of coal also changes. So, because of that the quality and color of fly ash will also change. Once we go to some of the physical and chemical properties we will discuss about how fly ash from bituminous and anthracitic coals are different.

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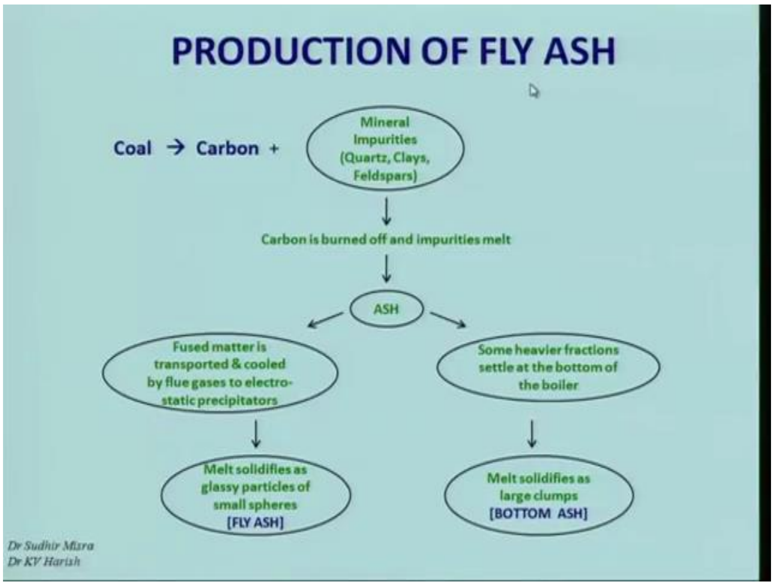

Now, what happens in the production of fly ash? Now you have coal as the main raw material that is basically used for energy production. And remember that it contains carbon along with minor impurity such as quartz, clays, feldspar etcetera. So, this material is basically burnt and the calorific value or the burning a part of it is used in the power generation. And on while doing this, what happens is the carbon is burnt of an impurity is basically melt since very high temperatures are used. And you get some form of ash.

And the basically there are 2 categories one is fused matter which is transported and cool by flue gases to electrostatic precipitators. The other category of ash is they are heavier fractions and they settle at the bottom of the boiler. These are generally referred as bottom ash while the one that is fuse and is transported through electrostatic precipitators. They are largely called as fly ash and that is what is primary the main topic of this lecture. So, they basically melt and solidify as glassy particles of small spheres.

So, what is important from this slide is that in the production process basically you get 2 types of ash even though both are called as ash you have to remember that fly at the properties of fly ash is very much different from the properties of bottom ash we basically get 2 varieties of ash one is fly ash the other one is called as bottom ash.

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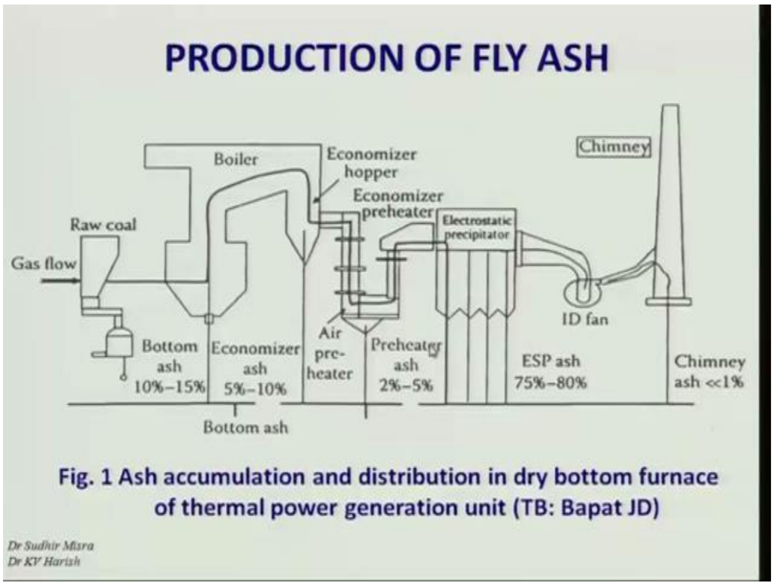

Now, an approximate production process schematic sketch is provided for the audience to get some idea about what are the different stages in the production of fly ash. So, basically gases flow because of the heating of row coal, and when the gases flow the energy obtained from the calorific value of coal is taken for power generation. And the heavier particles in the flow basically comes down which we have previously seen here as a bottom ash.

So, basically they get collected because they cannot basically fly. So, it basically gets collected at the bottom, and they cannot fly primarily because they contain heavier materials. So, they have to settle at the bottom the one that can actually fly along with a gas flow they basically or taken to the boilers. And remember that here also there may be some particles which are heavier and they are again basically collected that also constitutes bottom ash. And the one that can fly along with the gases they go to the next stage where economizers are used and then it has a hopper at the bottom. So, again if there are any heavier materials they are also collected.

So, that is referred here as economizer ash and then it goes to a pre heater. So, that is heated for some time and then it goes to electrostatic precipitator. And then it goes to chimney. And what is a boiler what is the economizer what is electrostatic precipitator what is a pre heater what is a chimney all these are basic information that you should know this information are extensively available in the website and you can go through each one of them in larger details. So, I am not discussing about all these things in this presentation.

So, what and, but what you may have to know is at the gas flow at this stage the temperature is very high. So, the boiler economizer electrostatic precipitator pre heater and all these components, what base what they basically do is they reduce the heat of the gases. And final before it gets out of the chimney, they will make sure that the temperature is somewhere between 40 to 890 degree Celsius and then it gets out of the chimney. And this can in the chimney again this hot gas can be used for several other purpose. Likewise, even in boilers and pre heaters they can be there may be some attached unit and these heating elements can be used for some other minor applications.

So, in this production of fly ash what is important is that you get bottom ash at about say 10 to 15 percentage. You may also get some more as like economizers 5 percentage to 10 percentages. Both together are called as bottom ash even though there is minor change in the definitions that is mentioned here it is called as bottom ash the other one is called economizer ash. Finally, what you get is actually bottom ash and this typically varies from say 5 percentage to about 25 percent. So, here what is given is 10 percentage to 15 percentage economizer ash is 5 percentage to 10 percentage. So, if you see the broad range it is between 5 percentage to 25 if you add 15 percentage and 20 percentage. So, typically you have approximately 25 percentage of the total ash that is collected as bottom ash.

Now, once you go at a later stage you have pre heater ash and electrostatic precipitator ash which is largely called as fly ash. So, these 2 together are called as fly ash. And remember that the pre heater ash is primarily very less because there are less heavy particle the heavier particles are basically captured at this level itself. So, primarily what you have here is the about 75 to 80 85 percentage of the fly ash of the total ash content that you get from the production of fly ash.

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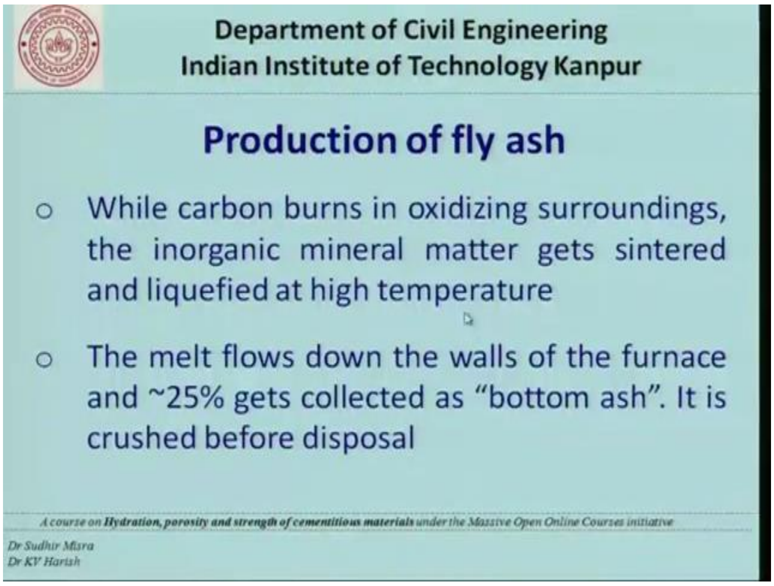

Now, some of the things that I have explained in this figure have been summarized. So, I am just going I am just reading it so that the audience can directly understand what I have said in a nutshell. While carbon burns in oxidizing surroundings the inorganic mineral matter gets sintered and liquefied at higher temperature. The melt flows down the walls of the furnace and approximately 25 percentage gets collected as bottom ash it is crushed before disposal.

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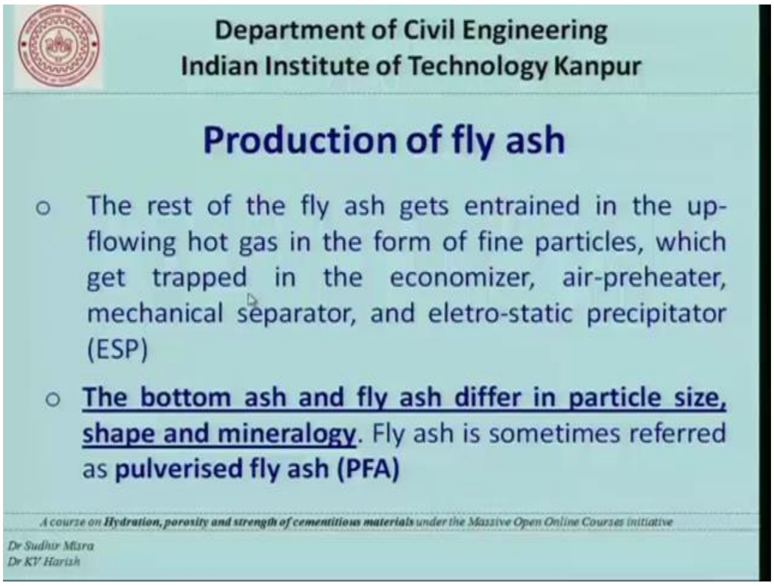

And the rest of the fly ash gets entrained in the up flowing hot gas in the form of fine particles, which get trapped in the economizer air pre heater, mechanical separator and electrostatic precipitator. So, all this ash is together called as fly ash.

Remember that the bottom ash and fly ash differs in particle size shape and mineralogy and fly ash many times is referred to as pulverized fly ash for the simple reason that it is fine and ground form and powdered form.

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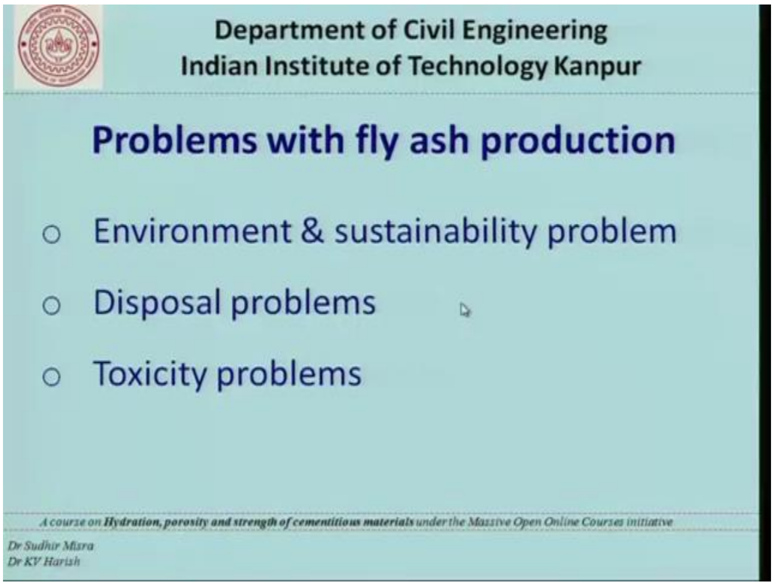

Now, what are the problems associated with the production of fly ash. As we have already mentioned coal is the raw material in the production of fly ash. And what happens is the quantity of fly ash creates several issues. Because fly ash is a byproduct of coal and it does not have very many properties, the amount of fly ash that a coal plant produces is extremely high. And since coal is used constantly and routinely for the day today purpose for electric generation and other huge amount of fly ash is available and remember that India may be having a many electric generation power plants and each plant has very huge amounts of fly ash. And over the years say last 20 30 years this quantity has become substantial, and the problem and has created problem both for the plant and also for the government. It is problem for the plant for the simple reason that the plant people do not know where to use this fly ash and they basically consider it as a waste material. And they do not have sufficient land space for disposal.

So, the primary problems from the fly ash production or summarize, one is the environmental problems and sustainability problems the other one is disposal problems the other one is toxicity problems. First of all, fly ash in powdered form if you actually do the chemical composition and the other tests, it comes under the category of toxic chemicals. Because of the chemical composition and others this fly ash finds a very less application in the industry. That is why fly ash cannot be used for all purposes. And again when it comes to disposal people tend to dispose this in soil fertile landfills as landfills. And what basically it does is the dumping of fly ash reduces the fertility of the land. And nowadays lands are very costly and be and because of need to conserve land and other things fly ash has basically become a new sense primarily because huge amounts are available.

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So, these are some of the figures that are shown just to indicate that the fertile lands are basically getting converted into infertile lands and this has become a huge environmental threat to the government. And this is for one reason why it is important to beneficiary used fly ash because it cannot be directly dumped in the landfill and in the construction industry it is beneficial to use, but use such industrial waste, but with some refinements and with standardization. So, we will see all these things in the subsequent slides and in next lecture. Now, this is about briefly about the production of fly ash and some of the environmental issues connected with fly ash. Now we will go to properties of fly ash.

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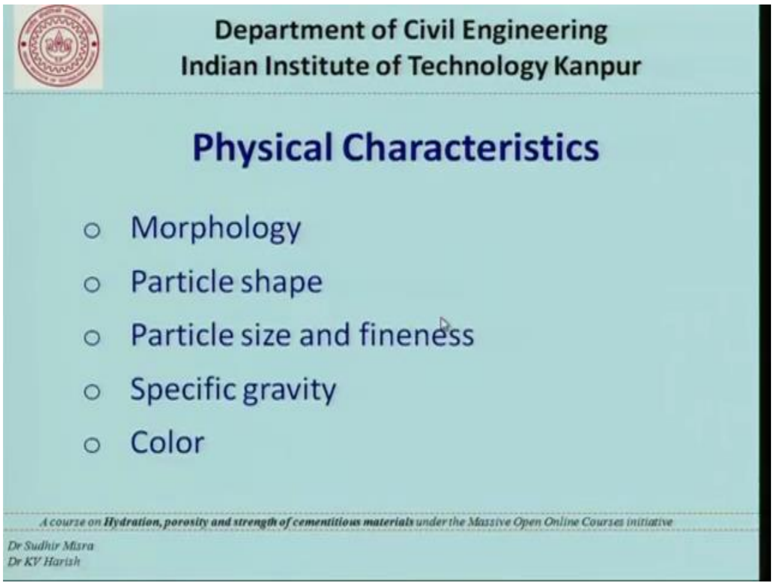

Primarily the properties are categorized into 2 categories one is physical characteristics other one is chemical properties and physical characteristics we will see morphology particle shape particle size and fineness specific gravity and color and we will see each one of them in detail.

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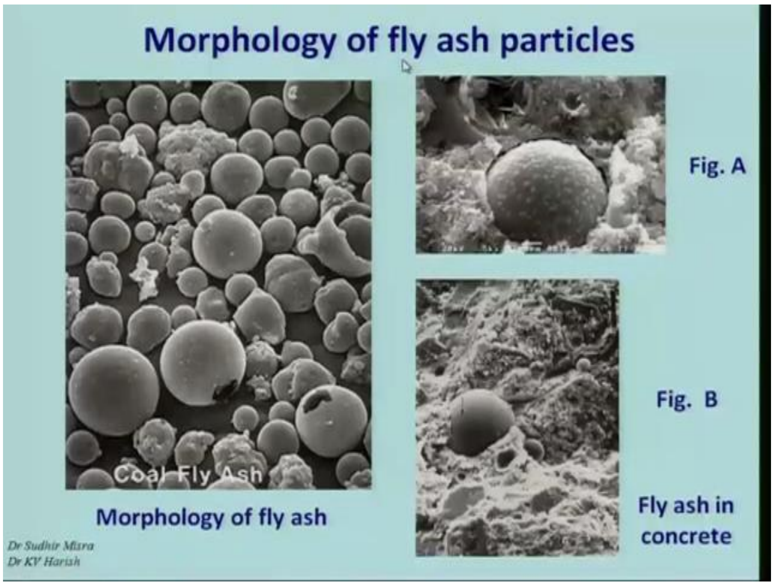

So, what is meant by morphology? Morphology refers to primarily to the shape of the particle. So, fly ash particles are spherical in shape that is a very important point, because in the naked eye we cannot really see whether it is spherical or not. Only in under scanning electron microscope you will be able to appreciate the shape of fly ash particles. So, these are scanning electron micron images. In the left side what we see is basically the fly ash particle alone. So, you do not have anything else. So, what you see is that they are more or less spherical in shape. So, if you take most of the small particles they are mostly spherical in shape.

And the figure that is provided in the right side is not just a fly ash particle, but when you used when you use it in Portland cement based phase systems. So, this this will be the type of image that you get in scanning electron microscope. So, basically the fly ash particles are embedded in the Portland cement based phase system. So, all these are actually the hydrated part hydrated part of, I mean cement hydrated compounds. So, if you actually closely look into the figure is here you can see that there is some sort of (Refer Time: 40:46), which refers to mono sulfo aluminates. If you get back to the scanning electron microscope images that we have seen in Portland cement based phase system.

So, what you find around this fly ash particle is actually some of the hydrated compounds of Portland cement based phase systems. And basically the fly ash article is embedded in the Portland cement based phase system. So, 2 different figures are shown just for understanding.

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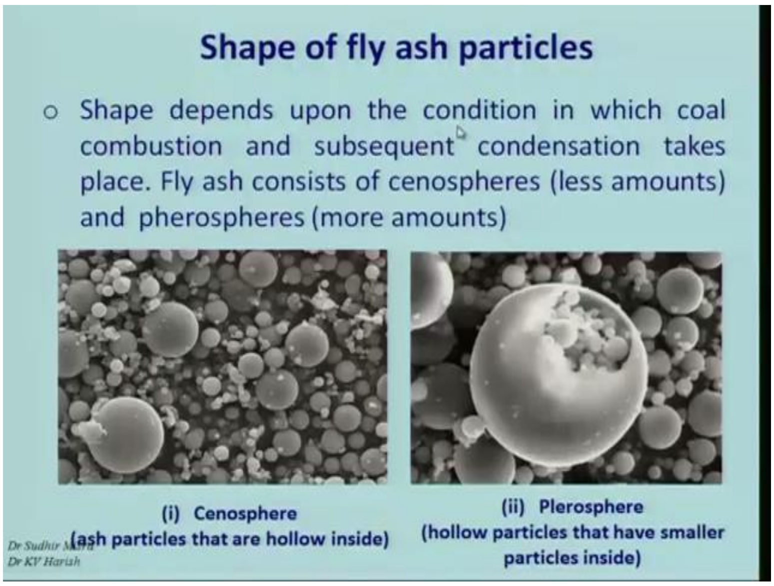

Now, more information about shape of fly ash particles, so fly ash particles generally exist in 2 different forms. One is called as cenosphere the other one is called as plerosphere. The difference between the cenosphere and plerosphere is that, in the cenosphere the bubbles or the particles are primarily hollow which means that in each of the particle inside each of the particle you do not have any other particle. That is called as cenosphere. In the case of plerosphere what you find is you will have particle and inside that you will have finer particles. And all will be spherical in shape more or less spherical in shape. Likewise you will see the same with each of these particles. So, fly ash particles have a 2 existing in 2 forms cenosphere and plerosphere. And which is actually higher. The cenospheres are usually in lesser amount compared to the plerosphere this is a very important thing.

So, when you have fly ash you basically cannot see it in your naked eye and, but you should understand that it is spherical in shape. And movement we say spherical in shape you should also understand that you have more amounts of pherosphere form compared to cenosphere form. So, you always have particle inside the particle much higher compared to this. Shape depends upon the condition in which coal combustion and subsequent condensation takes place and fly ash consists of cenospheres in less amount and plerospheres in more amounts.

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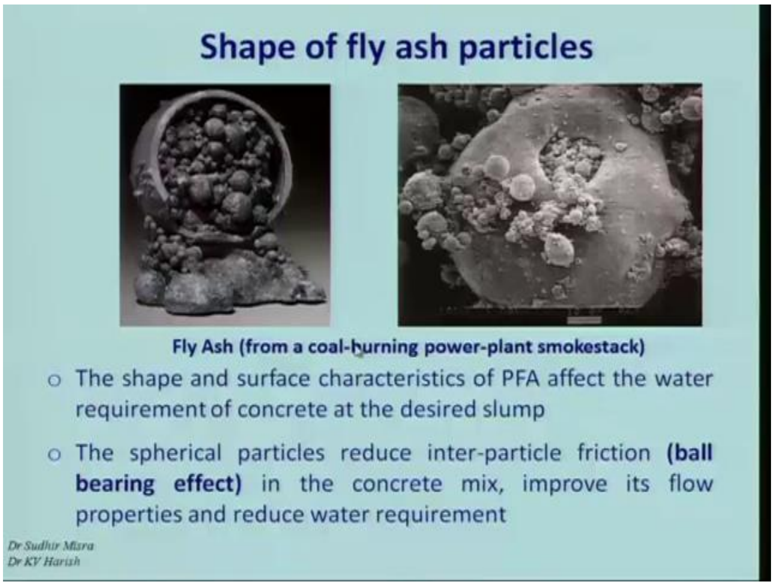

Now, some more information about this, the shape and surface texture of pulverized fly ash affects the water requirement of concrete at the desired slump. So, what is meant by desired slump are all already explained in Portland cement based phase system? So, please go to the relevant slides and understand if you are not thorough just go to the relevant slide and relevant slide and understand. And water requirement affects the water requirement again, water requirement is already explained in under Portland cement based phase system. So, again get back to those slides to understand what exactly it is. So, what is clearly said here is the shape and surface characteristics of fly ash particles are very important and they can affect the water requirement of concrete. Positively or negatively is not currently informed in this slide, but we will see in the next lecture at a later stage whether it positively effects or negatively affects.

Now, the spherical particles reduce inter particle friction, which is referred as ball bearing effect. In the concrete mixture there by improving it is flow properties or workability properties and reduce water requirement. So, briefly it is in informed that the spherical shapes of fly ash particle helps in improving the flow property, but have in mind that this also depends upon the dosage. So, if you go at a very high dosage, they it could have negative effect. So, this statement is valid only if you have recommended level of dosages. We will see all those things in detail at a later stage. So, so the shape and surface characteristics has plays a significant role in water requirement. So, that is the importance of the shape of fly ash particle on concrete properties.

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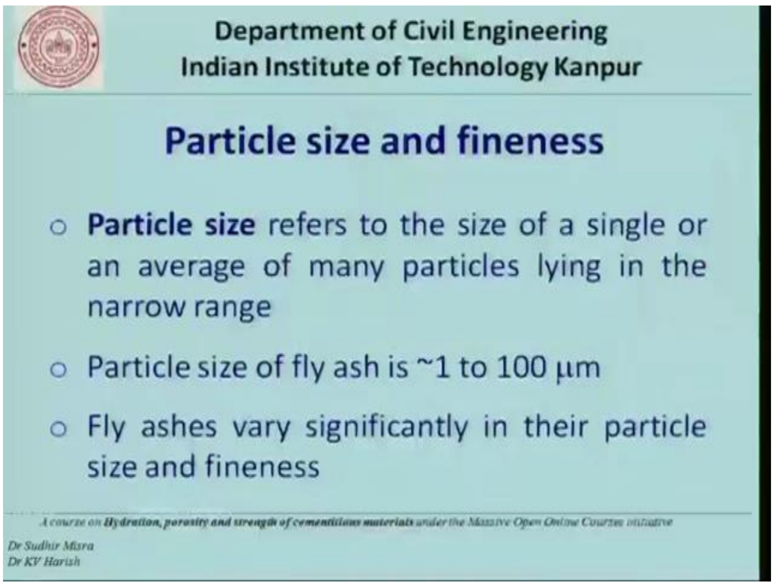

Now, the second important physical property is particle size and fineness. Particle size refers to the size of a single or an average of many particles lying in the narrow range. Remember that the definition of particle size particle size distribution fineness all these things are already discussed in previous lectures when we discussed about physical and chemical properties of cement. So, if you are not thorough in that I suggest that you get back to those lectures and understand; what is particle size and particle size distribution?

So, particle size of fly ash is in the range of 1 micron to 100 microns. This is very important range. So, are the audience may have in mind that with respect to quiz some information about this could be asked. Fly ashes vary significantly in their particle size and fineness. So, if you want to represent in the form of a single size as defined here, it could vary some fly ash from some sources could have say 20 micron average particle size from a particular source. Where as in another source it could be 40 microns in another source it could be 18 microns. So, the range is known to some extent in the sensor it is between 1 micron to 100 microns, but the average particle size is something that actually differs. That is what is mentioned in this point. Fly ash is varying significantly in their particle size and fineness.

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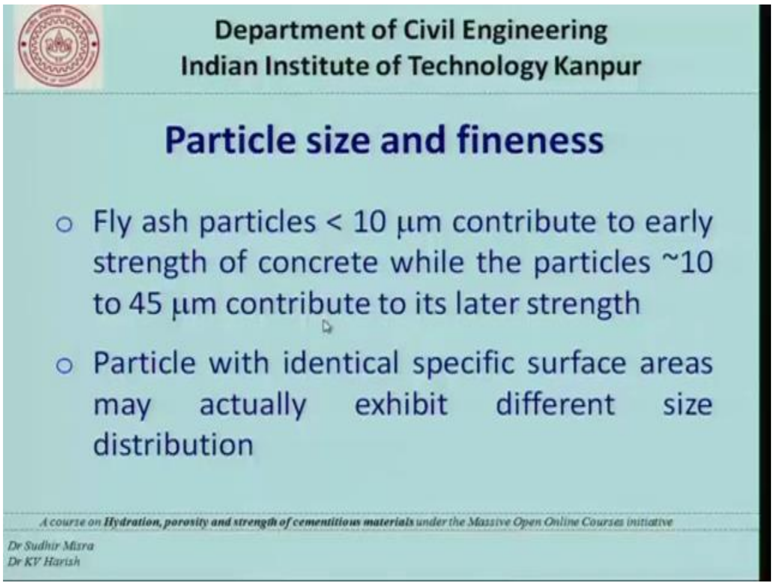

Now, fly ash particles lower than 10 microns this is a very important point. Fly ash particles lower than 10 micron contributes to early strength of concrete. Remember that the early strength of concrete in Portland cement based phase system is primarily because of the hydration of tricalcium silicate. And the compound that you get is calcium silicate hydrate gel. Remember it is a primary calcium silicate hydrate gel plus calcium hydroxide. So, if the fly ash particles are lower in size say lower than 10 micron, we are here talking about the average particle size. So, the range that is provided is a broad range in that if the average particle size is lower than 10 micrometer then those particles react substantially with the calcium hydroxide undergo pozzolanic reaction in the presence of water and produce more and more secondary calcium silicate hydrate gel and since the volume of calcium silicate hydrate gel is higher at particular instant of time you get increased early strength of concrete.

So, if the particle size is between say 10 to 45 micron, will it contribute to strength. It will contribute to strength, but the reactions will be little slower, and hence it can contribute only to the later strength. So, this is a very important point which actually gives the importance of particle size of fly ash, and with regard to properties of Portland cement based phase system. So, if fly ash particles have lower than 10 micron, then it then the benefit that you get is increased earliest strength. And if it is between 10 to 45 micron, then you get later strength probably after 28 days or 90 days if the particle sizes are greater than 45 micron usually they remain in the system as fillers micro fillers.

Particles with identical specific surface areas may actually exhibit different particle size distribution. So, that is that is one line which actually distinguishes the particle size from fineness. Particles identical specific surface area may actually exhibit different particle size; that means, if you have 2 particles, if you have 2 samples in which fineness or the specific surface areas are same, that does not necessary mean that the particle sizes are same. The particle sizes could be different, but still the specific surface areas could be same.

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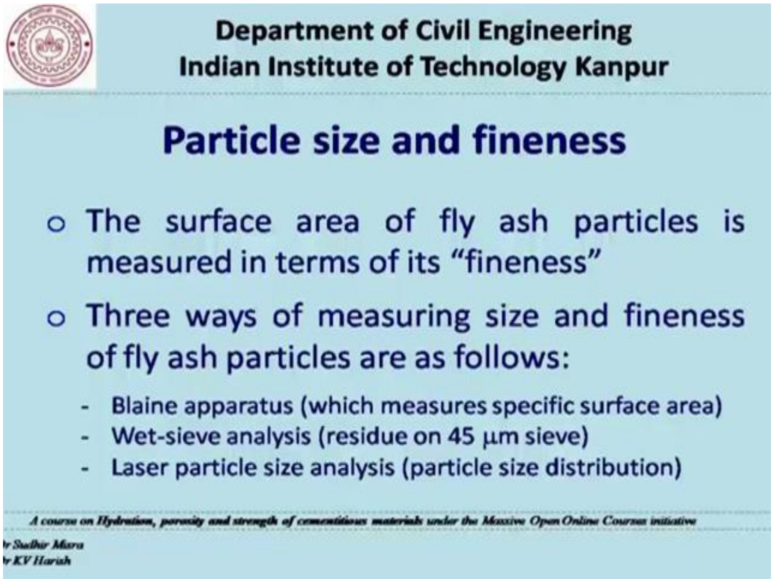

The surface area of fly ash particle is measured in terms of it is fineness. Remember again this is a terminology that we directly take from cement. So, we have already seen what is fineness how it is determined and all the things. We will see how fineness is determined for fly ash particles. So, primarily 3 ways of measuring size or fineness of fly ash particle is provided. One is a Blaine apparatus remember this is a standard IS method which we use for cement. So, the same thing can be used for measuring the fineness of fly ash particles. And this is measured in terms of specific surface area. And the unit is usually in meter square per kg or centimeter square per gram. You can also do a wet sieve analysis where basically you add water to fly ash and retain it in a 45 micron sieve. So, and the particles which are passing through the 45 micron sieve, the percentage material passing through 45 microns sieve is usually considered as the value for the fineness or particle size.

The third one is laser particle size analyzer which basically gives a particle size distribution over a broad range and in that d 50 value will precisely give the average particle size of fly ash. So, the blaines fine the blaine apparatus or blaines fineness and laser particle size analysis or are already discussed under cement.

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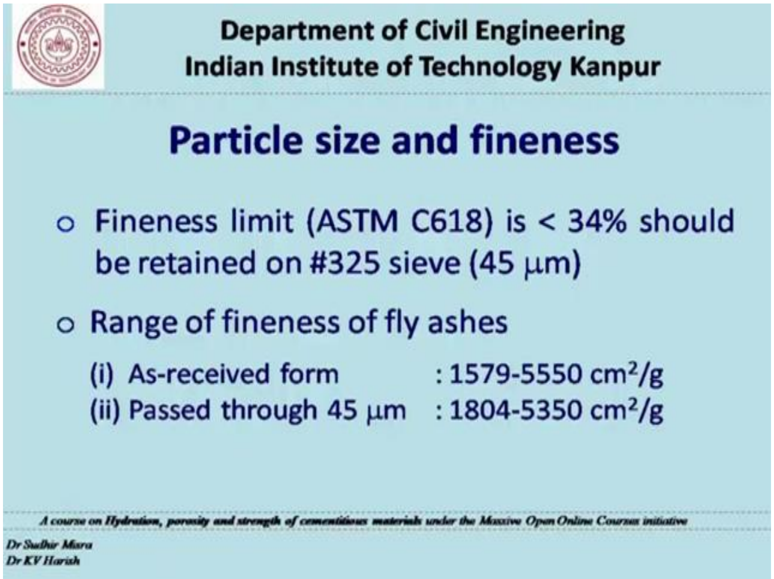

So, is there any limit the IS the Indian standard do not provide any limit; however, there is some ASTM standard the fineness limit for fly ash is lower than 34 percentage should be retained on 325 sieve or 45 microns sieve. So, if you go to the wet sieve analysis that we have seen you can notice that at least 66 percentage should actually go through the 45 micron sieve. And this 45 micron is primarily kept as a distinction to make sure that if the fly ash does not contribute to early strength at least it should contribute to the later strength. We usually do not prefer fly ash to remain in the system unreacted. So, that is one of the reason this 45 micron limit is provided.

The range of fineness of fly ash there are 2 ranges that are provided. One is in the as received form. So, whenever you get it from the plant directly for used in concrete the fineness ranges from 1579 to 5550 centimeter square per gram. And if it is obtained by sieving through 45 microns sieve as mentioned previous then it will be in the range of 1804 to 5350 centimeter square per gram, it could it could have a broad range. So, both these 2 are shown to indicate that the fineness could have a very broad range.

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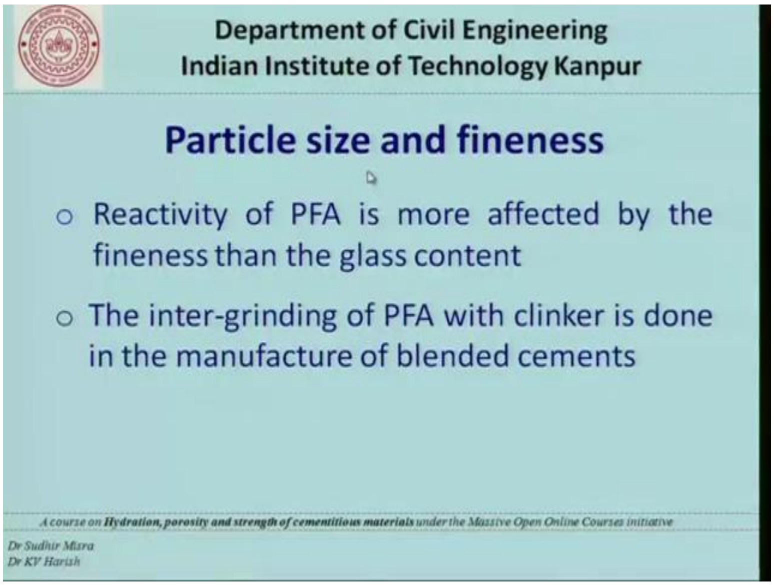

And more information about particle size and fineness; reactivity of pulverized fly ash is more affected by the fineness than the glass content. So, we have already seen that the presence of reactive materials reactive components is actually what it what actually reacts with the calcium hydroxide from cement hydration. In addition to that you should understand that the reactivity of PFA is more affected by the fineness. So, if you have a very fine fly ash that can actually perform better than a fly ash which has more glass content? Of course, glass content reacts, but the fineness property is many times more important from the standpoint of reactivity compared to the glass content of fly ash.

The inter grinding of pulverized fly ash with clinker is done in the manufacture of blended cement, this is a very important points and today we have different types of cement such as Portland, pozzolana cement slag cement and several other cements and some of them are primary obtained by inter grinding the specific pozzolan with a clinker and this is done at the plant level.

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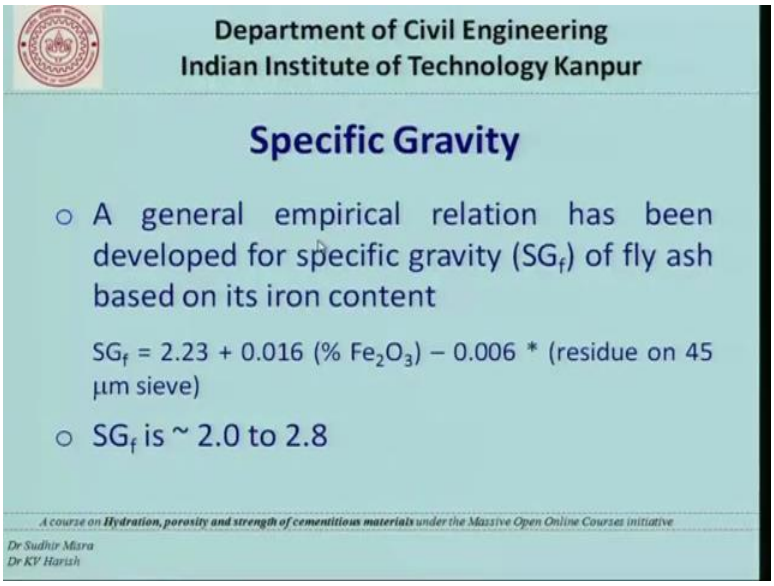

Fourth important physical property is specific gravity. And specific gravity usually can range from 2.0 from 2.8 and this also depends upon various other factors. And this is quite a substantial variation in the sense that if you take the mix design, where we use specific gravity in order to convert the volume to weight and weight to volume. And having already said that fly ash is used as a partial replacement or addition material. This value can significantly alter depending upon the dosage of fly ash that is used in the mixture. So, if you use higher dosage then you will have the specific gravity affect coming on the mixture and it could the and depending upon the specific gravity values for example, if it is high than the density could be density of concrete could be high if the specific gravity is lower for fly ash then, the sure that contains fly ash will also be lower.

So, broadly it varies from 2.0 to 2.8 and also approximately if you do not have the value and approximate equation empirical equation is given where this formula is used specific gravity of fly ash is equal to 2.23 plus 0.016 into percentage of iron content. Remember that the iron content can actually change the weight of the fly ash substantially. So, this is value into percentage of iron content that is oxide iron in the form of oxides minus 0.006 into residue on 45 microns sieve. So, seen that previously here that a 45 micron sieve is used; so the percentage passing through it can actually percentage passing or in other words the retained residue on the percentage retained on 45 micron sieve can actually affect the specific gravity to some extent. So and approximate formula is given. So, in case you do not have these values then you can use his formula to find out.

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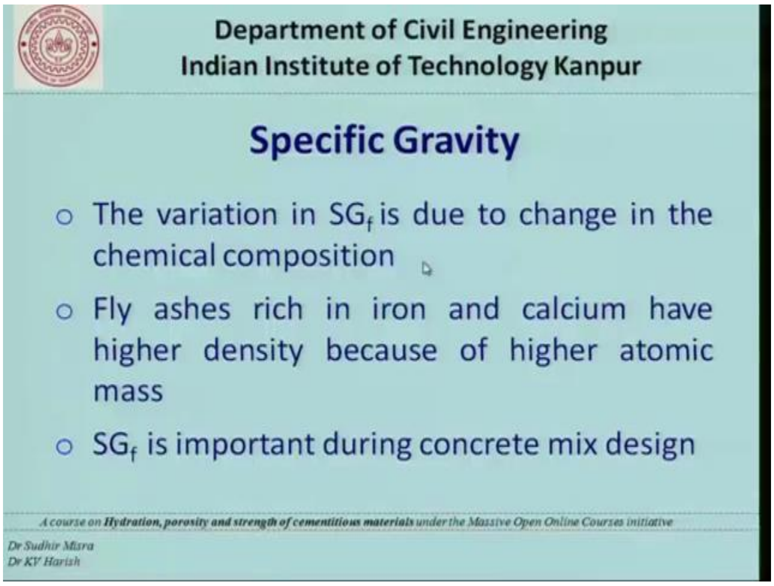

Now, what is the importance primary in the mix design we use this value the. Variation in specific gravity is due to the change in the chemical composition, if the iron content changes then again it changes and also the physical factors like fineness can also alter the specific gravity. Fly ashes rich in iron and calcium have higher density because of higher atomic mass. So, this is very important. So, in addition to iron you may also have calcium. So, at a later stage in the next lecture, we will be seeing about classifications of fly ashes where fly ashes are typically classified into low calcium high calcium intermediate calcium fly ash or it may be classified in other forms.

So, in that you see that in certain type of fly ashes say intermediate or highline fly ash the calcium content is higher. So, if you basically compare their densities, it will be higher compared to the fly ashes which have lower calcium content, and specific gravity is important during concrete mix design.

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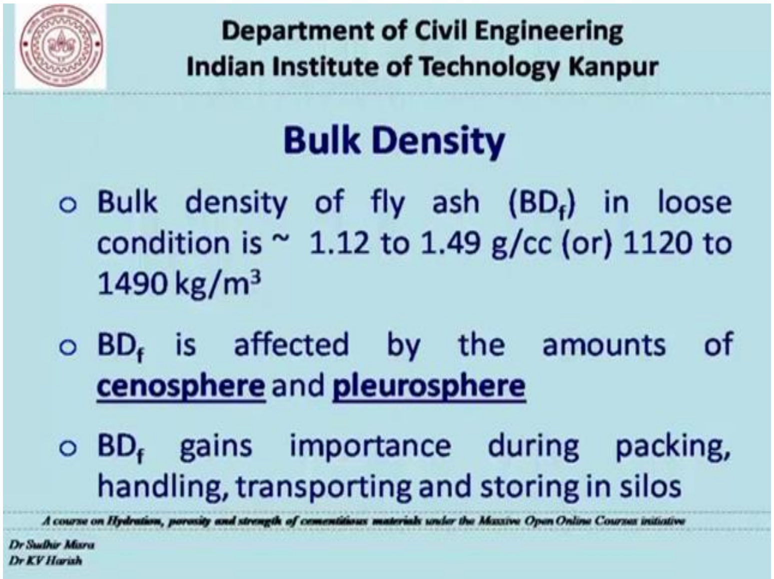

Now, we go to the fifth physical property which is bulk density. Bulk density of fly ash here it is indicated as BDF in loose condition is approximately 1.12 to 1.449 gram per centimeter cube or if you want to express in terms of kg per meter cube 1120 to 1490. So, this value is also important from a quiz stand point at least approximately you should know; what is the range of bulk density values and specific gravity values. And what are the factors which actually affect the bulk density. The amounts of cenosphere and pleurosphere remember; what is cenosphere cenospheres are just fly ash particles which do not have any material inside, it in the case of pleurosphere they have more spherical particles inside. So, if you have more amount of pleurosphere, then the bulk density of fly ash will be higher. If you have lesser amounts of pleurosphere then you will have the bulk density lower.

The bulk density gains important during packing handling transporting and storing in silos many times fly ash is used in the for packing transporting and other purpose and they are basically stored in silos like a cement. So, in such cases the bulk density values provided here gains importance.

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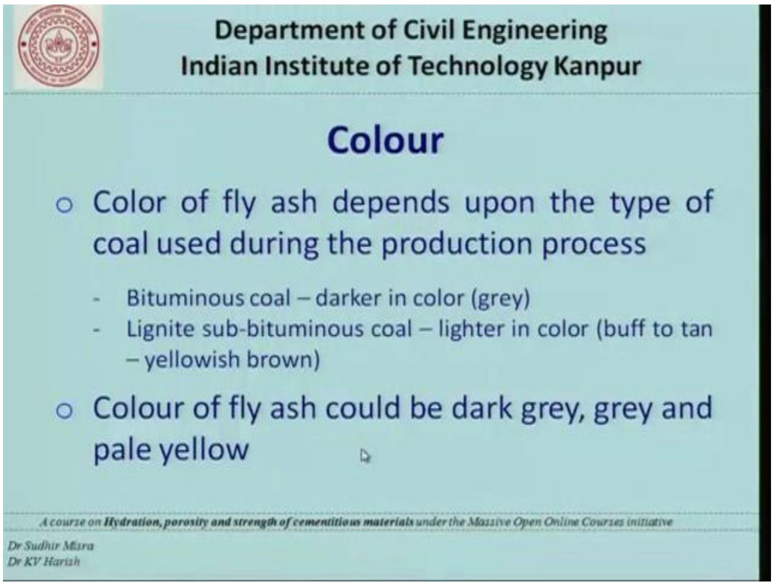

The next one is color. So, what is the color of fly ash to the when we see it in naked eye. Color of fly ash depends upon the type of coal, remember that in the in some of the slides we have seen previously 2 types of coals are available one is bituminous coal and the other one is sub bituminous or anthracitic coal. So, the color depends upon the nature of coal that is used in the production of fly ash. If it is bituminous coal, then they are usually grey in color or dark grey in color in the case of lignite or sub bituminous coal they are generally lighter in color and it could anywhere range from tannish yellow to brown. Brown is a very extreme color, but it will be largely tanning color to yellowish brown. So, for the naked eye what we generally see is that it will be in dark grey in color or grey in color or pale yellow or in other words called as tan yellow brown color. So, those are the 3 typical colors of fly ash.

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So, here one figure is shown. So, that you can understand that there is different color. So, here is dark grey color is shown here lighter grey color fly ash is shown and here you have a little more yellowish type of fly ash. And remember that the based on the color and based on the amount of calcium and silica present, fly ash is are classified as low line intermediate line and high line. We will see more about this classification at a later stage, but at this point what is important is only color. So, all these fly all these particles are fly ash, but the difference is actually in the color as well as the amount of calcium oxide silicon dioxide and others present in each of them

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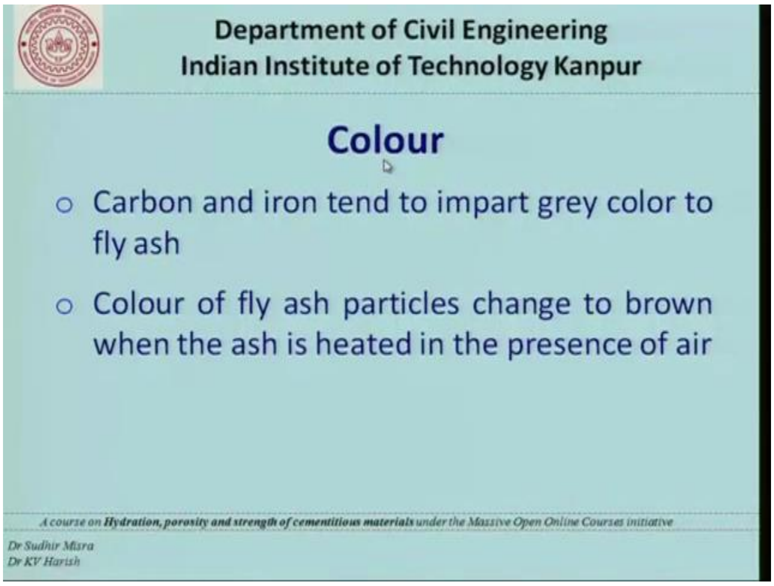

And what are the important parameter that constitutes color. Carbon and iron content tend to impart grey color to fly ash that is very important. So, if you have more carbon content and remember that carbon primarily comes from coal we are because carbon is the main element in coal. So, if some carbon content is carry forward along with the fly ash then they will be seen as more grey in color. And likewise if you have more iron content then you will also see that the fly ash is grey color of fly ash particle change to brown when the ash is heated in the presence air. So, this is just for information that the fly ash the color does not remain, the color remains as it is if it is not the heated it, but if it is heated in the presence of air then basically the color changes to brown.

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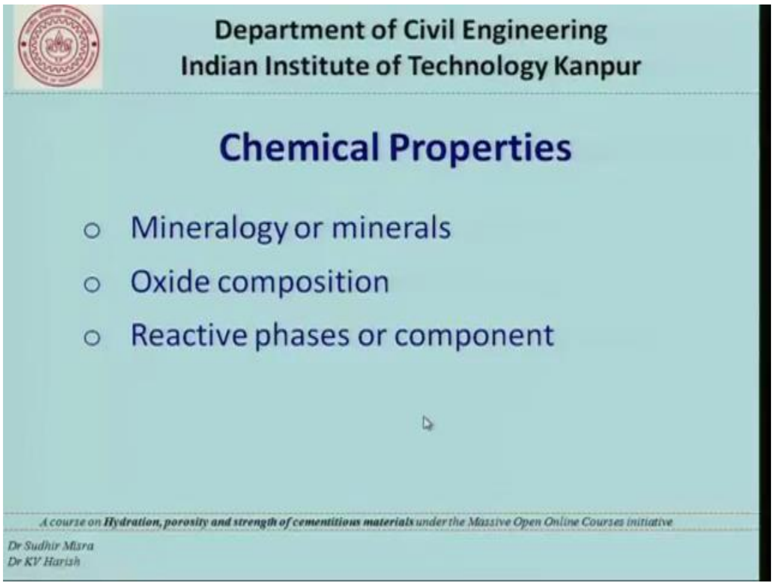

Now, coming on to the next set of properties called as chemical properties. We have mineralogy ore minerals that are present in fly ash. Oxide composition present in fly ash reactive phases or components present in fly ash.

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Now, coming onto the minerals or mineralogy present in fly ash, typically these are the set of minerals. The first one you have quartz this quartz is little bit different from the pure quartz that is stocked in material science. So, audience should have in mind. So, this is a type of quartz similar to the quartz that we find in material science when we read material science related topics we find quartz there. So, that is little different, but in terms of silicon dioxide it is quartz is a very rich in silicon dioxide.

Now, the second important component is mullite the approximate formula is 3 AL2O3 dot 2 SiO2. The formula is not very important for the simple reason and that it is the mineralogy of fly ash is not fully investigated at the research level. All that you have to know is that you have alumino siliceous material in the name of mullite that is present in fly ash. In addition to the main minerals you may also have other minerals in substantial amount. For example, free calcium oxide periclase which is nothing, but magnesium oxide anhydrites calcium sulfates alkali sulfates. And remember all these are also in substantial amount which means that if you get back to some of the lectures in Portland cement we have seen that many of these actually causes problems.

For example, free calcium oxide or magnesium oxide causes soundness problems. And anhydrite and alkali sulfate cause, that it is one of the reason why under physical and chemical requirements. These compounds are limited in Portland cement before using in concrete. So, we should also understand that when we are using fly ash these may be present in substantial amount when fly ash is are used at a certain dosage we have to make sure that these do not create problems for the Portland cement based phase systems and you may also have other minor compounds.

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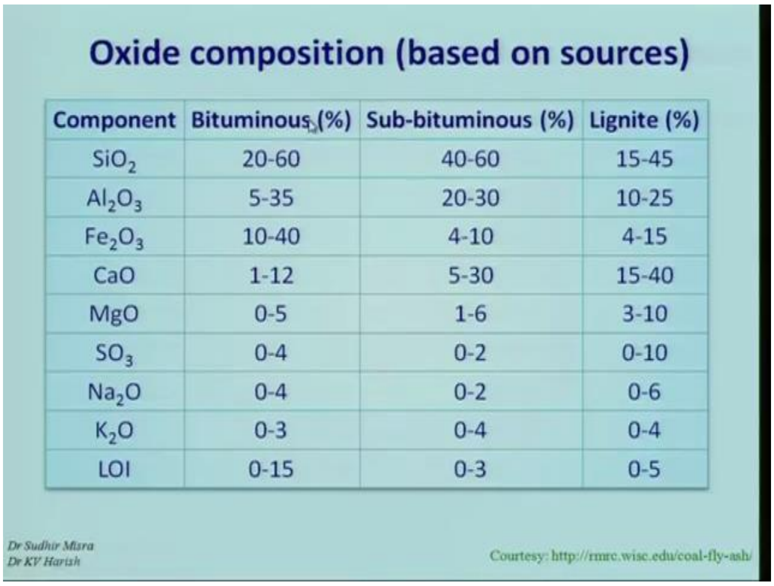

Oxide composition (based on sources)

Component	Bituminous (%)	Sub-bituminous (%)	Lignite (%)
SiO_2	20-60	40-60	15-45
Al_2O_3	5-35	20-30	10-25
Fe_2O_3	10-40	4-10	4-15
CaO	1-12	5-30	15-40
MgO	0-5	1-6	3-10
SO_3	0-4	0-2	0-10
Na_2O	0-4	0-2	0-6
K_2O	0-3	0-4	0-4
LOI	0-15	0-3	0-5

Now, with regard to oxide composition, and remember this is categorized based on sources. So, if you take the source you have one source as bituminous sources the other one is sub bituminous sources and other one is lignite sources. And what you find is that all these values are expressed in percentage, percentage by mass and the component here is ranges from silicon dioxide until potassium or alkali oxide, and some value of loss on ignition is also provided for this. So, if you generally see all the oxides you can see that the bituminous the fly ash obtained from bituminous source contains lower amount of silicon dioxide compared to sub bituminous. Whereas, lignite you cannot really say because the range is well within this range, in the sense that 15 to 45 percentage is within 20 to 60 percentage, but overall compare to bituminous the sub bituminous has a higher quantities of silicon dioxide.

Likewise, you can compare all these things, but the most important oxides in fly ash is the silicon dioxide aluminum oxide, iron oxide all club together and also calcium oxide. And all these other oxides since they are usually present in lower amount right now it is not important for us to get into the details. So, if you take the calcium oxide you find that the bituminous variety has very low amounts of calcium oxide in the case of sub bituminous it is much higher and in the case of lignite it is much higher, but some portion of it is also there in the sub bituminous range and likewise you can also see the values for silicon dioxide compare the values of silicon dioxide aluminum oxide and iron oxide.

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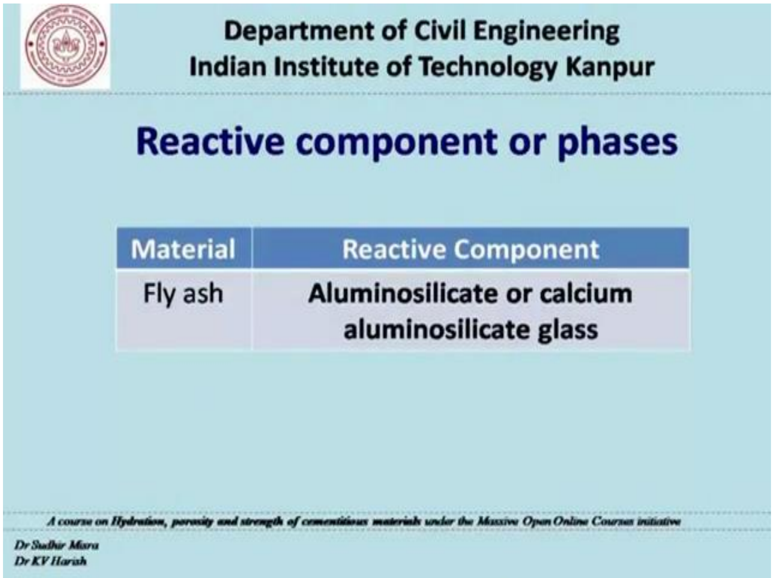

And reactive component we have already seen that fly ash contains 2 main things as they are 2 components. Either it could have aluminosilicate or it could have calcium aluminosilicate depending upon the amount of calcium that is present in the fly ash. And again the amount of calcium is a function of the source of the coal from which the fly ash is obtained. So, for bituminous sub bituminous and lignite the calcium content varies and accordingly the reactive component also changes.

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So, in summary what we have seen in this lecture is that we have seen mineral admixtures what are the different types of mineral admixtures and seen a big introduction for that. We have also seen the different sources of fly ash and how fly ash is produced and what are the factors in the production of fly ash which can affect the properties. We have also seen what are the physical characteristics of fly ash that can actually affect the properties when the when fly ash is used in concrete or Portland cement based phase systems. And also we have seen briefly the chemical properties of fly ash. With this these lectures are getting over.

Thank you.