Hydration, Porosity and Strength of Cementitious Materials
Prof. Sudhir Mishra and Prof. K.V. Harish
Department of Civil Engineering
Indian Institute Technology, Kanpur

Lecture – 25 to 27
Mineral Admixtures

Hi good morning to one and all. I am K V Harish assistant professor department of Civil Engineering IIT Kanpur. You are watching MOOC lecture course on hydration porosity and strength of cementitious material.

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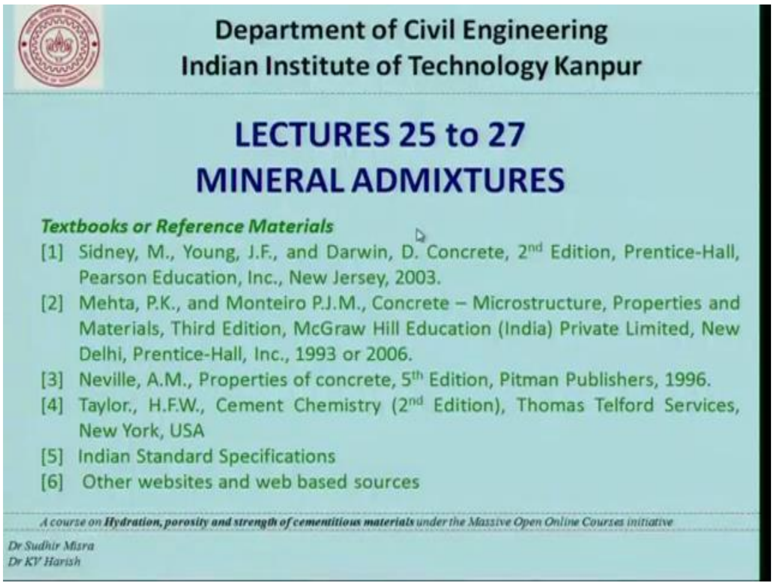

Today we will see lectures 25 to 27. Remember that we are covering 3 lectures together. So, it is expected that these lectures may take substantial time. So, of the audience or required to be little more patient to understand each and every slide carefully. Again the lectures 25 to 27 covers mineral admixtures. In the last 2 lectures 23 and 24 we have seen introduction to mineral admixtures we have seen different type of mineral admixtures such as the industrial by products which are also called as artificial pozzolans. We have also seen different types of natural pozzolans; obviously, for this course we have only industrial pozzolans and we will see only fly ash silica fume and slag.

So, in this lecture we will see more about the classification of fly ash, applications of fly ash chemical requirements that are stated in Indian standards. And how the addition of fly ash improves or decreases certain properties of Portland cement based paste system. So, we are going to see all these topics and finally, we will also see what are the general considerations and limitations with regard to quality control measures that we have when we use fly ash in Portland cement based paste systems.

the text books and reference materials are provided.

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So, the overview this lecture provides information about different construction applications for fly ash. So, when we say construction applications, it will not just stick on to Portland cement based applications alone. It will also go to other application such as a use of fly ash as a film material in other applications. In addition, the chemical and physical requirements of fly ashes as specified in the Indian standards is discussed in detail. The effect of fly ash addition on specific properties which actually place the most important part of this lecture. The effect of addition on specific properties of Portland cement based paste systems and some of the limitation associated while using fly ash as a pozzolan is also discussed though. So, the specific topics will include applications of fly ash chemical and physical requirements of fly ash. Effect on specific properties of Portland cement based paste systems, and some considerations limitations quality control measures while using fly ash.

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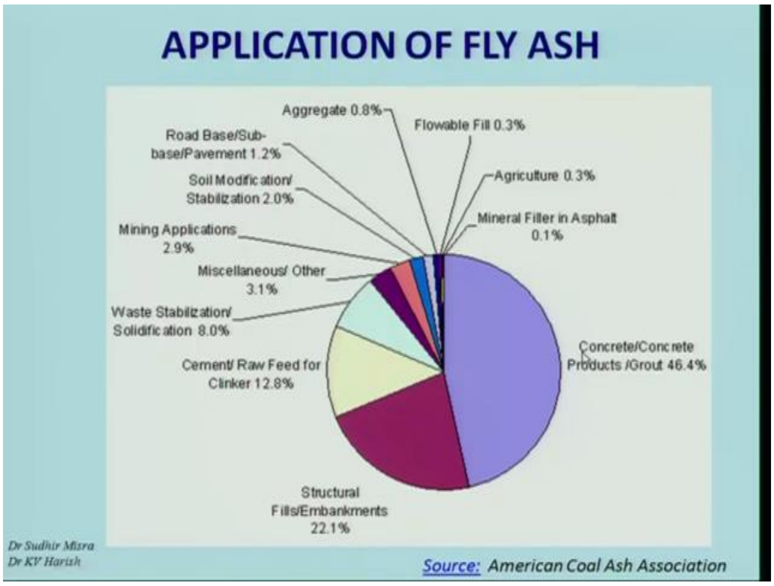

Now, the first is application of fly ash. So, what is shown in this figure is a pi chart where the area the shaded area indicates the applications of fly ash for a specific purpose. So, if you take the violet color or a light blue color what you find is that for concrete or concrete products or for use as a grout material typically out of 100 percentage 46 point 4 percentage of the fly ash can be used for such applications. And the likewise the second biggest shade area is this region. And you find that fly ash can also be use as a structural fill purpose and primarily these are use in embankments.

Typically this accounts for approximately 22.1 percentage. And if you consider the other area shaded area yellow color where fly ash is used as a row fed material in the clinker primarily in production of Portland pozzolana cement, where fly ash is a material use along with cement either pre blended or inter ground together and this accounts to approximately 12.8 percentage. And likewise for other applications such as stabilization purposes primarily soil stabilization purposes, again a quite substantial amount of say 8 rep percentage is utilized. And likewise you have other miscellaneous applications 3.1 percentage mining applications 2.8 soil modification or stabilization 2 percentage. Sometimes fly ash is also use as a material for a pavement construction. So, for a construction of a road base or sub base materials again 1.2 percentage is used and sometimes other applications like flow able fills and agriculture and other asphalt applications they use very minimal quantity.

So, this is about the application of fly ash, in the since that if you have particular quantity of fly ash during the past 10 20 years, the fly ash found this much applications and basically the percentages are provided in this figure, but you have to remember carefully that this just not indicate that all the fly ash that we obtain from the coal power of plant or the production plant has been fully utilized. We have to remember that out of 100 percentage of fly ash that is produced in the coal or thermal power plant, we hardly use only 10 to 15 percentage. So, the 10 to 15 percentage that we are using we are using in this propositions, like for example, we have just now seen that for concrete or making concrete products or for grout materials we are using approximately 46 to close to 50 percentage and other applications such as embankments and row feed material and clinker and waste and other materials. So, we are a typically utilizing only 10 to 15 percentage of the entire quantity of fly ash that is available in India.

So, remaining 80 to 85 percentages still has been dumped in landfills. So, there is a immense potential to use still larger amounts of fly ash and many applications are being explored for this purpose.

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Now, some of the specific applications are actually listed. One is that fly ash can be used for making building blocks. So, what is shown in this figure is that the different types of blocks. Like for example, you have hollow blocks, you have porous blocks. And you also have something called as colored block, where you can add some pigments and change the color primarily from aesthetic purpose. This is usually used for a minor application. And the you also have something called as solid block. So, these are the sample shapes and the these are the sizes that are specified and typically some information about molding time, how many number of molds pieces that you required is listed here and how much time to make one pieces actually provided here.

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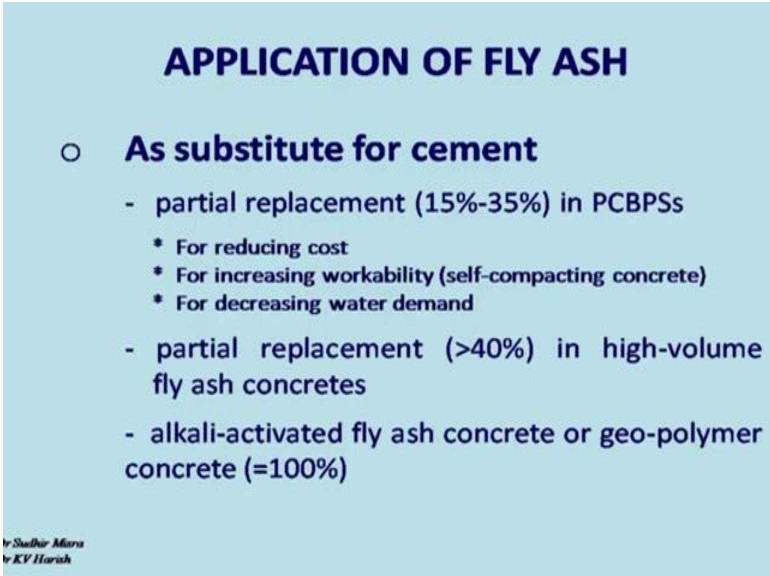

The second important application is that it is used as a substitute for cement. When we say substitute for cement there are a again 3 sub heads, and in the first sub head it is used as a partial substitute or partial replacement material. And typically the dosage that we uses between 15 percentage to 35 percentage. In Portland cement based paste systems, and whenever we use a fly ash there are several reasons to use fly ash at this particular dosage level. One is from the angle of reducing cost because if we use fly ash as a replacement for cement the cement is a costly product and if you replace even by 15 to 35 percentage that much amount of material reduction cost we get. And remember that in India fly ash is fly ash has 0 cost. So, all that all the cost that is associated with fly ash is basically the transportation cost. So, there is a immense potential to reduce the cost by merely replacing say 15 to 35 percentage of fly ash for cement in Portland cement based paste systems.

So, it is seen from 3 angles one is reducing cost the other one is the addition of fly ash also provides workability. So, as we have seen in the previous lecture the shape of fly ash helps in providing higher workability. And this is many times employed in Portland cement based paste systems. And we tend to land up getting concrete such as self compact in concrete where there is no need to compact the mixture through labors. So, there again we can get substantial benefit is from labor cost also, in the sense that the number of labors who are involved in a compacting the mixture can be substantially reduced by primarily designing the mixture for self compacting properties. So, the self compacting property primarily a becomes possible only with the addition of fly ash. So, the addition of fly ash increases the workability and creates situation that we can land up getting self compacting concrete there by reducing the labor cost as well.

So, the third one is for decrease the water demand when you use fly ash for decrease water demand when you use fly ash it increases the workability, and hence the water that is actually required to be added can be lowered. So, the water demand can be lowered and if you lower the water demand, that helps and providing higher strength. So, that is about partial replacement where typically we use 15 to 35 percentage; however, fly ash can also be use at a higher dosages. Typically greater than 40 percentage, but when you use greater than 40 percentage there are several problem such as setting time problems and low rate of strength gain problems. And these are these have to be addressed whenever you use higher dosage. Such problems have to be addressed by using other strategy such as a using accelerators or other materials into the mixture.

So, typically greater than 40 percentage is not use; however, for high volume fly ash concretes, where we prepared to go for higher dosages primarily with objective of reducing the cost or reducing the cement content. We can still go greater than 40 percentage. In such cases we have to be we have to take additional quality control measures to check whether the setting time and the strength or achieved at the appropriate periods of curing. In addition we also have a third category called as alkali activated fly ash concrete or geo polymer concretes. So, in this type of a concrete which was initially developed sometime in the 1970s or late 1970s. Now last 10 years it as gained huge popularity primarily because we take away completely 100 percentage of the cement and replace it with 100 percentage of fly ash.

Now, one could immediately wonder when greater than 40 percentage of effects the setting time and strength 100 percentage will it not effect. Yes definitely it will effect, but alternatively what we also do is that we use activators such as sodium hydroxide and sodium silicate in extremely high quantities. And that will react using process called geo polymerization. The hydration of the geo polymer system is totally different from the Portland cement based paste system. So, typically you do not have calcium silicate hydrate gel or tobermorite gel that that is getting formed as the a strength giving phase and Portland cement based paste system. The same will not be formed in geo polymer system there is a geo polymerization is a totally different process where fly ash reacts with a alka activator such as sodium hydroxide or sodium silicate. And in any case we are not getting into that, but it is important to know that alkali activated fly ash concretes are getting popular primarily because 100 percentage of cement I can be completely replaced by fly ash. The only thing that you have to understand that when you do such replacement. So, this is the high quantity of activators are required.

now coming on to the third application fly ash can also be used for pavements. So, here in this figure you see that the fly ash is basically added along with soil and cement.

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And of course, the soil may contain some water as well. So, this also forms type of system which can be used in the pavements primarily as a sub grade or a sub base material. And usually rollers or compactors are used for compacting this mixture. And remember that in these type of systems, the effect of water cement ratio on compressive strength is very different from that of the Portland cement based paste systems. In this case the water cement ratio is not a huge factor. Of course, a water content is huge factor, but the strength of the system is primarily from the amount of compaction that is achieved by using the rollers or compactors.

So, this system is primarily based on based on density soil, density strength relationship which goes along the principles that are used in soil. So, this is a again a totally different system.

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And the forth one is where fly ash along with a little water and lime can be directly used as a embankment material for structural fill. So, so here what you see is that the fly ash water and little bit of lime is basically field here. And the compactors basically do the same operation that we saw here except that here the fly ash is primarily used as a sub grade and sub base material. Where as in this figure it is basically structural fill, and remember that in structural for structural fill applications huge quantity of fly ashes are use. And hence since fly ash is a waste product industrial waste product, it finds enormous application as a embankment material. These are some of the photographs that are shown to indicate how spreading and compaction of a fly ash for structural fill application takes place.

Now, coming on to the next topic which is classification of fly ash. We have already seen in the previous class the physical properties of fly ash such as fineness, morphology shape and color and many others. So, now, let us go to the chemical properties, but again the chemical. Let us first classify the fly ash because the fly ashes are classified based on chemical composition.

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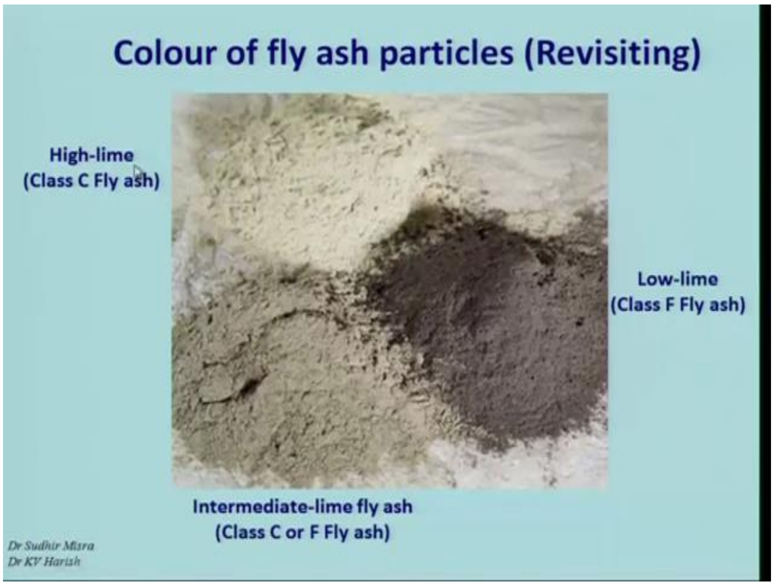

So, in classification of fly ash remember that we have already seen this slide we are revisiting, this slide where we saw 3 types of fly ashes in the previous lecture, one is the class C fly ash the other one is class C or F fly ash or the other one is a class F fly ash other ways of calling it is high lime intermediate lime and low lime fly ash and what we have seen in the previous lecture is the actually the color of the fly ash. So, for one it is yellow in color the other one it is light gray in color in a for other one it is dark gray in color.

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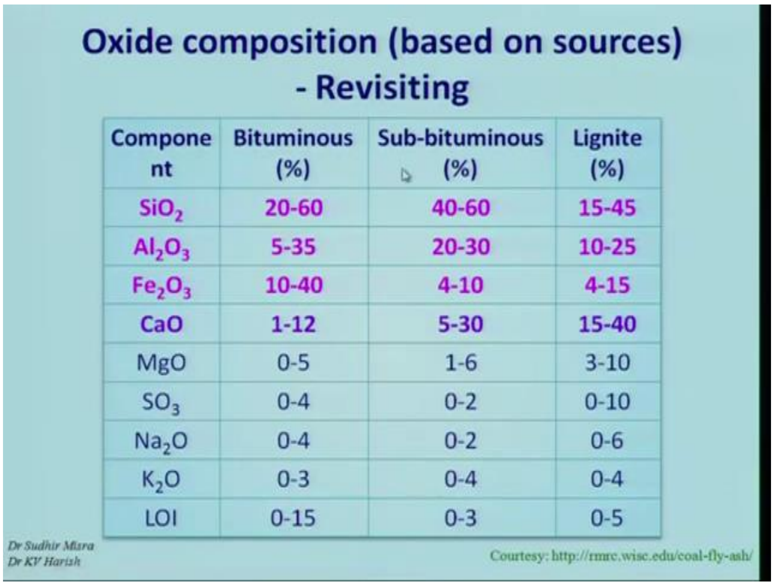

Oxide composition (based on sources) - Revisiting

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

Dr Sudhir Misra
Dr KV Harish
Courtesy: http://rmrc.wisc.edu/coal-fly-ash/

Now, again we are revisiting some of the oxide composition that we have seen, because before heading on to the classification we would like to know what are the important oxides that we have to consider for classification. So, this table we have seen in the previous class where it contains the component or oxides in one column, you have bituminous sub bituminous and lignite sources of fly ash. And out of all the oxides that are listed the one that is very important are the silicon dioxide aluminum oxide iron oxide and calcium oxide. The other things are generally considered as minor oxide, but that does not mean that these are present and very small amounts that you can completely neglected. These are also present in quite substantial amounts once we go to the limit is chemical requirements and limit is we will see what are the things specified by Indian standards, but right now for classification purpose these 3 are extremely important.

So, the silicon dioxide aluminum oxide and iron oxide the percentages for each of the sources of fly ashes are provided. And many times what happens is when it comes to classification silicon dioxide aluminum oxide and iron oxide are actually combined together and represented as a S plus A plus F factor. Remember S stand for silicon dioxide a stands for aluminum oxide and F stands for iron oxide. So, the combined all 3 together and call it as a S plus A plus F value and. So, that is one type of classification that we will see. The other one is merely based on calcium oxide percentage of calcium oxide accordingly we will the standards classify fly ashes into different categories and sometimes it is also important to know how our Indian standard classifies fly ash.

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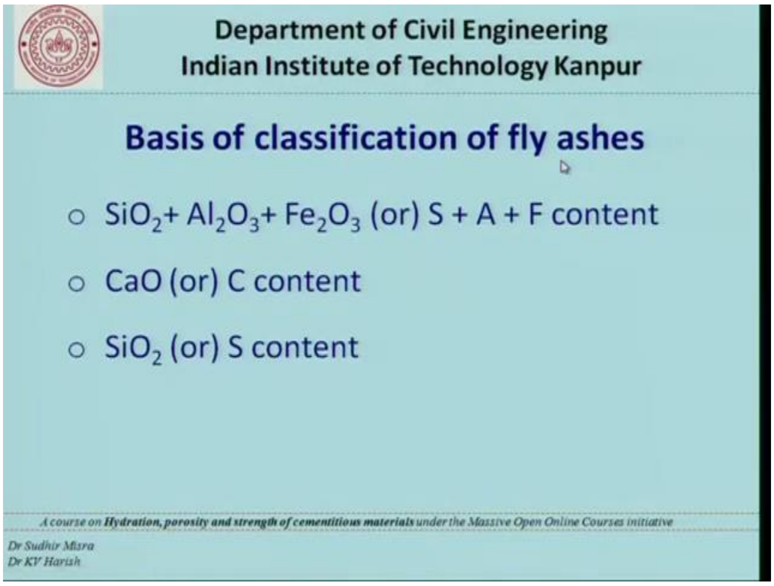

So, the basis of classification of fly ashes is 1 3 factors. One is as I mentioned S plus A plus F the other one is C content or calcium oxide remember C is not carbon this is abbreviation cement chemist abbreviation calcium oxide, and the other one is sometimes even the silicon dioxide present is specified.

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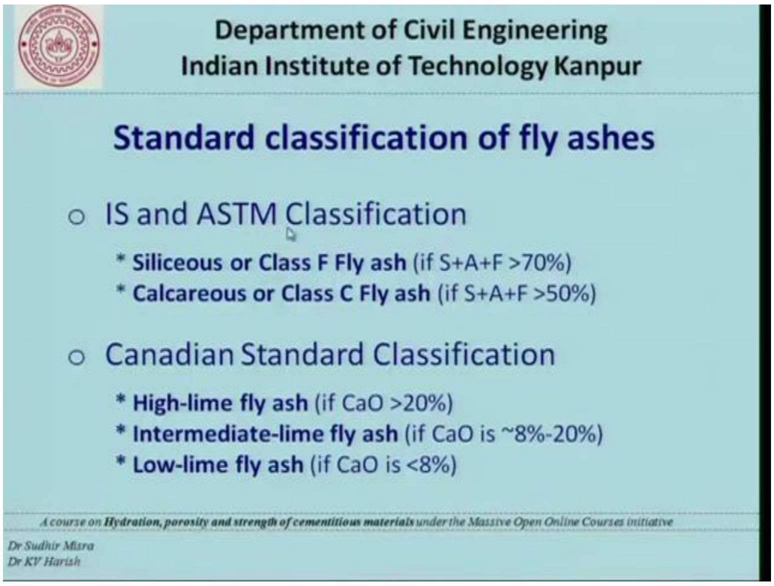

So, now. So, there are basically 2 classifications that are very popular. One is the ASTM classification the other one is Canadian standard classification. And remember that each country will have their own classifications as well, but generally they ASTM classification and Canadian standard classifications are very popular in the world. And our Indian standard classification is more similar to American standard classification.

So, our Indian standard classification classifies fly ash into 2 categories. One is siliceous fly ashes the other one is calcareous fly ash. In the case of ASTM, they classify into class F fly ash and class C fly ash. Basically the composition that is mentioned that is the S plus A plus F for the siliceous fly ash or class F fly ash are both. The same likewise the calcareous fly ash or class C fly ash are both the same. So, the IS also specifies and ASTM also specifies that S plus A plus F content should be greater than 70 for a particular fly ash to be classified as class F fly ash or siliceous fly ash. For other fly ashes the S plus A plus F content should be greater than 50 percentage. So, if you actually get back to the previous table that we just saw. So, here we have seen the silicon dioxide aluminum oxide and iron oxide contents separately.

Now, if we combined all 3 together, then what we generally tend to find is that the bituminous variety usually will contain higher amounts of S plus A plus F, compare to the lignite variety. Primarily because the silicon dioxide content is substantially higher for the bituminous variety compare to the lignite variety of fly ash. Likewise, also the other portions. So, sub bituminous will be somewhere in between the range of bituminous fly ash and lignite fly ash. And you can also understand that the calcium oxide content of bituminous fly ash will be substantially lower compare to the calcium oxide content of lignite fly ash. So, largely what we can understand is that the bituminous sources of fly ash typically or largely would be class F fly ash or in other words siliceous fly ash. In the case of lignite, it will be largely class C fly ash or in other words calcareous fly ash.

So, that is one classification which is very popular, but the difference between the IS and ASTM classification also exists in the sense that in addition to S plus A plus F content, IS also specifies minimum amount of silicone dioxide content for each of these fly ashes. So, that we will see at the next level, but coming on to the second classification which is Canadian standard classification based on calcium oxide, basically you have 3 classifications high lime fly ash, intermediate lime fly ash and low lime fly ash. Remember carefully that this lime is a very carefully used word. This as nothing to do with the normally lime that we have except for the fact that the formula of lime is calcium oxide. So, the limit high primarily comes if the calcium oxide content is greater than 20 percentages. And the intermediate levels come when the calcium oxide content is between 8 percent to 20 percentage. And low line fly ash is generally called if the calcium oxide content is lower than 8 percentage.

Remember that you have 2 classifications for ASTM and you have 3 classification for Canadian. And usually the high lime fly ashes will be of class C variety. And low lime fly ashes will be of the class F variety, and the intermediate lime fly ash could be either class F or class C, depending upon the percentage of calcium oxide as well as S plus A plus F.

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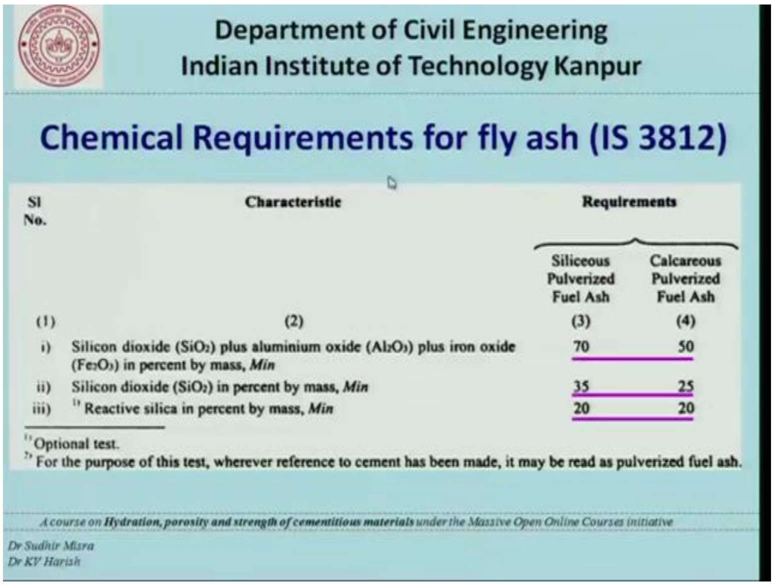

Now, let us see what is specified in Indian standards, as we have already seen that Indian standard classifies into siliceous fly ash and calcareous fly ash. And primarily this is based on a S plus A plus F greater than 70 percentage and greater than 50 percentage. In addition to this Indian standard also provides more limit is. So, which is actually shown in this figure, and this comes under chemical requirements for fly ash. This is as per IS 3812. So, what is shown in this table is that you have the characteristic that is specified S plus A plus F and it is mentioned as minimum. So, that is 70 percentage for siliceous fly ash and 50 percentage for calcareous fly ash. The terminology here could surprise you in the sense that here they have used terminology pulverized fuel ash. Likewise here also they have used pulverized fuel ash. If you actually read this code at the beginning it they have clearly mentioned that pulverized fuel ash could actually be very many different types of ash, but this codes specifically covers only for fly ash. So, pulverized fuel ash is the terminology that is used for many types of ash, but in this particular code they cover only fly ash. So, for siliceous fly ash 70 and calcareous fly ash it is 50. So, in addition to this we also have silicon dioxide that is benzene. So, as per IS the minimum silicon dioxide that should be present for siliceous fly ash is 35 percentage. And for calcareous fly ash it is 25 percentage. If it is lower than that then we are not supposed to use that fly ash for construction applications.

Now, in addition to the silicon dioxide expressed in percentage by a mass, we also have the minimum amount of reactive silica that should be present. Remember that even though the silicon dioxide could be substantial, only few of them or some portion of the total amount of silicon dioxide will be reactive in nature. Remember that this reactive silica is what actually takes parts in the pozzolanic reaction which we saw in the previous lecture. So, it is only the reactive silica that will take part in the pozzolanic reaction either at the early stage or at a later stage depending upon the fineness of fineness or particle size of fly ash particles. In the last lecture we have clearly seen that if the particles sizes are lower than 10 micron, then that will increase that will initiate the pozzolanic reaction and we tend to get strength at early periods, but if the particle sizes are between 10 to 45 then they usually take more time to react with calcium hydroxide form from cement hydration. And that will lead to later age strength, but if it is greater than 45 they basically do not take part in the reaction.

So, what is important from the third point here is reactive silica is also mentioned by Indian standards. And it should be 20 percentage at a minimum, if it is for a siliceous fly ash if it is for a calcareous fly ash it should be 20 percentage at a minimum. So, the code emphasizes that it is not enough if you merely have fly ash, we have to make sure that the there has to be some reactive elements in fly ash.

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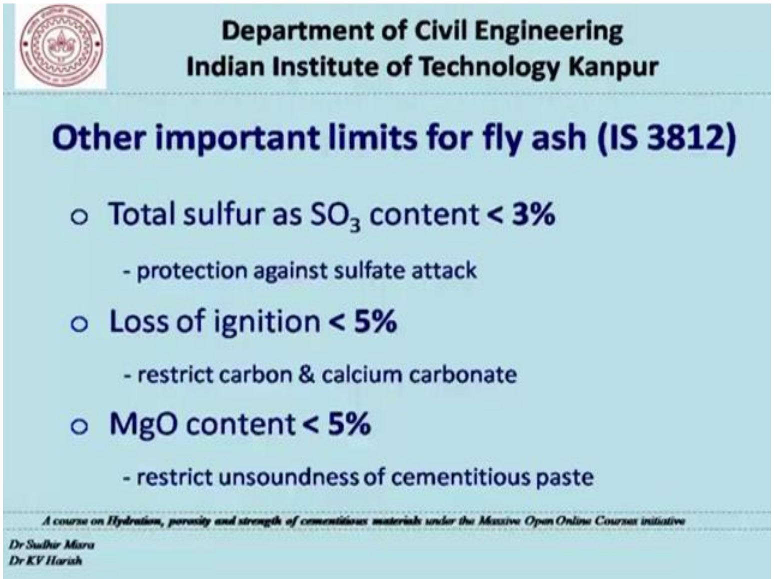

And other important limit is that we have briefly seen in the table discussed here where we have seen that the minor oxide such as magnesium oxide sulfur trioxide sodium alkalis or potassium alkalis. So, these are also present in fly ash, and although they have present relatively in minor amounts compare to the other oxides their presence is also gains important in the sense there their value should be limited. If they are greater than particular value specified by the limit is then they will cause serious problems partly we have already seen this under cement.

So, we will again revisit that. So, the other important limit is that are specified for fly ash in IS 3812 are total sulfur that is present as sulfur trioxide content, and that has to be lower than 3 percentage. The primary reason is that if it is greater than 3 percentage then it will tend to trigger sulfate attack. So, you may have to again go back to Portland cement based paste systems where we have seen hydration of a aluminates and others and hydration of aluminates and particular case, we have seen that the mono sulfo aluminates is little dangerous hydrator compound which can cause sulfate attack at a later stage.

So, for such for keeping that in mind the sulfur trioxide content is reduce to 3 percent. Likewise the loss of ignition should be lower than 5 percentage, because loss of ignition is representative of the amount of carbon that it is present in fly ash. This becomes a very important thing in fly ash primarily because fly ash is the raw material that is use in fly ash is coal and coal is a primary source of carbon. So, we generally tend to get more carbon that is present in fly ash. Now if you have carbon content or loss of ignition lower than 5 percentage, usually that does not cause any problem to Portland cement based paste systems in terms of property changing properties. Whereas, if it greater than 5 percentage then they affect a certain properties such as air entrainment and others.

Now, this loss of ignition is usually function of the carbon present in it or function of calcium carbonate that is present in the fly ash. Now the third one is magnesia content and we have already seen in Portland cement also that excessive magnesia content is not preferred. So, this is usually restricted to 5 percentage.

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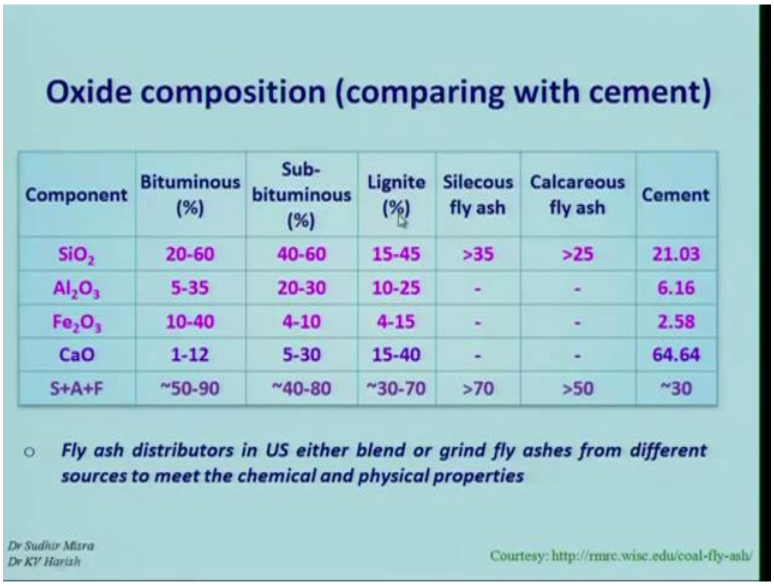

Now, what is shown here is comparative oxide composition of fly ashes that we have seen from bituminous source sub bituminous lignite. And also including the Indian fly ashes siliceous fly ash calcareous fly ash, the limit is that are specified and comparing it with the composition of the cement. So, typically only the oxide important oxides like silicon dioxide aluminum oxide, iron oxide, calcium oxide and S plus A plus F are shown here. And what you generally find is that if you take bituminous variety if you add all 3 approximately you will get S plus A plus F in the range of 50 to 90. Likewise sub bituminous you get somewhere between 40 to 80 lignite, you get somewhere between 30 to 70. So, you typically find that the higher ends 90, 80 and 70 for S plus A plus F for all these fly ashes basically reduced. So, the bituminous has a highest S plus a

A plus F and lignite has a lowest. And if you compare it with the requirements that is provided by the IS this has to be greater than 70 percentage.

So, and this is has to be greater than 50 percentage. If for some reason if the S plus A plus F is lower than 50 percentage, then such fly ash cannot be use for applications in India. Likewise if the S plus A plus F is lower than 70 we have to again check if it is lower than if that fly ash is lower than 50 percentage. If it is lower than lower than 50 percentage, you have to reject it if it is greater than 50 percentage that particular fly ash can be used as a can be designated as a calcareous fly ash and still can be used for application.

And if you carefully see what is the composition of cement, you find that a typical composition silicon dioxide of 21 percent 6.16 percent aluminum oxide iron oxide 2.58 and calcium oxide of 64 percent is shown for cement. And remember that cement composition usually varies by 5 to 10 percentage. So, if you count it to hundred there will be always 5 to 10 percentage variation for each of these. So, the S plus A plus F amount for cement is approximately 30. While that for fly ash either siliceous or calcareous it is substantially higher.

Important from the stand point of quizzes or exams or assignments. So, it is it is suggested that the audience pay little more attention to the important values that are mentioned for silicon dioxide, aluminum oxide, iron oxide calcium oxide and S plus A plus F. So, in the case of cement it has a lower S plus A plus F compare to fly ash and in the case calcium oxide it has much higher amounts compare to the fly ash.

Now, coming on to the next topic which is characterization test for fly ash as a pozzolan in cementitious material. Now that we know that we a get fly ash from different sources we also know that the fly ashes has different physical properties, we also know that the fly ash has different chemical properties. Now when it comes to use as a pozzolan in cementitious material or Portland cement based paste system is there any specific test methods and requirements that have to be followed.

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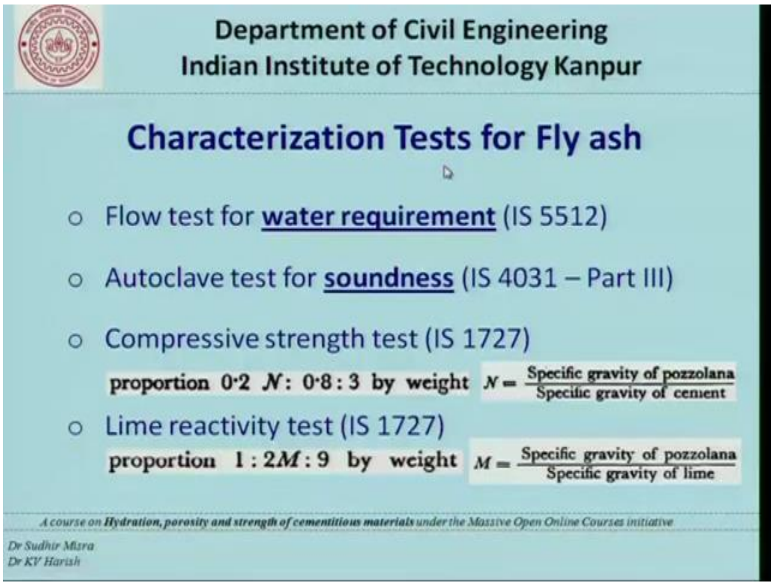

So, there are typically 4 characterization test that are mention in the Indian standards. One is the flow test. And flow test is primarily for water requirement. And it this is specified in IS 5512 and what is mean by flow test how the flow is measured and all those things we will see a little later.

The second one is autoclave test for soundness, and remember that the autoclave test is already covered in IS 4031 - Part iii, which we have already seen in previous lectures when we covered properties of Portland cement. The third one is that you have compressive strength test and remember the compressive strength test here is as per IS 1727 and this is our mortar cube test. And what you do in this test is we basically prepare a mortar mixture having the proportion of 0.2 times n is to 0.8 times is to 3 by weight 0.2 times n is the amount of pozzolan that we have to add. And 0.8 is actually the percentage of cement that we have to add and 3 is the percentage of sand and all are evaluated by weight. And this 0.2 times n this n refers to a value which is determine from the specific gravity of pozzolan and specific gravity of cement. Basically dividing one by the other. So, that value have to be inserted here. And the mortar cubes of this proportion have to be prepared in the lab and it has to be tested. Remember that the water is a very important parameter and code also provides some formula to determine what is the amount that has to amount of water that should be added in this mixture. And once you calculate that one you have to find the strength of the specimen at a particular 8 days 7 days or 28 days and then there are some limit is and if it is above that limit, then the particular pozzolan fly ash can be use for application if it is below that it cannot be used. Likewise in the lime reactivity test which is also as per IS 1727 this is this test is basically similar to the compressive strength test in the sense that you again form a you again prepare mortar cube specimen, but the only difference is that the proportion here 1 is to 2 m is to 9 is taken where 9 is actually the percentage of sand 2 m is the percentage of pozzolan and one is the percentage of lime.

So, the difference between these 2 test is that here you use cement along with fly ash or pozzolan. Here you use lime along with pozzolan. And the other difference is that the formula the proportion of the mortar is different compare to this, but; however, the factor n and m mentioned in these 2 are pretty much the same in the sense that it is the ratio of the specific gravity of pozzolan to the specific gravity of lime. Likewise, here it is the ratio of the specific gravity of pozzolan to the specific gravity of cement.

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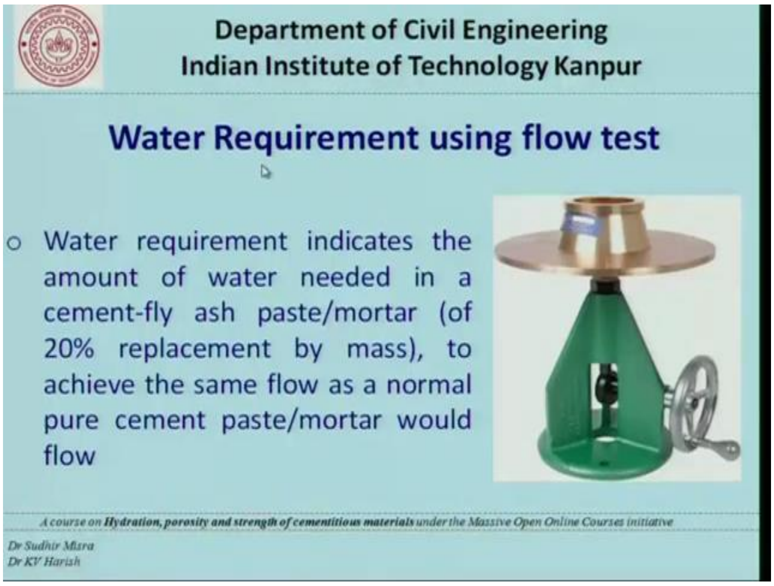

Now, let us go to the first test which is water requirement using flow test. So, what is shown here is basically flow table where here you have a cylindrical mold of standard size at the bottom the dime the diameter is 100 mm and the table diameter is typically 250 mm. So, what is done in this test is basically we prepare mortar or a paste samples of specific proportion, and water is appropriate quantity of water is added, and the wet mixture is properly mixed together and the prepared mixture is poured in this mold, and they are tamped in 3 layers giving 25 blows each time, and after filling the material at the top it is made it is flattened, and the mold is basically released and when the mold gets released what happens is the wet mixture tend to flow in the table, they try to spread and they try to occupy the largest space that is possible in the table.

So, that there is a jolting that is created and we have to jolt it 25 times in 10 seconds. And the jolting basically spreads the material as far as possible. And after jolting 25 times the spread diameter is basically measured. So, if the spread diameter is equal to or more than the table diameter then it is called as full flow. Or in other case it is not full flow you we basically measure what is the flow diameter and calculate it has calculate report it as a percentage flow with respect to the diameter of the mold at the bottom which is 100 mm.

So, water requirement indicates the amount of water needed in the cement fly ash paste or mortar approximately 20 percentage replacement is tried, but usually the dosages that is specified by Indian standards is between 15 percentage to 35 percentage. Many times what happens with fly ash is that we may have to try different dosages in the lab and get the optimized one which provides the highest flow.

So, in this case it is assumed as 20 percentage replacement. And what you basically do is you do the same test with without a fly ash. And with fly ash and basically compare which is giving a higher flow whichever gives higher flow that has lower water requirements. So, usually what we find in with fly ash is that fly ash paste mixture gives low has lower water requirement compare to reference mixture which does not have fly ash.

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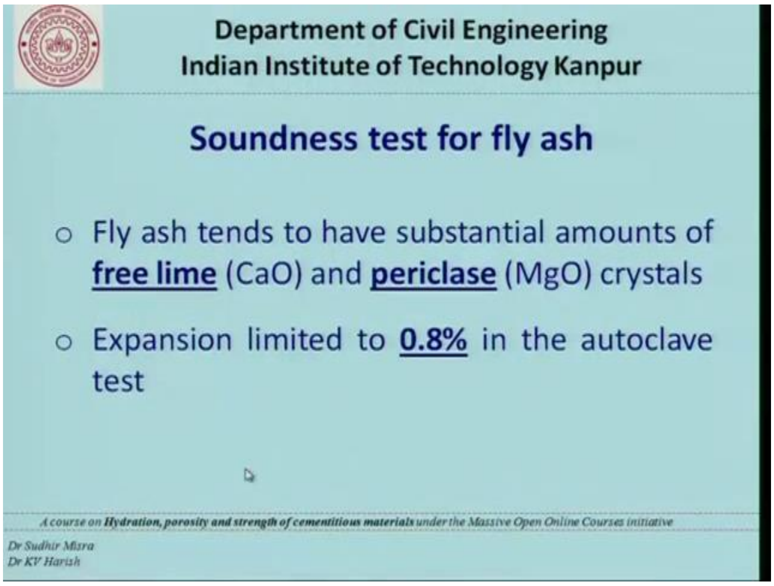

Now, the second one is soundness test where we have not getting in to the soundness test because it is already discussed in Portland cement. All that you have to know is that the soundness problems may exist if fly ash has higher quantity of free lime or magnesium oxide crystals and the limited expansion values are 0.8 percentage in the autoclave test.

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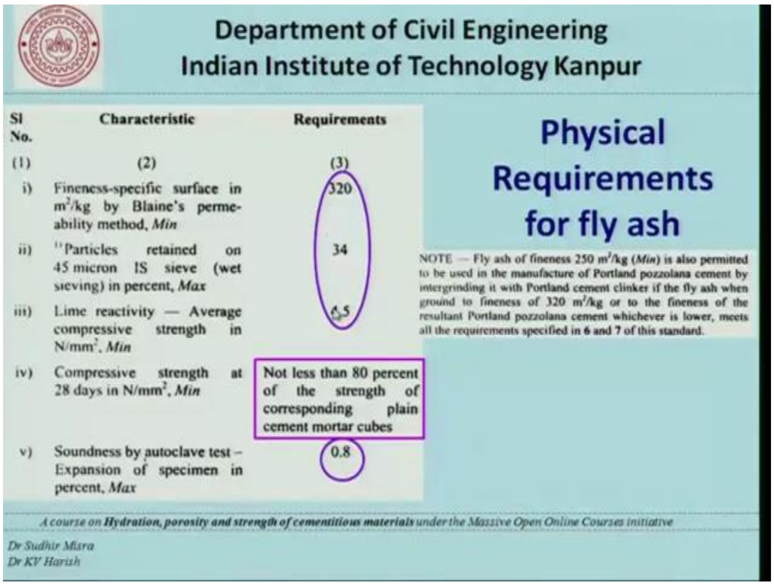

Now, coming on to the physical requirements of fly ash which are also provided by Indian standards. So, some of the physical characteristics are provided here. And the minimum require minimum or maximum requirements are provided as some values or some explanations in this column. Now if you take fineness which is expressed in terms of specific surface area measured by blaines permeability method remember that in the previous lecture we have seen that blaines permeability apparatus can be used to measure the fineness of fly ash like how we determine for cement also. So, the fineness of fly ash at a minimum should be 320. This is a very important factor and this is expressed in meter square per kg. So, 320 meter per meter square per kg should be the minimum fineness of fly ash when it is measured by blaines permeability method.

Now, the other ways testing can also be used if one uses wet sieving analysis where a 45 micron sieve is use. The particles retained on this 45 micron sieve maximum should be 34 percentage, which means the larger amount of particle should actually pass through the 45 micron. So, that is a again a very important value 34 percentage can only be retained the either it is h should be 34 or lower than 34. All other thing should pass through and a lime reactivity which we discussed here where we have seen that a specific mixture proportion is used and the compressive strength is found for that mortar and we use this formula to find out the proportion. So, what is specified is that when you test a such cube for compressive strength, it should give the mixture should give a minimum strength of 4.5 newton per mm square.

So, that is what is the specifications provide in Indian standards that indicates that there is some reactivity for fly ash. So, it is a representation of a strength if you have 4.5 then there is some pozzolanic reactivity that is happening and that is giving the required strength. Now if you take the strength test that we saw here third one what is specified by Indian standard is that when you do that procedure the 28 day test compressive strength test that you do the strength has to be at least 80 percentage for that mixture, when you compare it with a control mixture which do not have fly ash. So, if you have a reference mixture which does not have fly ash and if you have another mixture which has fly ash then the fly ash mixture should at least give 80 percentage of the strength that is given by the control. Which means 20 percentage redaction and strength the code is ready to accept. Now the soundness is also mentioned and the maximum value is 0.8 percentage which we saw just a while before.

So, this is about physical requirements. So, what we have covered in the last few slides is the characterization test for fly ash, primarily we have the water requirement soundness test. Remember that the water requirement is done on paste or mortars soundness test is done again on paste specimens. Compressive strength test is primarily done on mortars, and lime reactivates also done on mortars. So, when you do these characterization test this will give some idea about whether the available fly ash or the tested fly ash can provide the desired properties required to be used as a pozzolan in cementitious material.

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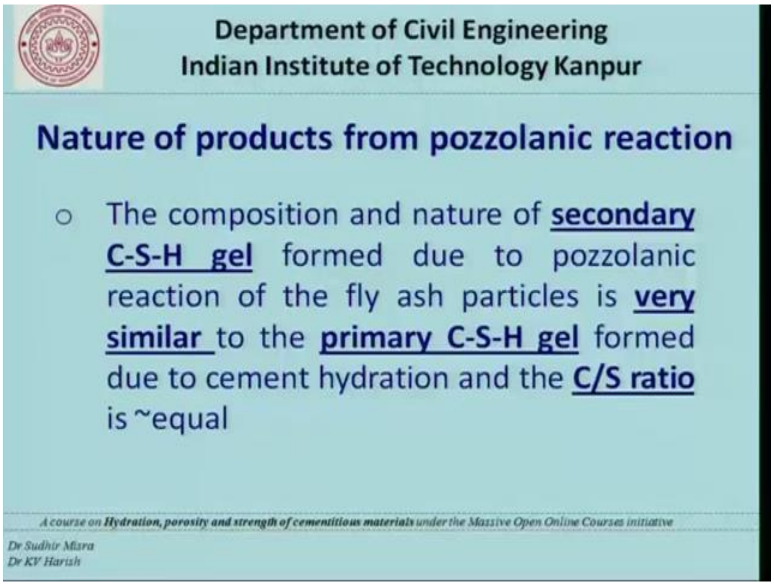

Now, getting into what are the nature what is the nature of product from pozzolanic reaction, we have already seen what is pozzolanic reaction. And we know that calcium silicate hydrate gel is basically formed because of the reaction of pozzolan and the calcium hydro oxide that is formed from cement hydration.

now and remember that the calcium silicate hydrate gel that is formed out of pozzolanic reaction is many times called as a secondary calcium silicate hydrate gel. So, the composition and nature of secondary calcium silicated silicate hydrate gel formed due to pozzolanic reaction of the fly ash particles is very similar to that of the primary calcium silicate hydrate gel formed due to cement hydration. And the approximate C by S ratio for both of them are is 1.5. They both are equal and the value is approximately 1.5. Please refer to the previous slides given in the previous lectures where we have clearly mentioned that the C by S ratio is 1.5.

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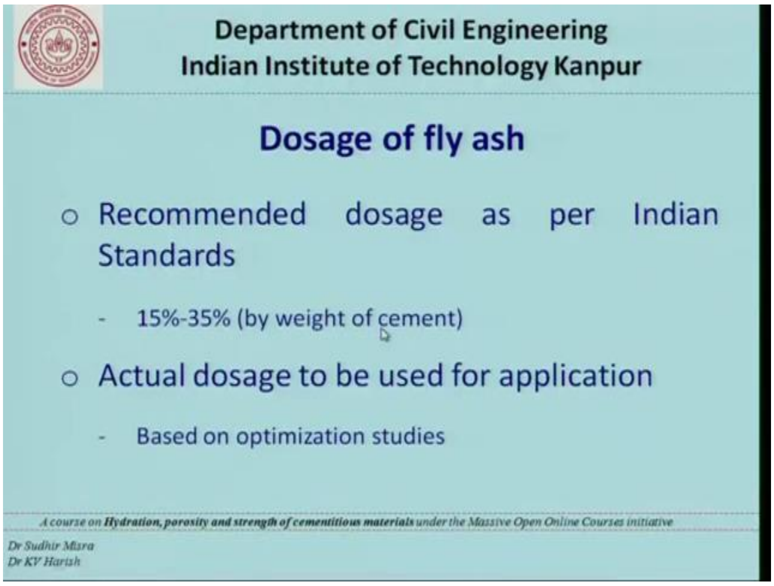

Now, coming to the what is the dosage that you have to use for application. What is recommended by Indian standard is that 15 to 35 percentage can be use by weight of cement as a replacement for cement by weight, but when it comes to application the actual dosage either can be taken somewhere in between this range or sometimes you may have to do some trial studies and find out for that particular application which dosage provides better properties. Because what usually happens is that applications are very diverse and for each type of application particular set of properties are more important compare to others.

So, in such in such cases instead of 15 to 35 percentage dosage range, probably 40 or 45 could also be more important. Or in other case lower than 15 percentage could also be more beneficial compare to the recommended ranges. It is for this reason usually whenever fly ashes is used for application, trial studies are required and one has to understand and do a atomization process to find out which one is which dosage have to be adopted.

Now, coming on to the very important topic which is effects of fly ash on specific properties of Portland cement based paste systems.

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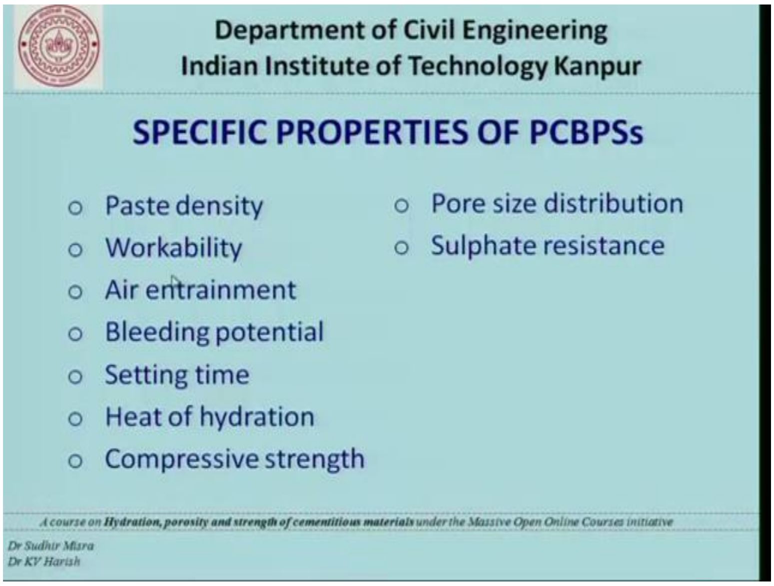

So, the specific properties that we will be looking today is paste density, workability, air entrainment, bleeding potential, setting time, heat of hydration, compressive strength, pore size distribution and sulphate resistance. So, these are generally a largely considered as important properties and remember that for application either a particular property could be more important than others or a particular set of property could be more important. For example, for some applications workability is a very important factor compare to others. Whereas for other application strength and setting time could be a very important factor. For other application heat of hydration could be a very critical factor compare to others. So, that is why selectively we have chosen property. So, we will discuss what happens when fly ash is added in the Portland cement based phase systems and how these properties change positively or negatively and we will try to get into the reasons and understand what are other variables that are involved in the in the and each of this properties.

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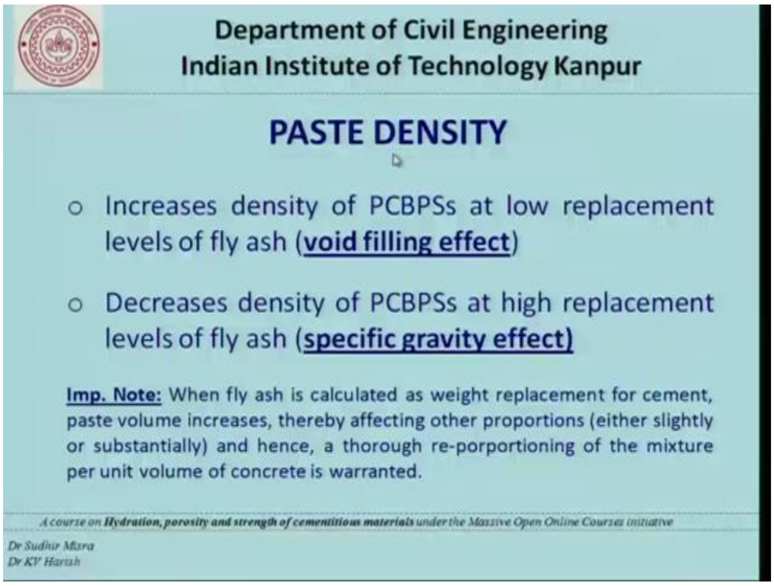

Now paste density. So, what is mean by paste density? We know that paste is nothing, but cement plus water and the moment you add fly ash fly ash also becomes a part of the paste. So, so what happens to the density, density of the paste is it going to increase or is it going to decrease. Now if you recall the specific gravity of water is one the specific gravity of cement is 3.15 and the specific gravity of fly ash could vary between 2 to 2.8. So, the fly ash specific gravity is something that we have discussed in the previous lecture.

Now, when you add fly ash what is happening is that since the specific gravity of fly ash is lower than the specific gravity of cement, the natural thing is that the density of the paste has to decrease, but a many times it may not happen why because you have the third ingredient which is water the specific gravity of water is much lower than of the specific gravity of fly ash and cement. So, what happens is the water content becomes a very important factor to decide whether the paste density substantially increases or decreases. So, so 2 points are given here, where and we have assumed that the water content is fixed. And we are changing only the cement and fly ash content because that is what is usually practiced in the site in the sense that whenever we go for a substitution or a addition of a fly ash for cement we usually do it as a replacement by mass.

So the first point to be noted is that addition of fly ash increases the density of Portland cement based paste system at a low replacement levels of fly ash. Which means the replacement level of fly ash is a critically important factor to understand whether the paste density increases or decreases. So, at very low replacement levels say 5 percentage 10 percentage, and if the fly ash particles are finer which means lower than 10 microns in that case you will see that there is a increase in the density. And this increase in density is primarily because the finer fly ash particles try to fill the voids between the cement grain there by pro there by providing a effect called void filling effect. And that helps in increasing the density of Portland cement based paste systems.

Remember that there are variables you cannot simply say that the paste density increases just because of the addition of fly ash. Because it depends on variable such as what is the dosage that you have used and the other one is what is the size of fly ash. So, if the size of fly ash is greater than 10 micron then even if it is a use at low replacement level then it cannot fully filled the voids in such cases it will decrease the density.

So only when fly ash is use at a low very low replacement level or low replacement level and if the fly ash size particle size is lower than 10 micron, then you will have this void filling effect and because of which the density of the Portland cement based paste system increases. When we increase we are saying that it only increases by 5 to 10 percentage not more than that. Now in the second case the fly ash tends to decrease the density of Portland cement based paste system. And this is the usual case that happens and at either at normal replacements level or high replacements level whatever and this is primarily because of the specific gravity effect in the sense that, fly ash has lower specific gravity compared to cement and hence the density for the fly ash mixtures will decrease.

So, in the second point decreases density is given specifically for high replacement level because at normal replacement level, there will be only marginal decrease in density there will not be a substantially decrease in density. So, substantial decrease will be see in only at high a replacement levels of fly ash. And this is primarily due to the lower values of specific gravity for fly ash particles over cement grains.

One important note I am just reading it is self explanatory when fly ash is calculated as weight replacement for cement paste volume increases. Thereby effecting other proportions either slightly or substantially depending upon the dosage that is used and other physical properties like fineness or particle size of fly ash and hence a thorough re proportioning of the mixture per unit volume of concrete is warranted. So, what it means is that since there is change in the density of the Portland cement based paste system, and what we have seen in mixture design sometime in the first 10 lectures we have seen that when there is variation in the density that affects the volume. And intern that also affects the weight a. So, if there are any changes in volume or density or weight a it actually effects the volume relationship and hence are proportioning of the mixture is required whenever fly ash is used at certain replacement levels.

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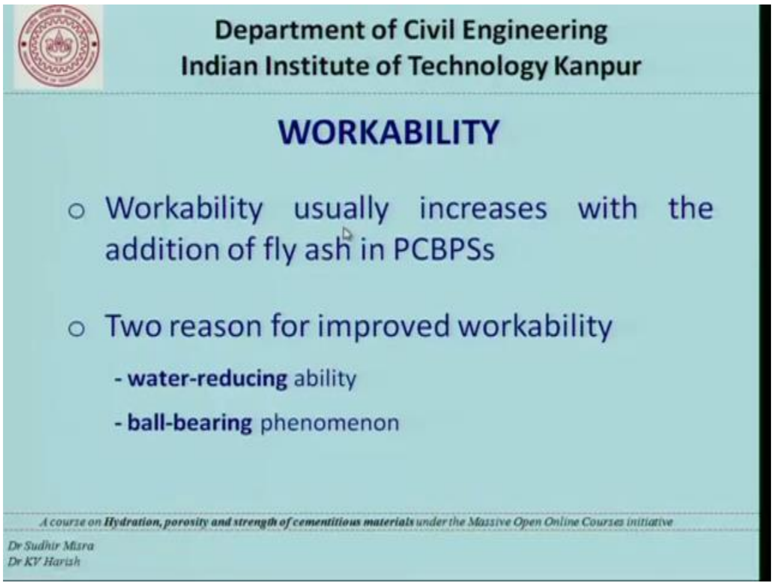

Now, the second property is workability. Workability usually increases with the addition of fly ash in Portland cement based paste system whenever we say usually increases we are assuming that fly ash is used at a recommended dosage levels that is between 15 percentage to 35 percentage. So, within that dosage the addition of fly ash increases the workability. And why do you get an increase in workability there are 2 reasons one is water reducing ability the other one is ball bearing phenomenon. So, we will see each one of them.

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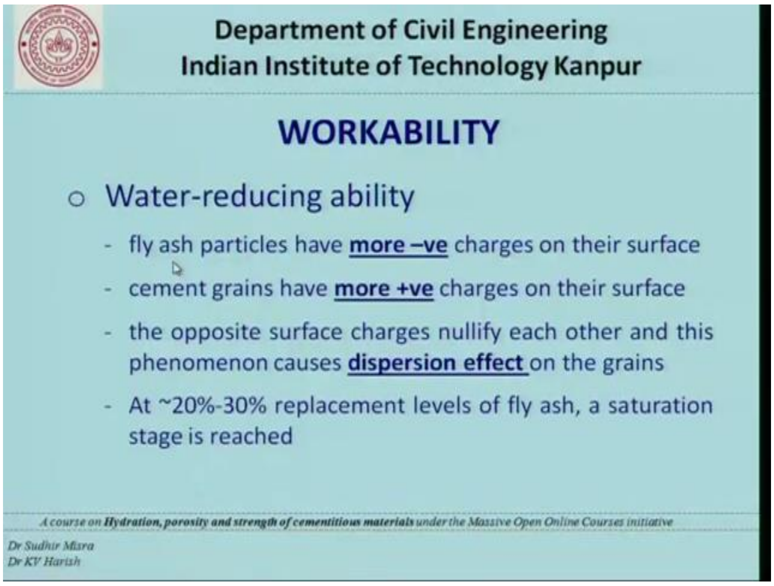

Now, what is meant by water reducing ability. Now if you carefully see the composition or the oxide composition of fly ashes, we see that substantially amount is silicon dioxide aluminum oxide and iron oxide. Remember that all these have negative charges. Calcium oxide has positive charges, but fly ash particles have generally lower amounts of calcium oxide compared to silicon dioxide aluminum oxide or iron oxide. Fly ash particles are largely negative particles or in other words they have more negative charges on their surfaces.

In the case of cement grain you see the calcium oxide quantity is substantially higher and hence the cement grains are consider to be largely carrying positive charges on their surfaces. So, cement has more positive charges, fly ash has more negative charges. The opposite surface charges nullify each other when they are used together in a mixture and this phenomenon causes dispersion effect. So, what happens is the cement grains are attracted to the fly ash particles or vice versa, but remember that the fly ash and fly ash particles will try to repel. The fly ash has a negative charge and another fly ash will also have negative charge, and the these fly ash particles tends to occupy the surface of the cement grain which has positive charges.

So, basically negative charge code is made on the cement grain each of the cement grain and because you have negative charge on their surface of each cement grain, that repels each other and you have something called as a dispersion effect. This is one reason why we get higher workability with fly ash a related mixtures. And at approximately 20 percentage to 30 percentage replacement level of fly ash a saturation is reached which means, if you if you go at higher dosage levels then it could affect the workability in other words, it can the addition of fly ash can decrease the workability because you were trying to put more fly ash particles into the mixture and the fly ash particles could have larger surface area compare to the cement grains.

Because of that the workability could decrease. So, this entire concept of dispersion effect is effective only at a replacement level between 20 percentage to 30 percentage or below 20 percentage. So, if we take any dosage greater than 30 percentage the workability is actually reduced. So, this is one reason why fly ash provides higher workability.

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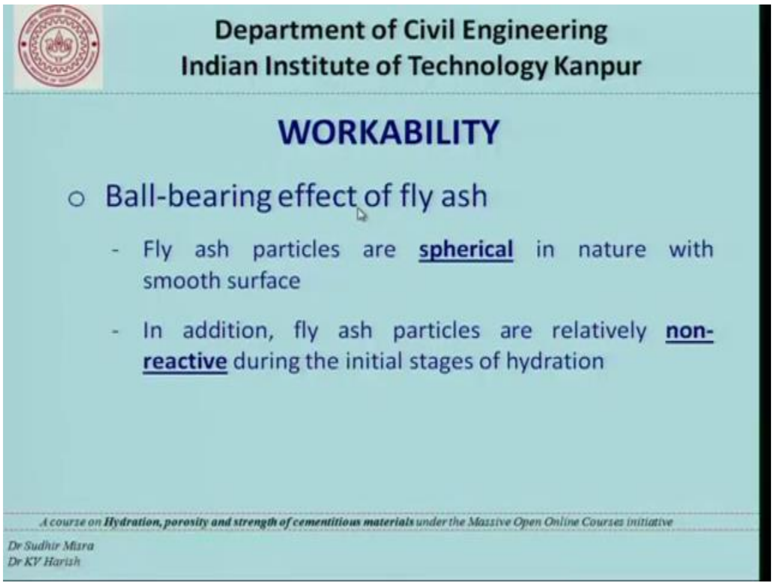

The other one is ball bearing effect. So, the word ball bearing effect is to indicate that the fly ash is spherical in shape. And when you have a smooth spherical shape then the particle to particle interaction is much lower and this actually helps and the additional thing is that the fly ash particles are non reactive at early stages.

So, basically the act the fly ash particles act as small a spherical particles in the mixture. So, the interaction between the particles is not much and thereby that gives the additional workability that is required. So, that is explained as ball bearing effect. And remember also that the ball bearing effect is also present only within the recommended dosage between 15 percentage to 35 percentage. Once the quantity exceeds 30 percentage the surface area of factor comes into picture because of which workability will start reducing. So, whatever is discussed as a positive factor for improved workability under water reducing and ball bearing, it has to be remember that it is only at appropriate dosage level between 15 percentage to above 30 percentage.

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Now, the other important properties air entrainment. Remember that air entrainment is primarily required only if there is a freezing and toying environment. If we go back to the previous lecture where we discussed about chemical admixtures and in that we have discussed air entraining add mixtures, you find that entrained air is not present in concrete you will have entra entrapped air voids and you may also have capillary pores and gel pores. So, entrained air comes into picture only when you have a air entraining agent. And air entraining agents are use only when you have when concretes are subjected to freezing and toying because you need additional air in the mixture in order to resist the expansion and contraction of ice crystals inside the concrete. So, all these things you may have to recall when you read this slide back.

So air entrainment the carbon content of fly ash negatively influences the air entrainment in concrete. We have already seen that fly ash may contain substantially amount of carbon primarily arising from the coal raw material coal. So, if you have carbon at larger amounts then you need larger amounts of air entrainment in other words you need larger amounts of air entraining agent. So, that you can get the desired range of percentage of air bubbles in the concrete.

So, recall that for freezing and toying the typical range of air content that is required is between 4.5 percentage to 6 percentage or 7 percentage closed to that. So, if you use fly ash then you will require more air entraining agent compared to a mixture which do not have fly ash. Because the carbon basically sucks many of the chemical admixture and in this case it will suck many of many of the air entraining agent that is present. So, whatever you use a whatever is the air entrainment dosage that you use for the conventional mixture which do not have fly ash, compared to that when you use a fly ash mixture you should have you require more air entraining agents. Carbon has tendency to absorb air entraining agents thereby rendering them in ineffective higher dosages of air entraining agents are required to achieve the desired range of air contents.

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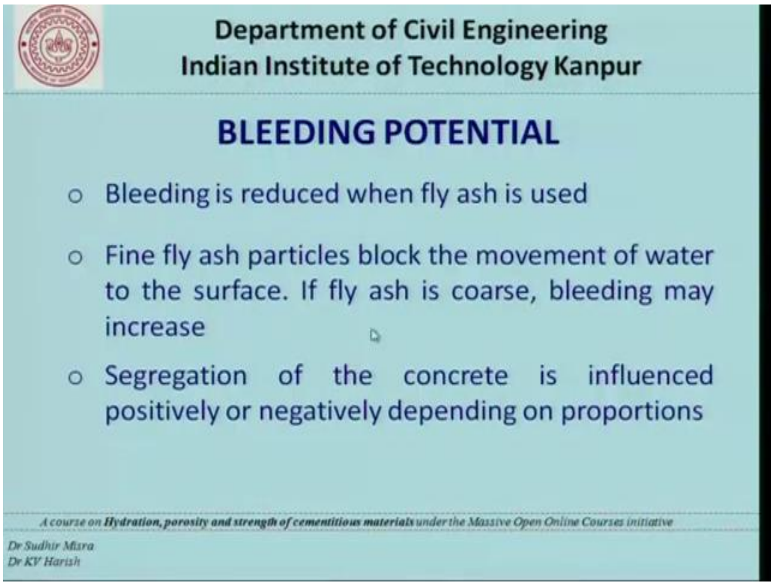

Now, coming on to the next property which is bleeding. Potential bleeding potential is reduced when fly ash is used, and what is bleeding potential bleeding potential is the ability of the water and other materials to come to the top of the surface, because of the low specific gravity. Bleeding is primarily seen in mixtures having higher water to cement ratio. So, when we use fly ash in such mixtures, what happens is that because fly ash has a finer particles size and higher fineness that will help in reducing the bleed water. So, it will not allow the bleed water to actually get separated from the rest of the mixture. So, fly ash basically will try to retain the excess water that may be present in a high water content mixtures, fine. Fly ash particles block the movement of water to the surface if fly ash is coarse bleeding may increase remember that the particle size distribution is a very important factor that could affect a any of the property that we are discussing.

So, if the fly ash that is used is very coarse. So, if you recall go to the particle size distribution of fly ash what we find is that we have to size range is one is lower than 10 micron the other one is lower than sorry between 10 micron to 45 micron. We have also seen that the particle size for fly ash ranges between 1 micron to 100 micron. So, if you have a higher particle size that is greater than 45 micron which is actually termed as a coarse fly ash, in that case the bleeding can also increase. So, we cannot merely say that just addition of fly ash reduce as bleeding that is not a proper. So, there are also other properties like size of fly ash which could actually increase a bleeding instead of reducing the bleeding.

Segregation of the concrete is influenced positively or negatively depending on proportions. So, in addition to the generally said information that fly ash will reduce bleeding, in addition to the information that the particle size of fly ash is a important factor. We should also understand that the mixture proportion is also a critical important factor to determine whether a particular mixture will bleed or not. So, you have very many factors, but generally we can say that the addition of fly ash within the recommended dosage if the particle size are lower than 45 micron will reduce bleeding. And the word segregation is use primarily because bleeding is a type of segregation that is present in concrete.

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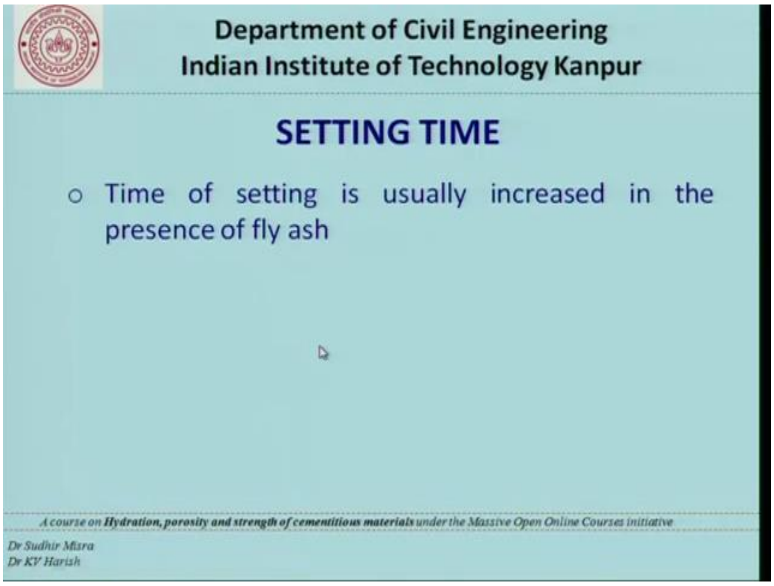

Now, moving on to the next property which is setting time the time of setting is usually increased in the presence of fly ash this is a very important point. The reasons are not a very clearly known, but one can generally understand that if you use the fly ash in the in the mixture we use it as certain dosage level. So, we generally tend to reduced the cement content and add a fly ash in a in to to it. So, if you reduce a cement content the cement is usually a reactive material more reactive material than fly ash and hence many time we find that setting time increases. We cannot call it as a retarder even though it does the function as a retarder.

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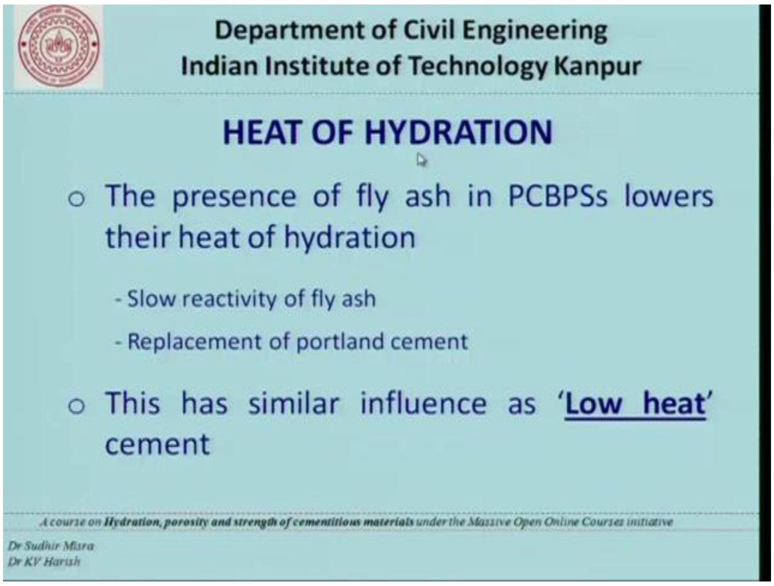

Now, the next property is heat of hydration. The presence of fly ash in Portland cement based paste system lowers their heat of hydration, very important point and this is one reason why in structure where heat of hydration is a very critical factor fly ash is used as a very important material in concrete. So, why a because number one the reactivity of fly ash particles is usually slow. So, they do not react within 2 3 days they take their own time to react probably in 7 days 14 days or 28 days.

So, when you have slow reactivity the heat developed during the because of the exothermic reactions of the different components and Portland cement based paste systems that actually lowers. And the other reason parallel which comes along with this this because many times fly ash is use as a replacement material or a substitute material and Portland cement will be use in lower amounts. So, usually when you compare reference mixture with mixture that has fly ash, the amount of Portland cement is lower and hence the reactive elements are lower and hence the heat of hydration is lower. This is also similar to what we are discussed in setting time where the portion of cement for the fly ash mixture are usually lower and hence the properties are beneficial when you use fly ash. And this lowering of the heat of hydration that we use for the fly ash mixtures helps to use such mixtures for low heat applications and in Portland cement, we also have several special categories of Portland cement such as low heat cement high sulfate resistant cement or in other words super sulfate cement and several other types of blended cements.

So remember that in low heat cement or super sulfated cement, we do not have any other additional ingredients, we have only the same ingredients which we have in Portland cement production of Portland cement like C 3 S C 2 S C 3 A and C 4 A. Here the only difference between these special cements and Portland cement is that the composition of the compounds are slightly changed in order to suit the requirement. So, if you need low heat then the compound compositions will be slightly different from that of Portland cement. If you need high sulfate resistant cement or super sulfated cement primarily for sulfate resistant property then specific compositions of the compounds in the Portland cement will be changed.

Now, the point that is mentioned here is that instead of using a low heat cement, if there is a heat of hydration problem and if you want to use a low heat cement, we can also use Portland cement added with fly ash to get the same performance that you get with the low heat cement. So, the properties that you get when you use fly ash in Portland cement based paste system, is similar to the performance that you get with low heat cement where the compositions are refine to suit that particular property which is low heat.

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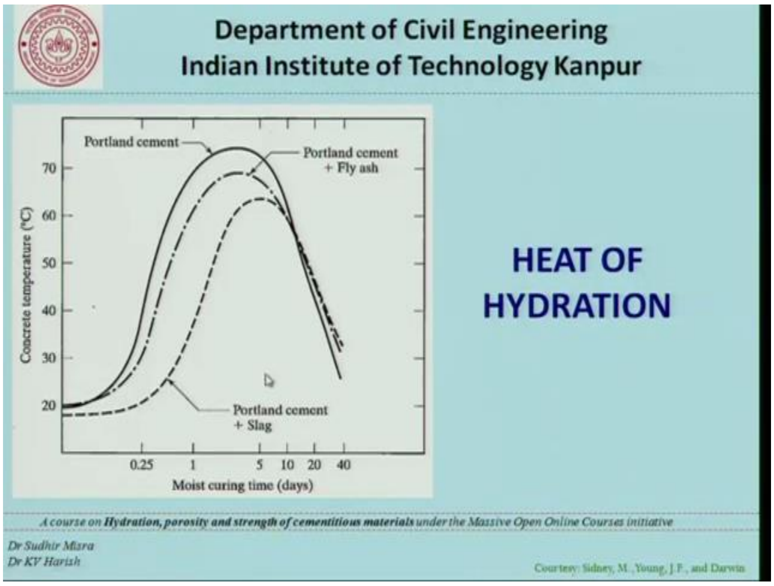

Now just to understand what happens with concrete temperature with time. This graph is shown. So, what you have in this figure is totally 3 curves. One is the reference mixture which has only Portland cement has binder. The other one has Portland cement plus fly ash. And in the third one we have Portland cement plus slag. So, for this lecture alone let us eliminate this Portland slag because we will have to go through what are the properties of Portland cement. And then we will have to come to this figure once again.

So, let us now compare only the Portland cement with mixture containing fly ash. And in the y axis what is given is the concrete temperature and in the x axis what is given is the moisture curing time, which is ranging from 0 to about see typically 28 or 40 40, usually 90 percentage of hydration takes place at about 28 days. So, they were given somewhere between 20 to 40.

now what you see generally with the Portland cement is that the concrete temperature increases with the time. And you see that the 20 degrees which is which could be the placement temperature at that particular point of time is a same as a concrete temperature that we have produced. And a since the water is just added to cement it is somewhere at the placement temperature range. So, once water is added with a time you see that the temperature concrete temperature increases substantially and this substantially increase you find during the first 1 2 3 days or close to 5 days. And after that it is slowly decreases and this steep increases a actually problematic if the volume of concrete is higher. If you go back to the lectures say 19 and 20 which was delivered by professor Sudhir Mishra where heat of hydration is seen as a very important problem especially when the volume of concrete is large, this steep increase in temperature becomes critical and can cause thermal crackings. So, we want to reduce this temperature as much as possible.

So, what we do is we use fly ash as we already discussed in this slide if you use fly ash it actually reduces. And remember here the dosage is not given. So, even though here the reduction that you get with fly ash addition appears to be less if you add more amounts of fly ash you get a substantial reduce in the concrete temperature. So, that that helps in reducing the thermal stresses, and concrete the thereby no thermal crackings are produced by concretes. So, this graph is primarily to show that addition of fly ash reduces the reduces the heat of hydration or in other words reduces the concrete temperature substantially lower and with increase the fly ash dosage this value reduces substantially, and thereby the concrete is not vulnerable to thermal cracks.

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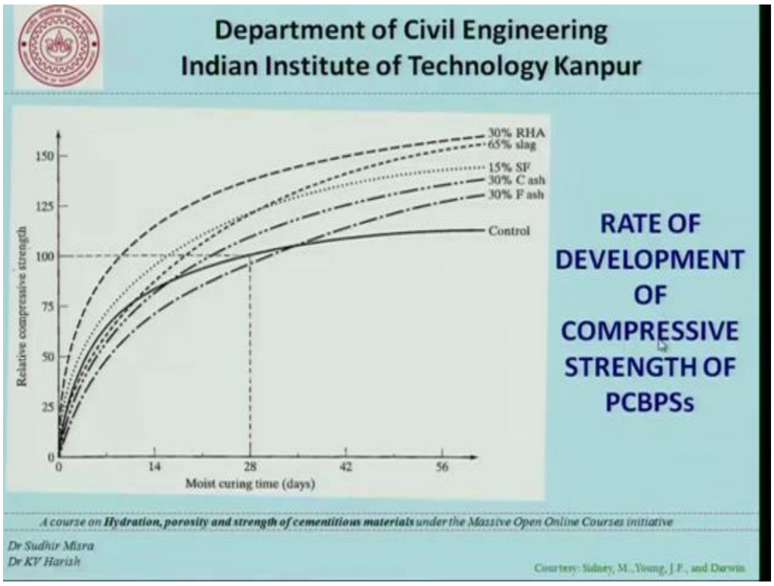

Now, the next one is how does the addition of fly ash affects the compressive strength of concrete. Compressive strength is a very important property primarily because in in the design of RC structures primarily the FCK is considered as a very important factor at 28 days. So, it is primarily used in the design of concrete structures and hence the compressive strength cannot be relaxed in most of the applications.

So, in this graph we have a moisture curing time taken in the x axis and relative strength taken in the y axis. And we have about 1 2 3 4 5 6 curves of which right now let us see only 3 curves which is a control curve the other one is 30 percentage class F fly ash classes means siliceous fly ash. And the third one is the 30 percentage class C fly ash fly ash which is the calcareous fly ash. So, other curves let us not compare right now, once we go to silica fumes slag then will again revisit all these slides to understand.

So, now what is shown is relative compressive strength is shown in the y axis, you have to pay little more attention because this is not just compressive strength it is relative compressive strength; that means, whatever 100 percentage. So, if you take the y axis it is given between 0 to 150. So, hundred actually represents the strength of the control mixture. So, with respect to the control mixture how is a fly ash mixture varying. So, that is what is shown in this figure.

So, if you take the control mixture you get a steep increase at the beginning and then slowly it is starts flattening at the later stage. Whereas, in the case of fly ash fly ash mixture and primarily class F fly ash this is very important. If you take a class F fly ash the behavior is very much different from a class C fly ash. In the case in the case of class F fly ash what you see is that the initial strength development is actually slower compare to the control mixture, which means if you take the initial strengths say at 3 days 7 days or up to 14 days you find that the fly ash mixtures may give lower strength than the control mixture, but slowly the strength increases because of the pozzolanic reactions and you see that at later stage say after say 28 days or so, the class F fly ash slowly picks up the strength and finally, say about a 50 56 days or over 56 days you find that class F fly ash mixtures gives higher strength compared to the control mixture.

Now, the same is not true when it comes to a class C mixture. Class C mixture also provides lower strength compared to the reference mixture, but typically only up to say 14 days. Immediately after 14 days it becomes very active and due to both pozzolanic reactions and reactions of the calcium oxide that is present in the fly ash, and you find that it gives much higher strength compared to even class F fly ash. So, this is very important and you find that a class C fly ash strength is much higher than the control strength or reference concrete strength. So, this is the strength rate of strength development graph that we should know from the angle of adding fly ash into the mixture.

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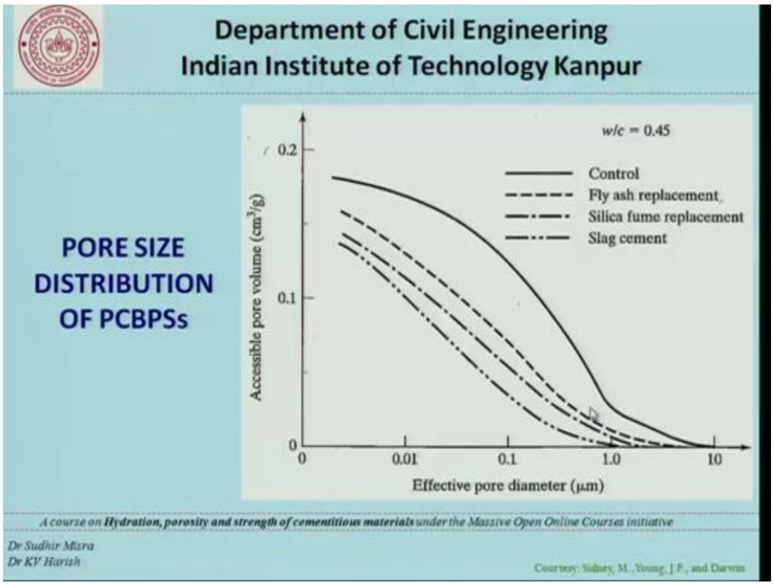

Now, the next important property is pore size distribution we at this point we you may have to recall the MIP curves a mercury intrusion porosimetry curves that we have seen in Portland cement based paste systems. So, if you are not sure about what it is just get back to the lectures that I discussed between say lecture 15 to 18 to understand what is MIP curves and the others. So, because the pore size distribution is basically from the MIP curves. So, what is shown here is the effective pore diameter shown in a micron meter ranging from 0 to 10 micron meter and in the y axis you have the accessible pore volume.

What is accessible pore volume and effective pore diameter all are discussed in lectures between l 15 to l 18. So, please go there and understand what it is and then get back to this lecture for easy understand. So, now, what you have here is a control mixture where we typically get a wide range of pore sizes. So, typically here we have somewhere between 0.001 micron meter to as high as 10 micron meter. Now what you find is that in this graph 4 curves are shown of which we will see only the control and fly ash, and we will see the rest after we discussed slag and silica fume. So, when you compare the control with fly ash replaced mixture, the fly ash replaced mixture has lower pore size range and also the diameter of the pores are also lower.

So, in this curve you basically find that the fly ash curve is basically parallel pretty much more or less parallel to this curve indicating that the pore sizes in the mixtures are much lower and the and the accessible pore volumes are also much lower. So, the addition of fly ash helps in reducing the pore size distribution or pore size range in Portland cement based paste systems. So, that is the bottom line in this figure.

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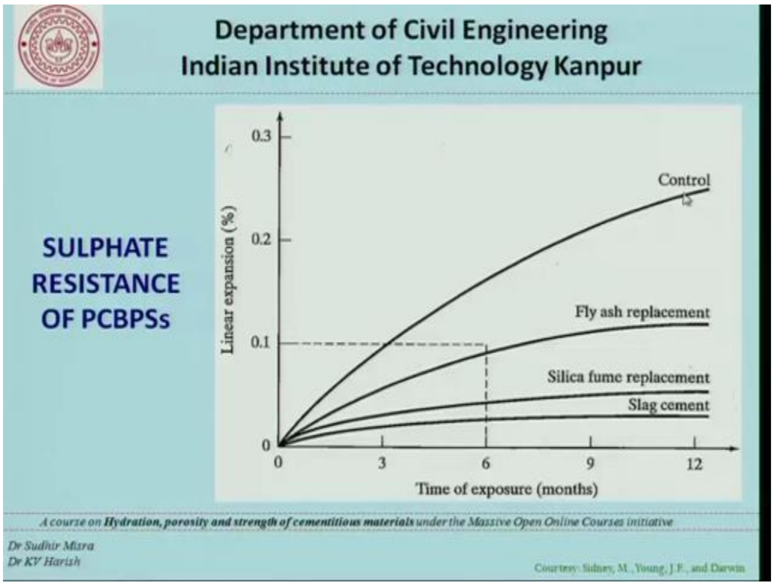

Now, coming to the next one which is sulfate resistance of Portland cement based paste systems. Again a graph is shown let us let us have see only the control and the fly ash replacement we will come to others at a later stage. So, what is shown here is time of exposure is shown and a expansion due to sulfate attack is shown. So, just for people to understand how these measurements are made again get back to what is meant by sulfate attack you will understand that the formation of monosulfoaluminates in Portland cement based paste system reacts with external sulfates. So, that comes from outside and forms ettringite, and that basically creates the expansion because you do not have sufficient space available in the mixture to expand and that creates a sulfate attack problem.

So, basically the Portland cement based paste system expands. So, in a sulfate resistance test what we do is we take a cement bar of standard size and soak it in a standard concentration of sodium sulfate or magnesium sulfate, and we measure expansions after every small intervals of time. Usually the test is conducted for about one year certain test we they conduct up to 6 months. So, that is why you find that the time of exposure is not actually the curing time. It is actually time of exposure in sulfate solution because in sulfate resistance you use a sulfate solution in which you soak the bar in that solution for about one year, and measure the expansions of the bar after particular interval of time.

So, in this graph what is shown in the x axis is intervals 3 month intervals 6 month 9 month and 12 month interval. And how the expansion of water bar takes place? So, usually for a control mixture if there is increase in the sulfate expansion. So, that is shown here and for fly ash mixture what we find is that the expansions are much lower at 6 months the reason. Why we chose 6 months is because one of the ASTM code it is specifically mentions that the expansion of mortar bars for sulfate resistance test should be lower than 0.1 percentage at 6 months' period. So, if you take a control sample it is above it is well above 0.1 percentage. In fact, it is well above.1 percentage even at 3 month period.

In the case of fly ash replaced a thing what you can observe is that this increase is not very substantial and the whatever is a limited expansion expansions are much lower at 6 month period; however, we can carefully see that with a time this expansion can go much higher than 0.1 percentage that is a different case, but at a 6 month period fly ash replace mixtures give lower expansion compared to the control mixture.

So, what we have seen until now is how the different properties are getting affected in Portland cement based paste systems because of the addition of fly ash. Remember that in most of the of these cases fly ash is added standard replacement levels or recommended replacement levels. If you add a much higher than that you may get appositive or you may get a negative and those since you can understand only when you do a optimization study. So, now, this topic gets over.

And now we come to the next important topic which is considerations limitations and quality control measures while using fly ash for construction application. Since fly ash is many times use as a positive material to give a positive material to replace cement do we have any limitations or consideration before we use fly ash in construction. So, we do have lot of limitations and we will see one after the other.

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Now, the first limitation is that there is material handling issue because many times fly ash from different sources has substantial amount of moisture. So, many times what happens is we have to dry fly ash and when we dry fly ash again we need energy and that may actually become little more expensive. So, also that is one type of a problem that we have when it comes to storage. Because we cannot store fly ash that contains moisture because it will be sticky. So, it will create lot of problems when we want to take fly ash from that particular storage units.

So, for a information you should know that fly ash is stored in silos like how we store a cement in silos. So, the moisture content and other things can actually play a critical part when it comes to handling and storage. Now the second one is while mixing placing and compacting some more additional precautions have to be taken if you do not take additional precautions, then you may not be able to achieve the desired a performance property that you initially target.

So, some of the problems that comes up whenever you use fly ashes sometimes we tend to excess vibrate the concrete. When you do that and when you find a fly ash in the mixture then it will contain air content issue. Initially you would have said that I am adding this much quantity of air entraining agent to the mixture to get a air total air content of between say 4.5 percentage to 7 percentage, but if you do extra excess vibration then you your air content may decrease. So, so those problems exists when you use a fly ash.

now the other one is checking and adjusting air content during production and maintain air content limit is. So, this air content problem is reported while placing, but many times what happens is the mixture is actually created at the plant. So, at the plant we again have to check one time to see what is a air content of concrete. And the mixture many times have to be transported over longer distances and while transporting usually the truck is in the rota truck usually rotates while it is transiting and those operations can again affect the air content. And once it comes to the placement again the air content could be different. So, from a quality stand quality control stand point it is extremely important that whenever you use fly ash mixtures you have to check the air content at different stages, one during mixing one during placing one during compacting.

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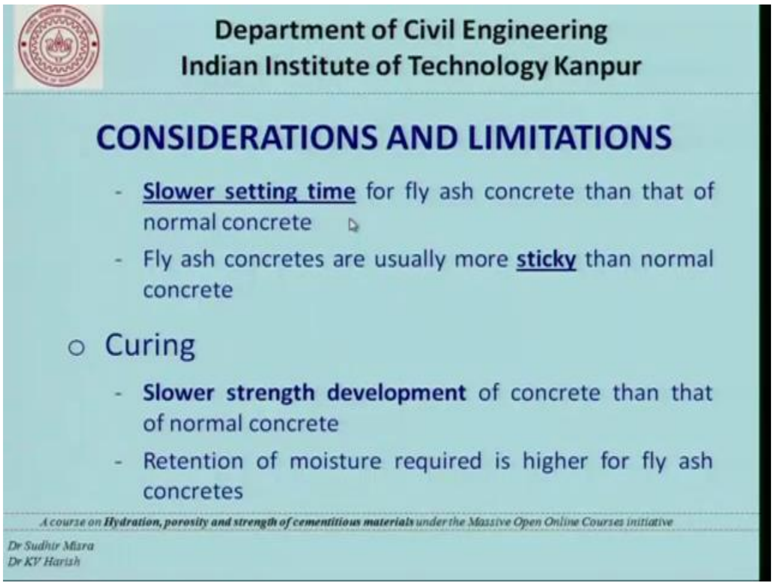

In addition to that other problems such as slow setting time. So, when you use fly ash we have already seen that it increases the setting time. So, and not only that on the other hand it also produces a sticky mixture. So, sometime these scenes create problems while mixing and placing operations.

The third important one is curing. In curing the problem largely is the strength development. So, for fly ash mixtures the strength development is usually slow that we have already seen in in the figure that we discussed here. The strength development is relatively slow compared to the control mixture. So, what happens is the desired strength may not be achieved. If the desired strength can be achieved only if you properly cure fly ash concrete in the case of a normal Portland cement based concrete typically the curing time is 7 to 14 days. That is what is specified in the Indian standard. When you have a fly ash as a as a substitute for cement in Portland cement based paste systems we have to cure it for a longer amount of time for a for making sure that we get the desired strength.

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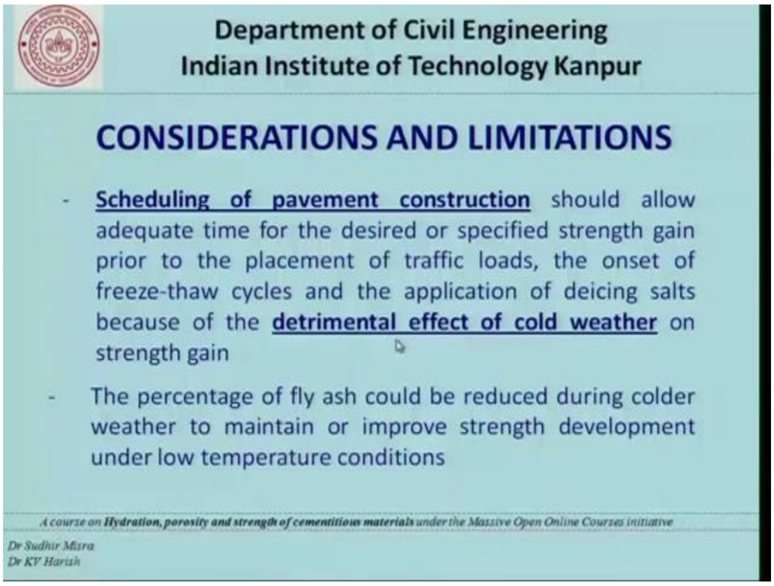

And this curing could be a problematic case not just for normal weathers, but even for cold weathers. So, if you take cold weather the hydration takes place very slowly. So, in that case even the cement hydration a goes very slowly and a such mixtures have very low strength at the early ages say between one day to about 3 day. So, in such cases we need a really higher a strengths and addition of fly ash could is not usually prefer under such circumstances.

Scheduling of pavement construction should allow adequate time for the desired or specified strength gain prior to the placement of traffic loads the onset of freezing freeze thaw cycles and the application of d deicing salts because of the detrimental effect of cold weather on strength gain.

So, there are 3 cases that are shown one is that we want we want the pavement to gain strength as early as possible. So, that it can be exposed to traffic load. Remember that if we want to exposed to traffic loads then the pavement should have gain substantial strength. Because we are using a fly ash and that to we are thinking of using in cold weather the strengths will be lower and such and hence we it becomes a disadvantage to use fly ash for such application. Likewise when we are talking about freeze thaw cycle we need a quick strength at early stages and this also causes problems. Likewise deicing salts just for people who do not know what is deicing salts. Deicing salts are salts which are added in the pavements and largely in airport pavements, primarily to deice the ice that is formed because of the freezing actions. So, because of the freezing actions many times what happens is the airport runways and other pavement structures they get frozen. So, because of that the planes cannot actually land smoothly, because it will skid if you have ice in it. So, for such applications what people basically do is when you have ice formation on pavements engineers typically use deicing salts and that will basically convert the ice into water form. And then you can proceed with whatever operation that has to be carried out. So, even for such situations where we one has to use deicing salts the pavement should be substantially strong enough to resist the expansions because of deicing salts.

So, when it comes to colder environments there are several issues connected with strength gain problems with fly ash based mixtures. The percentage of fly ash could be reduced during cold weather to maintain or improve strength development under low temperature conditions. So, 2 things you have to understand colder temperatures generally you have all these problems. So, if you are trying to use fly ash at a higher dosage levels then we may have to probably not do that we have to reduce the fly ash dosage primarily from the stand point of strength.

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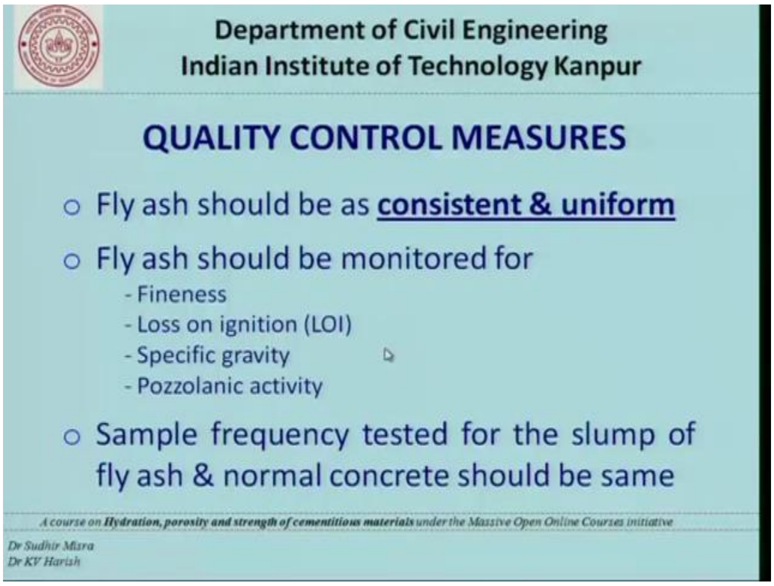

Now, some of the other quality control measures that we have to make sure before using in Portland cement based paste systems or fly ash should be as consistent and uniform as possible in terms of material properties both physical as well as chemical. Fly ash should be monitored for fineness very frequently loss on ignition very frequently specific gravity pozzolanic reactivity and all these things. So, these have to be monitored at regular intervals of time. And the sample frequency that is tested when we say sample frequency we are talking about the number of samples that are tested for fly ash concrete or normal concrete. So, both will be approximately the same primarily because whatever the frequency that is required for normal concrete that much is also required for fly ash; that means, some variability all ways exist when using fly ash and it is for this reason the sample frequency or number of samples tested for slump or any other property should be similar to that of normal concrete.

Now, the next important topic is blended cements for people who are relatively new blended cements or the very different types of cements where fly ash is directly added in the plant either inter ground or blended along with Portland clinker at the plant level itself and then gypsum is added and you get special type of cements called as blended cements. And again in blended cements you could have either Portland pozzolana cement where you have fly ash as one part or you could also have Portland pozzolana cement which is (Refer Time: 96:58) based. So, these are the 2 that are specified by

Indian standards. In addition to these 2 you also have Portland slag cement where slag is used as a ingredient at the plant level.

Now, we for in this lecture we will see only Portland pozzolana cement fly ash. We will see only the specific requirements we will not get into the too many details, but only the physical and chemical requirements and one has to understand how this is different from adding fly ash directly at the sight during application. So, basically there is not much difference between adding fly ash at the sight directly or adding it in the plant the only difference is that if we do it at the plant level, it will be much more consistent and more reliable the variability which will be much more lower all other property will basically remains the same.

So, let us get into some of them.

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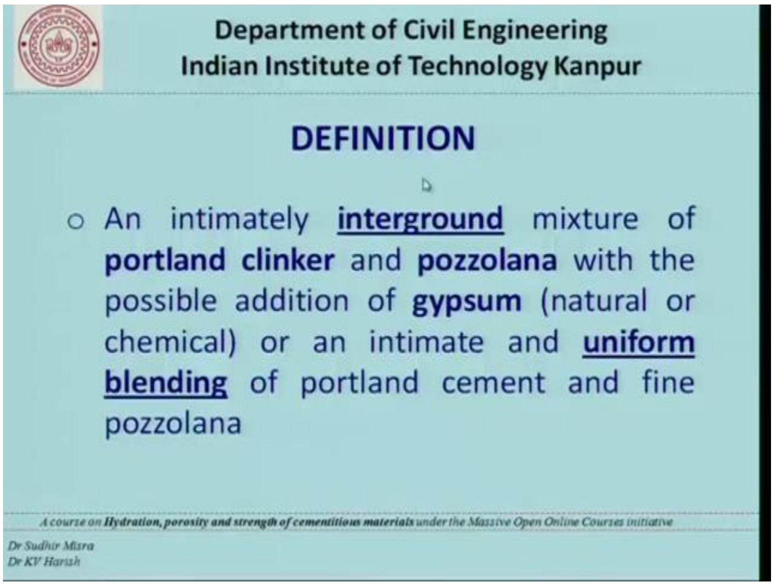

So, the definition of Portland pozzolana cement is defined as follows. And intimately inter ground mixture of Portland clinker and pozzolana with a possible addition of gypsum natural or chemical naturally available gypsum or processed gypsum anything that you can add. Or it is an intimate mixture and uniform blending of Portland cement and fine pozzolana. So, you can do it in 2 ways you can either inter ground in a ball mill along with fly ash and clinker and a gypsum together. Or you can basically mix together and blend it a more accurately. So; that means, by definition it can either be ground or unground. If you do not ground it you have to blend it very be accurately. So, say this accuracy is not usually achieved at the application level that is one of the reason why these things are done at the plant level. Plant level it will be much more you will get much more accuracy when it comes to grinding and blending process.

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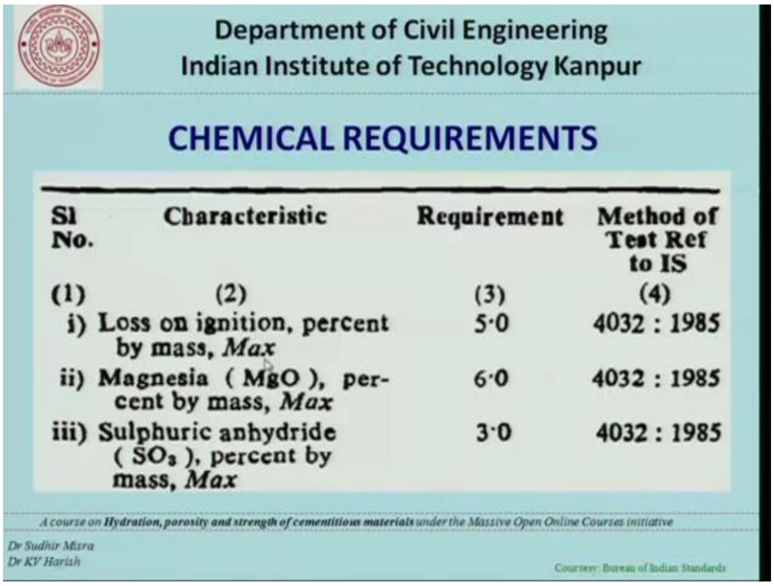

So, the chemical requirements are shown here. So, what you find is that the loss on ignition is mentioned as 5 percentage that is maximum the magnesia content is mentioned maximum as 6 percentage and sulphuric anhydride contain in terms of sulfur trioxide maximum is mentioned as 3 percentage. And remember that all these things are as per 4032. So, these are for a normal Portland cement which is applied the same thing is applied to even Portland pozzolana cement.

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And likewise in terms of physical requirements some of them are directly listed. I will not get in to the details of each one of them for a simple reason that these are directly similar to Portland cement Portland cement or fly ash. So, some of these thing are directly taken. So, fineness values for Portland pozzolana cement should be greater than 300 meter square per kg le chatlier soundness should be lower than 10 mm the same is the specification for even Portland cement based paste systems. And Le-Chatlier expansion should be lower than 0.8 percentage IST should be greater than 30 minutes FST should be lower than 600 minutes drying shrinkage should be lower than or equal to 0.15 percentage. So, all these things are pretty much similar to that of Portland cement

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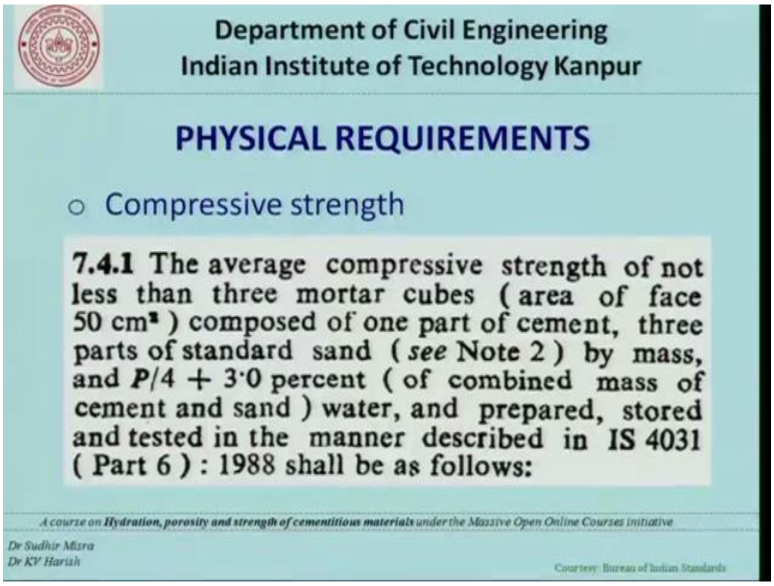

Now, with regard strength with Portland pozzolana cement and we have already seen that addition of fly ash sometimes reduces the strength substantially. Some information is provided for Portland pozzolana cement. So, regarding strength. So, what is stated is shown here the average compressive strength of not less than 3 mortar cubes and area of the each face is 50 centimeter square composed of one part of cement and 3 part of sand by mass and using the water to cement ratio p divided by 4 plus 3 which basically comes from the setting time and other things water consistency and other things and prepared stored and tested in the standard manner should be as follows.

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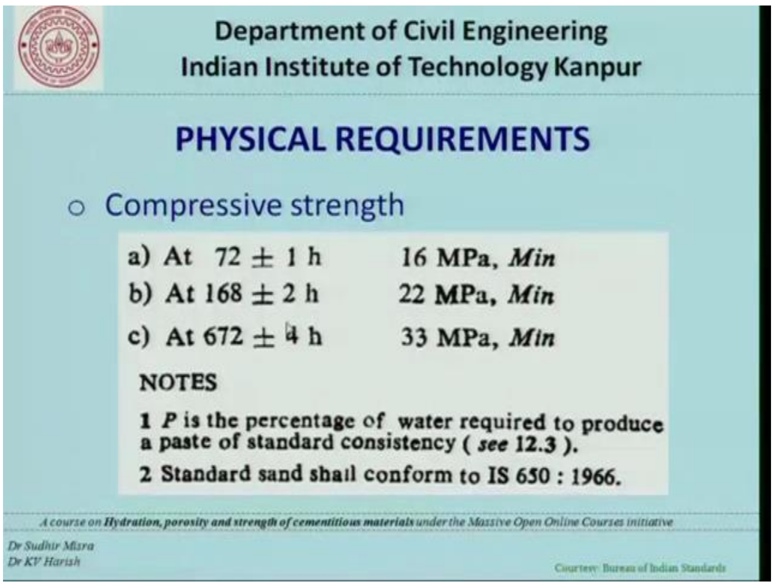

And what is shown is at 72 hours plus or minus one hour the mixture should give 16 MPa at a minimum and likewise at about 1680 plus or minus 2 hours. Remember these are expressed in hours. So, 168 plus or minus 2 hour you have to get at least 22 MPa. Likewise, at 600 and 72 plus or minus 4 hours it should give at least 33 MPa for easy understanding what is suggested is that you please convert these hours to days.

So, that is easier to understand. So, 72 hour is typically 3 days at around 3 days the mixture should give approximately 16 MPa and remember that at a higher periods see about 28 days or. So, typically you should give at a minimum 33 MPa and 33 is the minimum grade of concrete that is specified in Indian standards in the sense that for a particular cement that you used Portland cement recall that we have 33 43 and 53 grade. So, what is said is that whatever may be the mixture that may that may that the Portland pozzolana cement may contain finally, the strength should be at least 33 MPa that is specified for the lowest cement grade which is grade 33.

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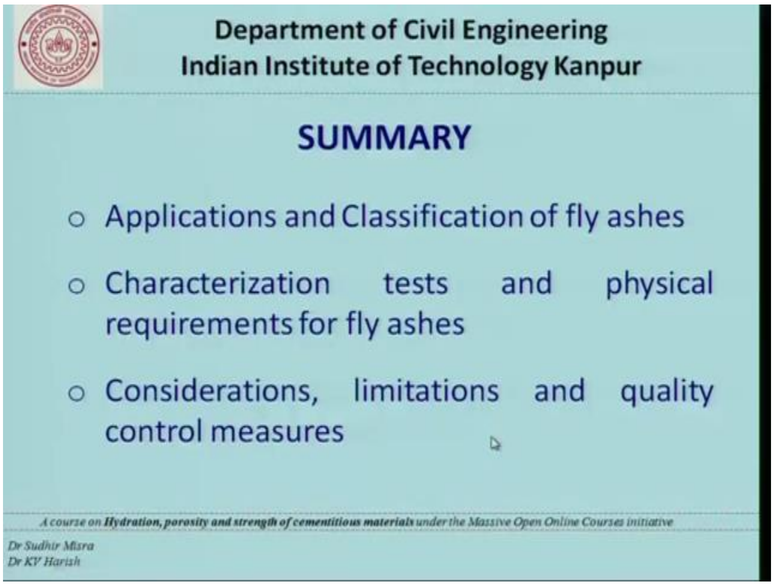

So, in summary what we have seen is all about blended cements and most of the properties which you get from blended cement will be similar to the properties that you get when you add fly ash at the at the application level in Portland cement based paste systems. So, with this we are coming to the end. What we saw is in an in summary what we saw is the applications and classifications of fly ashes, characterization test and physical requirements, considerations limitations and quality control measures when you are using fly ash. With this we are coming to an end with fly ash and in the subsequent lectures we will see silica fume and slag.

Thank you.