Admixtures and Special Concretes

Prof. Manu Santhanam

Indian Institute of Technology Madras

Department of Civil Engineering

Lecture -36

Mineral Admixtures: Fly ash - Part 4: Effects on hardened concrete

Effects on hardened concrete:

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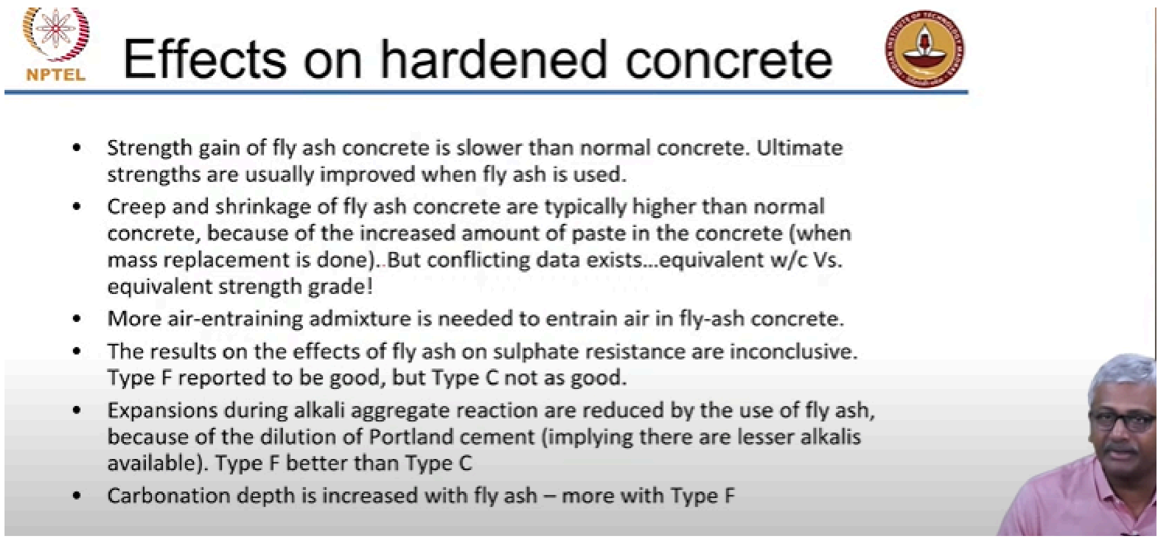

Now, on hardened concrete the effects are easy to comprehend with respect to mechanical characteristics. Obviously the strength gain is slowed down, but assuming we do appropriate curing, assuming sufficient curing the ultimate strengths are going to get improved. If you do not do sufficient curing there is no reason for the concrete to continue gaining strength. The strength gain may stop because there is not enough water available or your concrete water starts drying out which indicates that your pozzolanic reaction will not get completed fully. Creep and shrinkage again as I said there is conflicting data. We expect that because powder volume is increasing or paste volume is increasing we have a greater tendency for shrinkage or creep. However, data from research seems to have conflicting information. Some research says that yes shrinkage increased and some other research seems to indicate that there is not much difference or even a better performance is seen when fly ash is used as a cement replacement. Again you will have to be very careful about these papers where all such information is presented. You need to go into the details of how they have calculated shrinkage, how they have actually done the measurement, how they have done the mix design also is very important for you to consider.

More air entering admixtures needed to make a stabilized air void system in air entering concrete. Why is that? Because of the effect of carbon in the system. If you have carbon in your system it will interfere with air void parameters and you will not be getting a good air entering system.

Sulphate resistance again you do not get a perfectly clear performance. Now why does sulphate attack on concrete happen? We have not discussed this before but what is the primary mechanism of sulphate attack of concrete? So, we have external sulphates which are coming into the concrete, penetrating the concrete. What do they do? What do you expect sulphates to do?

The first product which is highly soluble in cement hydration products is calcium hydroxide. So when sulphates react with calcium hydroxide they should produce calcium sulphate or gypsum and this gypsum if there are aluminates present should form ettringite. So in a conventional sulphate attack the formation of ettringite in hardened concrete mind you because this is not happening in fresh concrete. This is happening when concrete is already hard sulphates are penetrating from external sources slowly converting your hydration products to ettringite. Why is that a problem? Because ettringite causes expansion and expansion in a hardened concrete system will lead to cracking. Now this is the reason why we design sulphate resistant cements as those which have less aluminate C_3A content in sulphate resistant cements is controlled to less than 4% to restrict the formation of ettringite.

Now what will happen if I substitute normal cement not sulphate resistant cement, but normal cement if I substitute that with fly ash what do I expect? Normal cement has a C_3A content of around in India about 7 to 8% or 6 to 8% if you are in the US or Europe they are close to about 10 to 11%. So this normal cement I am using for construction, but I am replacing let us say 20-25% of it by fly ash. So what will happen now? Silica will react with calcium hydroxide because pozzolanic reactions cut down the amount of calcium hydroxide available. So that means this gypsum formation is going to come down and it is going to reduce. What else will happen? Less additional ettringite may be formed, but if you think about the initial phase you are diluting your cement you have less cement available now more fly ash comes into the system so overall C_3A loading of your concrete also comes down of your cementing material also comes down. So it may if you balance your sulphate well enough it may turn out that you may end up stabilizing the ettringite in the early stages also and more ettringite in the long term may not form to a large extent because you have controlled the ettringite formation in the early stages. I will come back to this point when we discuss limestone, calined, clay cement, but essentially the use of fly ash siliceous fly ash is expected to help in sulphate attack because of this lowering of gypsum formation and also potentially lowering of ettringite formation in the long term.

But when type C fly ash is used you may not see the same benefit that is the reason why the type C is reported not to be as good as type F when it comes to protecting against sulphate attack. Now what other mechanism will you choose to protect against sulphate attack? You have chosen the use of either low C_3A or chosen the use of fly ash as a replacement. Let us say what other parameters protect against sulphate attack?

Low heat cement again chemically you are protecting, but what about the concrete itself? Because sulphates are penetrating from outside, poor refinement you need lower water to cement ratio and low permeability of the cover concrete that leads to better sulphate resistance. So if you look at the Indian standards and standards from around the world which talk about sulphate resistance, the primary line of defense is the choice of concrete with low water to cement ratio. When you have concrete with low water to cement ratio it is seen that even systems that have very high C_3A contents do not have a problem in sulphate attack. So the primary emphasis in sulphate is given to the reduction of permeability of the system. Anyway, that is a separate discussion and so on, but I thought that level of understanding was important for us to look at why blended cementitious systems can sometimes have very good behavior some other times not so good behavior with sulphate attack.

During alkali aggregate reaction the expansions are generally reduced by the use of fly ash because of dilution of Portland cement. So alkalis are generally contributed by Portland cement, you are reducing Portland cement content so dilution is happening. Secondly as I said this alkali that is there in the system gets bound within the structure of your mineral admission because of the glassy nature it binds the alkalis which is also basically like an alkali silica reaction. Your aggregates which are reactive are siliceous aggregates which have reactive silica in them. Your pozzolanic materials are also reactive silica, but the scale effects are different. Here with pozzolanic materials the alkali binding takes place very soon because of the extremely fine particle sizes.

In aggregate this alkali binding and the subsequent reaction takes place over many years and when moisture is available that leads to expansion and cracking. If these alkalis are not available to react with the aggregate and get bound by the mineral additive then you already led to an improvement in the performance. So the best way to protect against ASR is to substitute cement with any mineral additive. You will definitely see a reduction in the expansion that is happening because of ASR. Again the more siliceous the material generally the performance is better as compared to type C, but that is not the case when you consider slag. Slag also has a very beneficial performance when it comes to ASR.

Carbonation in concrete:

Carbonation depth is increased with fly ash. Why should carbonation depth be increased? What is carbonation? It is a type of concrete with atmospheric carbon dioxide. Carbon dioxide penetrates the concrete. What is going to do first? Again the first reaction will be with calcium hydroxide and what will that produce? Calcium carbonate is your lime mortar reaction. Atmospheric carbon dioxide reacts with calcium hydroxide to produce calcium carbonate that leads to hardening of a lime mortar. Your strength cane of lime mortar is basically this carbonation reaction. But in concrete which uses cement, what will this do? You start reducing the pH of the concrete because you are consuming the available lime and converting that into calcium carbonate. You are reducing pH of the system that leads to corrosion of your reinforcing steel. Now in plain cement there is a lot of calcium hydroxide available. The formation of calcium carbonate will keep happening. But in blended cement you do not have as much calcium hydroxide available. Some other calcium bearing compounds will now start having to react with this carbon dioxide. What is the other compound apart from calcium hydroxide? Calcium bearing compound. All compounds are calcium bearing. What is present in large amounts? Calcium silicate hydrate (CSH). This carbon dioxide when it does not have sufficient lime with it to interact, it will interact with CSH. That is the reaction that leads to an increase in porosity. More CO_2 is actually able to penetrate.

In plain Portland cement the reaction of carbon dioxide with the surface lime or surface calcium hydroxide leads to almost like a coating forming on the surface. You will have a coating of calcium carbonate formed on the surface because of the reaction of carbon dioxide with the external calcium hydroxide present in the cement paste. This coating forms almost an impermeable barrier and your CO_2 is not able to penetrate easily. In other words carbonation in plain cement concrete leads to densification of the surface. Whereas carbonation of blended cement concrete does not result in such densification it leads to more coarsening of the porosity. So all blended cement systems will generally tend to perform poorer as compared to plain Portland cement systems when it comes to penetration of CO_2 into the concrete. We looked at the mechanism of corrosion. When CO_2 reaches the level of the reinforcing steel it leads to de-passivation of the steel and lends it susceptible to corrosion. But the only thing there again to worry about is when that de-passivation occurs is the moisture content sufficient enough to propagate this corrosion or not. Because the moisture conditions under which carbonation is maximized are not the same as moisture conditions under which corrosion happens. Carbonation is maximized around 60-70% relative humidity but corrosion propagates only when RH is sufficiently high around 90%.

So just because blended cementitious systems allow more carbon dioxide to penetrate does not mean that reinforcement in such systems will start corroding early. It is a complicated thing to understand. We know that CO_2 reaching the level of the steel surface will lead to initiation of corrosion. But we also understand that if you do not have sufficient moisture availability you will not really get propagation of corrosion. So your blended cement may have a conflicting role in such cases. You have to really look for that evidence in actual corrosion experiments rather than just basing your material selection on the rate of penetration of CO_2. But for that to happen one needs to do more testing, gain more confidence and so on.

In the past there was a report released by CPWD based on some work that was done. I think in one of the CSIR labs that when you substitute cement with fly ash you are reducing pH. You will reduce some pH because calcium hydroxide consumption is happening. So what they said is because pH is getting reduced your concrete becomes more susceptible to corrosion. Now because of that report CPWD had banned the use of fly ash for a long time until all experimental evidence around the world showed very clearly that even if pH does reduce it is reducing to a level which is still highly alkaline. If your plain cementitious system has a pH of 13 and above your fly ash based systems are not even with 30-40% fly ash are not going to fall below 12.5. Even with silica fume which is much more reactive than fly ash which can consume much more calcium hydroxide pH levels of more than 12.5 only are reported.

So if you have mineral additives in your system pH does not reduce to a level which is dangerous for the steel. It does not and that is a big myth outside. Lot of people think that is the case. It is not correct. pH is still highly alkaline, steel is going to be protected even in a mineral admixture based system. So that is one aspect that you will come across very often in discussions. So when that line of defense went away people started looking at this fact that carbonation gets increased with mineral additives to stop the extra use of mineral additives in concrete. But again this needs to be supported by hard evidence that indeed such concrete is more prone to corrosion and that has not really been shown anywhere else, anywhere where blended cements have been used for a long time.

Applications of Fly ash:

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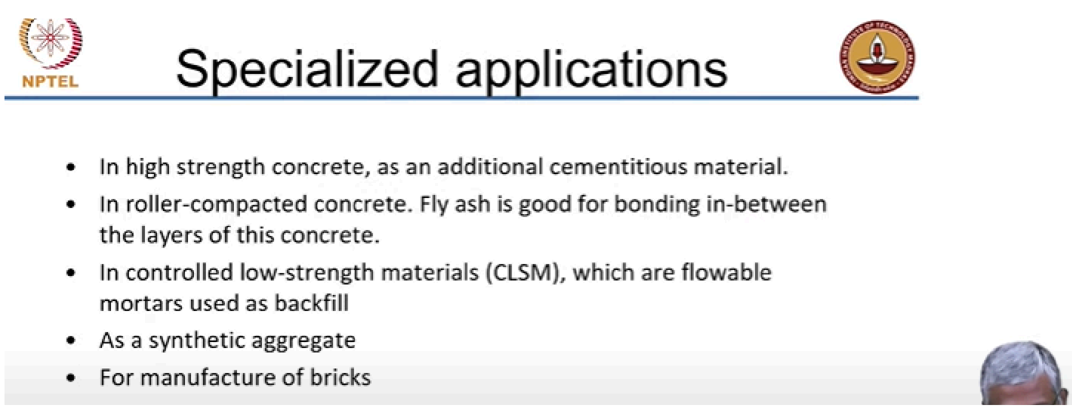

Now generally fly ash would not be used in high strength concrete because strength we are defining by 28 days strength. At 28 days you will probably not be able to see an equivalent strength performance by fly ash if you are trying to use it in large quantities. If you are using 15-20 % it is fine, but if you are going to 30-35 % maybe by 28 days you will not see the same level of strength as cement concrete. But nevertheless there have been instances where even for high strength concrete fly ash can be used as an additional cementitious material. So no replacement but you are adding fly ash on top of the cement. In most instances such systems will have a ternary blended system OPC plus fly ash plus either silica fume or metakaolin typically would be the kind of ternary blended system that you use for high strength concrete.

In roller compacted concrete fly ash is good for bonding in between the layers of the concrete. The name of the roller compacted concrete as the name implies it is a very harsh concrete mix which cannot be compacted by simple vibration. So you need to run rollers on top of it. It is highly preferred for dams and pavements. And the major advantage with roller compacted concrete is that you can restrict your cement content significantly especially in dams you have to rain because your heat of hydration can be significant so you have to cut down your cement content. So it is possible to produce regular 30 to 40 grades of concrete with cement contents of less than half of what it would take in normal workable concrete. So in such cases when you are doing layer by layer concreting the presence of fly ash is known to increase the bonding between layers and it allows the entire structural element to behave monolithically rather than having a layer type behavior.

There is also a use of fly ash in controlled low strength materials (CLSM). These are flowable mortars used as backfill. So let us say you dig a trench and you have a pipe like this which you are putting inside the trench. So what is typically done you pour soil into it and then start compacting the soil around the pipe. But this compaction can never be 100% efficient. So one way to do this pipe bedding is to pour the CLSM controlled low strength material. So it is a highly flowable material so it can completely occupy the volume. And if you have to access the pipe again you can simply dig open the concrete that is why the controlled low strength material has a strength of typically 1 to 5 MPa. When you have to have a repeated access to the pipe you will probably be closer to 1 MPa. When it is there for permanent pipe bedding you may be choosing it to go for 5 MPa. Same thing when you dig trenches for your electric cables and so on.

Our city municipalities have a habitual digging habit. Every time they start digging and in many places the dug holes have not yet been completely closed. So when they do it with soil you know that there is an immediate subsidence and driving over such roads becomes a nightmare for many people. For instance CLSM is a very good material. In CLSM we generally use a blend of 90% fly ash and 10% cement. So you do not need much cement in the system. You can maximize the use of fly ash. These are mortars or extended concrete also which are used as backfill which have a very high percentage of fly ash because you lean very less strength. So 1 MPa can be easily obtained with 90% fly ash.

Fly ash can also be used as synthetic aggregate. As I said earlier we can do pelletization of particles of fly ash and either subject them to sintering if it is type F fly ash or cold bonding in terms of type C fly ash. And again fly ash is used for the manufacture of bricks. Now this is a little bit of a policy because fly ash brick, the term fly ash brick should essentially mean clay plus fly ash which is molded and fired.

But if you go to the market and ask for a fly ash brick they will sell you a fly ash concrete brick where about 20% of cement is replaced by fly ash. It is not really a fly ash brick. It is just a fly ash concrete brick. Now of course the use of 80% cement and 20% fly ash for a brick makes the brick fairly strong. It also makes it less porous. So you get much more benefits as compared to your red brick which is not as strong. Red brick is not strong, I mean if it is not fired properly it is not going to be as strong and it is highly porous. It leads to a lot of water absorption. Such things will not happen when you use fly ash bricks.

But as a name fly ash brick should imply that clay and fly ash are molded together and then fired. I talked earlier about FALG also, fly ash plus lime plus gypsum. That is also another possibility of using a fly ash brick. So FALG bricks also are being used in different parts of the country.

Barriers to use Fly ash:

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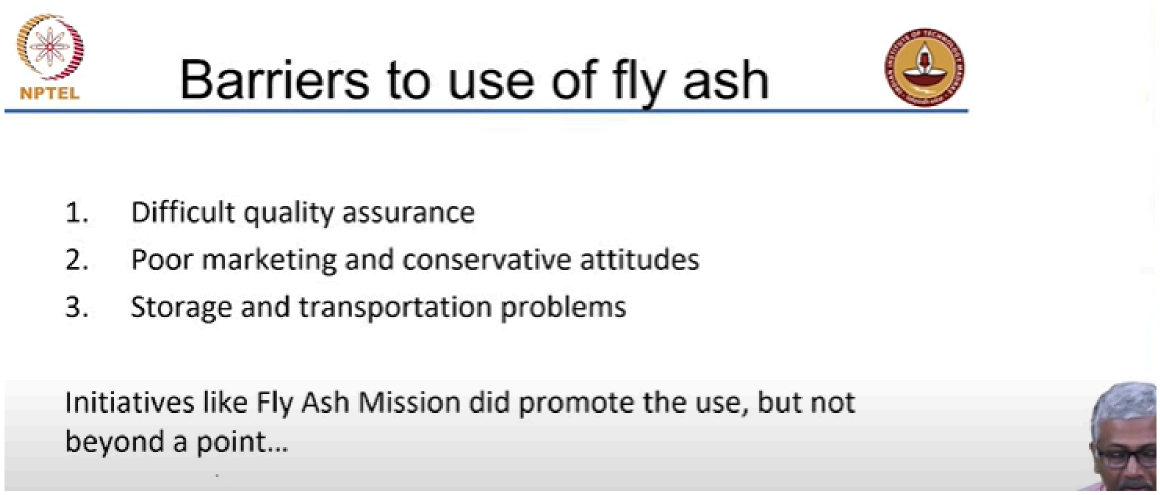

Now we have talked about this essentially quality assurance with fly ash is difficult because very often we are collecting it from sources where we do not have a control on the kind of coal that is being burnt.

Conservative attitudes, as I said, were brought about by incomplete reports like the ones that were previously used by CPWD to ban the use of fly ash. Even today the IRC and other such codal committees do not allow the use of fly ash even RDSO the railway design and standardization organization does not allow the use of fly ash in prestressed concrete members. Now why because these precast prestressed members are subjected to early strength or they require early strength gain in such systems. They think that use of fly ash will spoil that but if you look at data related to heat curing with fly ash it shows that with fly ash you can still get systems that get sufficient strength development when it is heat cured. Fly ash responds quite nicely to heat curing and because of such things there is no need to actually restrict the usage of fly ash. In fact it may bring you long term durability benefits.

Storage and transportation problems can also happen because excess moisture may be absorbed by the fly ash and you need more storage space in your RMC plants. You need to have an additional silo for fly ash storage and so on. Fly ash mission was an initiative undertaken by the government to promote the use of fly ash and that really worked well for several years. But again unless we overcome this issue of quality assurance the fear in the minds of the consumers will always be that you will not get a consistent performance with fly ash based concrete. So blended cementitious systems with fly ash are probably a lot more popular because you know for the residential market you can only get PPC these days. So fly ash is consumed significantly in making PPC.

The other aspect is that fly ash has to be available close to where you are making concrete for it to become economical. If your distance is more than 100-200 km even if fly ash is going to improve the quality of your concrete its use will be unjustified because it is going to increase the cost of your concrete. So again all these have to be very clearly worked out before deciding on the use of fly ash in concrete.