Pavement Materials
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Lecture 51
Types of Cement, Admixtures, Geo-polymers - 1

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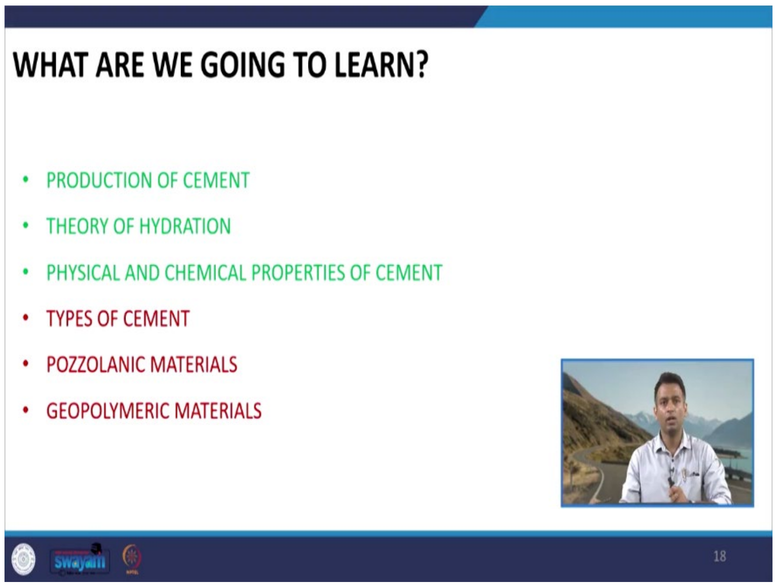

Hello everyone, if you remember in the last class we have discussed about the production of cement, we have discussed the theory of hydration and we have also talked about the different physical properties or important physical properties related to cement.

Today, we will continue our discussion and we will start discussing about the types of cement, we will also discuss about the common pozzolanic materials which are used in the production of concrete and very briefly, we will discuss about the geo-polymeric materials, the procedure the materials that are involved and how the reactions take place so, that the final product which we get is a geo-polymer and which acts as an alternative to cement.

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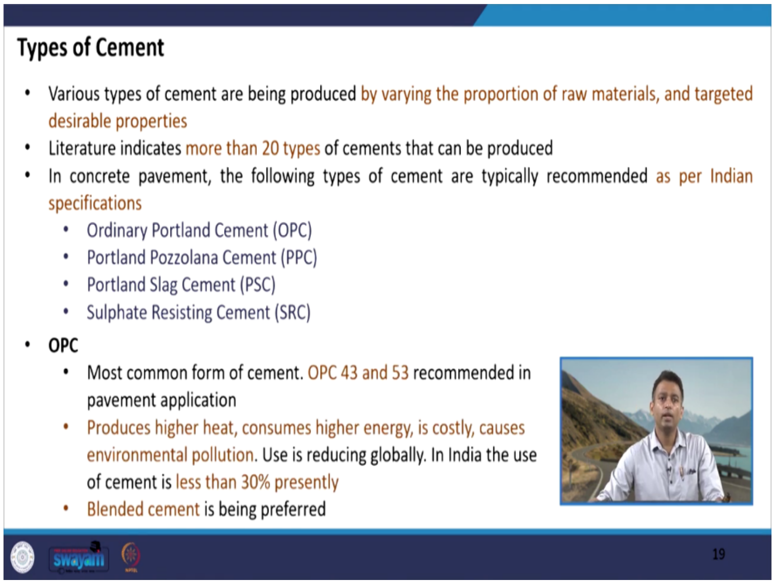

We will discussing about the types of cement various types of cement are being produced are being used in the construction activities and these cement the ideal procedure or ideal theory behind the process of getting this binding material is same which we have discussed that we need alumina, we need silica and then this alumina and silica are mixed together, they are heated together in some form and then the final product which we get when it reacts with water, it has to form hydration product or CSH gel.

Now, these cements these different types of cements data are available, they work on same principle, but the proportions of the raw materials that are used is usually varied and this decision on varying the proportion, it depends on the targeted desirable properties. If we see the literature, we can find that more than 20, 25 upto 30 types of cement are available are being discussed in the literature. However, all the types of cement they are not typically used in the construction of pavement or the construction of concrete pavements.

Usually in concrete pavement as per Indian specifications following type of cement are typically recommended and we will keep our discussion on these typical type of cementing materials. These typical cements it includes ordinary portland cement and under the ordinary portland cement we have OPC, 43 and 53 that are usually used in the construction of concrete pavements. We also have portland Pozzolana cement, we will discuss about why we call this cement as portland pozzolana cement and how it is produced, we have portland slag cement and we also use sulphate resisting cement in some specific conditions, especially when the structure is anticipated to be attacked by specific type of soil and water that beer sulphate materials.

Well, let us start discussing about OPC first so, OPC is the most common form of cement and we have already discussed about the ordinary portland cement we have discussed about the method of related to its manufacturing, we have also discussed about the hydration process. As I mentioned, OPC 43 and 53 are typically recommended in pavement application.

Usually in the OPC as we have already discussed during the hydration process, a lot of heat is emitted, because it is an exothermic reaction. So, we have a lot of heat which is being emitted, it consumes higher energy because we are making the mixture itself in the kiln which is heated to a temperature of about 1400 1500 degrees Celsius. It is costly on one hand because of the involved manufacturing process. Also it causes environmental pollution.

So, if you remember the calcination process under which these materials get fused together and they form new products, a lot of CO_2 is emitted and this CO_2 is it finally causes environmental pollution and therefore in the present situation where a lot of construction is going on and there is a huge demand researchers are also looking for alternative measures for alternative binding materials such that the carbon footprint in the environment can be reduced we will talk about that when we discuss about geo-polymeric concrete.

It has been seen because of these concerns the use of OPC generally is reducing not only in India but also globally. And in India presently, we are using less than 30 percent OPC in the pure form rather, we prefer to use blended cement and we will talk about that.

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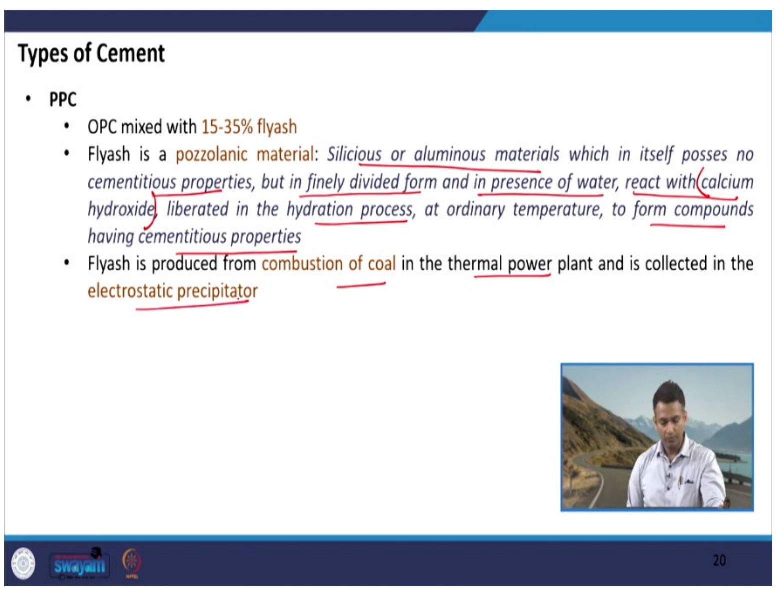

Let us talk about PPC which is a type of blended cement here what we do we mix OPC we have ordinary portland cement which is mixed with around 15 to 35 percent flyash. So, what is flyash, flyash is a pozzolanic material and how do we define pozzolanic material. So, pozzolanic materials are those or are basically Silicious or aluminous materials, which in itself posses no cementitious properties, which means, they cannot hydrate on their own the hydration process, which means, if you mix pozzolanic material with water, it will not give you a cementing product just like we saw in case of cement.

But in finely divided form and in presence of water it can react with calcium hydroxide, which we already know how do we get calcium hydroxide it is liberated in the hydration process of the ordinary portland cement and it forms compounds that have cementitious properties.

So, how do we define a pozzolanic material, these are Siliceous or aluminous materials which when reacts with the calcium hydroxide, which is already present, which is basically a byproduct of the hydration process of the cement. So, these aluminous materials reacts with calcium hydroxide to give us cementing materials, they themselves cannot react with water to give us cementitious materials or properties.

So, flyash is an let us now discuss that how do we get flyash. So, flyash is produced from the combustion of coal in the thermal power plant and it is collected in the electrostatic precipitator.

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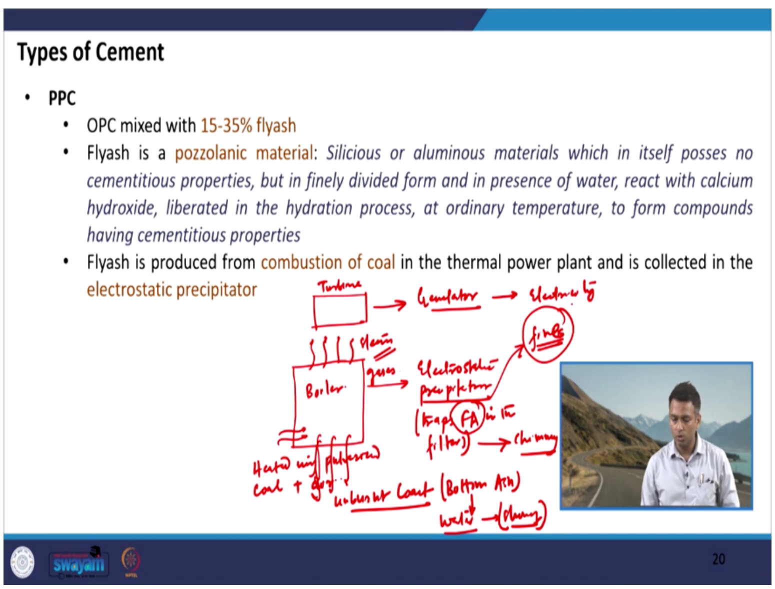

So, let us now see that what typically happens in the thermal power plant and as we all know that thermal power plant is meant to produce electricity and this happens using steam and then turning turbines.

So, we typically have a boiler which is heated you using pulverized coal and air. So, once we heat the boiler, we will have the formation of steam here and the steam will ultimately rotate turbine so, we have turbines which rotates because of the pressure from the steam and then this turbine is ultimately connected to a generator which will give us electricity. So, this is a basic flow diagram.

Now, during this process when we are heating the boiler several gases are emitted and this gases goes through electrostatic precipitator that traps the very fine flyash that is generated in the filter in several filters that are attached and finally, the remaining gases it goes to the chimney which is then finally sent to the air. Now, this flyash that is trapped inside the electrostatic precipitator is the typical flyash that we use in the construction process.

We also have other form of ash that are more coarser in size. So, this flyash which we are talking about, it is very fine and that is why filters are used to trap it, but during the process of heating the boiler, we will also have other waste particles that will because of larger density higher (dense) because of higher density and larger size they will settle down in the bottom part and this is nothing but the unburned coal and it is called as the bottom ash. This bottom ash is later on mixed with water it forms a slurry and it is typically then called as a pond ash a typical terminology.

So, anyways, this flow diagram was meant to explain you that what happens in the thermal power plant and how we get the flyash that we have to use in the production of Portland pozzolana cement.

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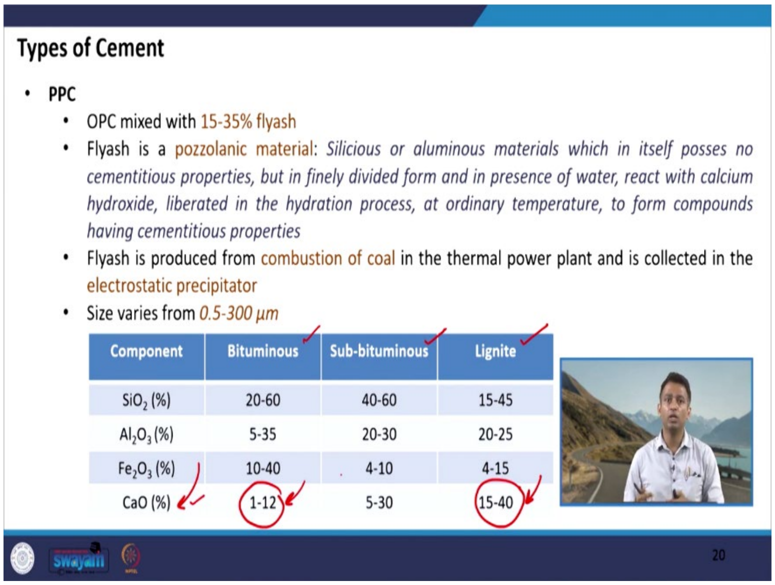

So, having said this, let us now talk about other characteristics of portland pozzolana cement. Its size varies from point 5 to 300 micrometers. And these are the different components in the flyash that we typically see. And just to inform you that flyash itself can be produced from different sources of coal, we have bituminous coal, we have sub bituminous coal, we also have lignite based coal.

So, depending on the type of coal we are using the proportion of the silica and alumina that are the primary ingredients that reacts with calcium hydroxide and then gives us CSH gel it will vary.

So, you can see that one very interesting thing here that in the flyash we also have calcium oxide some percentage of calcium oxide and now, if you remember that we discussed about the production process of cement and we said that we need a source of for calcium oxide which is typically the limestone and then we have clay and we use clay or shale that contains alumina and silica. So, these are the primary raw materials.

Now, one question is, if flyash itself has calcium oxide, why does not it why cannot it produce why we cannot get the hydrated product just like we are getting in case of the cement? So, here you see the calcium oxide content it differs in all the different types of coal as for example, in bituminous coal, the quantity is very less 1 to 12 percent and in case of lignite coal the quantity is high 15 to 40 percent.

So, if the flyash has higher percentage of calcium oxide, then definitely that calcium oxide will participate in the hydration process and the flyash in itself if it reacts with water can generate some amount of cementing products. But, because this percentage is very, very less in comparison to what we typically use in the manufacturing process of cement, they cannot be considered in itself to produce all the cementing products that we want and that is why we call it as a pozzolanic material though ideally, depending on the percentage of calcium oxide, it can produce cementing gels when it comes in contact with water.

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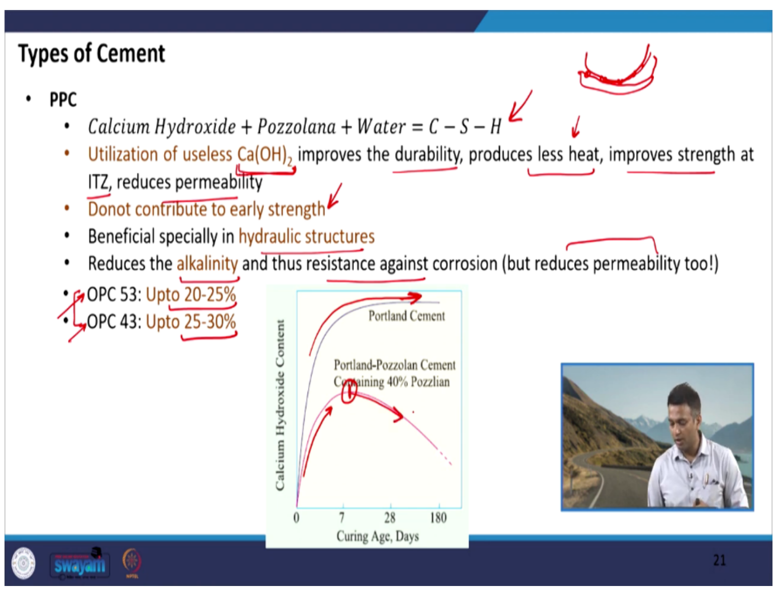

Now, let us discuss about some other features related to Portland pozzolana cement. Talking about the reaction this we have already discussed that we have calcium hydroxide, which we get through the hydration process of the cement, it will then come in contact with flyash or the pozzolanic material we are talking about and water and then finally we will get the CSH gel.

So, we can understand that once we add flyash with cement and add water to it, not immediately the flyash will start reacting with the system and produce CSH gel because pozzolanic material needs calcium hydroxide, calcium hydroxide itself will be generated after some time when the hydration starts.

So, when the components like try calcium silicate or die calcium silicate it starts reacting with water. So, this means that pozzolanic material or pozzolanic cement the pozzolana in it, it will contribute to the strength in the later part of the hydration process and the early strength will be because of the presence of cement and the hydration process of cement.

One of the benefits of using Portland Pozzolana cement is that it utilizes the useless calcium hydroxide this we have already discussed that excess amount of calcium hydroxide is not desirable, because it does not contribute to strength and if it comes in contact with sulphates, it can increase the volume of the mixture which can be detrimental to the durability of the concrete.

So, since it is utilizing this calcium hydroxide that is produced, so, the use of pozzolanic material it improves the durability. Now, the heat will also reduce because it will because we are using less amount of cement and we are replacing it with a pozzolanic material so, it (prod) produces less heat it improves the strength at the ITZ because this calcium hydroxide if it crystallizes it will occupy those space between the coarse aggregate and the cement paste and we have discussed that this ports are very critical when we talk about the strength of the concrete.

So, this interfacial transition zone we will be able to fill it with additional cementing product that will be generated during the reaction of calcium hydroxide and pozzolanic material and therefore, the permeability of the entire mix also reduces so, these are the advantages. As I already mentioned, it does not contribute to the early strength and that we understand because it will start forming cementing gel only after the production of calcium hydroxide which we get during the hydration of cement.

It is especially beneficial in hydraulic structures, because calcium hydroxide is responsible for the sulphate attack because it reacts with sulphate and then it will react with C_3A and C_4AF to further generate a ettringite which causes failure in the structure. However, if you remember in the last class, we discussed that one small benefit of calcium hydroxide is it increases the alkalinity in the mix. So, this alkalinity will help in resistance towards corrosion.

So, the utilization of calcium hydroxide by the pozzolanic material will ultimately reduce the alkalinity in the concrete and thus it will also reduce to some extent the corrosion of the reinforcements however, since it reduces permeability, this effect is not very significant. It reduces permeability which means the attack or the corrosion the chances of corrosion itself will reduce because water will not be able to percolate and then attack the reinforcements.

In construction of pavement typically we use OPC, 53 and 43 for example, 43 is typically used in the production of DryLin concrete for important highways the for national highways and state highways OPC 43 is used in the pavement quality concrete. So, in OPC 53 if we are trying to use Portland pozzolanic material, then the replacement of flyash is up to 20 to 25 percent whereas, in OPC 43, it is up to 25 to 30 percent typically.

Talking about the reduction in the amount of calcium hydroxide over a period of time by now, we understand that ultimately the pozzolanic material has to utilize calcium hydroxide and calcium hydroxide will start producing when C_2S and C_3S is in the cement will start reacting with water. So, this reaction this production of calcium hydroxide this is a time dependent process and with time more amount of calcium hydroxide will get released and only after the liberation of this calcium hydroxide the pozzolanic material will start producing CSH gel.

So, we see typically that in case of pozzolanic material, the amount of calcium hydroxide start reducing only after sometime not immediately in case of Portland cement, it will keep on increasing and once the entire reaction is completed, then it will stabilize over a period of time. But in Portland Pozzolana cement since again the reaction is slow, it takes time for pozzolanic material to react with calcium hydroxide.

First, the amount of calcium hydroxide increases because of the hydration process and then some parallel reaction with the pozzolanic material. But after some time, because of the proper reaction with pozzolanic material the amount of calcium hydroxide reduces inside the concrete mixture.

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Now, let us discuss about Portland slag cement, let me show you how a flyash looks like. So, again very fine material just like cement, but the color is light in comparison to what we see in for cement, again the color depends on the source of the flyash from where we have taken the flyash. So, the color also might change a little depending on the source.

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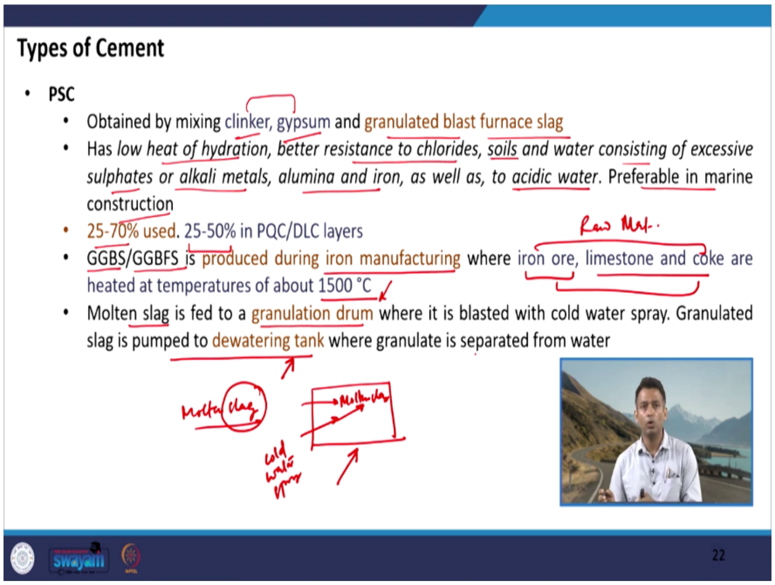

So, next type of cement that is Portland slag cement, Portland slag cement, it is obtained by mixing the clinker which we have during the production of cement gypsum which ultimately means that it is the Portland cement with granulated blast furnace slag.

So, this type of cement has low heat of hydration, it has better resistance to chlorides soils and water consisting of excessive sulphates or alkali metals which means this helps in prevention of sulphate attack alumina and iron as well as to acidic water and because it has high capability of reducing the sulphate attack or providing high resistance to sulphate attack, it is usually preferable in marine construction.

The dosage of the graduated blast furnace slag is typically 25 to 70 percent and if we talk about Indian specification, we typically use the graduated blast furnace slag in the range of 25 to 50 percent in PQC or DLC layers.

Now, talking about that from where are we getting granulated blast furnace slag or what actually is granulated blast furnace slag, so, GGBS or we also call it as GGBFS. So, GGBS is ground granulated blast slag and GGBFS is ground granulated blast furnace slag both are the same thing, it is produced during iron manufacturing.

Now, in the iron manufacturing process, what happens that iron ore, limestone and coke they are first heated so, these are the raw materials that are heated at a temperature of about 1500 degrees Celsius in a furnace. And then finally, what we have we have the molten slag here that is fed to the granulation drum.

So, once so, we will get molten slag so, this molten slag is the waste material which generates during the process of heating iron ore, limestone and coke. So, one part will produce your pig iron and the other part which is the slag it will deposit at the bottom of the furnace and that is the molten slag.

So, this molten slag is actually sent to a granulation drum it is sent to a drum where the molten slag comes in contact with cold water spray. Once it comes in contact with cold water spray, it breaks down into small granules. So, that is how we get the granules of the slag and this granule is later pumped to dewatering tank.

So, what is a dewatering tank because, at this moment, the slag is mixed with water the molten slag is mixed with cold water so, we have to remove water from the slag now, so, in the dewatering tank the water is removed from the granulated slag, then what we get we call it as glass granulated blast furnace slag.

One more reason of calling it as glass granulated blast slag is that we are basically reacting or we are combining the hot molten slag with cold water. Other way of looking at it is we can also allow the molten slag to cooling air, but air cooled molten slag they are not typically used for the production of the granulated blast furnace slag which we use as a replacement of cement for the production of Portland slag cement.

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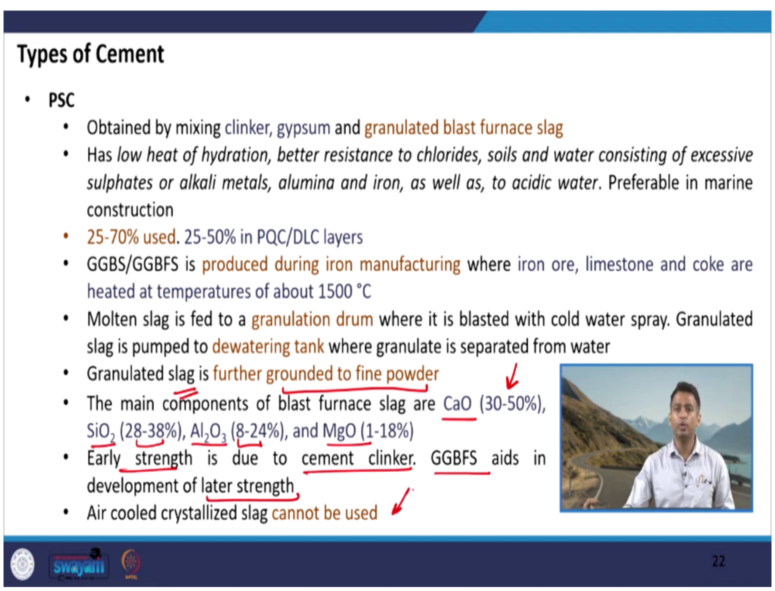

This granulated slag is further grounded to fine powder and this fine powder is the material which we have to add in in the Portland slag cement. If we look at the components, now, before even looking at the components, we should understand that this raw material should essentially consist of alumina and silica because only these materials will react with calcium hydroxide to form the CSH gel. So, you can see that the main components of the blast furnace slags are calcium oxide, which typically ranges from 30 to 50 percent.

Now, this also means that blast furnace slag in itself can produce cementing products if it comes in contact with water. So, it may not be a true pozzolana, but yes, it is a pozzolana because further reaction has to be initiated, where silica and alumina will react with the hydrated product of cement and then form more cementing gels in the mixture. So, it consists of silica which ranges from 28 to 38 percent, alumina typically 8 to 24 percent and also magnesium oxide, the range of which is between 1 to 18 percent.

Now, (similar) similarly, to what we have seen in case of flyash the early strength is due to cement clinker because only after the production of calcium hydroxide pozzolanic material will start reacting in the system and will develop strength. So, GGBFS it aids in the development of later strength. As I mentioned, air cooled crystallize slag cannot be used in this case.

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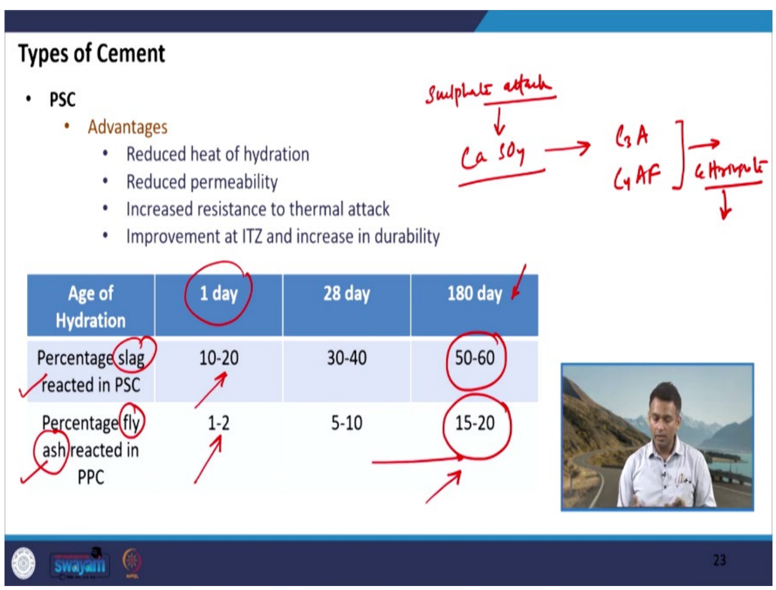

Now, some of the advantages of using Portland slag cement is it leads to reduction in heat of hydration, it reduces permeability. Now, these are some of the advantages which we also saw in case of flyash. It increases the resistance to thermal attack, it improves ITZ similar to what we saw in case of flyash and the reason we have discussed and it increases the durability.

Before I go further and discuss I think one point which I missed was to explain you that I said that the flyash based or the GGFS based cement it helps to resist sulphate attack. So, what basically sulphate attack, actually some soil some typical soils they have sulphate present which will dissolve in presence of water.

So, this sulphates or the ions which when it will come in contact with calcium hydroxide, it will form calcium sulphate. So, this calcium sulphate it will further react with C_3A and then C_4AF in the cement which will produce ettringite and this ettringite they it has a tendency to increase in volume and once the volume increases the durability of the structure get affected you will see cracking in the structure.

Now, everything starts by the production of calcium hydroxide in the hydration process. So, if we have some process of reducing calcium hydroxide ultimately we are also reducing the chances of sulphate attack and this is what pozzolanic material do they consume the calcium hydroxide since they consume calcium hydroxide they also resist sulphate attack.

So, this is just a comparison between Portland slag cement and Portland Pozzolana cement that how the slag and flyash in both the cements reacts with time. So, if you see that in the initial period in the in case of flyash, the amount of flyash that is reacted is less only 1 to 2 percent whereas, in the initial state Portland slag cement reacts relatively at a faster rate and therefore, the production of cementing gel will also be high.

But with time you see almost 15 to 180 days almost 15 to 20 percent of the flyash will be reacted which is again small the number is smaller in comparison to the reaction in case of slag cement. And therefore, flyash in the flyash based cement the increase in strength is relatively very slow, which means after a considerable period of time, you will see that the ultimate strength will be gained. While in case of GGBFS, the rate at which the strength is gained is fast. So, this is one difference between PSC and PPC.

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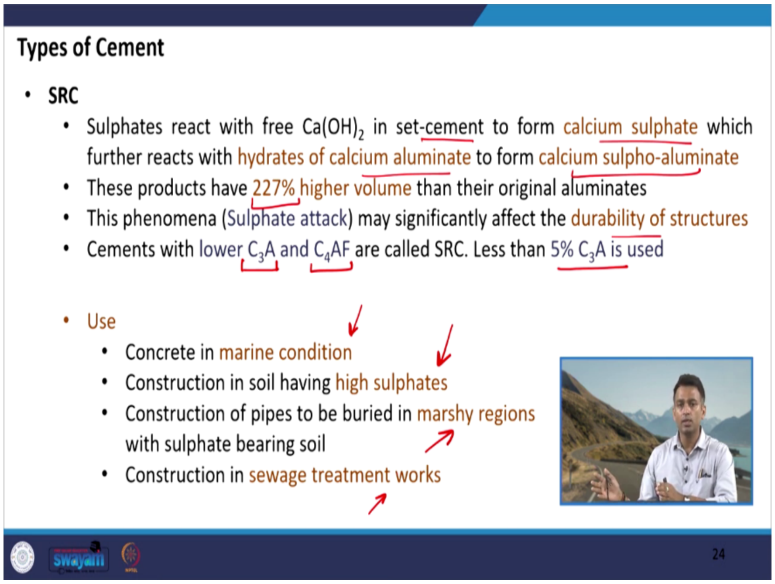

Let us now discuss about the next type of cement. In fact, this will be the last type of cement which we will be discussing today, which is sulphate resisting cement SRC. So, I think I have mentioned it here in detail that sulphates it will react and where do we get sulphate in the soil and then when it comes in contact with water, we will have it in the dissolved form.

So, sulphates react with free calcium hydroxide in set-cement to form calcium sulphate which further reacts with hydrates of calcium aluminate to form calcium sulpho-aluminate. So, these products have volume which is almost to 227 percent higher than their original aluminates. So, you can try to imagine that this significant change in volume can lead to failure in the contract system.

So, this phenomena it greatly affects the durability of the structures in case where there is a higher formation of calcium hydroxide and the amount of C_3A and C_4AF is also higher. So, therefore, sulphate resisting cement are those special cement were during the production the amount of C_3A and C_4AF are kept lower. Now, this is another way of dealing with the sulphate attack.

In case of pozzolana, we discussed that it consumes calcium hydroxide and that is how it basically resist sulphate attack. Here we are reducing C_3A and C_4AF because once calcium sulphate is formed, it has to react with C_3A and C_4AF to form finally, the calcium sulphate illuminate. If we have lower quantity of C_3A and C_4AF again that reaction will not take place or will not be significant and therefore, the formation of ettringite can be eliminated. So, in sulphate resistant cement the amount is usually less than 5 percent the amount of C_3A.

Where do we typically use SRC? We use it when we are using concrete specially in marine condition construction in soil having high sulphates construction of pipes to be buried in marshy regions again it is talking about the typical organic type of soil where we expect a presence of sulphate and construction in sewage treatment works. So, works which we have to do probably in in soils having high quantity of sulphate or underwater where typically such type of reaction can take place.

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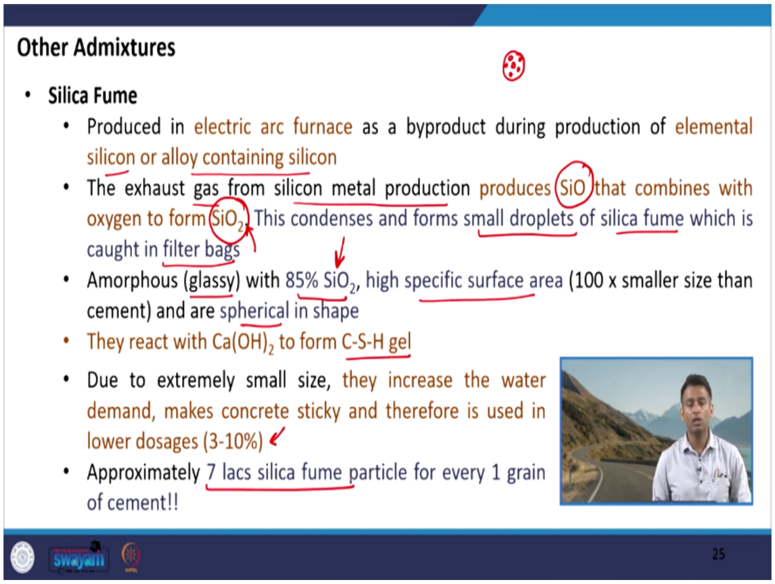

So, now, let us also discuss about few other mineral admixtures that are also used in the production of concrete. So, we have silica fume. So, how do we get silica fume silica fume is typically produced in electric arc furnace, which is as a byproduct during the production of elemental silicon or alloy containing silicon. So, during the production of silicon or alloy containing silicon in the electric arc furnace slag, we get a byproduct which is nothing but silica fume.

Now, what happens typically in the process that the exhaust gas from the silicon metal production it produces SiO. So, this SiO combines with oxygen to form SiO_2. Finally, this SiO_2 gets condensed and it forms small droplets of silica fume which is gathered or which is collected from the filter back again in the entire manufacturing process. Usually, if we see the characteristics of silica fume, they are amorphous or in in other words, they are glassy and contains almost 85 percent SiO_2 with some, some impurities, some other materials present in it and you can see that this is a very huge quantity of SiO_2.

Now, it does not typically have alumina that that we have talked about in case of other pozzolanic materials, it has high specific surface area, this is one of the very important characteristics of silica fume, the size is very, very small, it is almost 100 times smaller than the size of the cement and they are usually spherical in shape.

Now, because of the small size when they are added as a replacement of cement, you can try to imagine that per unit volume, more numbers of silica fume material can be packed or per unit weight, more amount of silica fume material can be packed therefore, the density of the mix increases to a very considerable degree. And finally, they have to again react with calcium hydroxide to form CSH gel which is very similar to what we have discussed in case of the other pozzolanic material, but here we have abundance of silica which will react with calcium hydroxide.

Now, as I mentioned that due to the extremely small size, they increase the water demand also, because if the size is small, which means you will need more water to wet the surface per unit volume of course, but unit volume because the number of material, the number of silica fume will be more, you will need more water to wet it. So, the water demand will increase, it will also make the concrete sticky because of this huge water demand and increase in density.

And therefore, when we talk about silica fume, it is used in relatively lower dosages in comparison to the other pozzolanic material. So, the range which we use is typically 3 to 10 percent of silica fume depending on our targeted properties. Talking about the size again just an interesting fact that in comparison to 1 grain of cement, you have about 7 lakh silica fume particles so, that is you can imagine that that is a huge number.

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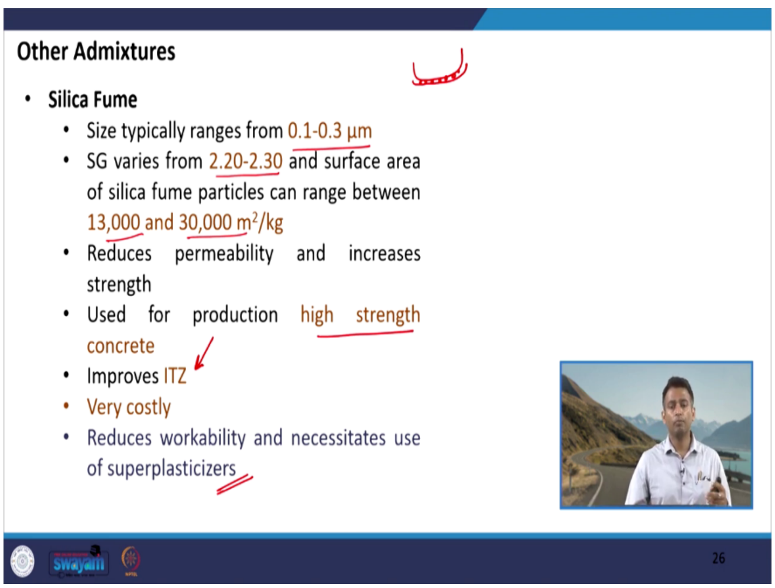

The size of the silica fume is very small, about point 1 to point 3 micrometers its specific gravity usually very strong 2.2 to 2.30 and the surface area, it can range from 13,000 to 30,000 meter square per kg, it reduces the permeability and increases the strength specially in the ITZ location where these pores which are created will be filled by this the fine CSH gel which will be created when silica fume reacts with calcium hydroxide and it increases the bonding between the cement mortar or the cement paste and the aggregate system.

So, therefore, and this is one of the reason that it is used for the production of high strength concrete. We have already discussed that it improves ITZ however, the cost of silica fume is very high because the process of synthesizing silica fume itself is costly and therefore, the unit cost of silica fume is very high in comparison to the cement or any other pozzolanic material.

Another problem related to silica fume is because it consumes a lot of water the water demand is very high, it has a tendency to reduce the workability and therefore, whenever we are using silica fume, there is a necessity to use superplasticizers which are again some type of a type of product that is used to improve the workability in case of concrete production we will discuss about superplasticizers in further slides.

And because the size is very small the surface area is very high, we need proper mixing for the proper reaction to take place. So, whenever we are using silica fume in the production of concrete, we should do a very thorough mixing so, that the entire surface of silica fume is wetted by the presence of water.

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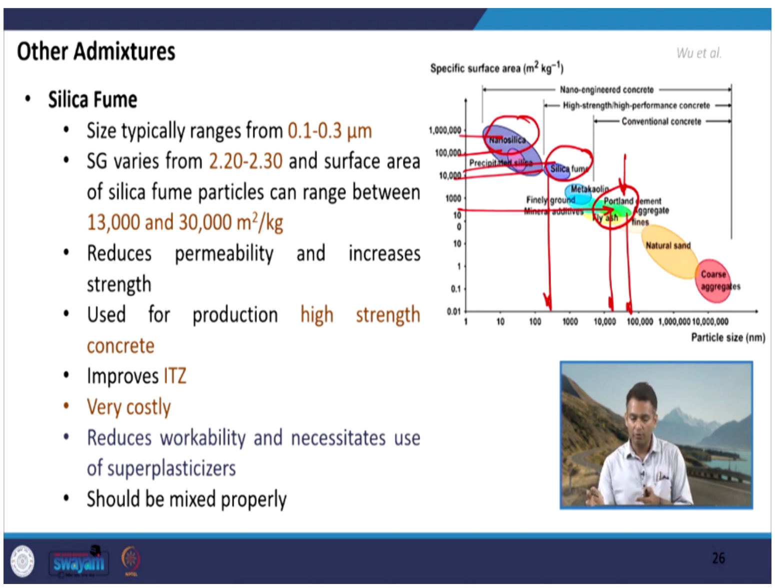

This is just a figure from one of the studies which shows that how the size of different material varies and since we have already discussed about most of the materials, let us see Portland cement is somewhere here the fineness of Portland cement in flyash is almost similar and then we have silica fume here and in fact, if further we are going for smaller size let us say nano silica you can see that how the range of surface area in comparison to what you see for Portland cement and also the particle size.

We also have another product which is somewhere between the fineness of which is somewhere between silica fume and flyash or cement that is metakaolin and this is something which we will be discussing in the next slide.

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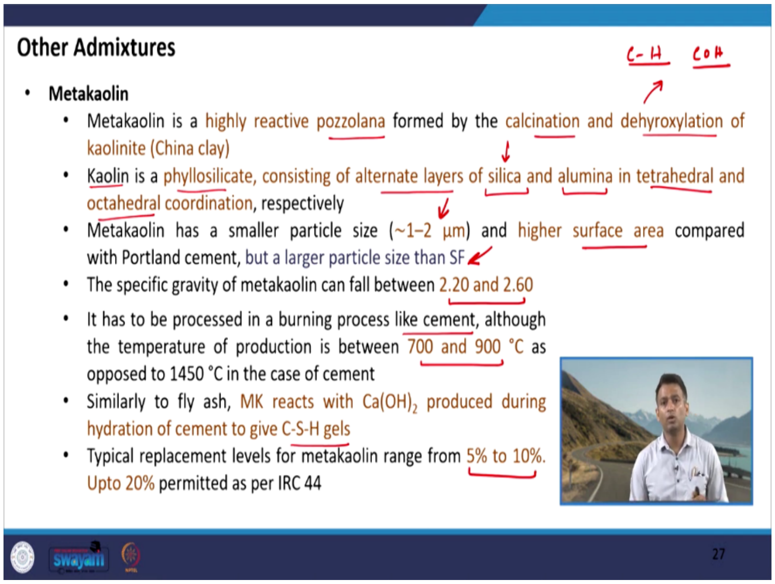

So, let us discuss about metakaolin now, again this is one of the products that is popularly being used in the production of concrete because of some of the unique benefits of this product. So, what is metakaolin it is a highly reactive pozzolana and we get metakaolin by calcination and hydroxylation of kaolinite.

So, hydroxylation is a process where the CH bond oxidizes to form a COH. And we have already discussed about calcinations. Kaolin is a type of mineral again, I have mentioned about Kaolin when we have discussed about soil in the initial lectures. So, kaolin is a type of mineral which we find in some specific clays and it is a Philo silicate which consists of alternate layers of silica and alumina in tetrahedral and octahedral coordination.

So, silica will be in tetrahedral orientation, and there then we will have a sheet of tetrahedral alumina and then again we will have the repeating sheets of silica and alumina. So, these are placed as alternate layers in the mineral system.

So, metakaolin also has a smaller particle size somewhere between 1 to 2 micrometers and we have seen that it is somewhere between silica fume and then flyash type of material and it has high surface area compared to Portland cement, but it is larger than silica fume the specific gravity of metakaolin it ranges somewhere between 2.2 to 2.60 it is it has to be processed by a burning process like cement.

Now, the process is same, but here we use a lower temperature. So, there we were also using clay or shale as our raw material, but we are processing it to a very high temperature of about 1400 to 1500 degrees

Celsius. So, in case of metakaolin, again we have to heat the raw material, but the production can take place at a lower temperature which is around 700 to 900 degrees Celsius. So, therefore, the requirement of heat reduces in case of metakaolin.

Similarly, to flyash and also GGBFS metakaolin reacts with calcium hydroxide, which is which we get during the hydration process of cement and finally, this reaction will yield cementing products in form of CSH gels. The typical replacement levels of metakaolin is somewhere between 5 to 10 percent as per IRC 44 we can use up to 20 percent of metakaolin for the production of concrete.

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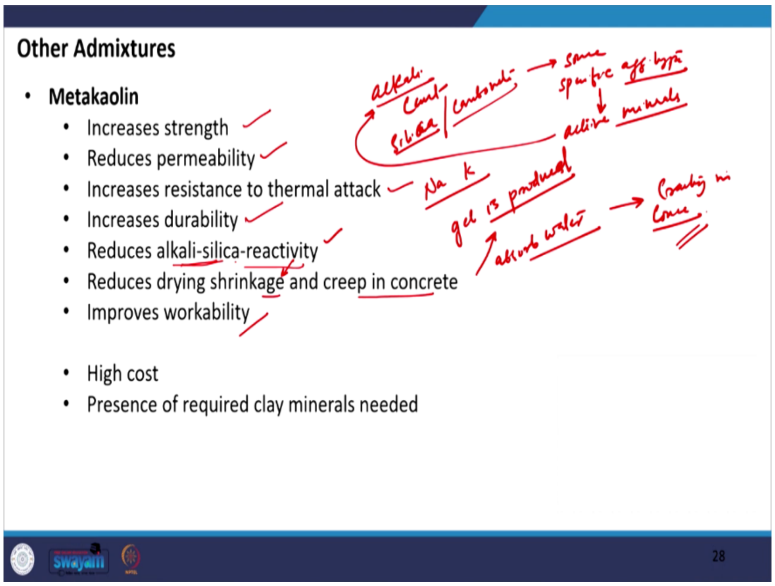

Some of the advantages of metakaolin includes that it increases strength, it reduces permeability, it increases the resistance thermal attack, it increases durability, it also reduces alkali-silica reactivity or we also call it as alkali silicate reaction and then it also reduces drying shrinkage and creep in concrete.

Well, I hope you understand that in the drying shrinkage, there is a reduction in the volume of the concrete because of the expulsion of the capillary water which is present and it also improves the workability of the mix. Talking about the alkali silica reaction, so, what happens here that we have alkali from cement and then we have silica sometimes we also have some carbonate aggregates. So, it is either alkali silica reaction or alkali carbonate reaction. So, we can have silica and carbonate from some specific aggregate type.

Usually, the aggregates are more inert in nature, but some of the aggregates can have active minerals. So, it is important that in order to in order for these reaction to happen, you should have active minerals present in the aggregate. So, when these active minerals react with alkali from this cement this alkali can be in the form of sodium and potassium metal ions or it can be in form of because of the presence of calcium hydroxide also. So, it reacts with the alkali of cement and it produces a gel. So, this gel which is produced in this process, it has a tendency to absorb water.

Now, since this has a tendency to absorb water, because it absorb water the volume increases which further leads to cracking in the concrete, so, this is about the alkali silica or similarly, if we have carbonate then alkali carbonate reactions and the use of metakaolin can reduce such reactivity.

Now, the problem is again related to metakaolin is that the cost is high and we also need to have the presence of this special clay mineral or kaolinite for the production of metakaolin. So, in case we have a project site where we do not have the presence of such minerals, then it will not be very beneficial to transport metakaolin from some other location and use it as a replacement of cement.

So, let us stop here today and we have few more discussions to do in this topic on cementitious material and we will continue and we will try to complete our discussion on these topics in the next class. Thank you.