Advanced Concrete Technology

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Lecture – 20
Mineral admixtures – Part 3

In the last lecture, we discussed general characteristics of concrete when cement is replaced with the mineral admixtures and some potential benefits the concrete can obtain when it is replaced partially when cement is replaced partially by mineral admixtures. We also talked about some methods of looking at the structure of the mineral additives and understanding their typical pozzolanic reactivities. Then we started talking about how fly ash can be collected in thermal power plants by the means of electrostatic precipitators and the fact that you also get these days super classified or fly ash that is highly super classified in terms of the particle and you can actually grade the specific characteristics of fly ash with respect to the particle sizes.

So, these days you get increasingly fine particle sizes of fly ash which sometimes in some markets are also sold as competitors to silica fume which is a much finer cement replacement material. In general we know that fly ash is used as a mineral admixture or cementitious replacement in concrete. But there are some cases where fly ash can also be used as filler. So, for instance, if specification does not allow you to use a cement replacement material, very often construction companies or concrete produces tend to use fly ash as the replacement partial placement of the fine aggregate of the concrete.

In one of the projects in Chennai there was a need for concrete to be produced with very low chloride ion permeability. Unfortunately the specs also said that you are not permitted the use of any cement replacement materials in this case. But the issue is rapid chloride permeability test is heavily in favor of concrete systems that incorporate mineral admixtures. So, especially if you have silica bearing mineral admixtures like fly ash or slag; you get very good performance in that test. So this concrete producer now is in a dilemma because they cannot use a cement replacement material to get ordinary Portland cement to perform at that level of durability which would mean that you need to go for a very high grade of concrete. That means totally your economy would be lost asyou have been asked to only produce M30 or M40 grade concrete. But to satisfy the durability criteria you may have to actually go up to 60-70MPa. So, the solution proposed was that they could use fly ash as a replacement for the fine aggregate.

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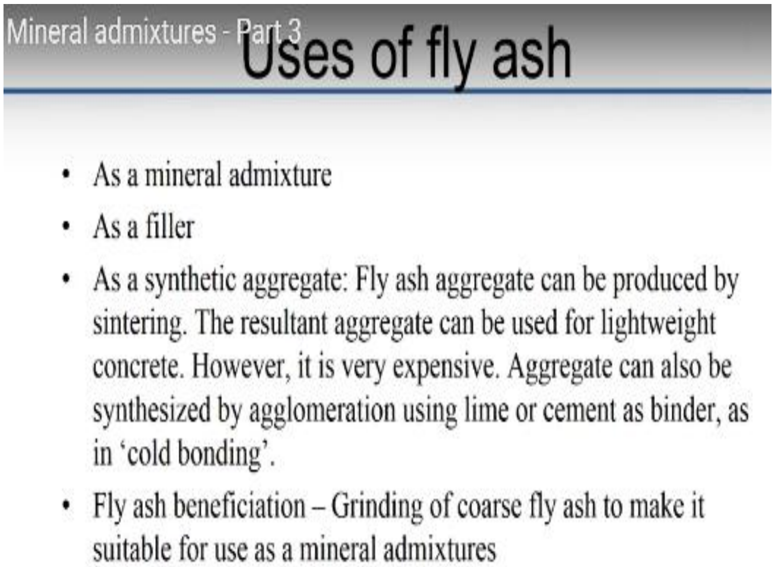

So, that way they had fly ash in the system but they were not showing it as an additive or a replacement of the cement. So, they still had the same quantity of cement as they had at the control mixture but all they did was they replaced part of your of the aggregate with fly ash and this led to a performance that was as expected in terms of compressive strength as well as durability.

So, fly cash can be used as a filler but in some cases especially the high performance concrete or high strength concrete when we need additional cementitious material, we do not want to replace the cement because requirements for strength are quite extensive especially in the early ages. Because of that the fly ash can be used as filler or an additive over and above the quantity of cement that we already have in the system.

The other use of fly ash is as synthetic aggregate. These are done by sintering the fly ash particles that are pelletised. So in a drum, fly ash is made to mix with a little bit of water and also sometimes a pelletising agent like clay can be added to give sufficient cohesive characteristics of the particles to ball up into coarse aggregate sizes. Then these particles which are pelletised are put in the furnace and burnt at a high temperature around 1000°C. At that, the silica and alumina in fly ash they get sintered; that means that you form a ceramic bond.

The sintered flyash particles form a very nice lightweight aggregate. Sometimes if you have type C fly ash, which is high calcium fly ash, you can even form these aggregates by simply pelletising and then curing just like you cure a normal concrete because then you end up forming CSH with these pozzolanic cementitious systems, and that process is called cold bonding as it happens at regular temperatures. We also talked about the fact earlier that the cold fly ash does not fly out and it is collected at the bottom of the boiler as bottom ash and ultimately it is mixed with the ash that cannot be used later and then dumped into the pond as pond ash. This ash which is coarser in nature can also be ground much finer in the hope of making it more reactive or probably as filler. That process is called fly ash beneficiation; that means we simply do additional processing of this material to ensure that we get some performance characteristics out of it.

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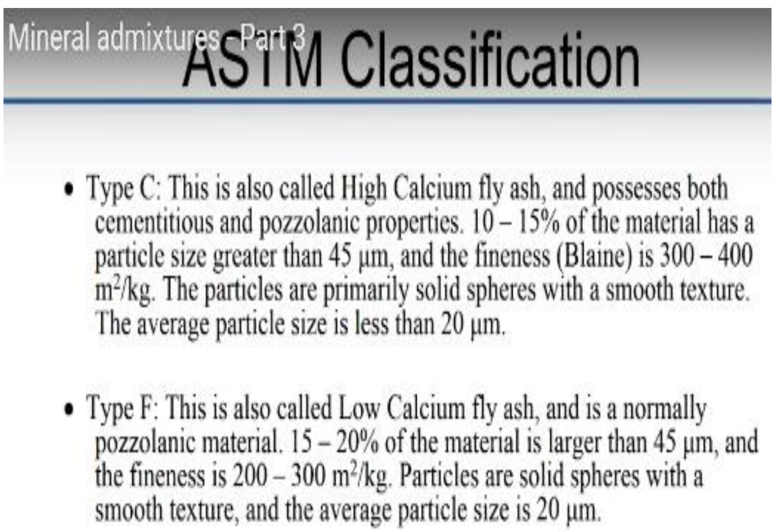

As per ASTM classification, fly ash is classified as type C and type F. In India we typically classify fly ash in terms of high calcium or low calcium, which essentially means the same. Type C is high calcium and type F is low calcium fly ash. However, in India we would not call the fly ashes that type C or type F because the classification system as type C and type F are based on ASTM.

So, type C is high calcium fly ash. It generally has around 10 to 20% calcium oxide and because of that significantly high proportion of calcium oxide, it possesses both cementitious and pozzolanic characteristics. So, in terms of particle size there is not much difference between type C and type F fly ash and probably even cement. Most of the particles of flyash are in the range of cement.

So, you have 10 to 15 % of material will be retained on a 45 microns sieve. That means nearly 90% of the material is finer than a 45 micron sieve which is very similar to what cement typically contains. The fineness is typically represented in terms of Blaine air permeability and that works out to be about 300 to 400m^2/kg, in the case of fly ash. In class F fly ash sometimes you may get a smaller particle size but that again depends on the efficiency of your collection from the ESPS. But for the most part, the type F and type C fly ashes that you get in the market would essentially be of the size range which is quite similar to that of cement.

In both cases particles are solid spheres with an average particle size of about 15 to 20 microns. So, this spherical particle shape of fly ash is what essentially helps it in providing better workability in a concrete system. Now that I have said that I will also add one more aspect to that that very often in the laboratory when we actually do the replacement of cement with fly ash, depending upon where the fly ash has been collected, we often find that the workability is actually reducing and not increasing.

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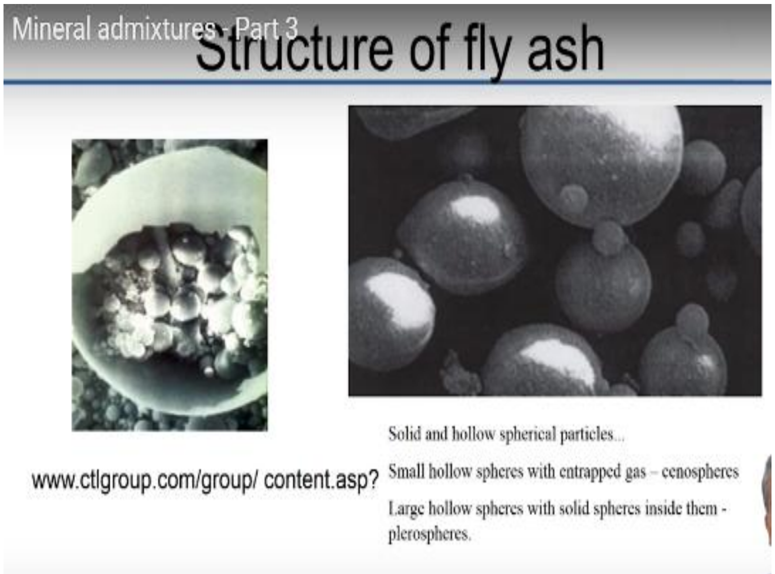

But based on the shape of the particles, we expect the fly ash to have better workability in the concrete system. So, as shown above, the fly ash particles are spherical particles; some are small and some are large and in some cases you can get extremely large spherical particles also, which have a collection of smaller fly ash solid spheres inside as shown in the left side image. That is primarily because fly ash is flying out with the flue gas and there is some condensation which is happening along with the flue gas and that leaves a formation of this hollow glassy spheres which can contain some solid particles of silica of fly ash based silica inside this. So, these are the solid particles of fly ash inside a larger glassy, almost a hollow spherical particle of fly ash.

So, based on this there is a lot of classifications that are done for the type of particles. The small hollow spheres with entrapped gas are called cenospheres and large hollow sphere as shown in right side image are called plerospheres. So, you have 3 types of particles inside; one is the large hollow spheres which contain the solid silica sphere, which are essentially the reactive fly ash particles and you also contain small hollow sphere which are called cenospheres. These days most of the companies that are supplying fly ash are also trying to actually collect the cenospheres separately because you can sell the cenospheres as a lightweight aggregate. The third one is plerospheres.

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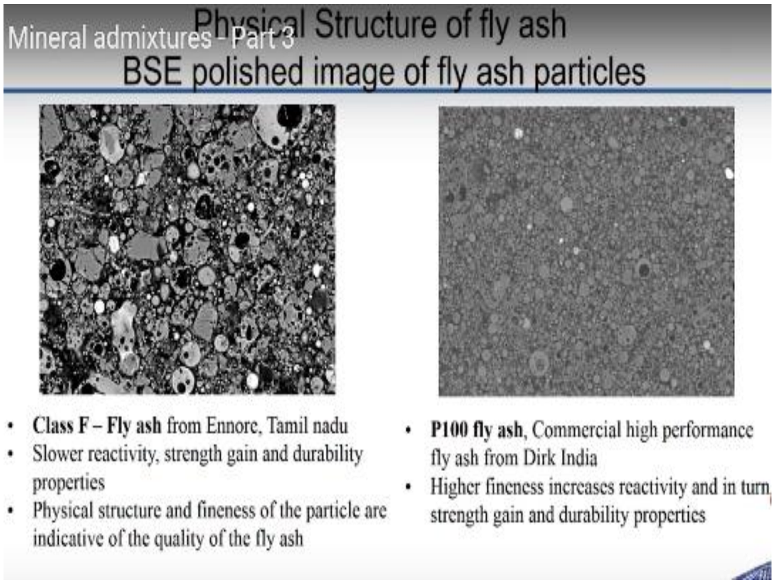

This is an image of fly ash particles which is not from a secondary electron image; that means we are not seeing the morphology. But we are rather seeing a polished section of a collection of fly ash particles together. What I want to show you in this picture is the difference between a fly ash that is simply collected from the thermal power plant versus fly ash that is actually collected and then processed.

On the left image, is a class F fly ash from Ennore which is northern part of Chennai in Tamilnadu and essentially you can see the kind of particles; there is a lot of these hollow spheres, and there is actually a hollow spherical particle where the glass on the surface has been broken. There are smaller solid particles also which are the ones which we really need for better reactivity. On the right hand side is a P100 fly ash which is actually a commercial high performance fly ash which is manufactured or rather processed and sold from Dirk India which is actually now owned by Ambuja cements. You can very clearly see the extent of smaller particles, which are present in this case, are much greater than the extent of smaller particles that you see from the fly ash that is randomly collected from the thermal power plant.

So, what I want to point out with this is that very often the kind of fly ash that you find at ready mix concrete industries the fly ash that they store in their silos is of this type which is the bulk supply from the thermal power plants. Now this is the reason why a lot of RMC when they use fly ash the characteristic the quality of the concrete is sometimes difficult to maintain at a very specific level. In other words, there is a very large variability in the properties that is brought about by the use of this as collected fly ash. But the processed fly ash on the other hand is the one that behaves the same way irrespective of where you are applying it. The problem obviously is you spend a lot more money in trying to get this processed fly ash.

Very often, because we typically take fly ash as being a material that is available free of cost except the transportation charges that you can pay for it, sometimes we are not willing to pay additional costs for the processing. So, unfortunately this creates a condition where you have the possibility to choose between an unprocessed or a processed fly ash. If the economical consideration are actually driving your project, then you will end up choosing the unprocessed fly ash and having a much more variable concrete mixture throughout your construction project. In the west there is no such thing as an unprocessed fly ash you actually get everything in the form of a processed fly ash.

Dirk India they sell different types of fly ash as P63 P100 and P500 which are increasing in the levels of fineness of the fly ash products. So, you get smaller and smaller particles as you move from P63 to P500. This enables a concrete producer to do is use a combination of characteristics that are required to produce specific types of concrete. For example, we are currently doing a project in our lab which deals with the production of high performance grouts. So, these grouts are intended to fill up the post tensioning cable strands. So, the post tension strands you know that after you put the strands, when the sheeting is there, you need to cover that area properly otherwise the strands will be liable to corrosion.So, if you do not fill up that space well with the grout, it can create a lot of problems in your prestress concrete. So, you can produce it with particles which are a very small sizes so that they can flow long distances into the sheathing and fill up the area around your prestressing strands.

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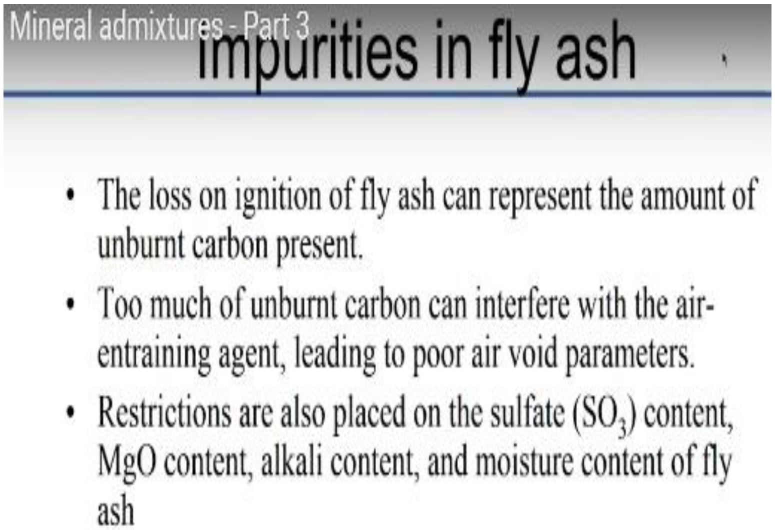

Very often people, when they use unprocessed fly ash, complain of some black coloration on the surface of the concrete and that black coloration indicates that there is a significant amount of unburned carbon that maybe still present in the fly ash. Now we know that fly ash is obtained in a thermal power plant; so the coal is being burnt off and some very small particles of carbon may fly out with the fly ash and get collected in the ESPs.

So when you are actually using fly ash for your concrete you need to first conduct a loss on ignition (LOI) test to determine the extent of unburnt carbon that is present in your system. If the LOI is too high, then this unburned carbon can actually create a lot of problems. Not just aesthetic problems of coming up to the surface and causing discoloration, but it can also lead to interference with the air entraining agent and leading to poor air void parameters. In terms of hydration there is not too much data on what unburnt carbon does to the actual hydration characteristics of the cement. But in general people have associated the unburnt carbon presence to lowering the strength characteristics of the concrete with fly ash.

So, this is something that needs some degree of control which is what the processing is able to bring about also. The other aspects to look at, is the sulfate content because sometimes coal may have some sulfates which can get into the fly ash, magnesium oxide content, alkali content and moisture content of fly ash. And of course if you remember we had this discussion with the person in the cement plant.

Pet coke can actually bring in lot more sulphur in your mix. So if you are trying to use the ash that is generated from the cement kiln, you need to be very careful about how much sulphate that is actually going to bring it into your system. Fly ash is typically from thermal power plants; if you are burning coal you are not going to get that much of Sulphur in the system.

The moisture content of fly ash can also be significantly high sometimes, especially in the final stages of cement manufacture when you are doing the blending with the clinker and grinding. We have discussed that there was some excess heat from the kiln process that was actually supplied to even drying up this moisture from the fly ash. So, that is also an important part of the final grinding stage. Because this moisture in the fly ash can otherwise interfere with the kind of grinding that we want between the clinker and the fly ash particles.

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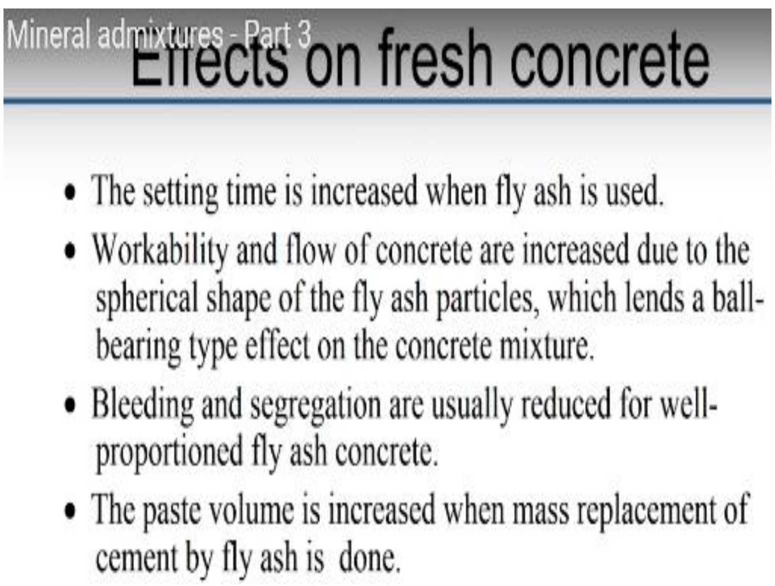

The effects on fresh concrete properties you when we use fly ash as cement replacement are lowered rate of reaction and because of it setting happens much slower. The workability and flow of concrete are increased because of the spherical particle shape of fly ash particles.

And essentially the spherical particles are acting like ball bearings increasing the flowability of your concrete. Again I say this with a caveat that you actually have to test it to find out whether you are actually getting this effect or not. Very often we have seen the opposite effect of having reduced workability when cement was replaced with fly ash. That sometimes happen when you are not very careful about where you are collecting your fly ash. Because even in a thermal power plant like I showed in the previous picture,

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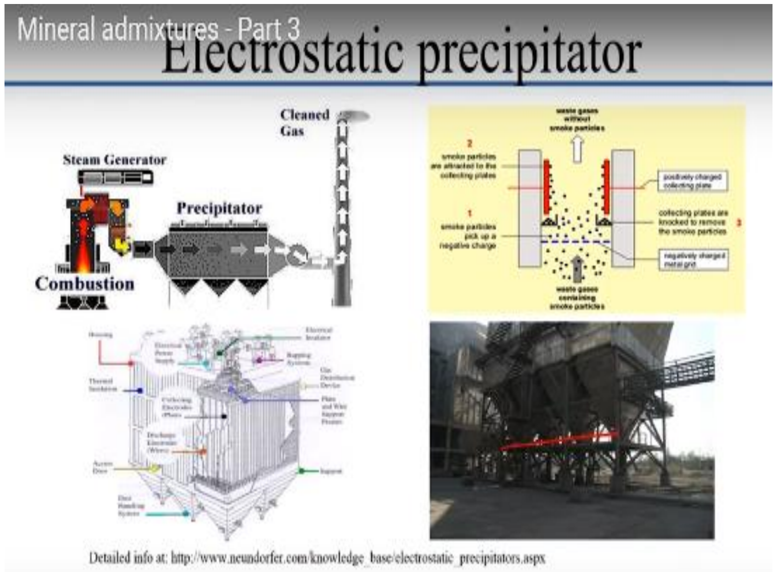
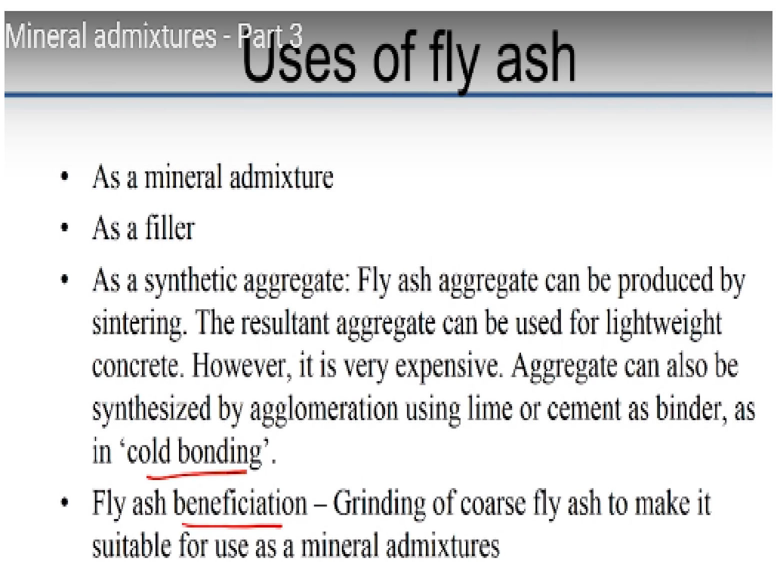


you can actually have several stages of collections. As you see there are 4 ESPs in a row here in this thermal power plant and depending upon which ESP you are taking your fly ash from, you will get a mixture of coarse or fine particle characteristics. So, again that is something that you need to qualify properly to get the best material for substitution of the cement **(Refer Slide Time: 19:21)**



Bleeding and segregation are usually reduced for well proportioned fly ash concrete. Because again what you are doing here is replacing cement with fly ash; fly ash has a lower specific gravity. So, the specific gravity of fly ash is typically about 2.2 whereas cement has 3.15. So, if you are replacing with the material that has a lower specific gravity the overall volume of the paste is going to increase.

So, you have more fines in your system which results in an improved resistance to bleeding and segregation. So when you do a mass replacement of the cement with fly ash you are going to be increasing the paste volume and that can lead to interesting considerations; one is obviously that bleeding and segregation is going to get reduced.

But the other aspect is that the creep and shrinkage of concrete are dependent on the extent of aggregate that you have in your system. So, the amount of paste that is there in the system is the one which is going to shrink or creep when a sustained load is there. So, when you have greater amount of paste there is a good chance that you may get higher creep and shrinkage.

The research data is not that conclusive with respect to that because very often we tend to design based on different characteristics. One is we design based on an equivalent strength level. So for example if I design a M30 concrete with plain cement with fly ash I will have to reduce water cement ratio slightly as fly ash reaction is slower and will be gaining strength in a much slower rate, if I use the same quantity of cement or water cement ratio So, if I lower the water cement ratio slightly and produce concrete at the same strength grade then my creep and shrinkage may not be affected significantly. But if I am just replacing cement at the same water cement ratio, creep and shrinkage will go up as opposed to plain cement.

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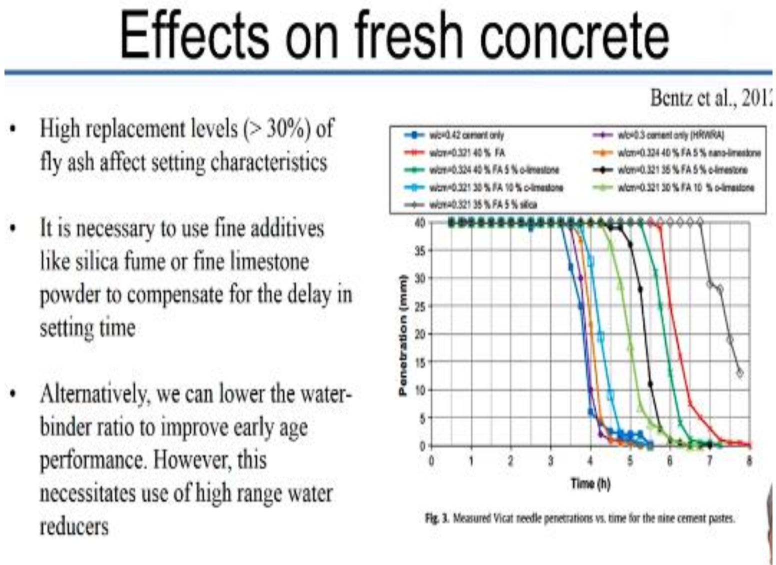

So, this is a result of a research study where it was shown that for a particular water cement ratio of 0.42 for instance, when fly ash was used as a substitution there was a retardation in the setting. All these mixes are the mixes with fly ash.

So, what this is telling you is the penetration resistance of the cement paste with respect to time and you can see that as the quantity of fly ash replaced increases, you have 30 to 40% fly ash as a replacement for the cement, as that quantity of flyash replacement is increased, the setting time also increases. You have more and more slower hydration because of which you have increase in the setting time.

So, very often what people do is to compensate for that increased setting time, a fine additive like silica fume or fine limestone can be used as a very small replacement and that can actually push your fly ash performance to more acceptable levels for example this orange and blue curves are basically with fly ash and limestone.
But to compensate for this delay in setting of fly ash often times you can use fine particlulate systems like silica fume or lime stone. Or we can lower the water cement ratio to improve the early age performance.

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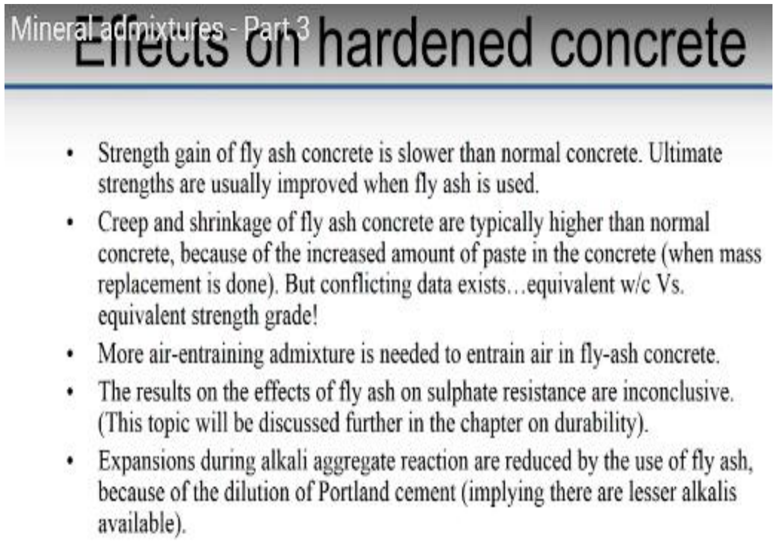

As far as hardened concrete is concerned we expect a delay in the strength gain characteristics. We talked about this earlier that with type F fly ash at 20 to 30% it will take nearly 14 to 28 days for concrete to achieve similar strength characteristics as a plain concrete. But then if you were curing for a long period of time the ultimate strengths which means that the strength beyond 28 days, 56 days, 90 days, or up to 1 year, those trends can be significantly improved as compared to plain cement because the fly ash reaction will continue to happen until there is lime available from the cement system. Creep and shrinkage are generally higher; again we discussed this primarily when mass replacement is done but there is a lot of issues with how we can actually judge the data with fly ash do you do that on an equivalent water cement ratio basis or an equivalent strength basis.

When air entrained concrete has fly ash you generally need a little bit extra air entraining agent to entrain the same quantity of air in fly ash concrete. This is because you have some carbon presence of unburned carbon in fly ash that can interfere with the action of the air entraining agent. With sulphate resistance the results are inconclusive.

And like all other pozzolanic materials the expansion due to alkali silica reaction can be reduced significantly when fly ash is used as a replacement for Portland cement because when you replace Portland cement you are reducing the alkali content in your system and if you have lesser alkalis you do not have as much potential for ASR.

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So, in specialized applications like high strength concrete fly ash can be used as an additional material. You do not use it as a replacement of cement but as an additive over and above the existing cement quantity in the cement. Roller compacted concrete is another application where fly ash usage can be quite beneficial. In roller compaction what we do is a layer of the concrete is compacted using rollers and then the next layer is build on it and so on and so forth. So this is especially used for pavements and dams. And the advantage with fly ash there is when you have 2 layers of RCC or roller compacted concrete there is improved bonding between these layers when fly ash is used. There is another specialized application of fly ash in controlled low strength material.

This is quite an interesting concept; why would we control the strength of the concrete to be low. In applications for example backfilling or trench filling applications or pipe bedding applications when you are laying a pipe inside the ground sometimes we need to spend a lot of energy trying to compact the soil around it to create the bedding for the pipe. Instead of that if you use a highly flowable material to go and occupy that volume then the pipe can be easily bedded and the advantage of this low strength material is that you can actually re-lay the pipe or recover the pipe by digging through the through this material as it is low strength. So, we are talking primarily about 1 to 8MPa strength. In these kinds of materials fly ash is typically 90 % and only 10% is cement.

So, cement you need only minimally to provide some little hydration as fly ash is mostly responsible for the fine particles in the system which provides a flowability in the system. Synthetic aggregate; we already talked about and fly ash is also used for manufacture of bricks. In fact the ministry of environment and forestries actually made it mandatory for all big manufacturing units to only use fly ash if they are within a certain distance from the thermal power plants okay. So, brick manufacturing units are increasingly using fly ash either as a partial replacement for clay or they are producing fly ash bricks that means fly ash concrete bricks to produce concrete with fly ash and simply make it into a brick shape. \

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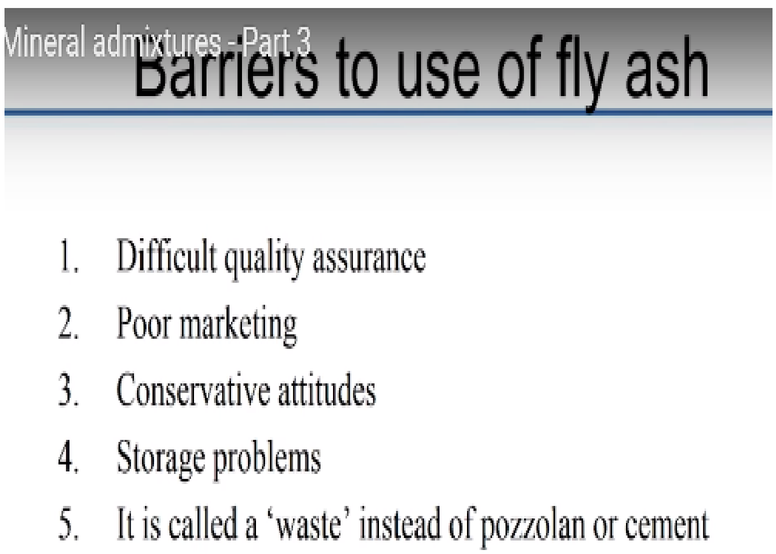

So, in spite of years and years of research of fly ash, in spite of years and years of usage of fly ash we still have difficulty in selling fly ash for typical construction applications especially when large infrastructure projects are involved. Where there are clients who are from the government very often they do not want to use fly ash, again because of conservative attitudes.

Quality assurance is one major issue with fly ash. Because you get high degree of variability in the concrete which leads to storage problems. You need to store fly ash in a separate silo and very often if you get moist fly ash how well can you use it in concrete can be quite questionable.

Marketing could be some of the reason why fly ash is not used as much we call it a 'waste' instead of a pozzolan or cement. Part of this problem will go away if we do not rely on the supplied fly ash and we only get the processed fly ash. So, there we are getting a value added product so we know we are paying a value we are paying some amount for this. So, that will bring about a slightly better attitude on the parts of people.

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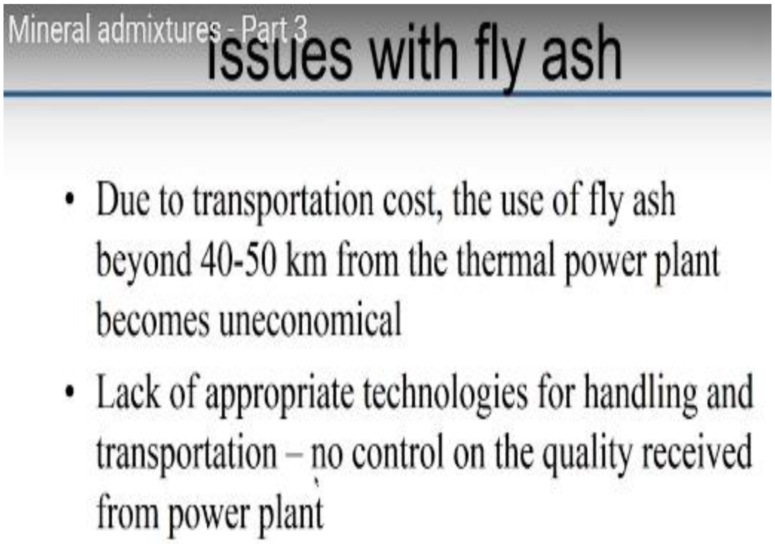

There are issues of transportation of fly ash. Whenever the fly ash has to be transported to more than 40 to 50 kilometers maybe even hundred kilometers it becomes uneconomical to use in construction projects. So, you have to look at the geographical map of the country, decide where fly ash can be useful and try to push for fly ash usage in those segments only. Otherwise transportation cost would become too high for justifying the usage of fly ash in concrete for all the difficulties that you need to encounter with fly ash as a cement replacement.

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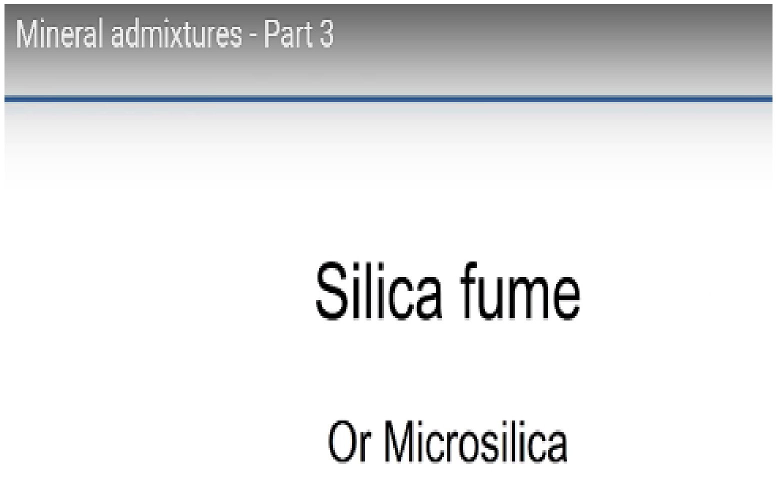

So, the next admixture that we consider is silica fume or often it is called micro silica. As opposed to fly ash silica fumes is being obtained from a very specialized industry.

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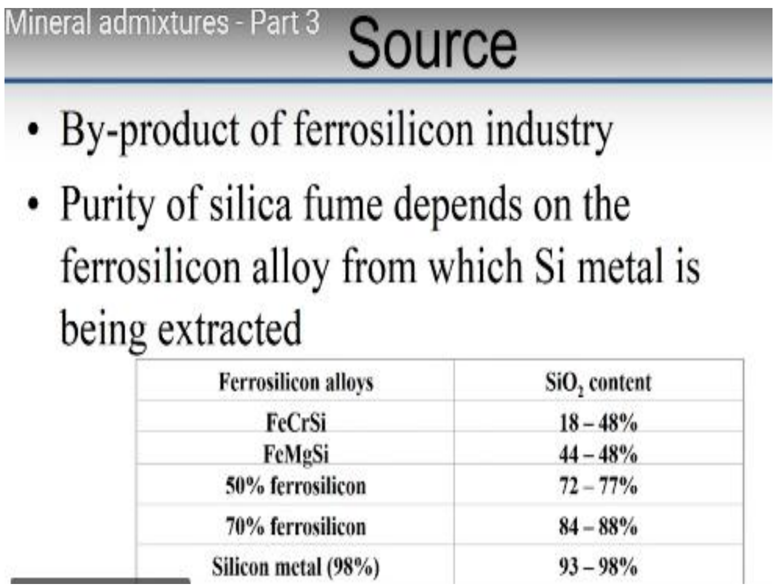

That is the ferrosilicon industry where they make silicon metal from silicon bearing alloys. So, ferro silicon alloys are actually mined and then these are processed to get the silicon metal and based on the type of alloy you can actually get different purities of silica fume. So, you can get anywhere between 20 and 100% of silica contained in your silica fume depending upon the type of alloy that you are choosing.

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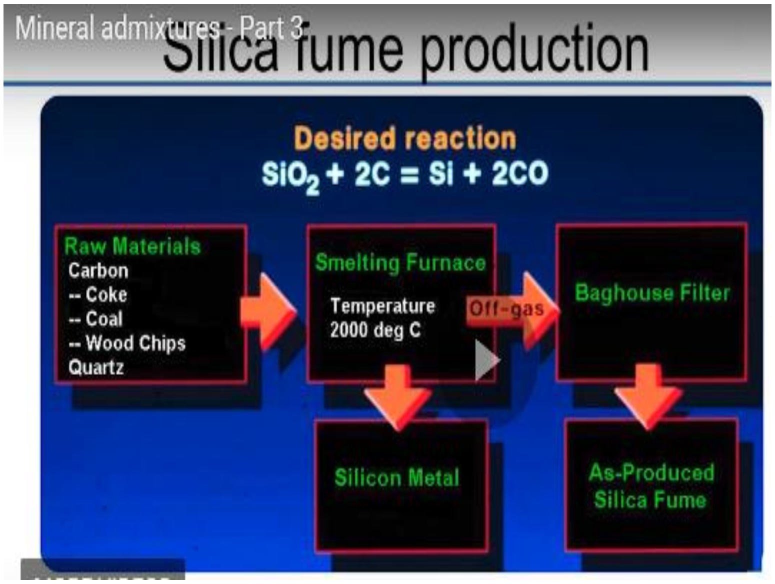

The process involves very high temperature calcinations. You have raw materials which is carbon and the quartz which are smelted together at very high temperature, 2000°C. So, this leads to the formation of silicon metal. By this reaction basically your silica and carbon are combining and the oxide is taken away by the carbon as CO, carbon monoxide and then you get the silicon metal.

But some of the silica which are extremely fine basically flies off with the off gas and it is collected in the bag house filter. That is another system of collecting very fine particulate matter just like an electrostatic precipitator. So, from the bag house filter we get the 'as produced silica fume' the particles of silica that are collected from this process.

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This silica fume after it is collected over the furnace it is transferred, cooled and trapped physically with the bag house filter. So, here this picture is showing the bag house filter and this process. So here the large pipe on the left is bringing the silica fuel to the furnaces. The vertical elements are cyclones which are used to remove oversize and other unwanted materials that are present in this system. There is a large building that is the bag house where the silica fumes is actually captured.

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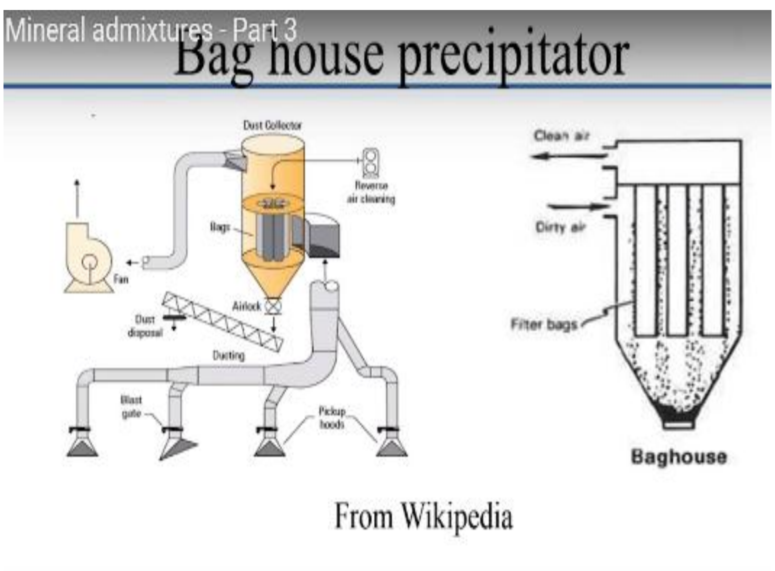

This is a basic indication of what happens in the bag house. So, the bag house as the name implies is intended for collection of fine particulate matter with the help of bags. So, these bags are actually put inside this dust collector. So you have the dust which is coming in at one end and then you have the fan which is driving out the gases at the other end. So, essentially all the dust is collected through this bag house and then it is removed and disposed in most cases.

But in this case you want to make use of the silica fume; that is why we are going to be packaging it. The problem with silica fume is that when you collect the powder as it is, it has a very light characteristic and very fine particle size, about sub-micron size particles. Because of that it becomes very difficult to handle. But now you get the primary silica fumes available in the market out in the form of condensed or dry densified silica fume.

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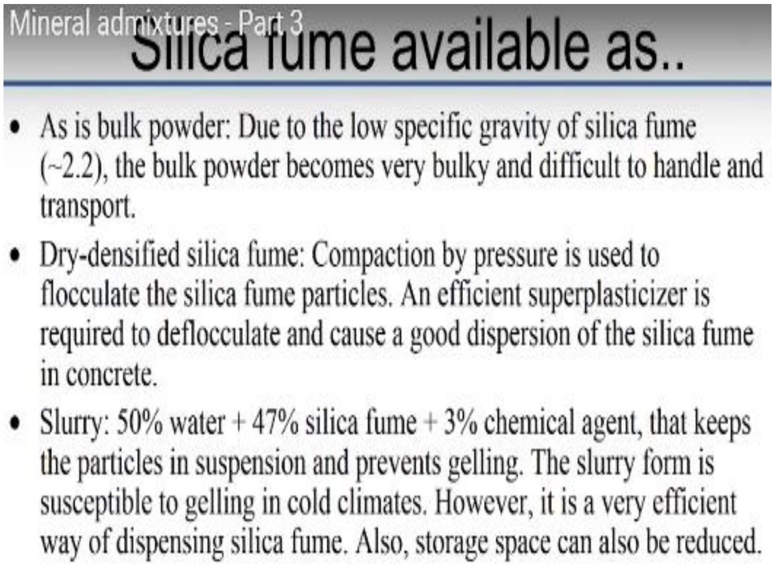

They take these fine particles of silica fume compact them in the pressure and make them into dry densified separate particles which are more like cement size particles. As a result, they can actually end up packing that better in bags and you can get silica fume in 25 kilogram bags typically. But what is important is when you mix this in concrete you need an efficient super plasticizer to deflocculate the condensed particles of silica fume and convert that into the finer particles that we really want in the system. Because the finer particles are the ones which are reactive silica which give the high quality filler characteristics. So, if you do not deflocculate them we are not going to get the required characteristic that we want. Secondly as talked about this earlier that when we do mixing of the concrete the abrasive action of the aggregate can also lead to further deflocculation of these particles. So, that abrasive action is required so that you need to mix a longer time when you have silica fume concrete. We had a discussion earlier about mixing time with concrete under RMC; typically they do 15 to 30 seconds which is really very small when we are dealing with something like silica fumes. We need at least 4 to 5 minutes of good quality mixing to bring out these particles in a better way.

In western countries, silica fumes are also available as slurry where they simply make a suspension of the silica fume; where they use nearly 50% water and use a chemical agent to stabilize silica fume in suspension. The problem with the slurry obviously is that you will have storage issues; you need to have very large tanks to store this material. And if the temperature is dropping too low then it will start jelling up this material inside the slurry. So, there is always a problem with the use of slurry but the advantage obviously is that when you use this in concrete you do not need to worry about dispersion as you have an automatic dispersion of the silica fume.

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So, here these are the different forms. One on left side top is the 'as collected' powder, and below it is the dry densified powder. So you can very clearly see the distinction in the characteristics; so in one case you have dust flying all over the place and in fact in the past, when before dry densified powders were used, there were a lot of health issues related to the handling of silica fume.

Because these fine particles of silica can get into your respiratory tract and lead to problems like silicosis and other respiratory issues. So, the dry densified form is a lot easier to **(Refer Slide Time: 37:19)**

The color of silica fume is governed by the extent of purity that it has. If it has more silica or it is more of a pur,e it will be the white quality. If it is less pure, that means of about 80 to 85% or 90% silica, it will be the grey colored silica fume. Generally there is a tendency when we use silica fume that it tends to make your concrete a lot darker as opposed to plain cement.

That is primarily because most of the standard material is of a grey shade that is a little bit darker than cement. So, when you substitute cement with silica fume you end up with a darker color of the concrete. Now that depends depends on where you are geographically; that can be advantage or a disadvantage.

In India, mostly a darker color concrete is an advantage because people think that if the concrete is light they did not put enough cement in it. If you go to the northern European countries, they want everything to be white. They do a color classification and they reject concrete which is of a darker shade than what they actually want. So, the use of slag also can be problematic in India.

Because slag leads to a whiter color in your concrete. While that is highly acceptable in a country like England where they want very nicely colored concrete surfaces, in India using slag is problematic as people are not used to the lighter color of the concrete. If you go to the northeast India where no fly ash is available, slag is very popular and they are using blended slag cement for a long period of time.