Building Materials and Construction
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Module - 4
Lecture - 2
Cement and Cementitious material

Today, the lecture 2 of module 4; we shall be discussing cement and cementitious material. In the last lecture, we discussed about cement and its hydration. Today, we look into some of the other material as well.

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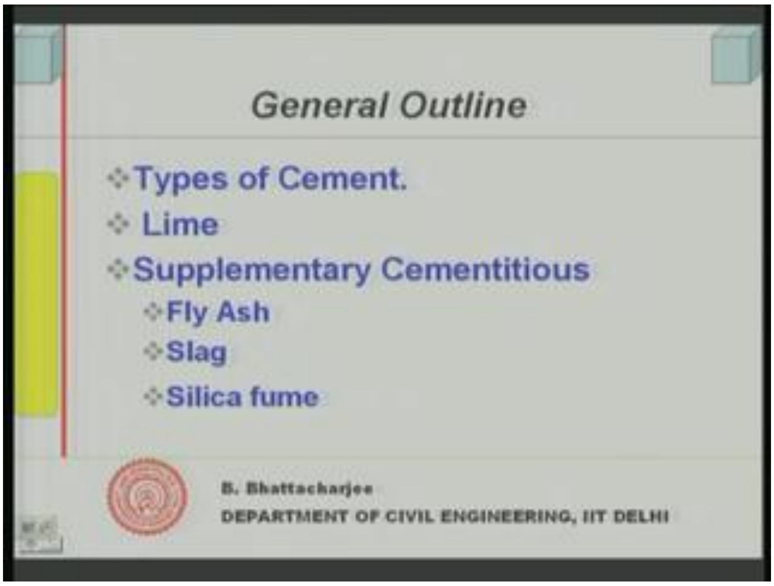

So, general outline of the talk would be types of cement, there because various types of cement are possible, we only talked about ordinary Portland cement yesterday. Then we will just mention about lime and then look into supplementary as supplementary Cementitious material such as fly ash, slag, silica fume etcetera. There are several others, we will discuss mainly this 3, all the mention few right.

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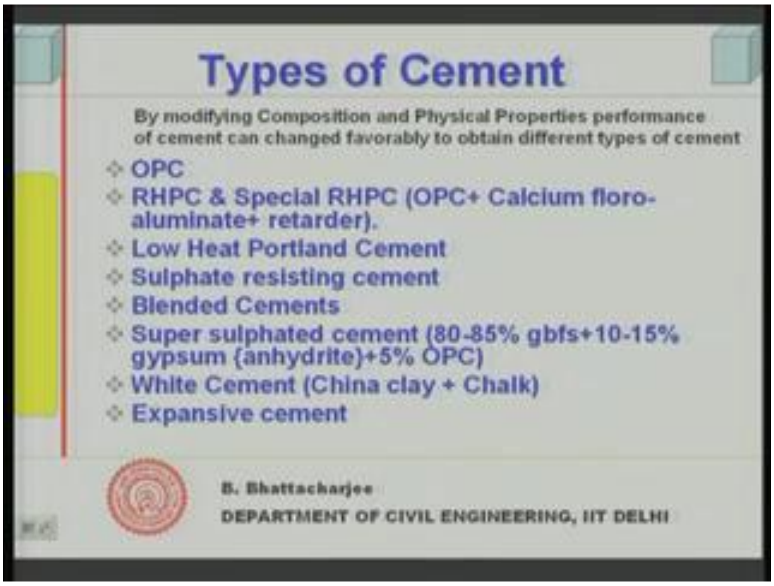

So, let us look at the types of cement right. So, what we discussed yesterday was ordinary Portland cement. And we have also seen that various compounds of the cement namely c 3 s c 2 s c 3 a; they have different roles. For example, c 3 s gives early strength whereas; c 2 s gives long term strength, c 3 a on the other hand increases the heat of hydration and susceptibly to sulphate attack in long run.

Now, therefore, by modifying the composition of the cement and also by modifying their physical properties, performance of cement can be changed favorably to obtain different types of cement. Let us see how do we get them. So, OPC we have discussed and we have also seen; what is a rough composition in terms of oxides or in terms of compounds in them. Then this next important class of cement or type of cement is RHPC.

RHPC stands for rapid hardening cement; it stands for rapid hardening cement; Portland cement. So, if you see that it must harden rapidly. That means if I want high early strength, this cement I am going to use and how can I do that? Well the chemical way of first chemical way would be to increase c 3 s because; c 3 s gives the high early strength. And the physical way would be grind it to a finer particle sizes, because finer the particle sizes its reactivity will increase, it will react at a faster rate, because reaction of cement is through its surface. So, if we increase the surface area reaction rate will be faster.

So, in case of rapid hardening cement, setting characteristic will remain same, but I want its strength development to be early which we can of course, get by some other means also, like steam curing I mentioned yesterday. But if I want to get it through cement, it will be rapid hardening cement. So, in this cement c 3 s content is generally more, its fineness is more it is grinded to a finer more, you know a finer particle sizes right.

Now there can be varied rapid hardening cement or special rapid hardening cement something like jet cement. A jet cement is 1 which will actually harden very quickly, even setting time may be relatively small; less than 30 minutes some time, 1 to 30 minutes can be there, but they are specifically used for used for repair purposes. And this specific cement jet cement is produced with OPC plus calcium fluro aluminate and some sort of retarder such as citric acid. So, this is a special cement.

So, there could be special cements which you require let us say in a airport runway; you cannot stop the traffic, immediately want to repair it, you would require very fats hardening cement and jet cement or you know special RHPC of various kind they can be the solutions there. Why do you use otherwise simple RHPC, where I want high early strength development. Say for example, as I mentioned yesterday, if I want to release the mould very quickly, then I have to use high I used rapid hardening cement.

So, this is 1 type of cement commonly used, where I want quick strength of course, I can also use steam curing together with that to get still high as well. So, this is 1 of the solutions right. So, this is 1 type of cement. Low heat Portland cement; now remember you know if you are increasing the reaction rate; heat of hydration will be higher. So, rapid hardening cement RHPC will have high heat of hydration. So, 1 must remember this right.

But all places I cannot if I know all structures cannot tolerate high temperature or high initial high heat of hydration, development of high temperature in the early stages or rate of hydration rate of you know heat of hydration, should be relatively less in some sort of structures, particularly in mass concrete in massive structures why, because in mass concrete where you are doing a bulk of concrete, something like a dam let us say gravity dam, where the thickness is very large.

Now, here what will happen; heat of hydration if it is high, then it will not be dissipated fully, because it gets dissipated only through the surface. So, what happens; surface becomes cooler and inside remains still warmer, because all heat has not been dissipated, lot of heat of hydration came rate of hydration was pretty high, it immediately in the beginning itself came lot of heat and this hard heat is if not dissipated it will remain stored inside.

So, outside when it is cooled what will happen; the outer surface it will actually shrink, but inside still being relatively hotter would not shrink, resulting in a restrain to the shrinkage of the surface, what does it mean? The bottom is warmer not trying to not shrinking, but top is trying to shrink and this may result in cracking at the surface anyway. So, that is why heat of hydration has to be controlled in some particular structures. And there you use low heat Portland cement.

Then what should we do; low heat Portland cement surely would have lesser of c 3, a lesser of c 3 s will have less grinding, the opposite of the previous 1. Of course there are other means of getting low heat cement also we will see later on, but essentially it will have less it should have less rate of reaction in the beginning and therefore, c 3 s you reduce down, increase c 2 s, also reduce down c 3 a c 3 a and should not be grind to a high level.

Sulphate resisting cement; now this sulphate resisting cements are used in places where sulphate is a problem; let us say ground water contaminated with sodium sulphate or any other sulphate. We will discuss about some time later on about the sulphate attack, but 1 I have mentioned yesterday in the last lecture that, sulphate attack c 3 a tri calcium aluminate, it reacts with sulphate gypsum which is calcium sulphate forming ettringite and which expands in volume. This volume expansion causes cracking of concrete, because in a hardened concrete if something is tried to expand, it will essentially mean that is actually causing disruption of the cracking of the concrete. So, because it is time to expand it has got no space to expand. So, that is why sulphate attack the component in the cement, the compound component in the cement that is responsible for that helps in sulphate attack is c 3 a.

So, we actually reduce down the c 3 a content to make it sulphate resistant. So, sulphate resistant cement is of 1 which has got less c 3 a. Then we have got this class of new class of materials or cements, they are called blended cements. So, these blended cements are cement OPC cement blended with pozzolana. We will come to this pozzolana when you talk about supplementary Cementitious material, may be 1 pozzolana can be more. So, you can blend the cement with some other material, which are helpful which are supplementary Cementitious material, like cement fly ash is a pozzolanic cement, you know OPC PPC pozzolana Portland cement like OPC ordinary Portland cement, Portland pozzolana cement is a blended cement, where fly ash may be the blending material. Somewhere you can have slack cement, blast furnace slack cement. So, that is again slack blend blending and so on.

So, therefore, we can blend and we will understand its action when we look into the supplementary Cementitious material more. Now, this blending does 2 things: 1 it reduces down the clinker use of clinker which means, sustainability increases lesser carbon dioxide efficient to atmosphere. So, you are using the cement judiciously. It will be cheaper also, if the ash for example, is available with very little transportation cost, so it can even be cheaper. And they have some positive effects in terms of concrete properties.

So, blended cement are the other class of cement which are going to which are there. And it is very likely that in future, because of the sustainability environmental sustainability, you know concern of energy and so on, this cement is likely to be more and more is likely to be more and more popular than any other cement of course, every cement has got its specific use. This is a special class of cement called super sulphated cement; about 80 to 85 percent ground granulated blast furnace slag mixed with 10 to 15 percent of gypsum anhydride is called dead burned gypsum and 5 percent of OPC and grinded together.

So, you see it has got large amount of slag; blast furnace slag GBFS ground, you know granulated blast furnace slag and this granulated blast furnace slag plus 10 to 15 percent of gypsum. So, gypsum and slag together is this formed. So, this 1 this because it is you know it is already gypsum is already there in the system and this 1 is highly sulphate resistant. So, this is a special cement used for high sulphate resistant area, where you have high sulphate content.

Now interestingly sulphate resisting cement which I mentioned earlier is not good in case of sea water. Sea water also contains sulphate, both calcium sulphate and magnesium sulphate, but it also contains chloride. So, where sulphate and chloride are present together, sulphate resisting cement is not so good and just by reducing c 3 a content you do not get a proper cement. But, super sulphated cement gives you adequate protection against both sulphate attack as well as chloride ingress and corrosion etcetera, reinforcement corrosion. Chloride or sea water attack 1 of the major problem is of course,, not directly attack on to the concrete, but attack on to the reinforcement inside corrosion rusting or steam. So, this cement is good for both this purpose, so very high durability of the cement.

White cement; you know for aesthetic purpose this is a cement. In this production there should be no trace of iron oxide, because that is what gives colors. So, therefore, what is used china clay and chalk. I mean 1 combination could be china clay which is white colored clay and chalk calcium carbonate very little oxides iron oxides in this; it should not be contaminated with such oxides which will give color. So, it is a little bit costly. Or other pigmenting as it can be added to give color to the cement.

Expansive cement; which expands normally cement will shrinks. So, supposing you want to fill in a grout hole some hole you are made or in repair works, you have made some hole you want to fill, old concrete is already there you have made a hole. And now you want to fill it with something. Now this should be done with expansive cements or shrinkage compensating formulation. Now this uses again gypsum and c 3 a in a fresh state, in a soft state, in a plastic state they cause expansion. Therefore, they compensate for shrinkages.

So, these are some of those types of cement. There can be several other cements possible, which I have not discussed, but main types are here. Let us what happens to their strength characteristic in the next slide.

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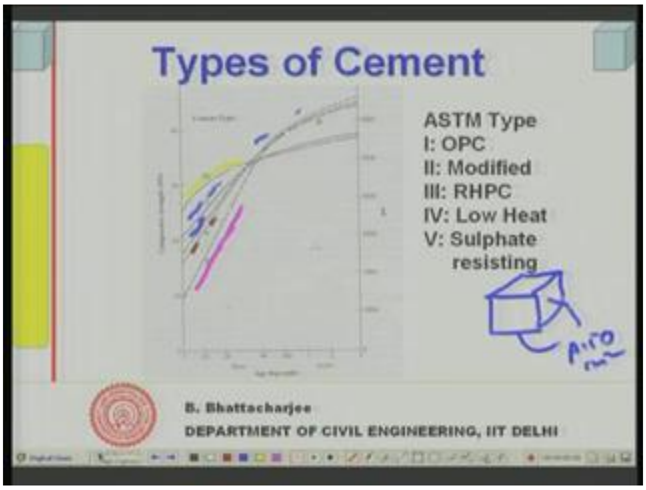

Now this is from this is as per the American society of testing material classification, you know the IS 450 IS 269 is the code, we have code for cements and cements are 3 grades in Indian situation; 43 grade 33 grade and 53 grade, 33 grade 43 grade and 53 grade. 33 grade is 1 which attains 28 days strength of 33 MPa. 43 grade is 1 which attains 43 MPa 28 days strength and 53 grade of cement is 1 which actually attains 53 MPa strength on 28 days, when you test the cement in the standard manner. Now how do you test? You test the cement making cement mortar cube of 50 centimeter square base area.

So, what you do is you make cubes with a base area 50 centimeter squares. So, area of the base or any area, all this area equals to 50 centimeter square. So, you actually make cement sand mortar cube 50 centimeter square base area. And then crush it under load in a standard manner. That is how strength of cement is measured. Now strength is a standard, then amount of water you add is also standardized in terms of standard consistency I mentioned earlier, which will give you right kind of flow. Standard consistency you will make it a uniform consistent mix and give a right kind of flow as well.

So, that is what is standard, you know the amount of water that would be added is related to standard consistency. And you test this cube in a standard manner, at standard rate of loading. So, preparation is standardized, curing is standardized, vibration everything is standardized, the sand that you are using is standardized except for the cement. So, therefore, this gives you the relative measure of the strength of the cement, you know how good it would be when used in concrete, it is a relative measure you can they are absolute. I mean it is not possibly very wise to relate concrete strength directly to cement strength although it is sometimes done, but it definitely a relative measure of you know which cement is better than the other from strength point of view.

So, we have 3 grades of cement 33 43 and 53. 33 grade of cement is 1 which gives you 33 MPa strength at 28 days age when tested in the standard manner. The standard mortar cube is tested in standard manner. This is 1 is to 3 cement sand mortar cube and sand is again standard. So, everything is standardized except the cement particle. 43 grade is 1 which 43 MPa on 28 days at testing. When you test at 28 days under specific rate of loading, everything is specified. So, that is are the 3 type.

And this corresponds to type 1 cement is the OPC cement as far as American society of testing material is concerned. We too have rapid hardening cement, we have low heat, we have to rapid hardening cement, sulphate resisting cement and also we have Portland pozzolana cement Portland slag cement. These are there on an Indian standard code, Indian standard codes are there all those. But very popularly all over the world, this ASTM type 1 type 2 type 3 type 4 and type 5 are used together, with other types IP etcetera, which I think I'll not go into details of this.

But just to the point that I wanted to mention is the composite strength of cement, when you get from different cement types right; you can see that, type 1 which is a Portland cement is here. Type 1 is here you know its strength development is here type 1. Type 2 is modified, which is somewhat you know low between low heat and OPC. So, it does not gain strength very as good as OPC, but slightly less it, but it has got less heat of hydration.

So, we can see the type 2 would follow, you know type 2 is very close to this type 2 is here, type 1 is this type 2 is here. And type 3 is nothing but rapid hardening cement, so RHPC. Type 4 is the low heat cement. So, type 4 is the low heat cement and type 5 is sulphate resisting cement and type 5 is sulphate resisting cement is here. So, we can see that, rapid hardening cement although it gives you very high early strength relatively higher early strength, but on some days where on 90 or so its strength actually start is lower than the other cements.

OPC of course, is better than rapid hardening cement; it will have you know much strength than anything else right. And then low heat cement that low heat cement on the other hand, type 4 shows low strength in the beginning. But in the long run it shows higher slope. So, this diagram shows you how the strength development takes place. Now you can understand the same thing. How do you get rapid hardening cement? We get it by grinding, the mould and increasing c 3 s reducing the c 2 s.

So, what we do; we actually increase the high strength, but when we are reducing the c 2 s long term strength would be relatively less. So, if you increase c 3 s you get high early strength alright, but long term strength will be affected. If you grind it more, rate of reaction will increase in the beginning, but what about the final? Final situation is ultimately it will it is not going to affect.

So, final strength is lower in case of rapid hardening cement. So, you get initially high strength at the cost of long term strength and that is what we have seen in other cases also. When we use steam curing you get high early strength, but in the long term you do not get strength. So, if you want to get very high strength early, it will affect the long term strength. So, cannot have both together high early strength it is not easy to get that. So, that is the point and that is how it is. And in case you want reduce down rate of the reaction, well in the long run there will be uniform structure and you will have much higher strength at your end right.

So, that is what the type of the cement the various types of cement and their strength development is concerned. If you look at the durability or other issues, setting characteristics by enlarge should not change. Setting characteristics of all this cement should remain same; that means, I must have at least 30 minutes available for placing my concrete, because initial setting time is related to placing concrete. I can disturb the concrete within that period of time, without actually disturbing its final properties. So, we re-mould, mould and revive things I things like that, you know you can do that, actually vibrate it or handle it during that period of time.

So, initial setting time I need a minimum 30 minutes during which I will handle the concrete place and compact. Now this is more or less same for all the types of cement. And final setting time also should not be more than 10 hours because; I have to remove the mould after that. So, the maximum limit is this. So, by enlarging should remain for this, but we must understand if I want to take out the bottom support from the shuttering, low heat cement would require longer period of time. You know shuttering support to the shuttering or the bottom shuttering of a slag let us say. So, we kept for longer period of time if you have low heat cement. So, where you have reduce down the rate of reaction, all this issues comes here.

And 1 has to take a judicious decision at the moment of you know planning design as well as at the site, when you are using what kind of cement you know depending upon the type of cement. We have also seen that, this are this might have some effect on the curing, because the 1 which has got less lower rate of load rate of strength development, may require slightly higher curing. Long term durability; obviously, would be better of the low heat type, because where it will have an much uniform structure compared to this,, but then this is 1 can design system even with RHPC durability situations and you have to take care of it, design it you know by design you have to take care it, not by default that by design you can take care of this alright. So, this is this is something about the type of cement.

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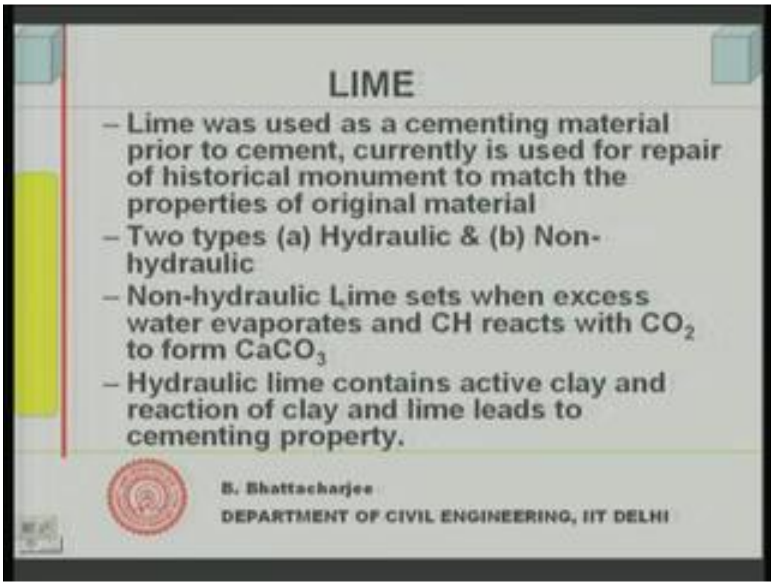

Now, let us look at a another material lime a little bit. This was historically this was used very much, I would have mentioned it earlier that, all the monuments all over the world actually used lime in some form or other. Either the hydraulic lime together with clay using what is known as pozzolanic reaction or the lime which is non hydraulic lime. So, this material was historically used, all the monuments all over the world used this material. And of course, cement came and replaced material very much, because cement is much more versatile, much higher, quickly you can get the strength. There are many more things can happen with cement which is not possible with lime.

But still lime is used for repair of historical monuments to match the properties of original material, because originally lime might have been used and that is why it is right. 2 types of limes as I said hydraulic and non hydraulic lime, so this is hydraulic lime non hydraulic lime. Now non hydraulic sets when excess water evaporates from them. What is the mechanism of non hydraulic lime? Actually it is calcium hydroxide. You know it will be calcium hydroxide and then when excess water gets evaporated from CH, the CH will react with carbon dioxide to form calcium carbonate. And this is a solid hard material. So, it should take long time to actually long time to harden, but this will harden to this.

So, non hydraulic lime sets and evaporates to give you this. So, this was also used in past in historical monuments this non hydraulic lime. Hydraulic lime on the other hand, it contains active clay nothing but silicon. And reaction of clay with lime leads to cementing property. This has been used very largely lime and surky in India. Lime and surky is similar sort of thing, surky is nothing but the dust that you get below, brick in a clink. You burn the brick in a clink and below that the dust find that those is surky. So, lime surky or similar material has been use in past very much.

So, this is how lime is used, but right now of course, it is very much used in all sorts of all heritage structures, because originally limes were used and you must replace them by the same material without changing much, because they can create all kind of incompatibility if you are using in different or modern material without understanding its property of course, not that 100 percent, but preferably it should be whatever the material used also from aesthetic and other point of views. Same material must be used to replace and that is why lime finds it unique. But more importantly, lime has a role although it is not added, but lime has a role in the supplementary Cementitious material.

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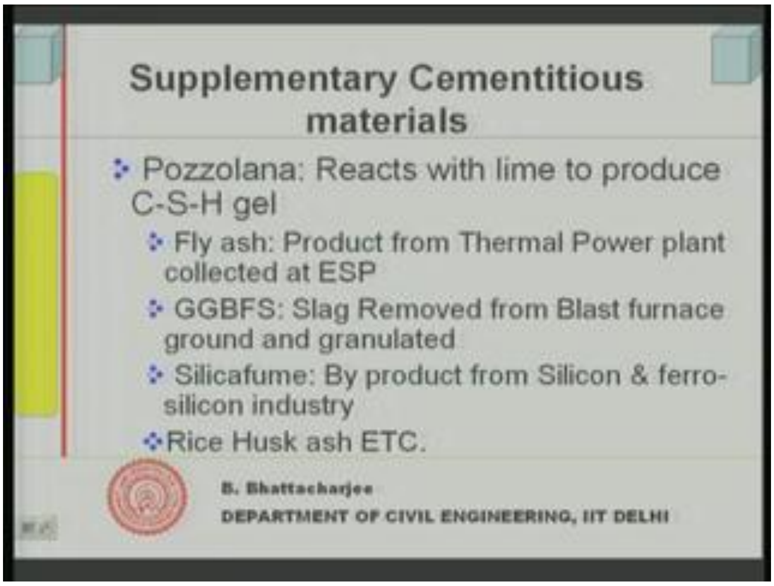

There are supplementary Cementitious material we are now talking of they are mainly the pozzolana. This pozzolanas are nothing the name it derives from the volcanic ash.

Now, this volcanic ash in Italy evaporates actually you see there is an interesting thing, this is also clay, this also clay silica, clay is clay consist of silica alumina. So, volcanic ash you know when eruption from volcano takes place, the ashes come comes out of it, actually they are they are heated up, the clay is heated up to a high temperature. And the fine ash will come first flying in the heavier ones; obviously, will come with the lava right, the molten material without the molten material.

But the fine ones dust type very fine ones come out into this time as smoke or dust and they get deposited all over. Now this when at a you know very heated up clay suddenly exposed to the atmosphere, air temperature which is much lower. They get rapidly cool in the process actually you know you have heated it up heated up the clay. So, it structure has changed and suddenly you are pulling it, the structure that is formed that has some amount of energy or heat locked into it.

So, its chemical potential is higher than the crystalline silica, quartz for example, they are crystalline silica and this is not reactive, where as the surky I mentioned earlier or volcanic ash they are reactive. They there are certain amount of reaction capability, they can react, but they do not react with water directly, what they do is they react with lime, because silica can react with lime and they form similar sort of material as C S H gel what cement produce. You see in case of cement, we are actually adding lime and silica before burning and they were burning them together. In this case, the reactive lime and reactive silica you know they are reacting later.

So, this reaction is called pozzolanic reaction. So, originally the volcanic ash the name comes from volcanic ash, this shows its characteristic, but there are modern other many other materials, which are actually sort of earlier would have been, 1 would have caused the waste product 1 would call them by products like fly ash which is generated by thermal power plant or for that matter, the slack the blast furnace slag. Or even some other slag copper slags that has been attempted, but not as popular. Some other material as meta kaolin, rice husk ash it has to be processed, silica fume which it comes from ferrosilicon industry.

There are several other products, which have similar sort of property, because they have also silica and silica which can react. Which silica can react? The 1 which has been possibly very fine relatively fine and which is not crystalline, which is amorphous usually and actually you know usually once you have heated it up it has been exposed to atmosphere for a short period of time. So, it could not dissipate all its energy, short timing you know years in terms of years, not in terms of million years. Silica is there it in earth crust in abundant and know mostly the silica do not react; only active silica or active clay can react. So, that is what it is.

So, this are pozzolanic material, which you can, which can react and essentially they are amorphous in nature by and large, there will some crystalline component in them, but it is an amorphous 1 which is responsible for reaction and this can react with lime producing similar sort of thing, as the cement produces with water. So, lime, water and pozzolana can gives you same C S H gel. Similar sort thing which happen, which you will find after cement is added to water right, but only thing is this reaction is relatively slow and generates much less heat of hydration obviously.

So, it is an advantage, but the disadvantage is of course, is relatively slow reaction. So, 1 of them I have mentioned is a fly ash. Fly ash is product of thermal power plant, it comes out comes a product from thermal power plant, you know it comes out from thermal power plant. And it is collected in electrostatic precipitate. So, what happens; thermal power plant will have coal coming from the mines, may be vast if you want to reduce the clay content of the coal. But usually the coal coming out from the mines have lot of clay in them. This clay comes together with the coal and this is grinded before burning to fine powders, the coal itself in a whole thing, only large ones which you cannot grind they are called mill eject. They are thrown out for the rest of the material is burnt.

So, when you burn at about 1800 degree centigrade at so a coal goes a carbon part of it gets converted into carbon dioxide. And other oxides will be coming out together like sulphur dioxide and so on, some may be even Mn O 2 and small small quantities, they will be there. But what about the Si O 2 which has also been grinded together with the coal the clay, the clay part of it which was there as an impurity in the coal mine coal and then it has been grinded together. So, this will also get heated up, but this will is already oxidized. So, Si O 2, Al 2 O 3, Fe 2 O 3 etcetera, all these material they are solid particles, the finer ones tend to come out with the flu gas. The heavier ones of course, goes to the bottom and we call them as bottom ash. That is not much about concern at the moment, although they can also be used in various ways.

But the fly ash is what is of our concern at the moment, we trust in you know with reference to cement system. This fly ash which comes out with flu gas, you know flies away is collected at, because they are charges particles. So, they can be collected in electrostatic precipitate ESPs, as they are called ESP. So, they can be collected in ESP; electrostatic precipitators which charged plates, where this charge particle will get collected. And they are collected from this hopper, ESP hoppers ESP hoppers and possibly should be handled dried by enlarge handled by dry condition pneumatically and stored in shadows for future use.

So, this is a material which is again clay, because clay is the impurity that was present in coal and this clay burn together gives you fly ash. There are types of fly ash c and f type; there are 2 types as per again American society of testing material ASTM classification. American society of testing material; that is called ASTM classification c and f, c is the 1 which has got relatively higher lime content and f is 1 which has got less lime content. It depends upon source of the coal; anthracite coal or lignite coal, it will depend upon 1 a, it will any way, that we will I think we have to stop the discussion at the moment not too much.

But we understand 1 thing for the time being that, fly ash a product from thermal power plant is a pozzolana. And it shows similar reaction; that means it reacts with lime, because it is a clay heated and then suddenly cooled exposed to the atmosphere. The fly, the flu gas is you know it was hot at 1800 degree centigrade, suddenly it has been exposed to air which is at about 25or 30 degree centigrade and then it rapidly cools. But while rapidly cooling it cannot get crystallized to into stable structure. So, its unstable structure which can react, certain amount of chemical potential or chemical, you know some amount of energy is locked which is available as chemical potential.

So, it can react with lime to form the C S H gel like product. So, this is 1 of the pozzolana, most commonly used is this, which is most commonly used is this. And then we have other main pozzolana, which is also very commonly used is ground granulated blast furnace slag. Now, this you know in blast furnace for iron, iron ore or iron or iron ore also contains impurity clay, because ore does not you know the clay is the abundant material in the earth crust. So, it will have Si O 2 etcetera, all these clay minerals Al 2 O 3 mixed up with the iron ore.

So, to separate that what you do; you actually add up lime in the blast furnace and this lime forms a kind of slag which floats about the iron or you know the molten iron and molten iron is taken from the bottom from the top molten iron is removed from the bottom. And the top this material, molten material of lime and silica etcetera is taken up. So, this is what forms slag, you know which is removed which is taken out from the blast furnace right, it is removed from that.

So, this slag when it is granulated made into granules and grinded, that is GGBFS. Now again since clay was the impurity and you added lime to remove them this will have some amount of clay and eventually it will have some amount of lime as well. We shall see the chemical composition in little detail a little bit later. So, it will have some amount of lime as well as some amount of lime means; calcium oxide C in our chemistry notation right, this and this. All this materials will also be there; in this 1 in the slag and this material is a same oxide as that of those of cements.

So, there this can, it will add water this does not react, but it reacts in presence of an activator. If you have some sort of an activator this has got similar oxides. So, although the proportions of the oxides are different, they do not react it does not readily react with water to form something like harden stone as the cement does. But if you have add an activator to this, this can actually give you Cementitious behavior and it can behave like a cement. Since the proportion of the Si O 2 is quite large in this compared to Ca O, there is certain amount of excess Si O 2 available and which can act as pozzolana.

So, GGBFS is a supplementary Cementitious material, which comes out from the blast furnace slag, it can be cementitous with an activator, but otherwise if you add lime to it; obviously, the pozzolanic reaction will get. But interestingly if you add cement to this part of the cement you know it take cement and mix some slag to this, the slag is getting gets activated by the cement itself, because cements have got certain amount of alkalis; sodium and potassium oxides ,the gypsum etcetera, which can act as activator for the slag also.

So, cement slag combination; they can be very useful material. And when as talking of blended cement, you have 1 cement with slag, with OPC some other cement with fly ash with OPC. So, when you have fly ash or similar pozzolanic material mixed up with OPC, we call it Portland pozzolana cement PPC and this is slag cement, you know this is I mean Portland slag cement PSC. This would be if I add some amount of slag to this 1. So, this are 2 kinds of blended cements that we have as mentioned. Well you can have composite cement, made up of not only simply Portland cement and pozzolana. I have all Portland cement and slag, but you can have some amount of Portland cement with fly ash with slag etcetera. So, all possible cement designs are possible and its being its being tried now, composite cements have been tried.

So, this is what the blast furnace slag is the next supplementary Cementitious material. And if I look at the next material by far is very popular for very high strength matrices is this is the silica fume. And this material is the by product from the silicon industry, it is you know its relatively recent than fly ash or GGBFS and this silicon or ferrosilicon industry, were actually to produce the silicon what you do is; you heat up the quartz. And some amount of fumes come out from this process of production of cement, this fume when condensed gives you what is called condensed silica fume. This is very rich in Si O 2, because its only quartz that you are burning know burning and then the fumes that comes out and that you are condensing. It is also called micro silica elementary process micro silica.

So, silica fume is the other by product coming out from silicon or ferrosilicon industry. It is very rich in Si O 2 the silica and this silica again since you have heated it up and cooled it suddenly, you see there are certain amount of chemical energy locked into it and this can react with lime producing same pozzolanic reaction. We will look into the details of this 1. So, these are some; in addition to this I mentioned to you rice husk ash.

So, when your rice after husking, the husk that you get right, this can be burnt and the ash again will contain lot of silica and thus to be processed. And this is another material. Similarly meta kaolin is another material, which is could be pozzolanic. There are other metallic copper slag for example, has been tried, as you know pozzolanic material, because wherever you have that you know you have clay and you are heating it up and then you are cooling it rapidly, this expose to atmosphere and materials are fine that can act as pozzolanic material. Surky I mentioned was a traditional historically used material, coming out of burnt clay bricks.

So, the clay bricks when you burn, in the bottom some dust accumulates very fine dust which is actually nothing but clay heated up to high temperature suddenly cooled down.

And those are so all of them can serve as supplementary, but at the moment the first 3 are the most popular and we will look more into details of this.

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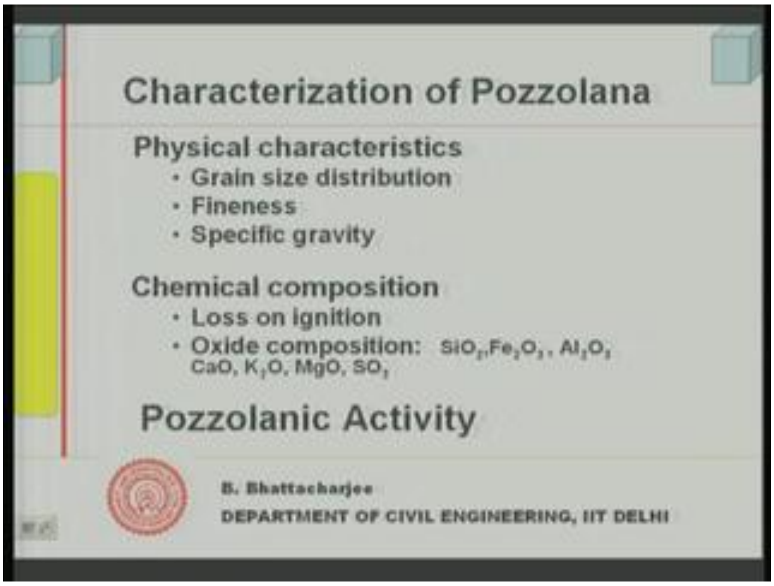

Well, first how do I characterize this pozzolana, I must do some characterization; whether it is really worthwhile to use in concrete or not. 1 thing we do is we find out the grain size distribution, the particle sizes are important, very coarse particle will not act or will not react with cement. So, the grain size distribution and their fineness there are various ways of measuring them, by simple hydrometer analysis used in geotechnical engineering could be 1 of the ways, but use such material which you know use an inert fluid or liquid, where you can hydrometer analysis.

There are modern particle size analyzer based on various principles, through which you can find out particle size or grain size distribution. Fineness is measured like it is measured for cement, 1 of the ways is of course, the blains fineness where specific surface measured. You know you measure actually the specific surface; that is meter square per kg. How much is the specific surface? Surface area of the material for inert mass of the material or in centimeter square per gram meter square per kg, for fly ash minimum should be 180, but it can be much higher.

Similarly, for cement ordinary Portland cement 33 kg it should be 225, but they can be still higher. So, minimum is specified in most of the codes, this fineness is usually measured by blains method. What you do is find out the air permeability and from the air permeability how much air is passing, there are 2 more than 1 methods, but what is most commonly used method is blains fineness method. So, you pass air in a specific manner and from, you know from the passage of this air, you try to find out the surface area, because larger the surface area relative time taken for flow would be higher.

So, there is a there is a method of measurement 1727 IS code gives you this measurements. So, we are not discussing those measurements, but this fineness is usually measured in terms of blains method in the unit of meter square per kg. You can of course, find out the surface area or fineness from the grain size distribution as well, but do not they do not match, conventionally this is what is done. This is 1 where was waste or specifying characterizing pozzolana.

If you have grain size distribution; that is also good enough, but they do not match, not necessary same value you will not get, you can calculate out the specific surface from this, and also from this they would not match never, 2 methods will not match. So, that relative means for relatively comparing 2 different pozzolana, also 2 different cements. Specific gravity is the other important property that we would like to know. And then of course, chemical composition, oxide compositions that is we have understood that much very, very important, loss and ignition is 1 which is actually quite important.

Now what is loss and ignition? What do we do is; we take the sample heat it up to 1000 degree centigrade for half and keep it there for half an hour. So, whatever material un oxidized materials were there will get oxidized, because it is in a furnace in air, air furnace; air is there. So, it will get oxidized and whatever can go away, for example, if there is unburnt carbon is there that will be a give us carbon dioxide. If there are some moisture that will go away moist the way or you know will just get out. So, there will some amount of mass loss, there may be little gain in mass also.

So, the net effect is the mass loss and that is what we call loss on ignition. In fact, it is a measure of how much carbon unburnt carbon is there in the system and as decremented, we do not want too much of unburnt carbon. It consumes a lot of water with the concrete and therefore, it creates the other kind of problem. So, we do not want really high loss and ignition, the code specifies the specification various you know even IS code for various specific pozzolana would mention, because we have codes for fly ash, we have codes for ground granulated blast furnace slag and we have now a code for silica fumes. So, they specify what should we do and this is what we look into.

So, that is how we characterize pozzolana. Most important characterization of course, is pozzolanic activity; that means, how much reactivity it will have and 1 of the ways you measure is called lime reactivity. This I like to highlight, this is measured using what is called lime reactivity with it right.

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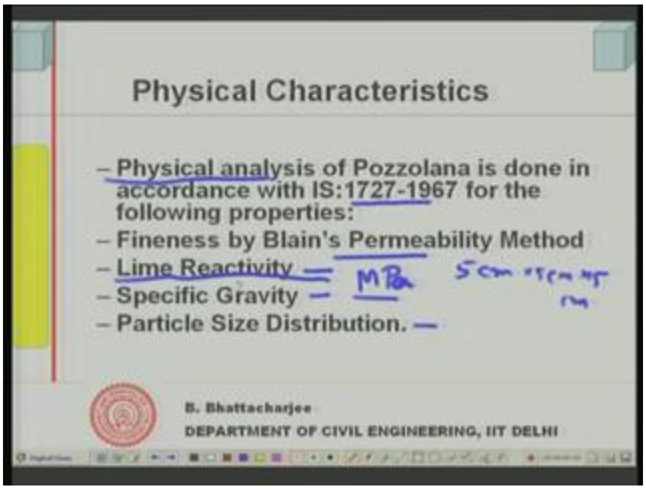

So, let us see physical characteristics right. I mentioned physical analysis, physical characteristics of all this analysis of pozzolana is done using IS 1727, this is what it is blains permeability method, lime reactivity this is pozzolanic activity, specific gravity and particle size distribution. So, that is what is done. So, specify it what should be your limits, how much minimum blains permeability should be there or surface area calculated from blains permeability. What is the minimum lime reactivity, let me just mention something about this lime reactivity. What is done in this case is or similar other tests are there. This is 1 of the test for pozzolanic activity.

Lime reactivity is nothing but you make again a standard cubes, say in this case 5 centimeter by 5 centimeter by 5 centimeter cube, you make cubes of 5 by 5 by 5 cubes. And this you will make with lime, cement lime and silica or your pozzolana lime silica pozzolana in a given manner roughly 1 is to 3, but it will depend upon the specific gravity. And then add standard sand rate in a given proportion, make this cube cure them in a standard manner for 10 days 248 hours just cover under glass, another 8 days in a specific relative humidity and temperature. And then test them under load for crashing strength again; testing is also in standard manner.

In other words, its product the making of the casting of the cube, casting the cube, curing the cube, testing of the cube, materials used in the cube; all are standardized except the pozzolana which remains as a variable. So, you finally, find out the crashing strength at that age 10 days or whatever it is. And there is a minimum value suggested for using cement, for using concrete etcetera. So, these values are expressed in MPa and strength of 5 centimeter cube, 5 centimeter cube and this strength is specified and that gives us how you know how it would react with the lime. Is it good pozzolanic, because the finer pozzolana with high reactive more amount of reactive silica will show you high lime reactivity.

There are other ways to measure this pozzolanic reactivity as well. For example you can have cement reactivity, you can have pozzolanic activity index through concrete cube and several other. So, this is what is done to characterize the fly ash.

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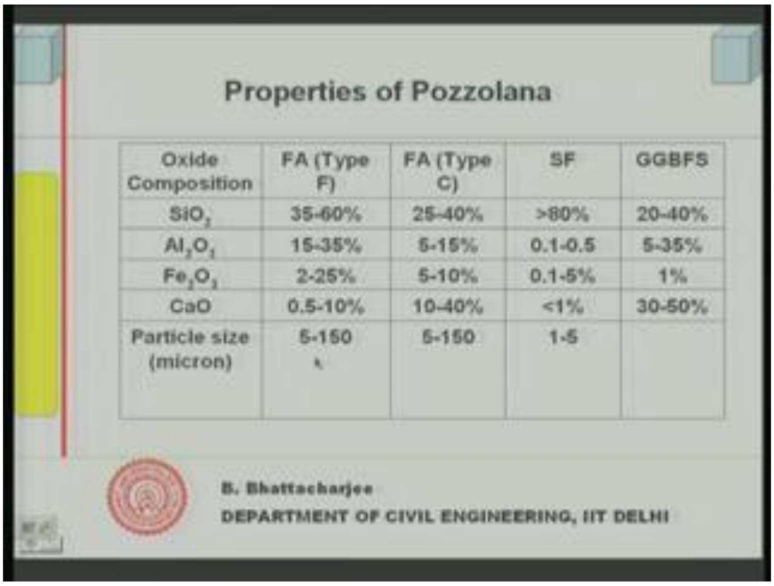

Oxide Composition	FA (Type F)	FA (Type C)	SF	GGBFS
SiO_2	35-60%	25-40%	>80%	20-40%
Al_2O_3	15-35%	5-15%	0.1-0.5	5-35%
Fe_2O_3	2-25%	5-10%	0.1-5%	1%
CaO	0.5-10%	10-40%	<1%	30-50%
Particle size (micron)	5-150	5-150	1-5	

Let us see properties of the pozzolana, the 3 main pozzolana as mentioning, let us say fly ash. Now I mention there are 2 types, there are other ways of classifying fly ash again since our time is restricted we will like to keep it to this ASTM classification. ASTM that is ASTM which is American societies of ASTM type F you know F and c; these are 2 types. So, type F type c; these are a classification based on ASTM American society of testing materials.

And what they say is; this classification is based on the source of the coal. For example, lignite coal would give you type c, which will have high calcium carbonate 10 to 40 percent and this has got calcium content for type F fly ash never exceeding 10 percent right, it is between this. So, this are the ranges of oxide composition as you can see 35 to 60, 25 to 40 etcetera. This is the main difference between type c and type F fly ash.

In the northern India most of the fly ash belong to this, whereas somewhere in the Konkan region, you will have or the southern part of the country Neyveli etcetera will have close to them you know fly ash those are available can be of this type. Silica fume on the other hand contains very little of all other materials, no calcium oxide, no iron oxide, no aluminium oxide very little, but mostly it is Si O 2, because this is produced from quartz. So, it is highly rich in silica content. GBFS it has got lime also, because lime is used to remove this. So, that is why it can show what is somewhat Cementitious properties. So, this can also show a little bit of Cementitious property sometimes, but this is purely pozzolanic, this is purely pozzolanic, so this are the oxide composition.

If you see the particles size distribution, fly ashes are 5 2 150 micron sizes. This is very fine; that is what I want to highlight, this is very fine 1 to 5 micron size very very fine size. So, its characteristics is very fine rich in silica highly pozzolanic. So, this is the characterization or properties of pozzolana and properties of pozzolana.

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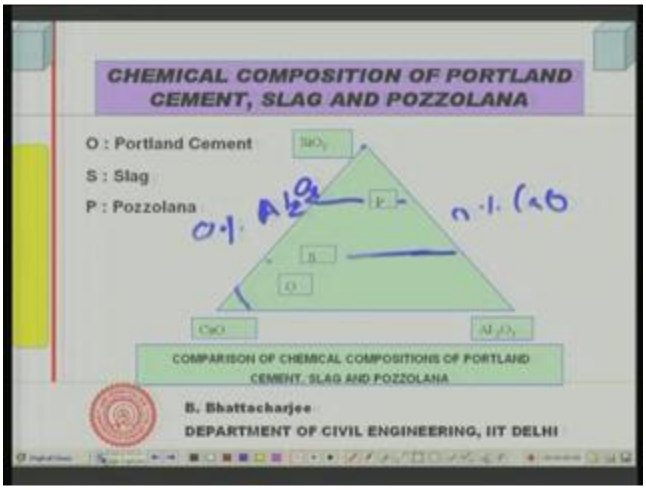

And if we see their chemical composition in a diagrammatic manner, they will look like this, where you know this is 100 percent calcium oxide, this is 790 and so on so forth. This is 0 percent Ca O. So, if you go along this lime, calcium oxide increases. Now a P stands for pozzolana, it will have very c type F of fly ash, let us say where little Ca O, whereas S stands for slag has got some amount of lime, some amount of lime Ca O lime. And OPC has got the 67 percent over this, this is a lime. So, you know if you distribute this 0 to 100 along this line.

And then if you look at slag, slag is here Al 2 100 percent here, 0 percent here. So, 0 Al 2 O 3 along this and 100 percent here. So, if you see Al 2 O 3 is more or less similar in all of them as silica slag and fly ash pozzolana and OPC, but you come to Si O 2, that is, Si O 2 is here the third main oxide here, which is 100 percent here and less here. So, this has got maximum, the pozzolana has got the maximum Si O 2, where as OPC has got less slag has got somewhat higher Si O 2.

So, this diagram shows you the chemical composition of the various kind of pozzolana, we say we Portland cement right. So, this is what the characteristics of pozzolana cement. Let see what it does; what is this and what were its effects.

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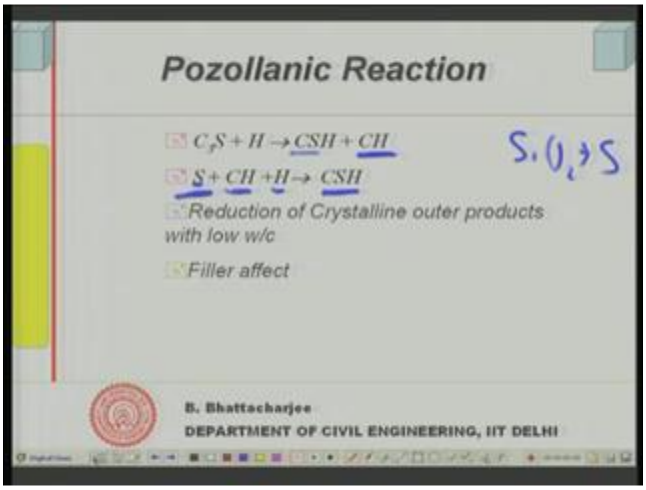

You see this pozzolana reacts with, this is the pozzolana, this is the pozzolana this is calcium. It is because we know Si O 2 is denoted by S, you know we denote it by S abbreviated as S. So, S stands for Si O 2. So, pozzolana is rich in Si O 2 and that is what reacts actually.Now we have seen the C 3 S reacts with water to form C S H gel and calcium hydroxide. That is we have seen in the previous lecture. Similarly C 2 S also reacts with water and produces this and C H.

Now when we are adding cement and pozzolana together; cement will react with water producing lime. And this lime can react with silica, in this case pozzolanic silica and water producing same C H S gel. So, that is what it does. So if, you add a little bit of or even if you put some amount and if you mix cement in pozzolana together and then add water to it, the cement will react fast and then produce lime. Once the lime has been produced lime can react with pozzolana producing more C S H. What it is doing then; it would actually removing the non sealing precipitate calcium hydroxide which was use useless really from that sense; from strength point of view or cementing property point of view. And C S H gel is a 1 which gives you cementing. So, actually producing more cement to give you cementing property. So, therefore, this what it does; it gives you crystalline outer product I just mention what it is and then it gives you what is called a filler effect, filler effect is given.

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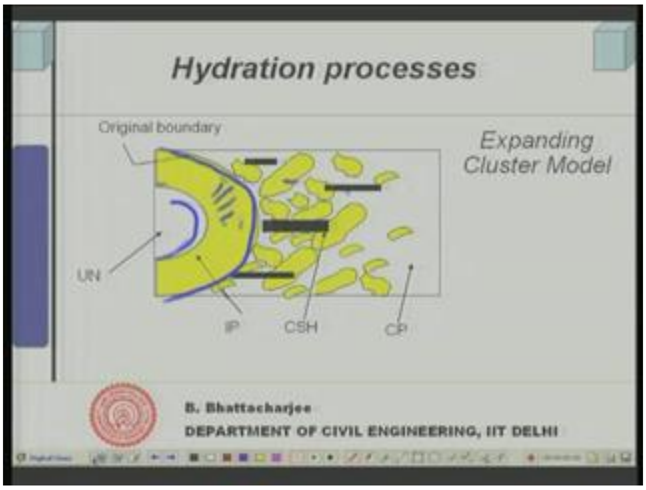

You know its fine material. So, go into the pores of the cement itself right. So, this what is called cement you know, yesterday I mentioned to you about the hydration process of cement. If this was the original cement grain boundary, then as the reaction progresses its grain boundary will change to this, because this product material might have reacted with water. And the product settles here, but some product goes outside also. This is called expanding cluster model. Now we can use this model to depict the reaction of pozzolanas.

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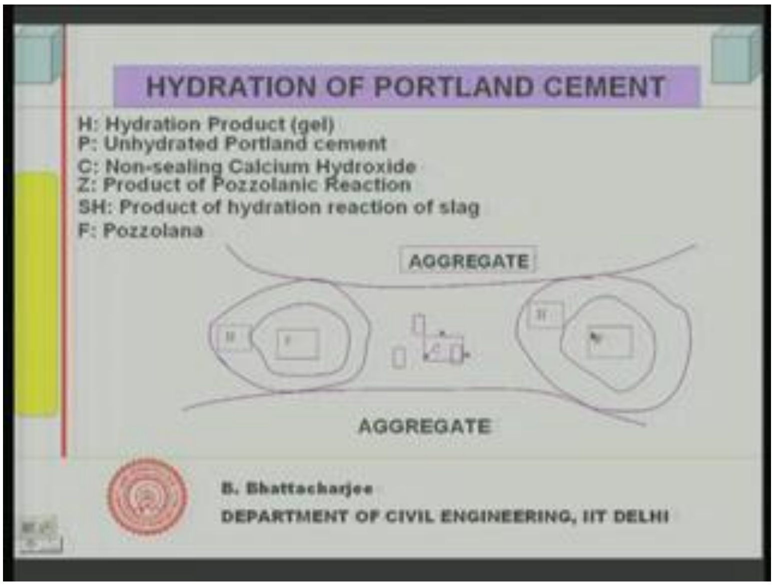

Now say hydration of Portland cement will produce, this is the Portland cement. Portland cement P stands for un-hydrated Portland cement, this is the hydration product and some product will come here. This is the cement, this is again another particle of Portland cement this is 1 particle of Portland cement. This are aggregates and this is the aggregates and the hydration product will accumulate here which will also include calcium hydroxide. If I go to the next slide hydration of cement and blast furnace slag.

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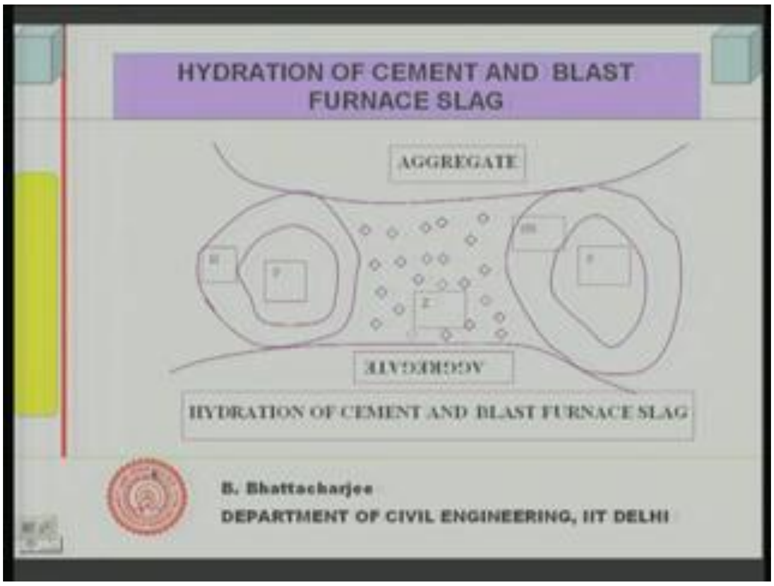

Now, slag is partially Cementitious. So, this is my slag, since it is Cementitious some product will form here also, but the pozzolanic product form the calcium hydroxide that was produced earlier, with the silica here would fill in this space. So, you can see it will have much lesser void. And aggregates are here; this is the aggregate and this is aggregate.

Let us go to fly ash or some other pozzolana. In this case, you see pozzolana does its not Cementitious So, this is the fly ash it only gets consumed, but the space between the cement particles are now filled in by the additional C S H gel. So, it will have a much denser structure. So, that is how this 3 materials work.

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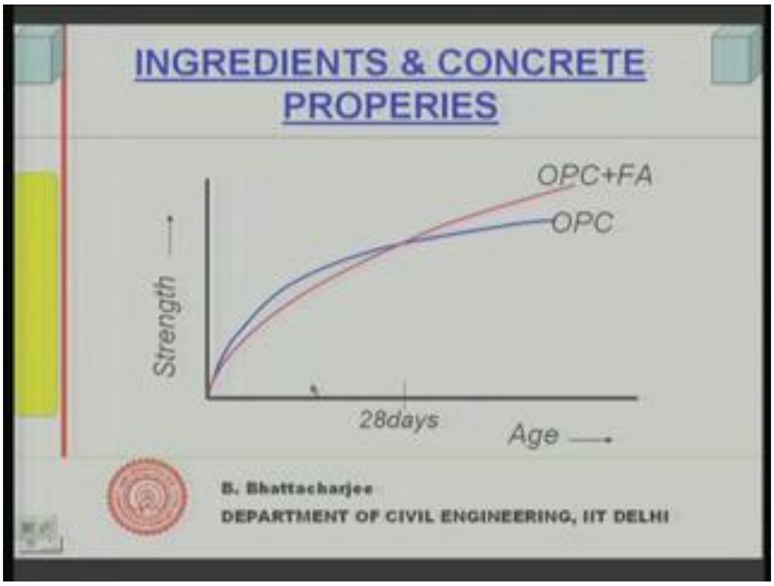

This 3 materials work you know this is how Cementitious work. What they do; they actually will give you better strength, reduce down the porosity capillary porosity. So, therefore, they will increase the they will improve the strength. Since the capillary porosity is reduced, durability is more better durability nothing can come in. Supposing you see the twentieth, but 1 thing if you replace part of the cement by pozzolana, it strength gain will be relatively lesser, because pozzolana has to wait for calcium hydroxide to produce and its process itself reaction process itself is slow, I mentioned earlier. So, therefore, this process is relatively slower process. So, initial strength gain is less, but long term strength is very little. So, with Portland pozzolana, with Portland cement and pozzolana fly ash strength long term strength is much higher better durability, but initial strength are relatively less.

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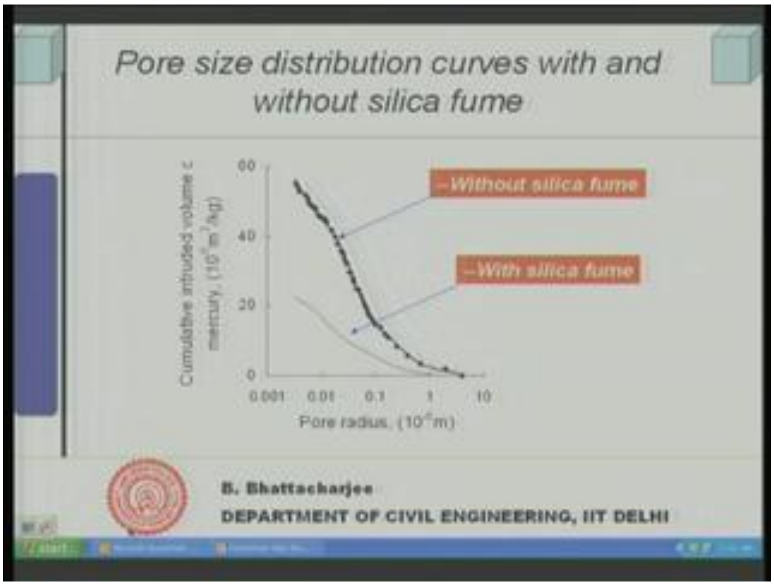

Silica fume if you can see it refines the port sizes significantly, without the silica fumes the port sizes the porosity would be this much, the porosity would be without silica fume the porosity would be this much. This would be the volumes of the total volume of port, but if you add silica fume this pore volume reduces down, also the sizes in you know with silica fume ranges from this to this, whereas overall sizes was original something else. So, both these materials they actually improve the porosity, and therefore long term strength.

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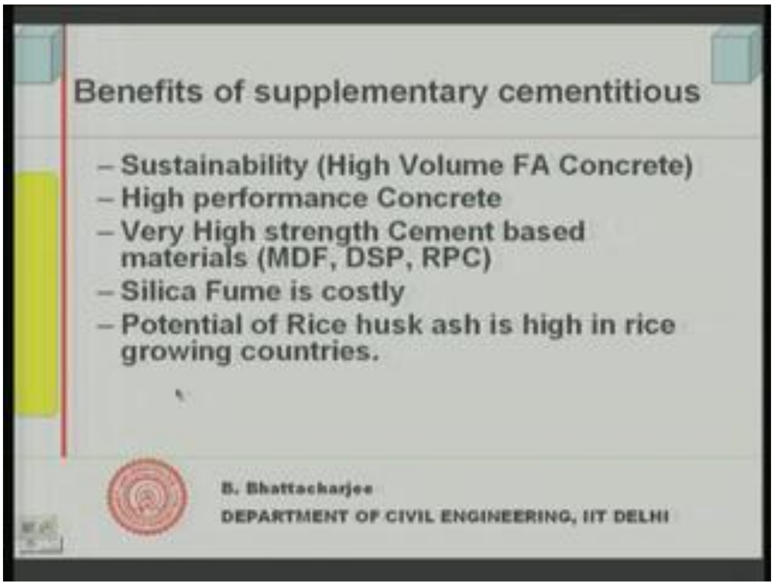

Now what are the benefits of this material therefore sustainability; this gives us sustainability. You know you were using less of clinker, less of carbon dioxide you were producing. You were using other waste material, so this is more sustainable. High volume fly ash concrete is 1 such example, where you use as much as 50 percent fly ash. Very strong high performance concrete can be designed by silica; use of silica fume, because it can reduce down the pores to a very, very fine size, very low total porosity reduces. And we have seen yesterday that, days are the main factors which controls the strength and durability of concrete. Therefore, high performance concrete can be produced with this. Very high strength cement based materials are produced by silica fume. But remember silica fume is costly and rice husk ash potential has to be still seen. So, if you summarize now.

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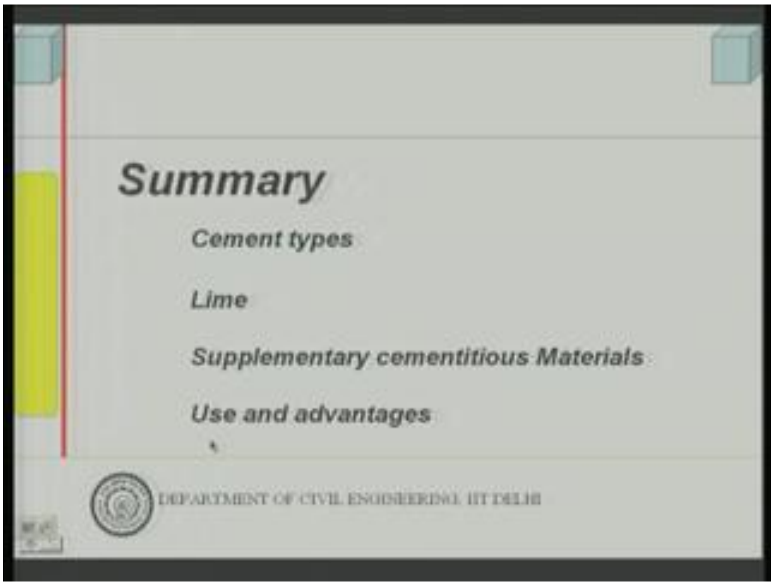

We have talked about cement type. We have also mentioned about a lime little bit. But we have discussed something about supplementary Cementitious material and we have talked about their use and advantages. Well, I think that is all for the day.

Thank you.