Admixtures and Special Concretes

Prof. Manu Santhanam

Indian Institute of Technology Madras

Department of Civil Engineering

Lecture -38

Mineral Admixtures: Silica fume - Part 2: Effects on fresh & hardened concrete

Water requirement and hydration:

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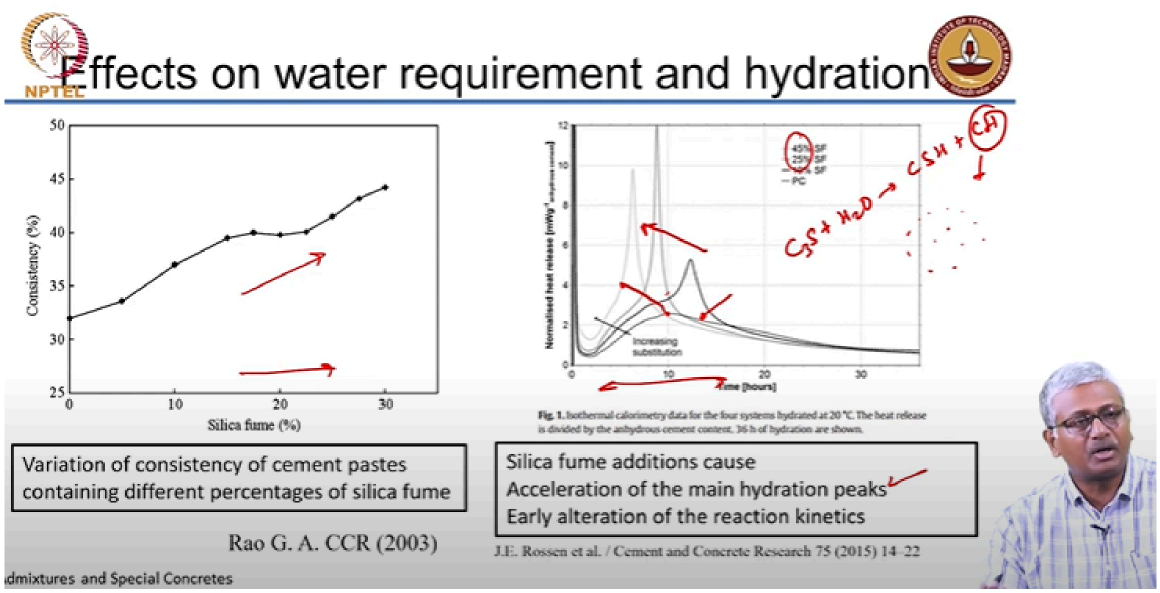

Some examples from published literature about how the consistency goes up significantly with more silica fume in your system which is expected because silica fume is much finer than cement. Your hydration characteristics studied with the help of heat evolution studies using calorimetry can also indicate what happens when silica fume is used. For instance, this is your Portland cement with increasing amounts of silica fumes. What is happening to your system? The time of your peak heat rate is shifting to the left indicating that you are accelerating your reaction.

Now is the silica itself reacting so fast that is causing this kind of reaction? Is the silica itself going to react so fast with the lime? Lime has to come out first, only then silica can react but why is this presence of fine particles of silica fume increasing the rate at which your reaction is happening? No, more surface area particles are small. But silica fumes itself may not be reacting at that point of time. It is a cement that is reacting in the early stages. We are talking about 10 to 20 hours only or up to 10 hours. In this stage only cement is reacting. So why is this acceleration in heat evolution happening in the presence of silica fumes? So what happens is when your cement is reacting silica fume particles are offering a large amount of surface area on their surfaces and availability of more surface is a good indication for your nucleation of compounds like CSH. It gets more area to settle upon and start growing.

So when you have any fine particle it matters even if you take very fine quartz and put it in a mix with cement the early hydration characteristics may seem to be getting enhanced because your CSH now has additional surfaces on which it can nucleate and grow. Crystal nucleation or compound nucleation is aided by the presence of very fine particulate matter. It turns out that when those fine particles are those of calcium bearing compounds for instance if you take limestone and use very fine limestone as substitute for cement the extent of CSH forming on these fine limestone particles is even greater than on the fine silica particles that are of silica fume. Any fine particulate matter will lead to some increase in the rate at which nucleation of CSH happens and that will cause this initial heat rate or initial rate of reaction to go up. The other thing you can realize is that now I have replaced part of my cement with something else so that means more water is now available for my cement to react. Of course dilution more water is now available so greater amount of water coverage of particles can actually happen more reaction can take place because of that also. That is the other reason why we start seeing these effects in the early ages because of the replacement of cement by a fine particulate filler.

Now of course here in a paste system you can actually do these studies with 25% and 45% silica fumes. In reality one would not be using this extent of silica fume as cement replacement. So you are accelerating the main hydration peaks and there is some alteration of the early age reactions that are actually happening in your system. But the silica itself may not start reacting. Soon the silica reacting with lime depends obviously on how fast lime is available and all these heat rates are being produced because of the reaction of tricalcium silicate with water that leads to production of CSH and lime. So now lime is getting available to react with the silica fume particles and that is when it can really start producing additional CSH. That is why we said earlier that the effective time when silica fumes are used as replacement is quite small, up to one day itself. Within one day you can start creating strengths which are similar to that of plain Portland cement mixtures or even more sometimes because of this effect of acceleration of early age hydration. So C_3S hydration is always accelerated in the presence of very fine particulate materials. Even inert materials can lead to some level of acceleration of the C_3S at early stages. .

Fineness of Silica fume:

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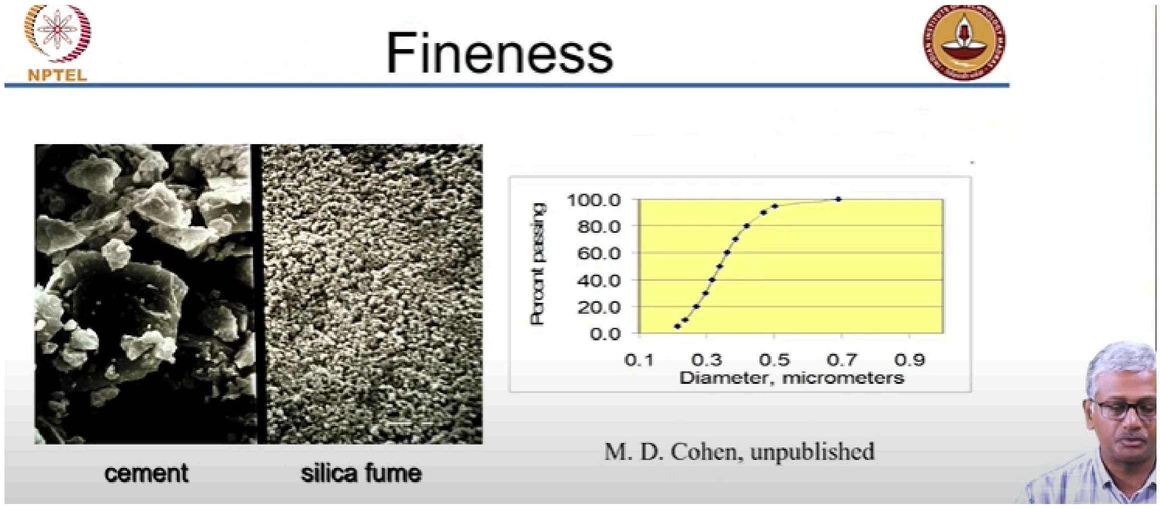

Now just to show you the fineness of these particles again this is a microscopic image comparing cement particles to silica fume particles. You can rightly imagine that particles of silica fume are much finer than cement. As I said the average diameter in this case of course in this unpublished study by my PhD guide the D_{50} is of the order of about 0.4 µm. So the percentage passing D_{50} is about 0.4 µm in cement; the same D_{50} will be about 15 to 20 µm.

Plastic Shrinkage Problems:

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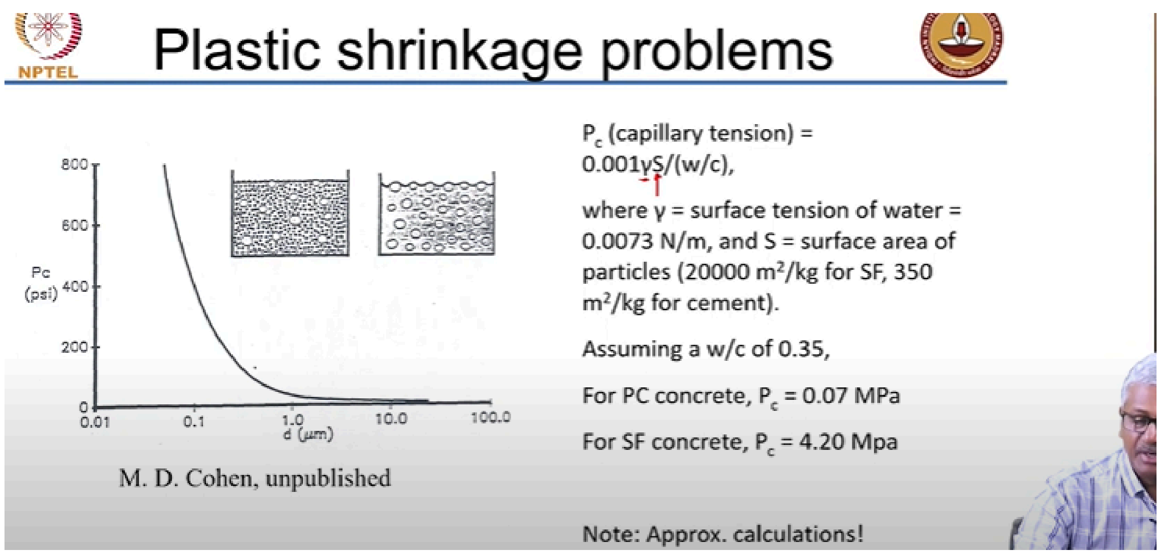

Now because of the particle size again you can imagine that the capillary forces felt between the particles are going to be extremely high. You can do this simple calculation of the capillary tension by taking surface tension of water, surface area of the particles that are available and the water cement ratio in which you are actually doing the preparation of the concrete. So assuming a water cement ratio of 0.35 the surface area of particles of silica fume at an average let us say it is 20,000 m^2/kg and cement is about 350. If you take that just for the purpose of calculation again this is not something which is perfectly accurate but what you can imagine is the extent of capillary tension because of water drying between these particles.

During plastic shrinkage what is happening is the water is drying out from the concrete. So there are a lot of fine particles available. The extent of capillary tension felt by the system because of drying out of water is going to be significantly higher when silica fume is there as opposed to plain cement being there. Again unpublished data the capillary pressure versus diameter is given. So as the diameter goes below 1 µm there is a significant increase in capillary pressure. So you need to be careful about plastic shrinkage. It has been theoretically also proven that yes when plastic shrinkage happens a cementitious mixture incorporating fine mineral additives will be more prone to plastic shrinkage problems.

Effects on hardened concrete:

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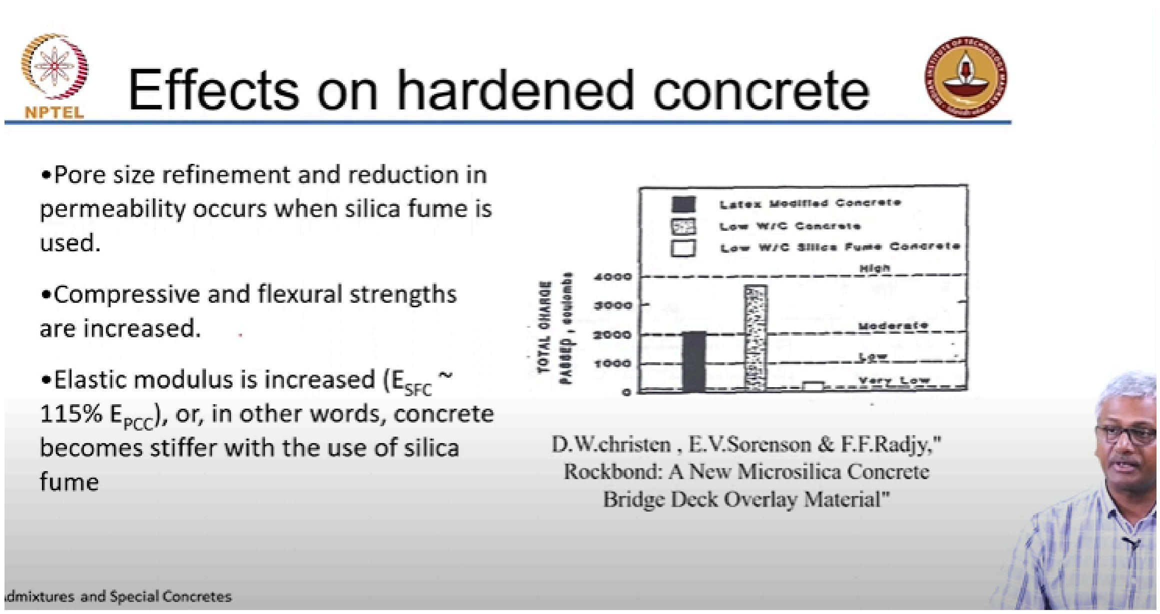

So fresh concrete what you need to worry about is how to compensate for the increased water demand by choosing the right super plasticizer, how to mix the concrete properly so that silica fume gets dispersed properly and then how to protect the surface from plastic shrinkage cracking. So those are the 3 main things when silica fume is used. On the other side after concrete becomes hard the performance more or less is very well controlled because of the refinement of pore sizes that happens when silica fume is used and the reduction in porosity the strength is increased generally the flexion strength also undergoes an increase because your why does the flexion strength also increase? I can imagine compressive strength increases because your structures with a much denser microstructure have a lot less porosity available but what about flexion or tensile strength why should that increase? What does the tensile crack resistance depend on? How does the cracking go in tension in concrete? What path would a crack take typically?

I am not talking about the inclination in a specimen but inside the concrete what path does a crack typically take compression or tension does not matter. The weakest link is the ITZ or interfacial transition zone. So here you are strengthening your ITZ and the existence of the ITZ is the reason why concrete has a poor tensile strength as compared to flexion strength but in the case of silica fume concrete your ITZ is getting strengthened densified and because of that you are also increasing your flexion strength and generally you are also making concrete stiffer about 15% greater stiffness for the same compressive strength for the same grade of concrete when you use silica fume your stiffness also goes up by about 15%.

Now this is of advantage when you are planning concrete for high rise buildings. So high rise is when you want to keep the lower stories to have a much higher stiffness because again the maximum moment is felt at the lowest stories of a high rise building. The stiffness of the material is what dominates the behavior but in general to increase that stiffness we also go on increasing the grade of the concrete. We use a very high grade of concrete to meet the demands of high stiffness but if you choose materials like silica fume you can keep the grade to a more controlled level and still increase stiffness because of the presence of silica fume. So you can take advantage of the fact that you are getting higher stiffnesses and you do not need to go for much higher grades of concrete to get that level of stiffness. So it is very important to understand that because again many people are also trying to do this today with Nano materials. There are some Nano materials like carbon nanotubes or carbon nano fibrils which are sometimes being used by researchers to show that at the same grade of concrete you can produce significantly higher stiffness values and that is an advantage because now higher grade of concrete means substantially higher cost and more cement. Why would you do that if you can actually? I am not saying nano materials will be less costly, they will probably be much more expensive but you use very small quantities of these nano materials.

In terms of durability of course this is an example presented about the charge passed in the rapid chloride permeability test. So you see here that a typical low water to cement ratio concrete is able to get your permeability levels only at the moderate level. Latex modified concrete, what is latex? Rubber basically, what rubber? What was latex admixture when we discussed it? Styrene butadiene mixture, it is an emulsion basically which is used along with the concrete. The emulsion polymerizes to form a polymer film that increases the water tightness of the concrete also. So latex modified concrete is able to down the permeability significantly but when you use silica fume concrete you get completely different levels of performance in terms of RCPT and interestingly the popularization of RCPT rapid chloride penetration test as a durability indicator was in the early 1980's around the same time when silica fume was also gaining a lot of prominence. And the fact that silica fume produced concrete with such low RCPT values that were simply inconceivable using any other material led to the company promoting silica fume also promoting the test method itself. It need not mean that you are producing durability in all possible ways but the performance of this durability test with silica fume was so much superior to any other concrete that there was a promotion of the test method by the company manufacturing silica fume and eventually obviously promotion of silica fume because of the usage of this test method on a worldwide basis.

So this test method got highly popularized thanks to the manufacturers of silica fumes. Even today, unfortunately, I do not know if we will have time to discuss the problems with this test method because this test method relies on applying a potential difference.

So this is your concrete cylinder or disc that we take. We apply a potential difference of 60 volts across this concrete and on the negative side we have chloride and positive side we have hydroxide and what we try to do is because the potential that is applied we expect that the chlorides will be driven through the concrete to the positive to the anode and because of this if the concrete is more permeable more chloride will be driven and that will further increase the current carrying capacity of the concrete. But what happens now is initially itself as soon as you apply any potential difference to a concrete there will be some charge passing through the concrete initially itself and the charge is carried by the water present in the porosity. Now the pores are not just having plain water. What are they having? They are also having ionic species. What are the ions typically present in the pore water? Alkali ions, right sodium, potassium and hydroxyl ions are typically present in pore water. When you replace cement by silica fume what will happen to the alkalis? They will get reduced because alkalis will be taken up by the silica fume and embedded in the glassy structure of the silica. So you have less alkali in the pore solution so what is going to happen to the conductivity? It will reduce. So automatically any siliceous material that you put in as a replacement of the cement will lower the conductivity of your system and automatically improve performance in your RCPT. It need not have anything to do with actual durability at all. But of course I am not saying that silica fume does not produce durable concrete. It does but the impact in the RCPT test is so significant that people may tend to believe that even with some silica which is not essentially silica fume you may still be getting this kind of an effect. So you need to be a little bit careful by looking at the results. So you have to ensure that you understand the physics of the test method and what could be the parameters affecting it.

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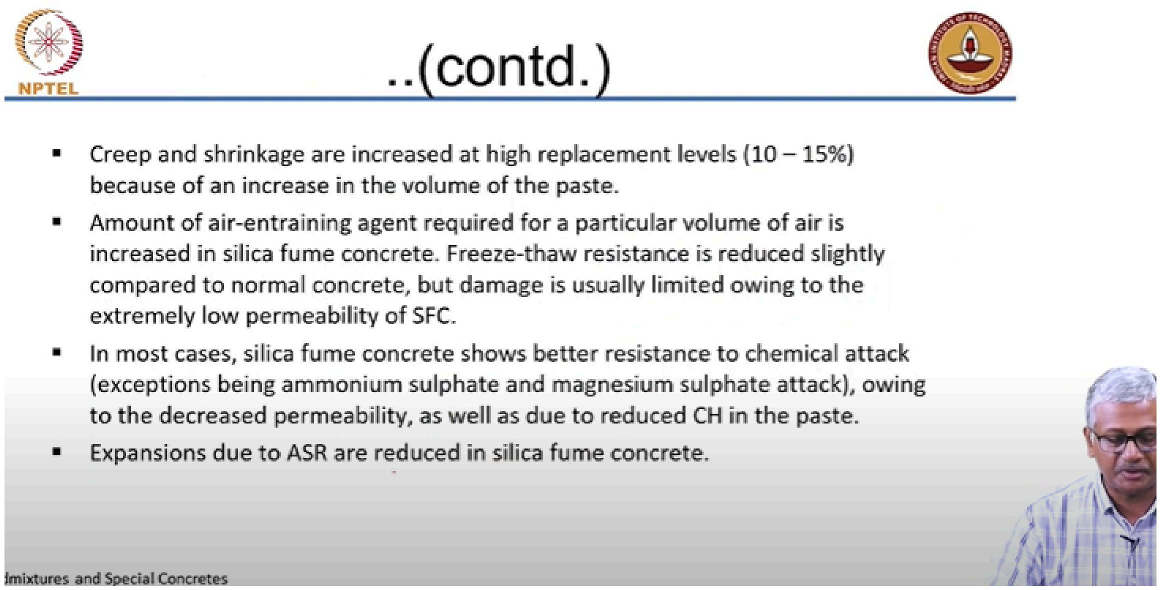

Now again it is a debatable issue whether creep or shrinkage will increase because although you are increasing the volume of the paste please remember that your concrete is also getting stiffer. On the one hand you are increasing the volume of paste but your concrete stiffness is also increasing. So any deformations because of creep and shrinkage may be compensated by the increase in the stiffness of the concrete. May be creep and shrinkage are not significantly affected. That is why in research papers you never find a very clear cut understanding of what happens when cement is replaced by mineral additives to the creep and shrinkage property.

So that also means that when you are designing concrete which has these mineral additives you need to evaluate these properties and get an estimate so that you are not using the wrong kind of coefficients that are prescribed in the IS 456. So any other design guide gives you coefficients that you use for creep. Now these creep coefficients could be quite different if your cementitious materials combination starts changing. So you need to start evaluating those things also.

Now as an air entertaining agent you may require a lot more because the stability of the air bubbles becomes difficult in the presence of such fine particles. So you may need more air entrainer. But if you really imagine if you have a good silica fume concrete which is producing extremely low permeability and very small pore sizes the water inside such pores may not freeze at all. Why should water inside fine pores not freeze? Because there is high capillary pressure, very high capillary pressure so you really need to depress the freezing point significantly to cause the formation of ice in such circumstances. So in silica fume concrete which has low water to cement ratio you may actually not get any freezing of the water at all. So freezing the resistance of silica fume concrete is usually good. It will be quite good.

Now in terms of chemical attack, sulphate attack typically you will see you are completely eliminating the formation of gypsum because you are going to consume calcium hydroxide so gypsum will not form. But further your decreased permeability of the concrete will further lead to an improved performance in chemical attack.

The main thing of course as I said earlier any mineral additive will have positive effects on the performance of concrete and alkali silica reaction. So whenever any alkali reactive aggregate is present you have to choose a blended cement issue system or a mineral admixture in your concrete for optimal performance.