Sustainable Materials and Green Buildings
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Lecture: 10-
Cementitious / Supplementary Cementitious materials and their characterization

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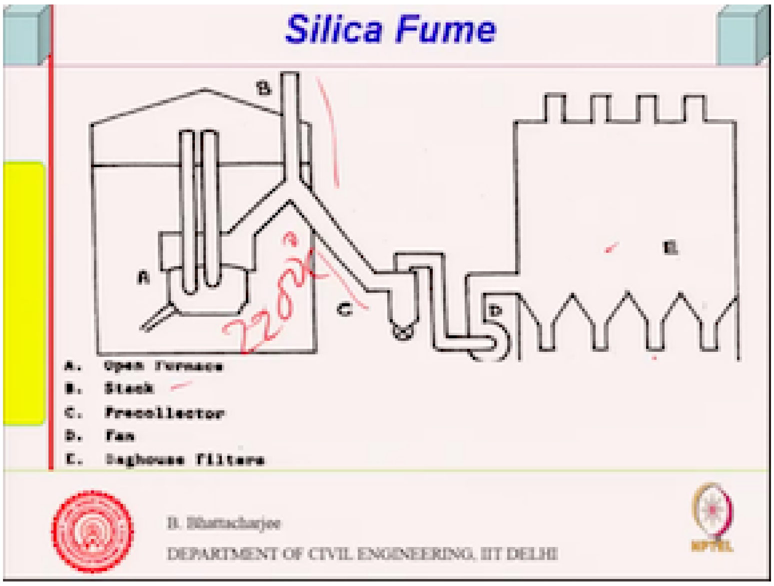

So, followed forms fly ash we have silica fume. Now silica fume as you can see from this diagram, this is the open furnace, this is a stack through which the fume goes out and this is collected ~~here, C~~here. there is a fan right, D is a fan which blows it and here basically the fumes that comes in which condense to ambient temperature is that hot is around 220 ~~C~~ around this degree Celsius and then this is ambient temperature so ease that they are filtered and collected the fine ones are collected so ~~that's~~that is silica fumes.

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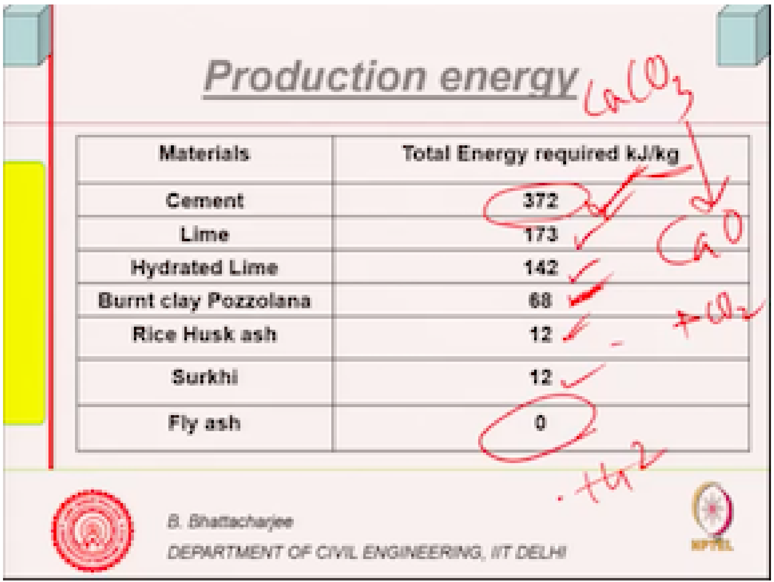

If you look at production energy typically this will be kilo joules per kg ~~you know~~, for 1kg you need 372 total energy required. We have seen earlier 0.142 multiplied by 0.4 and something etc ~~etc~~ but total energy required would be because there are grinding energy, ~~you know~~ there are others that some ~~some some some~~ of the fuel energy is also recovered. Then ~~you know~~ there is many other there is total energy that is one accounts for them then you get something like relatively you can see that this is 372.

If you are producing lime that is calcium oxide from calcium carbonate from calcium carbonate to calcium oxide and actually carbon dioxide. So this would be 173 and hydrated lime of course you add some water 142. Burnt clay pozzolana, rice husk ash because you have to burn them, so you to actually initially heat them up, ignite them etc ~~etc.~~ using some fuel then you get 68 rice husk ash 12 some other burnt cake meta kaolin for example meta kaolin is kaolinite Clay heated up to 600 to 700 degree centigrade, ~~right~~ and then again cooled rapidly.

So, this should need somewhat higher energy rice husk ash is this. Surkhi is product coming from brick clay~~(2:46)~~, ~~clay bricks, you know~~ clay bricks you mould it, heat it, some dust is collected in the bottom, which is again the heated up clay, cooled rapidly. So that also has a little bit something like rice ash husk, fly ash zero,~~0~~ because you are not heating it. No Pros unless you process it use it in a classifier grind it or something you do not~~n't~~ really need very much energy.

So fine fly ash straight away you can use it directly and effectively the amount of energy required is zero~~0~~ so therefore,~~ you know,~~ you can see that whether sustainable like sustainable like fly ash. Generally, these materials are characterized physical characterization and chemical characterization.

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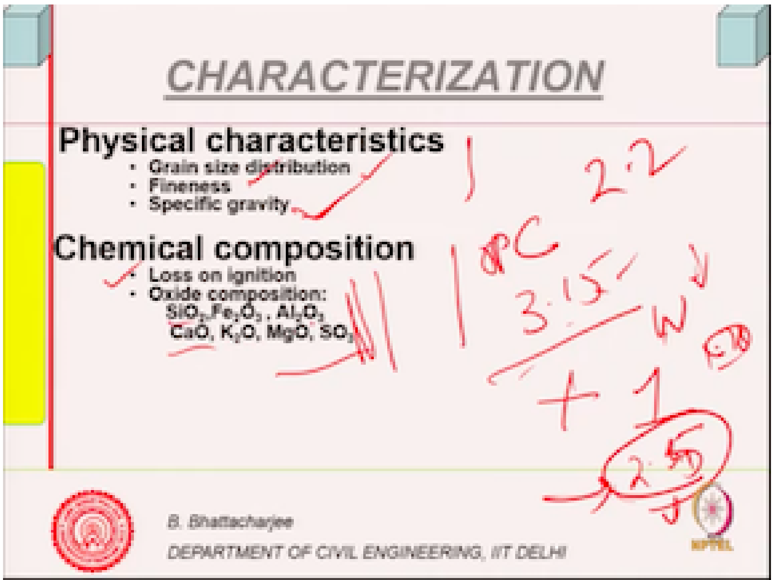

So physical characterization is grain size distribution. These are important particle size distribution. This is important, fineness is very important, ~~fine~~fine it will~~ness to~~ react faster and specific gravity is also important in the sense that specific gravity gives you how much volume because we know the cement specific gravity ordinary

Portland cement clinker specific gravity is around 3.15. A~~a~~nd it reacts with water which specific gravity is, so this is same and OPC OPC.

This is your water and produces a product which might have a specific gravity much lower and therefore this hydration product occupies a space occupied by water. So this would be something of the kind of 2.45, 2.4, 2.49 or 2.5. If you do not~~n't if you know,~~ if~~if~~ you take care, there are two types of force in the cement system, one we called capillary pores, and another is gel pores.

So if you take gel pores the specific gravity would be~~ you know~~ of the, the pores separate around and it will be slightly different. But whatever it is, if you take gel pores also has a part of the solid then this gets reduced because then obviously the air comes in so it becomes 1.78 or something of that kind. So specifically the hydration product is 2.5 ~~, right~~ this is so therefore if this product your pozzolana would have specific gravity of 2.2.

It reacts with water to form your product. So therefore the volume changes are related to this specific gravity. ~~That's~~That is why a specific gravity is important. How much solid volume will have after reaction? Supposing initially it was 2.2 and reacts with water and forms a product of the kind of 2.2 itself then or 2.3 or something it will occupy very little volume. But if it is~~'s~~ specific gravity 3.15 initial volume was much small now reacts with water and final solid specific gravity, lets is 2.5 or something, it will occupy larger space. So it will fill in the larger void space so this is also important, specific gravity is important.

Chemical composition this is loss on ignition actually indicate the carbon content and the carbon is not very good in the sense that they are flaky their absorb water and ~~that's~~that is there are problem with them,~~ you know,~~ and that oxide composition sometime we would like to know because how much calcium oxide how much SiO2 etc we should like to know. Some sulfur dioxide traces also comes in.

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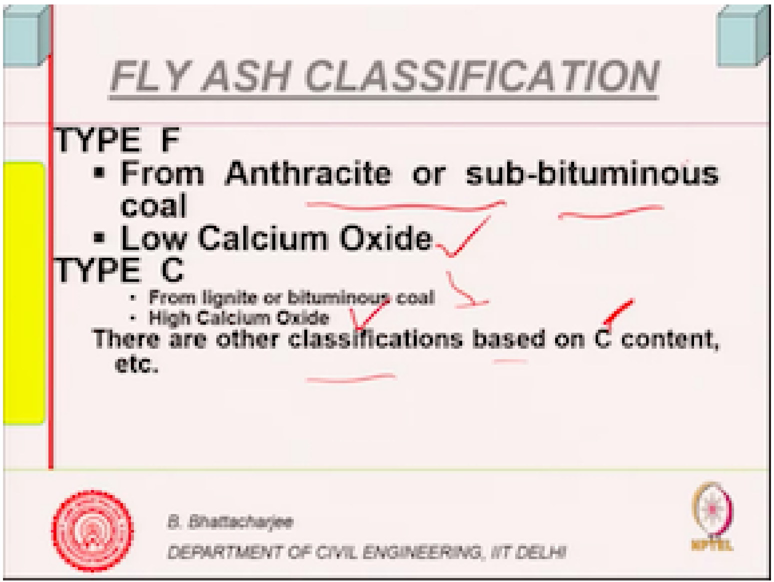

So type F, type C, I was mentioning this comes from anthracite or sub-bituminous coal and this comes from lignite coal,~~ you know,~~ this comes from lignite or bituminous coal, so they the coal they have two types of classification one is lignite coal, other is anthracite or sub-bituminous coal,~~ you know~~ lignite and bituminous or bituminous.

This has got high calcium oxide and this has got low~~s~~ calcium oxide so that is what and their performance is also different with cement system because it has got some lime,~~ right.~~ There are other classification of course several other classification based on carbon content and several others we are not interested, this is the most accepted type of classification.

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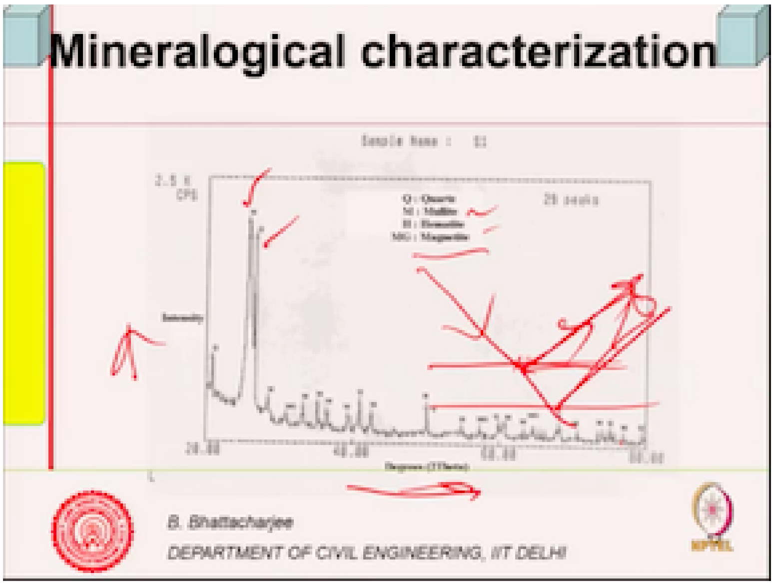

So, if you look at mineralogical classification I mean characterization x-ray diffraction, which is another characterization, then you will find that this is basically for~~ you know~~, you will have in case of different in x-ray diffraction. Basically what we do we find out the distance between,~~ you know~~ it is~~, it's~~ related to the crystal planes.~~ right?~~

Because x-ray as it passes through crystal~~, right.~~ Bragg’s law a coherent source, and this pass from the top there at this it passes from the top layer you have in crystal plane, then they will interfere, constructively or destructively depending upon the path difference between the two this Bragg's law.~~, right?~~

So what is done, specimen is rotated at a different angle you see the intensities and ~~that's~~that is what you are seeing decrease theta and this side is the intensity and ~~you know~~, this is for Mullite, it is~~s~~ one of the crystals, this is for Quartz, this is called hematite, is iron and magnetite is also iron, ~~you know~~, iron oxides.

So this crystals you can see and therefore what is the crystalline material present in the system we can find out, this for fly ash, this for fly ash and this bottom actually tells you how much is amorphous material non-crystalline the peaks indicate crystalline material and no bottom hump shows you how much is amorphous material. Crystalline materials are relatively stable, not necessarily all are stable they might get dissolved, sodium chloride dissolves in water very easily. Therefore reaction will but generally sister and metals are relatively more stable.

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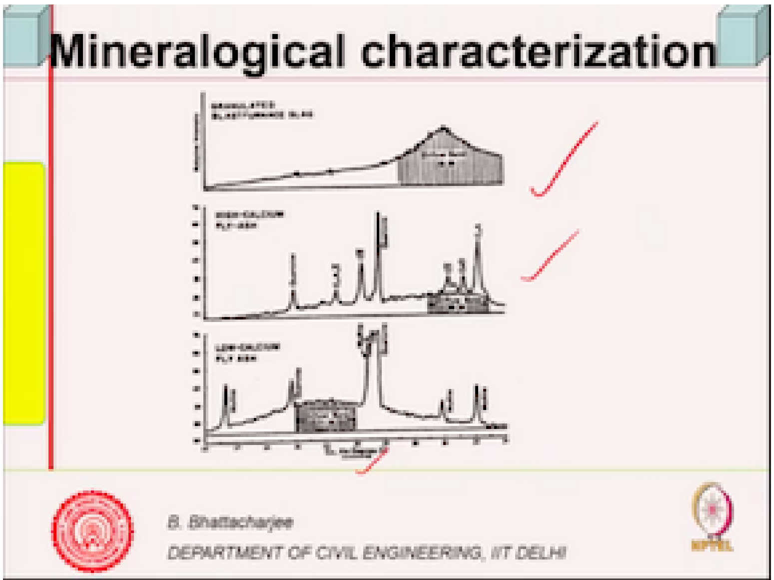

~~Crystalline materials are relatively stable, not necessarily all are stable they might get dissolved, sodium chloride dissolves in water very easily. Therefore reaction will but~~

generally sister and metals are relatively more stable. So if you compare this for generated blast furnace slag you find it is mostly amorphous, there are no peaks. High calcium fly ash is something like this, right and low calcium fly ash is something like this. So, the point that I a'm trying to make is GBF is more GGBFS is general ground granulated blast furnace slag is more amorphous has contains more amorphous material than let us say fly ash, cement has got of course, there are a lot of crystalline material available in cement.

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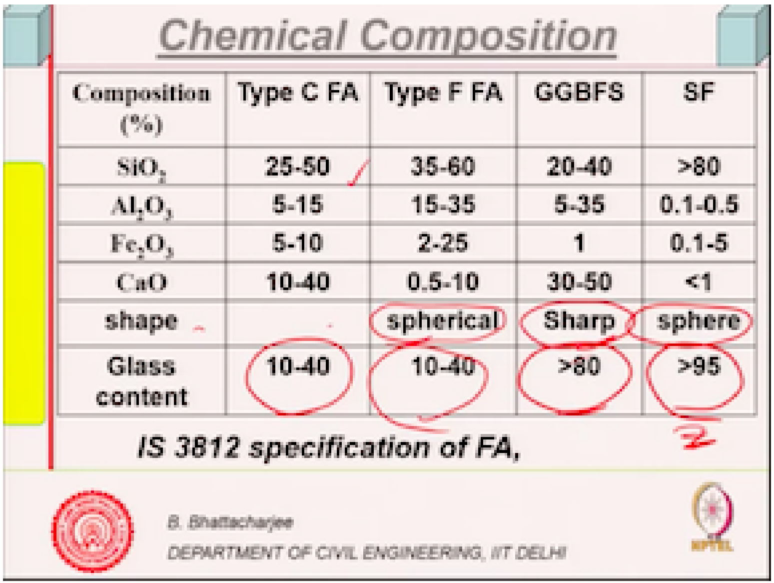

Chemical Composition

Composition (%)	Type C FA	Type F FA	GGBFS	SF
SiO_2	25-50	35-60	20-40	>80
Al_2O_3	5-15	15-35	5-35	0.1-0.5
Fe_2O_3	5-10	2-25	1	0.1-5
CaO	10-40	0.5-10	30-50	<1
shape		spherical	Sharp	sphere
Glass content	10-40	10-40	>80	>95

IS 3812 specification of FA,

Chemical composition wise this I have already said~~ you know~~ this I have already said but what and now I want to say is this shape business shape is also important. T~~t~~ype F fly ash is spherical, type C fly ash is also spherical because they are grinded and burned so when you burn the coal the clay which is there intermingle with the coal system, ~~right? ~~It will burn from all sides and in fact it might bloat and forms what are called ~~sino~~Sino spheres and things like that. So they are spherical in nature because the process of production is such, while ground granulated blast furnace slag because I a~~'~~m grinding it. So when I grind something it will have sharp edges because they will fail in the filler planes. So this is sharp edges while silica fume is very spherical again it is one product.

So glass content means amorphous content 10 ~~in~~to 40 percent, this has got high glass content~~, right.~~ This has~~as~~ got very high glass content again, most of it is amorphous, silica from Quartz has been introduced. S~~s~~o reactivity of this one is very high~~, right.~~ ~~This~~this one has got lesser reactivity compared to this, o~~. O~~f course Indian standard 3812 gives you specification of fly ash, ~~right, ~~so ~~that's~~that is what it is.

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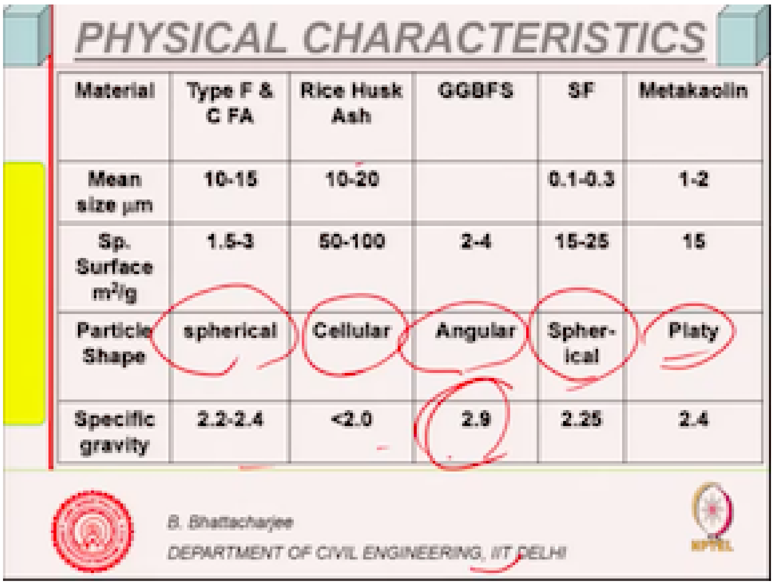

Material	Type F & C FA	Rice Husk Ash	GGBFS	SF	Metakaolin
Mean size μm	10-15	10-20		0.1-0.3	1-2
Sp. Surface m^2/g	1.5-3	50-100	2-4	15-25	15
Particle Shape	spherical	Cellular	Angular	Spher-ical	Platy
Specific gravity	2.2-2.4	<2.0	2.9	2.25	2.4

Physical characteristic if you see I have added now this time rice husk ash also, this is important, it has got highalso clay about 80-85 percent SiO_2 also. Rice husk has also got 80 percent SiO_2 but important issue here is it is cellular, itss shape is cellular, while this was spherical as I told you, this was angular or sharp edges, this is spherical, meta kaolin is platy. So meta-kaolin is a barned clay you know pozzolana, heat it up, kaolinite clay to 600--700 degree centigrade and cool it down rapidly you will get platy specific gravity somewhere here.

Now this has got high specific gravity. The reason is it has got lime, lime has got higher specific gravity than SiO_2 system. So it since it has got larger quantity of lime it tends to show more also there would be iron content might be more. So this adds to the special gravity of this one high.

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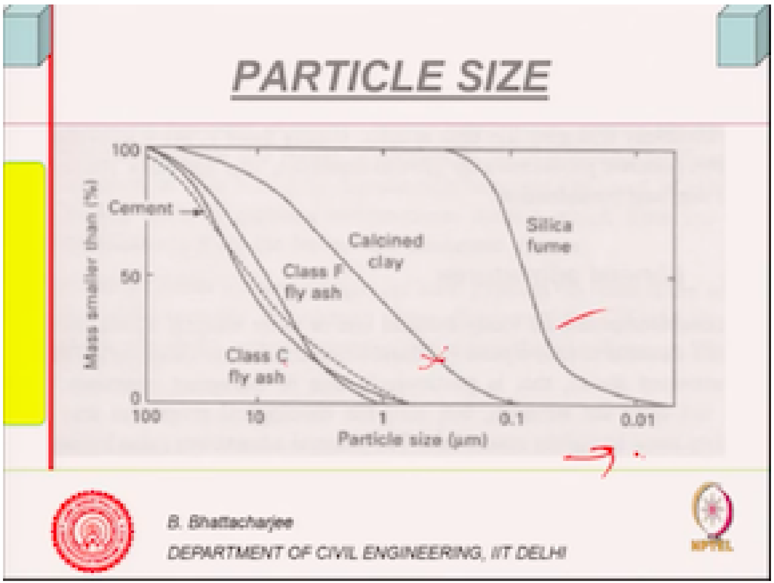

~~Now this has got high specific gravity. The reason is it has got lime, lime has got higher specific gravity than SiO2 system. So it since it has got larger quantity of lime it tends to show more also there would be iron content might be more. So this adds to the special gravity of this one high~~ Aand if you see the particle size distribution silica fume is the finest 01,~~ you know,~~ and cements classifiers are somewhere here calcined clay are like meta kaolin some of them.

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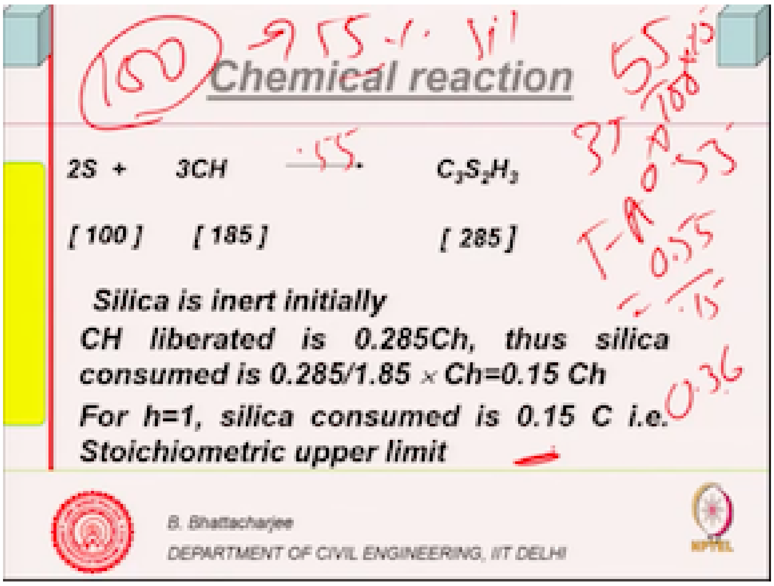

So these are the pozzolanic material, which have been used to reduce down the cement the clinker cement clinker. That'sThat is how it is related to sustainability. Obviously, their addition would not produce carbon dioxide, right, silica fume production, there is no carbon dioxide and quartz I am burning right and I am getting it as a waste product silicon industry or ferrosilicon industry would notn't have known how to use it.

But this is a highly beneficial product for cement concrete because you can make high strength concrete out of it very high strength concrete ultra highultra-high strength concrete out of that, right.

So chemical reaction was this that'sthat whatis what I said 100 of this reacts with 185 of these to produce 285 so, you know calcium hydroxide, so in case of cement in case of cement if you are doing liberated calcium hydroxide you can show is around 2.

Bbecause we know that 100 grams of C3S produces 49 grams of lime, you know from stoichiometry of cement reaction we know that C3S reacts with water whatever 6 H2O or whatever it is to produce about 49 grams of calcium hydroxide. -

So it is 100 grams this around 21;-22 grams and for 49 grams of calcium hydroxide CH plus how much it would be 75 or so 76 or 75.~~, you know,~~

S~~s~~o this is might be 21 or 22, 75 grams of CHS, but 49 grams of calcium hydroxide, ~~right~~ and C2S the other compound major compound in cement which produces lime 100 grams of this reacts with about 24 grams of water H2O if I may call it 24 again, it produces around 22 grams of lime.

It produces lesser lime, nearly half as that one, so~~, so~~ I know if by composition of the cement is known. How much is a C3S, how much is a C2S? ~~which~~Which I can calculate out from oxide composition. ~~,~~ C~~c~~alcium oxide, silicon oxide how much it is, I can calculate out or measure it better through various kinds of techniques, like even x-ray diffraction, etc. ~~etc.~~

Calculation is done by an empirical formula called (14:08) formula. I a~~'~~m not interested in this. I a~~'~~m not interested in your class about that, but you can calculate out but this we know that cement produces lime. So, therefore how much CH is liberated from the unit mass of cement that is known. So it is around 0.285, ~~you know,~~ sorry this point this is around 0.285 and one can actually calculate out how much, ~~you know~~ how much lime is ~~you know~~ how much silicate can how much lime will be consumed in ~~you know~~ how much maximum lime I can consume for silica, how much silica I can consume for, ~~you know~~, like 1.85 grams of lime produces a 100 grams of silica.

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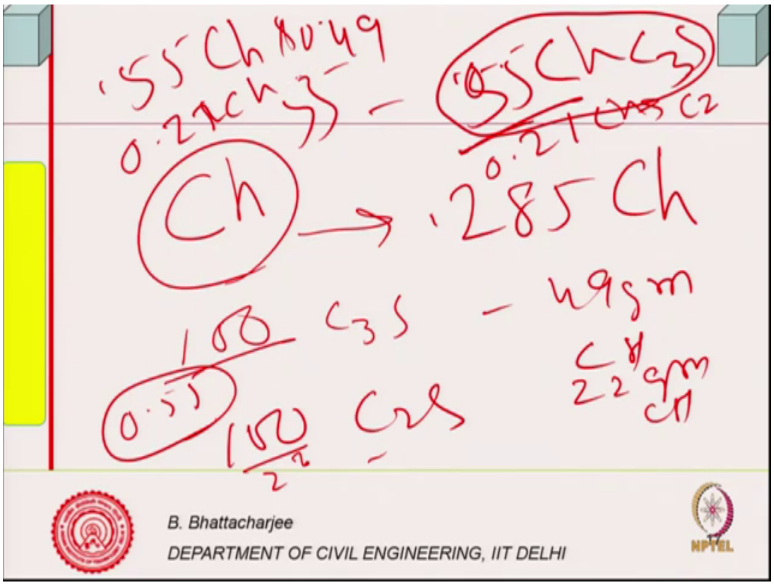

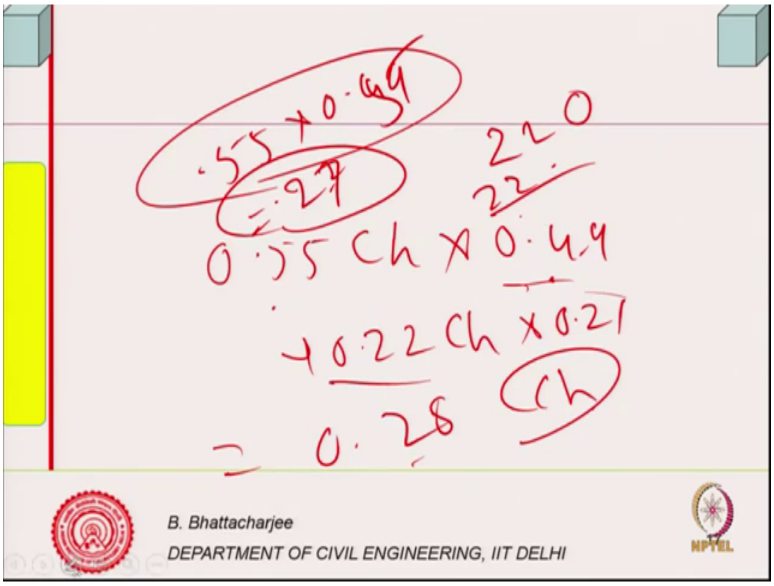

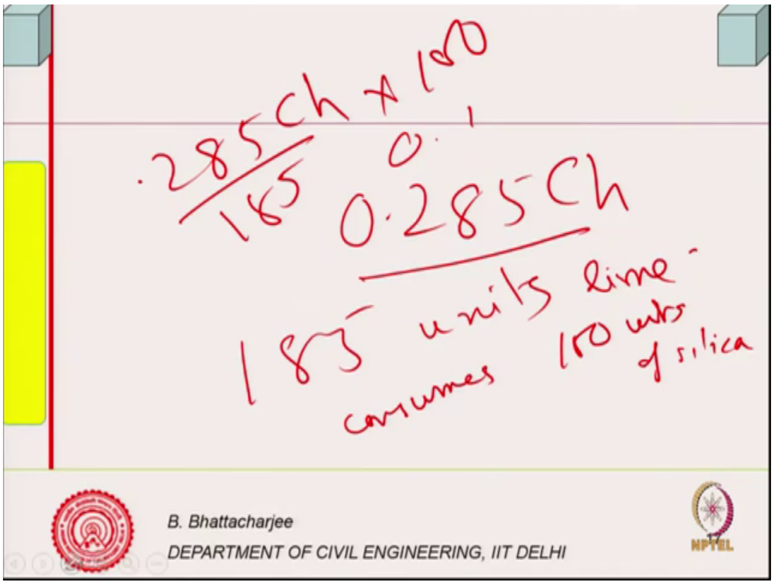

So, if I am producing 2.85 CH, C stands for quantity of cement H is this degree of hydration, proportion that has reacted is H. So, if C amount of cement which is reacted ~~I~~ from cement if CHS.~~take C amount of cement I take that means C amount of cement I take it would you know and it proportion that as hydride reacted is H.~~

So CH ~~CH~~ is amount of cement which is reacted from cement if C is CH is a cement CH is a amount of cement which has reacted it will produce 285 CH~~H~~ amount of amount of lime that I can find out from stoichiometry of cement reaction because I said a 100 grams of C3S produces 49 grams of lime CH~~H~~ and 100 grams of C2S produces 22,~~ you know,~~ approximately 21 or 22 grams of CH~~H~~ I think it is 21 or 22 does not~~n't~~ matter but in cement this will be around 55 percent and this will be around 20-~~-~~21 percent. ~~Right?~~

So therefore if I take a 100 grams of cement I will have about 55 grams of CH~~H~~ and about 20 grams of 21 grams of C2S and a 100 grams of C3S producers 49 grams of lime, 100 grams of C2S produces 22 grams of lime, so 55 grams of lime will if you take 100 grams of cement if I take C grams of cement or C kg of cement then I can find out so C means if I take C kg of cement is 0.55 C will be 0.55 C will be C3S, 0.21 C would be C2S,~~ right,~~ am I right? A~~a~~nd this produces CH~~H~~ has reacted so point C,~~ you know,~~ this is and this also is CH~~H,~~ this much as reacted and we know 185 grams of~~ you know~~, like a sorry first of all, so this should be multiplied by 0.49 this should be multiplied by 0.22 because~~ you know~~, ~~a~~ 100 grams of C3S produces 49 grams of lime.

So if this is my C3S 0.55~~55 ~~Ch~~H~~ this multiplied by 0.49 would be the amount of amount of lime produced and if this is 0.2~~22~~1 ~~C~~C~~C~~h~~H~~ and this producers multiplied by 0.22, so let us~~'s~~ just look at the quick calculation part of it 0.55 CH~~H~~ multiplied by 0.49 plus 0.22 approximately this a multiplied by 0.21. L~~l~~et us say if you sum this up how much does it come? I~~i~~t will come to somewhere around, somewhere around 0.2 something.~~, right.~~ 0.2 this will be 0.24 or 285 or something of that kind,~~ you know, that's~~that is what we said.

So, approximately those amount of so CH~~H~~ I can actually find out how much 285 my calculation showed would it be nearly same may be some error here and there so it will be nearly same so basically No, no 0.55 into 0.4, 0.5 into 0.4 is how much? Ya 0.2 this will be 0.29 so 0.55 into 0.49 how much is this or lesser 0.5. Let me put it as this so this will come out as 0.27 ~~ right ~~roughly, 0.27 it comes it comes out 0.27, which 0.27 amount is small 0.2 into 0.2 is 0.4, 0.2 into 0.24 is 0.4.

So this is this is 0.27 no, 0.55 into 0.5 let us say half of 0.55 roughly 0.27. So it comes out to 0.285 around that~~ you know~~, because my values have just offense telling you so it will come out to be this.

~~That's~~That is what s~~S~~o the amount of li~~a~~me produces lime produced will be 0.285 CH~~H~~. I mean some near about values and 185 units of lime units of lime consumes ~~consumes~~ 100 units of silica. So this 0.285 CH~~H~~ divided by 185 into 100 will be the amount of silica consumed will be the amount of silica consumed. How much does it come to, I~~i~~t comes to how much does it come to~~ you know~~ this how much does it come to actually how much does it come to? I~~i~~f I~~ if I~~ 0.15 or so, ~~right? That's~~that ~~what~~is what I was trying to say.

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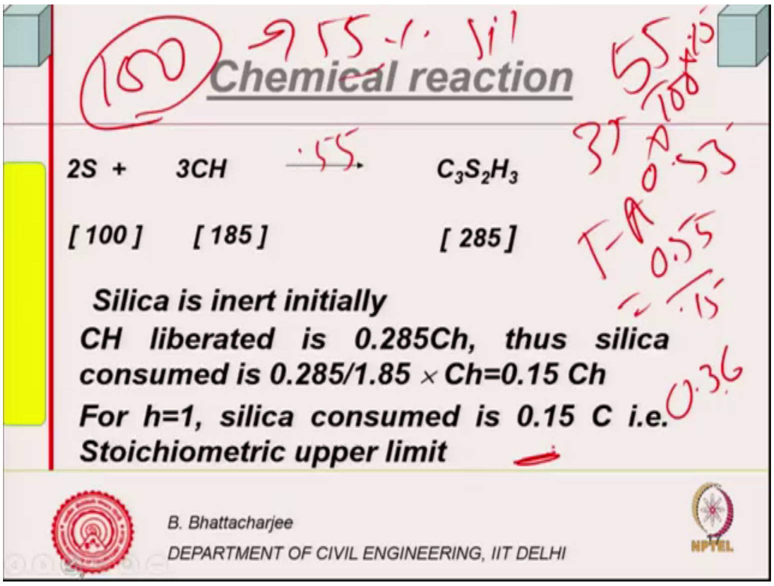

So, therefore this says that this says that you will have 0.15 CHH silica consume silica consumed. So silica consumed is 0.15 CHH 0.15 CHH 0.15 CH is a silica consumed right? So, if you have C supposing now all cement reacts then the value of H is 1, value of H -is 1 so how much is the maximum silica that will be consumed? 0.15 C. So only 15 percent of the you know 15 percent of the cement that will be the quantity of silica maximum silica that can be consumed if you had more silica than that. Some of them will remain unreacted right? Some of them will react remain unreacted right?

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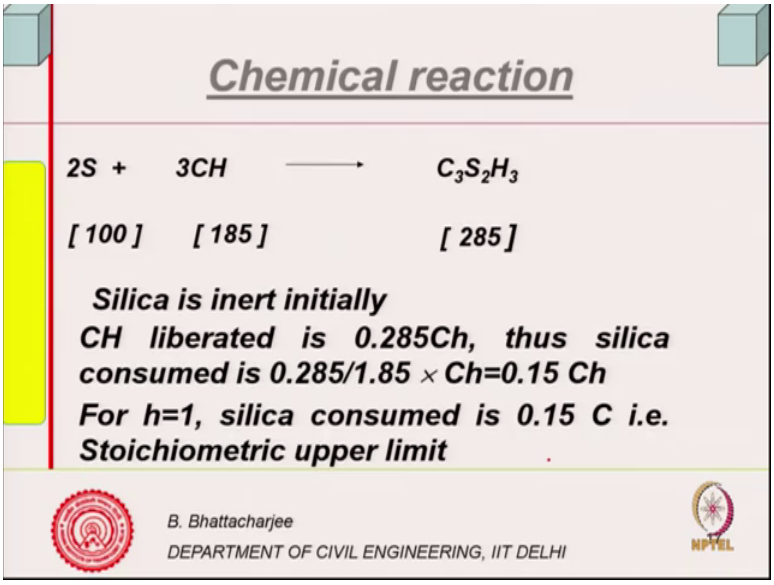

So for H equals to 1 0.15 C that is stoichiometric upper limit of silica consumption structure metric upper limit of silica consumption, right? So if you are using fly ash, which has got around 55 percent silica, right? So, you know 55 percent silica. So that is fly ash how much to quantity of fly ash because fly ash quantity would be 0.55 divided by 0.15, right because 15 percent right? So, 15 percent, that is the if I have so this will be how much about how much is this? 0.15- somethingSomething like this will be how much 0.3 something, 0.36 0.36 or something. yeah, something like that.

So supposing I have got 55 percent silica in the fly ash I can add about 35 percent fly ash because 35.35, 35 percent silica 35 silica will have something like 0.15, you know, something like want you know, this this is the point is 15 percent is still you know, 15 percent will be sorry sorry, if I take if I take 35 percent its 55 percent is 0.55 is the amount of silica 35 is 55 percent will be amount of silica, right and or 35 or 36 whatever it is. And that is the maximum that can be consumed.

Bbecause 0.15 I think I might have made some mistake somewhere 0.15 I would want to find out the so, a 100 fly ash contains let us say 55 percent silica, right and yeah so 55 percent silica so so 0.55 silica in one unit of fly ash and in how much you need of fly ash I will have 0.15 you know 0.15 silica. That'sThat is what I should find out that is the quantity of proportion of the cement that you can use.

So 155 by 100 into 0.15 I think that'sthat is what it should be. How much does it come to know? Is it correct? Hmm? Yeah so 27 so 27 is a amount of fly ash if you add you will get 0.15 fly ash, you know silica which can react with 100 cement which can react with 100, you know 100 even that'sthat is what I a'm trying to say.

So these are stoichiometric upper limit of fly ash that can be added to or pozzolana or silica that could be added. If you are adding silica fume, which has got 90 percent silica, you can add only about 15-20 percent slightly. I mean as as good as 15, in fact, it is 's best to add only 10 percent of silica fume, 10 to not more than 15 percent because it is rich in silica. Everything is silica. So if you add more it doesn't go into the reaction system it will remain as unreacted product, sometimes it is beneficial, so that is it.

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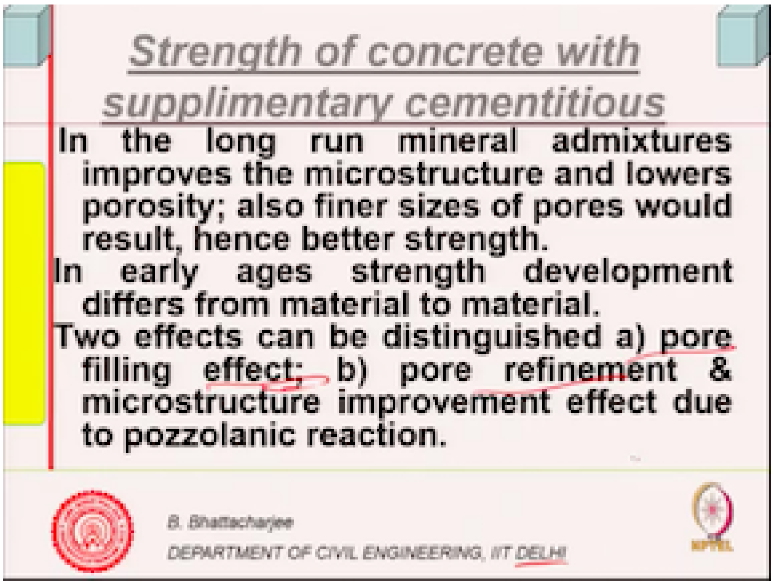

So if you add more it doesn't go into the reaction system it will remain as unreacted product, sometimes it is beneficial, so that's it. But one issue with this kind of materials when you add to the cement to reduce your improve your sustainability they improve the microstructure in the long run, but their strength development is somewhat slower except for silica fume, right and the lower the porosity and finer size pores would result hence better strength to get in the long run but initial strength is not high because what you have done is you have actually replaced some percentage of the OPC by fly ash.

So it will have now OPC 70 percent let us say plus fly ash 30 percent, so this will initially react this does not react till the calcium hydroxide comes out from this. For its reaction I need calcium hydroxide cement is C3S C2H etc, only when it reacts it produces calcium hydroxide and this calcium hydroxide then can react. So first my cement must react then fly ash will react.

So it is you noticed in instantaneously it is not going to react while cement reacts to relatively more instantaneously. The next aspect is even this reaction of pozzolanic reaction of S Plus CH in presence of water to CSH, this is a slow process. This is a slow process. So therefore the moment you had some percentage of fly ash into your system of cement the reaction rate is slower. It does not~~n't doesn't~~ but that reaction is slower is fine, but it does not~~n't~~ affect~~have like~~ the solidification part which we call setting in concrete science will call it setting~~ setting~~ is solidification, hardening is strength gain, hardening is strength gain, ~~right~~ hardening is strength gain.

So the moment you dilute out the OPC reduce the OPC strength gain hardening process slows down, setting is marginally affected but significantly not affected does not~~n't~~ affect negatively to the system. So ~~that's~~that is what we are ~~'re~~ trying to look at how do all this material effect. So in the real long run, it improves but later on the fly ash starts reacting and the water filled space, which was there originally, originally occupied by calcium hydroxide now gets occupied by the CHS product and this improves the microstructure this improves up microstructure.

So calcium hydroxide is replaced by CHS because silica fume are not silica fume, fly ash or similar sort of thing pozzolana will react but the thing is that calcium hydroxide CH has got a specific gravity of around 2.2 something fly ash has also got specific gravity of the same, product is also of the similar specific gravity, you do not~~n't~~ find it does not~~n't~~ occupy more volume only same space which has occupied by calcium hydroxide and silica the product also occupies the same space because of specifically features are similar, but this is a non-~~-~~ceiling precipitate.

It is precipitate it can dissolve and come out. ~~right?~~ So leaching can occur this can leach out but when it forms this together with this now, it is~~'s~~ a solid product solid product and it will not leach out easily. It will get destroyed in the long run. If you have calcium carbon dioxide from ~~atrose~~ atmosphere coming and carbonation occurring in the long run, ~~you know~~ billion years so or thousand years at least it would take a very long time inside the concrete to go and things like that.

So what we see is early ~~only~~ a strength development differs from material to material. They do not~~n't~~ show high early strength for filling effects of what some of them can feel the poor because strength this is a function of porosity and pore sizes. ~~Okay,~~ W~~w~~e may look into something like this in this class or may not, it might have to do some time, but we may not also but we have seen that we know from concrete science, ~~you know~~ strength is a function of porosity as well as pores sizes.

This is our day to day experience also, you take a porous material it breaks easily and if you take as a bricklayer or a single large hole, but same break with all the holes distributed all over the place. You will find that the one with the larger hole can be broken much easily. So strength is a function of porosity and pore size and it can be explained from fracture if it is fracture concepts, but at the moment I am not interested.

So if the pore sizes are if you reduced by pore filling effect and they are in between they are bound by hydration product they are not lose then they can also show you strength improvement inert material supposing inert material has gone into the pores and bounded by binding material then reduce also pores. So this is for filling effect and some for refinement means size reduction and reduction in the porosity. So this is this is what happens with pozzolanic material for journaling materials.

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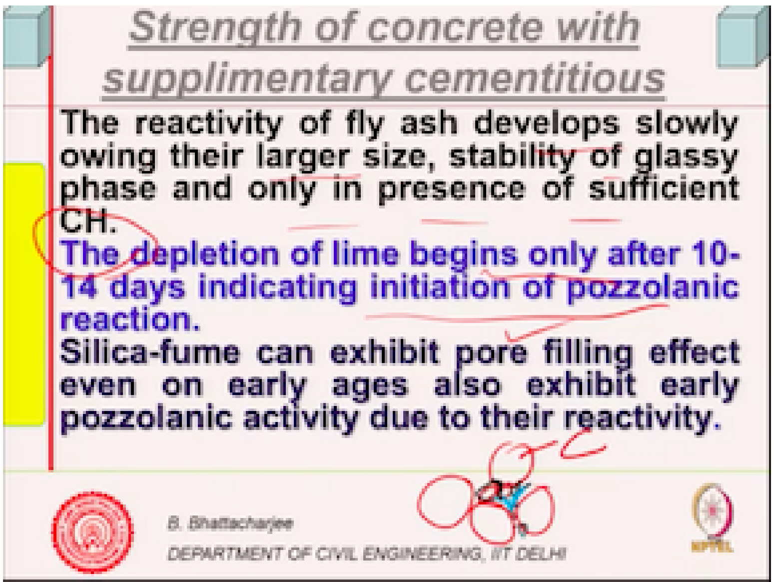

So reactivity of Fly ash develop slowly going to larger size. They are relatively larger size 5 to 150 micron compared to silica fume which is 1 to 5 micron and stability of glassy phase only in presence of sufficient CH. So only in presence of sufficient CH, they will actually react the depletion of lime begins only after 10 to 14 days and indicating initiation of pozzolanic reaction.

So pozzolanic reaction occurs later silica fume can exhibit more pore filling effect, ~~right~~ because very fine so it goes into the interstices of the cement itself. So this this is your C silica fume silica fume might go inside silica fume might go inside this So silica fume is the same color coming almost, no ~~no~~ I want this ~~colour~~color black. Yeah, silica fume might go into the interstices of the cement itself. It is so fine finer the cement ~~that's~~that is why you have seen particle size distribution.

We are now looking at it is on to the right ~~right~~ hand side, so it goes into the instances of a cement itself and if the cement is hydrating ~~right~~ in the beginning hydration products of cements are coming straight away. Let us say hydration production of cement is coming somewhere here. They will be already inside those hydration product system ~~right~~ hydration products system, ~~right?~~ So ~~that's~~that is what ~~that's~~that is what it is.

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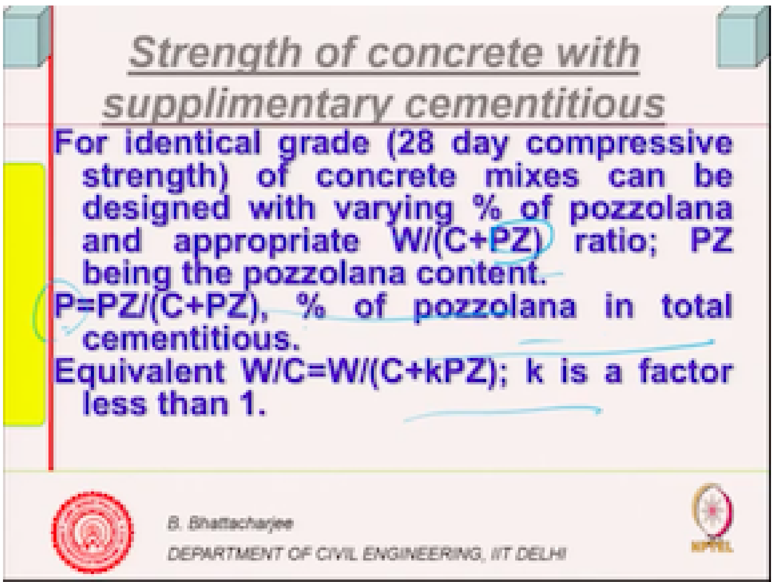

So they give you pore filling effect. They give you pore filling effect and therefore they can show somewhat high early strength also so high early strength also so for identical grade it has been seen that 28 days compressive strength of concrete mixes can be designed with very varying percentage of pozzolana with appropriate water to C plus pozzolana. What are two pozzo cement plus pozzolana ratio and pz being pozzolana content.

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So it is~~'s you know~~, it is~~'s~~ a percentage of pozzolana in Pz. We defined as the percentage of pozzolana in total cement and we can talk in terms of equivalent, ~~you know~~ water to cementitious ratio is equal it so I can design now, why did I say 28~~0~~ days strength because character, ~~you know~~, wee ~~we~~ take the strength of concrete at the age of 28~~0~~ days for structural design purposes.

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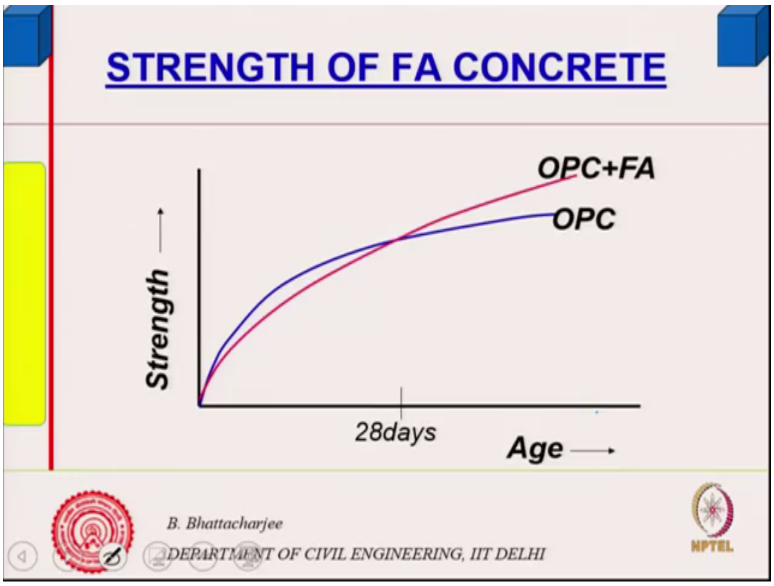

So 28 days strength is taken so I can design system as design system here so the 28 days strength is same for OPC plus fly ash and OPC somewhere here, but initial strength will be lower, it can be lower this gain strength, but later on I can have highest strength.

So this materials can be used GGBFS behave similar. So next class we look into GGBFS another material of the similar kind and all the purpose of this one is to cut down on the OPC clinker because you seen OPC is the major cuts in the cement concrete scenario after fossil fuel. It is the major culprit for carbon generation carbon dioxide generation, right? Soso we will'll take a half a minute. If you have some questions you can answer, otherwise, we'll start from here in the next class.