Admixtures And Special Concretes

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Lecture -56

Special concretes - High strength concrete - Design attributes, fresh and hardened properties

Typical HSC Design Attributes:

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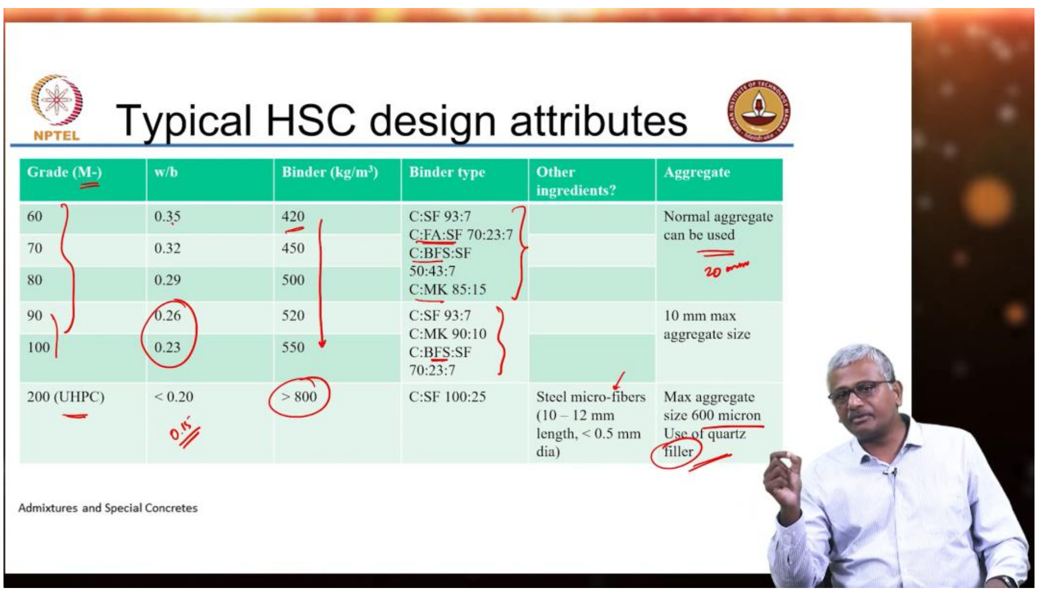

Now, this is just a table that presents typical design attributes for high-performance or high-strength concrete. Now, in most of the cases, your guidelines for mix design will help you design conventional grades of concrete up to about M55. When it comes to high-strength concrete there are no specific guidelines everything is based on trial and error. But for the most part what I have done is sort of compiled data from various sources and given a very generic idea about what could be a starting point when you go with a design mixture for these kinds of concretes. Let us say for M60 concrete with the water binder ratio 0.35 the binder content of 420 there are different binder types that can be used different binder combinations that can be used, cement to silica fume of 93 is to 7 assuming that we are optimizing silica fume usage at about 7% replacement.

10% or more can lead to a lot of problems with the workability retention. So 7% is more or less agreed upon as the upper limit in most cases or you could choose a ternary combination with cement fly ash and silica fume. You do not want to put too much fly ash in there because it is going to reduce your strength at 28 days because all these M basically corresponds to mix designation for 28 days strengths. All these strengths are based on 28 days unless your job specifies that your strength attainment is at 56 days or 90 days or whatever it may be.

For the most part, most engineering projects tend to specify strength at 28 days. So, that is one issue that can arise if you choose higher fly ash contents. That is why we have fly ash contents in the range of about 20 to 30% max being used or you can go with cement, slag and silica fume in a ternary combination 50 to 43 to 7 because you are maximizing the slag content because of its latent hydraulic properties and the fact that in most cases slag is available much finer than cement and is able to contribute to the early age strength development also. Metakaolin combinations could also be used. Metakaolin gives a slightly higher fraction of usage as compared to silica fume.

You can go up to 15% without too much of a loss of workability but then you need to be still aware of the fact that because of the clay structure your super plasticizer effectiveness can reduce if you do not do a proper assessment of the compatibility issues. When you are going to 90 and 100 you are going to very low water-cement ratios 0.26, 0.23, and like that. So binder contents are progressively increasing.

Binder contents are going up from about 420 to 550 but the purpose of particle packing is to ensure that you can get the strength while minimizing the binder content. So, this is a conventional system. If you do particle packing you may further reduce the overall cementitious content. So, again these are the combinations typically used for very high-strength mix designs. So, when you go to 90 and 100 megapascals you probably want to cut down on your slag also.

You may not want to use very high amounts of slag. Now one thing in these 60 to 80 grades your normal 20 mm aggregate is okay. But when you get to higher and higher grades you want to make the concrete as homogenous as possible. That means the range of particle sizes needs to start coming down from the upper end. You need to reduce the particle sizes at the upper end.

And that is where for very high grades like 90 and 100 you would tend to choose 10 mm size aggregate. What is happening here by 10 mm size because what we essentially end up doing is increase the bonding area between the paste and the aggregate. The individual properties also are improved. The system becomes more homogenous and you want to actually obtain failure by individual crushing of each of the aggregate particles. If you compare the failure of normal strength and high-strength concrete in normal strength you will see that when you actually break the concrete cubes the failure crack tends to go around the aggregate.

If you notice the fractured surface closely the crack would have gone around the aggregate. The aggregates would get completely separated from the paste. But when you go for such high grades 60 and above you will see that the explosive failure actually happens. The crack goes right through the aggregate. So, when you are putting more number of aggregates small-sized aggregates in the picture the crack has to go through more number of aggregate and that maximizes the strength that you can actually obtain because the paste aggregate interface now becomes a strong component because of the low water-to-cement ratio.

When you go to ultra-high performance or ultra-high strength concrete of grades 200 MPa and above you are talking about very low water binder ratios close to 0.15. I have just generically put 0.2 but close to 0.15 is what you will be using for such high grades of concrete.

Here the binder content will typically be more than 800 kg per cubic meter. The concept of your IS 456 rules stop applying in this case. You cannot start thinking about 450 as maximum cement content. It is not going to work to provide a binder like this. And what will also happen is you may want to use fillers and you will restrict maximum aggregate size to 600 microns.

Once again you are strengthening your paste to such an extent that you are failing the aggregate and if you have more number of aggregates in the path of your failure crack you will maximize the strength potential. That is why we want to reduce the aggregates to as low as possible. Additionally, you may want to use microfibers, steel microfibers. Why do we do this? Because when concrete fails cracking first initiates in the interface and then spread into the matrix. So, cracks initially are extremely small and those small cracks need to be bridged by microfibers to enhance the strength characteristics of the cement.

So, steel microfibers can help in further enhancing your strength capacity in ultra-high strength concrete and we will look at some designs later on in this chapter.

Fresh properties:

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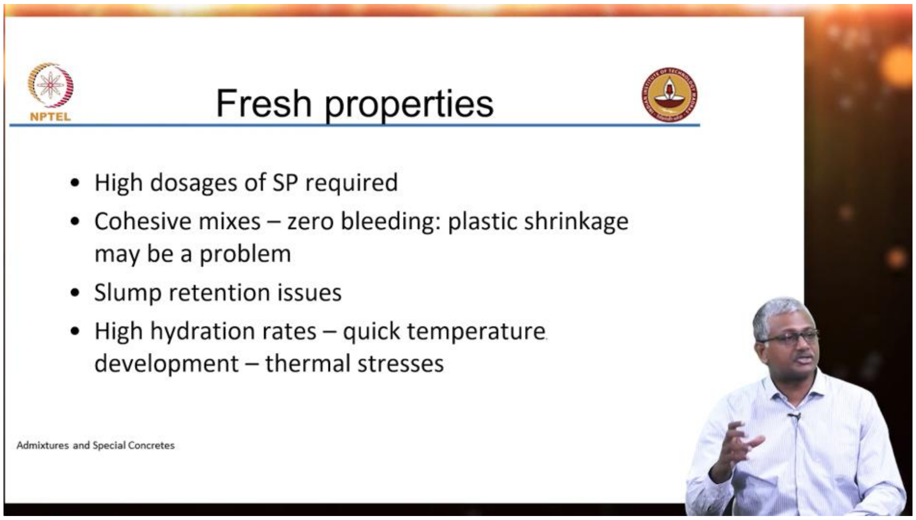

Now, it is not difficult to imagine that fresh properties of high-strength concrete are going to be extremely difficult to manage. You need high dosages of superplasticizer; you will get cohesive mixes which have zero bleeding so high-strength concrete mixes will be prone to plastic shrinkage problems. They will also be prone to issues of slump retention because water content is very low. Invariably you are using silica fume in your system or metakaolin in your system, so slump retention will be a realistic thing to live with.

And you will get very high hydration rates because of the low water-binder ratio, high cementitious content so there will be more temperature development and thermal stresses resulting from such concrete. So, one has to be aware of this to be able to design appropriate construction methodologies to overcome these problems.

Thermal cracking in HSC:

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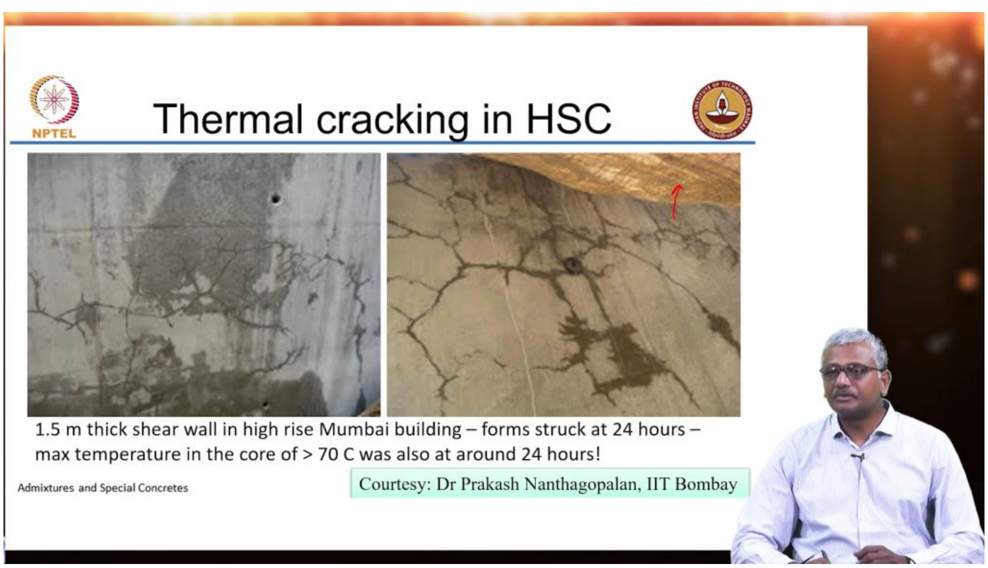

So, let us look at this specific aspect of high hydration rate. So, thermal cracking can be a very big problem in the case of concretes of 60 MPa and above. So this example is from a 1.5-meter thick shear wall in a high-rise Mumbai building. The forms were struck or removed at 24 hours. Now generally that is the tendency in most sites at 24 hours we will remove the formwork and start curing of the concrete. What really happened in this case they used a M60-grade concrete.

1.5 meters is a fairly thick section it is almost like a mass concrete anything more than 1 meter can be considered as mass concrete. In such instances what happens is the concrete which is at the core is almost at an adiabatic condition that means there is no heat exchange with the surroundings any temperature development continues to happen at the core and in this case, it so happened that with the mix design that was chosen the core temperature rose to 70 degrees or more at 24 hours and their conventional practice was to strike the form work at 24 hours and start water curing. They did exactly that in this case they removed the formwork at 24 hours and sprayed water on the surface. So what happened the surface got cooled very rapidly the core was still at 70 degrees Celsius. So, you have extremely high thermal stresses and that leads to cracking on the surface.

So, you start forming cracks on the surface. So, thermal cracking on the surface happens because of temperature gradients caused by quick cooling of the surface and retention of heat at the core. So, you can see the kind of cracks that were created they look wet obviously because of the wet curing that was done in this case with the help of this Hessian cloth you see on the top it was removed and then they saw all these cracks happening on the surface. So your core is expanding where the exterior surface is contracting because it is losing temperature. So the core is restraining the exterior surface from contracting and that leads to cracking.

So thermal stresses are realistic in high-strength concrete. So what does this tell you to control such problems what do we need to do? What would have been the strategy in this case? Wait longer for? So the formwork can be kept for a longer period of time so that the heat slowly dissipates from the core also. As the structures become larger and larger this formwork removal becomes more trickier. So we have to really plan that in fact today I am seeing many projects where this is a major problem. We saw a similar problem in the Chennai metro rail construction also recently where we were using piers of size 2.5 meters and above.

In such piers also we saw effects of thermal cracking. What else could be done? Use ice in the concrete lower the temperature of the concrete while placement. The lower temperature of concrete while placement implies the temperature rise will only take it up to a certain level and the differential between the core and the surface will be reduced. That is the first and most efficient strategy for mass concrete lowering temperature. This is very important for those of you who are going out in the field and going to be practicing concrete technology.

Convincing your bosses to put up an ice plant in any situation is an absolutely important thing because these days we are seeing massive concrete structures coming up. We need ice plants to give the flakes, ice flakes that can be put in the concrete for very efficient lowering of temperature. We will come to that again in the mass concrete chapter. So those are some strategies by which you can do this.

Hardened state characteristics:

- **Autogenous Shrinkage:**

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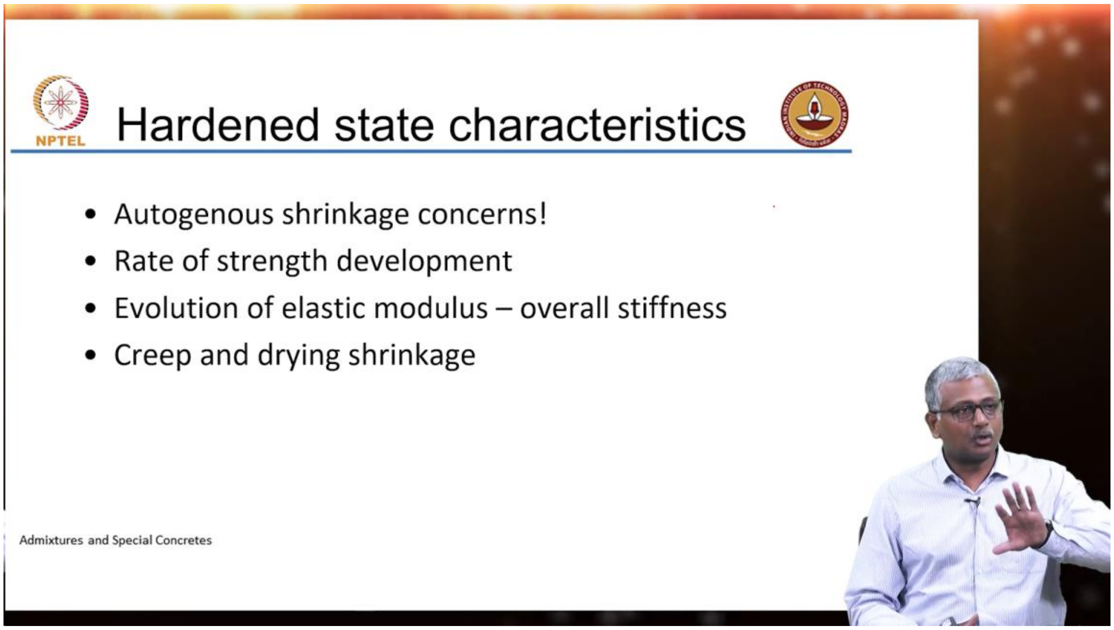

The other problem is autogenous shrinkage. Now, autogenous shrinkage is a major problem with high-strength concrete and what is autogenous shrinkage? We know about drying shrinkage. Concrete has water. This water dries out when the conditions outside have a low relative humidity. That is an obvious thing that is going to happen. But autogenous means it is shrinking from within without any drying on the exterior surface.

Even if I seal the concrete, it is still having shrinkage. And this is happening because in high-strength concrete, you have extremely low water-to-cement ratio. You have less water available in the system. So, if there is unhydrated cement available, the water has to travel through the very fine pores to reach and hydrate this unhydrated cement. So, there is something like an internal drying that actually happening.

Without the water getting lost outside, the water is internally moving and that creates this strain which we call as autogenous shrinkage. I will talk about that and then come back to the other things.

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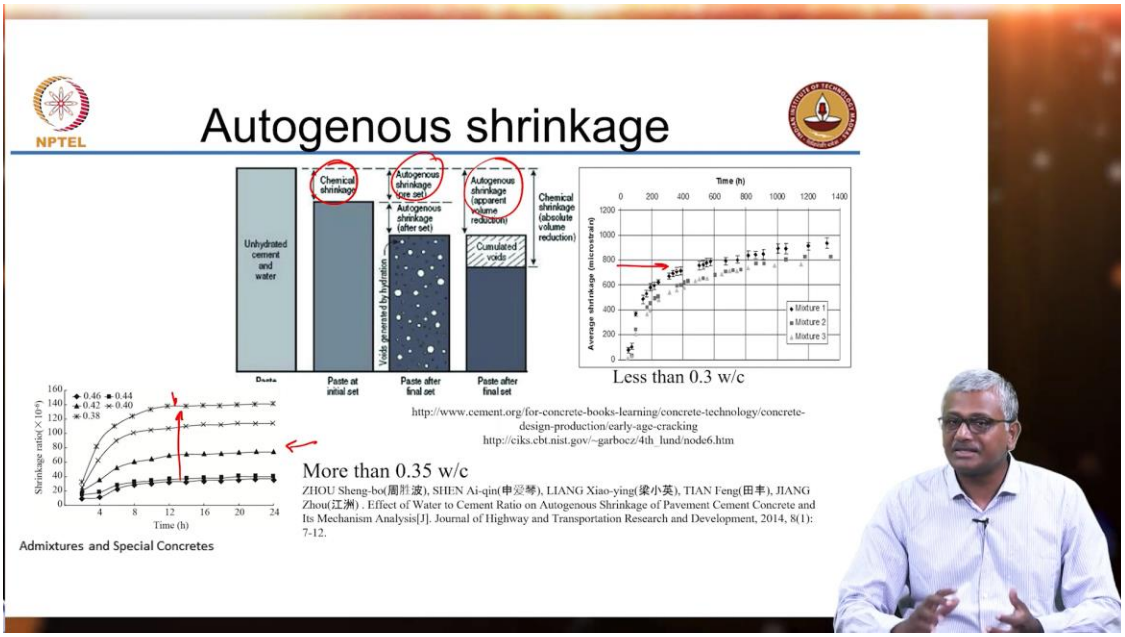

So, we have issues of chemical shrinkage which happens inevitably when cement reacts with water. The reactants have a greater volume than the products that are formed. But autogenous shrinkage is something that can be volume reduction that happens because of this movement of water within the concrete.

And this can be substantially high for concretes which have less than 0.35 water-cement ratio. In this case, there is an example of concrete which has more than 0.35 water-cement ratio. You can see that the extent of autogenous shrinkage is only about 120 or so microns.

But when you come, when you increase the water-cement ratio or sorry when you reduce the water-cement ratio, the extent of autogenous shrinkage basically goes up significantly. In the other case less than 0.3 water cement ratio you are seeing data which has nearly 7 to 800 micro strains of autogenous shrinkage that is significant, very large autogenous shrinkage. So, when you start going to mixtures that have extremely low water-cement ratios, you will have very high levels of autogenous shrinkage. So, you need to be prepared for this to understand what could contribute to early failures of your concrete system.

Now compensating for an autogenous shrinkage implies that you need to keep your concrete moist for a longer time. Your curing compounds may not be effective. You have to supply external moisture that will reduce this internal drying to a large extent. So, for high-strength concrete or high-performance concrete moist curing as far as possible should be an option to choose. But the situation gets very tricky when you go to mass concrete which is high strength.

For instance, the condition that I prescribed previously for the shear wall which is M60. Right? In that case, water curing early is going to be very difficult and most of your autogenous shrinkage will happen at the early stages. So, if shrinkage is going to cause cracking what do you need to do in a reinforced concrete structure? If shrinkage is supposed is going to be causing cracking what should you do? How do you prevent in normal concrete structures in slabs and other concrete members what is done to counter the stresses that happen due to shrinkage? Providing joints in that slab is okay. But what if you cannot provide joints what do you do? What takes care of the shrinkage? No, no. Drying shrinkage you cannot prevent evaporation of water it is going to eventually happen. You have to accommodate that through your design.

What do you need to design for? What takes care of shrinkage? In a conventional concrete, let us forget about admixtures for now. How is shrinkage and thermal effects taken care of? Reinforcement we provide reinforcement that is why even when there is no tensile requirement we provide minimum reinforcement to take care of temperature and shrinkage effects. We call it distribution steel. In such cases, when your concrete is bound to have higher shrinkage strains your provision of steel also has to increase. Now, inevitably the problems leading to cracking of high-strength concrete is not just because of shrinkage it could be also because of thermal effects.

So, all your steel that you provide should be also looking into shrinkage and thermal effects. So, reinforced concrete design itself has to start accommodating these numbers and for this you need to actually do a calculation to determine what is the possible shrinkage that can develop in these systems and for that you need to do concrete mixture design over a certain period of time to understand what are the stresses or strains that are happening because of shrinkage and thermal effects. Essentially, I am trying to convey is that when you are designing special concretes like this you need a significantly large amount of time to really answer all these questions that will ultimately feed into the concrete design to accommodate the strains because of thermal effects and because of shrinkage. You cannot expect to do a normal concrete design and then get away with it. All these problems will creep up during the early stages of your concrete need to counter these effects appropriately.

▪ **Rate of strength development:**

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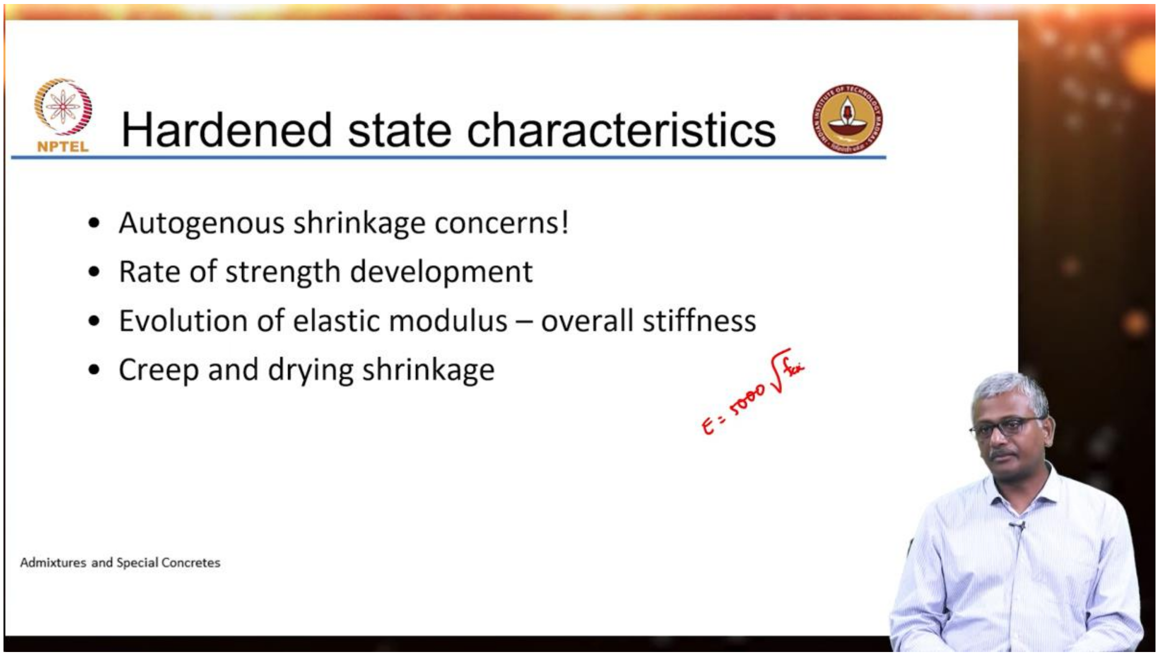

So other thing of course is the rate of strength development. You need to ensure that you are providing curing at least until the strength develops to nearly about 70% of the required strength of the ultimate strength. Usually, by 7 days most concretes would develop a strength at least equal to their characteristic strength. By 28 days, you will get the target strength or more.

So at least 7 days of curing is absolutely essential. Now, issue of water curing versus curing compound becomes a strategic decision when you go towards mass concrete structures that have very high levels of cementitious materials. In the case of dams, the cementitious material content is very less but it is mass concrete there the consideration has to be given for the fact that the temperature rise has to be prevented in all excess. You will not get autogenous shrinkage there because water-cement ratios are quite high, cement contents are quite low. So you do not have a problem of autogenous shrinkage there but in such instances when you have high-performance concrete shear walls, very massive shear walls which have requirement of extremely high strength autogenous shrinkage should be properly designed against.

▪ **Evolution of elastic modulus & overall stiffness:**

Evolution of elastic modulus and overall stiffness of concrete members. Now again your elastic modulus is what is really required to provide the deflection resistance in high-rise buildings. In high-rise buildings, the bottom story is basically you need to look at the elastic modulus also. So if you look at the tall building code they say that elastic modulus has to be specifically determined when you go for very high grades of concrete because the relationship between modulus and strength which is prescribed in IS codes what is that? 5000 square root of f_{ck} $\left(E = 5000\sqrt{f_{ck}}\right)$ that is not valid for concretes that are beyond M55. So, you have to start looking at data carefully to really arrive at this number objectively.

Creep and drying shrinkage:

Creep and drying shrinkage again have to be evaluated properly you cannot use the guidelines given in the code anymore.

All this has to be backed up by data that has been collected over long period of time. So when you start designing high-strength concrete for tall buildings as one application you have to start looking at all this data very carefully and then do a proper design of the concrete mixture.

Autogenous shrinkage- more results:

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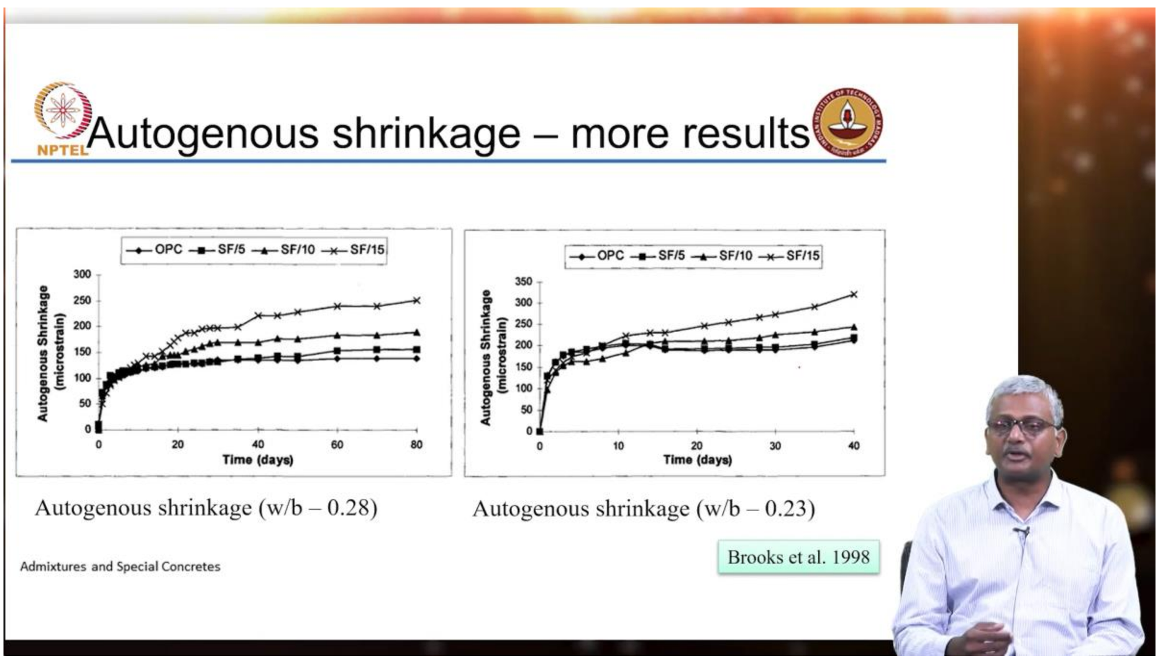

So, we will stop with this again some more results of autogenous shrinkage are presented for concretes with low water binder ratio. Again this is depending on the silica fume replacements of 5%, 10% and 15%. As more silica fume is used in the system the autogenous shrinkage levels are also going up because your pores are getting smaller and smaller so any movement of water inside will be associated with high levels of strain.