Admixtures and Special Concretes

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Lecture -26

Chemical Admixtures: Curing compounds

So, this is the last segment of the chapter on chemical admixtures. So in part 8 we looked at mechanisms of corrosion, use of corrosion inhibitors, shrinkage reducers, SBR latexes and other specialty chemicals that are added in specific situations.

Durability:

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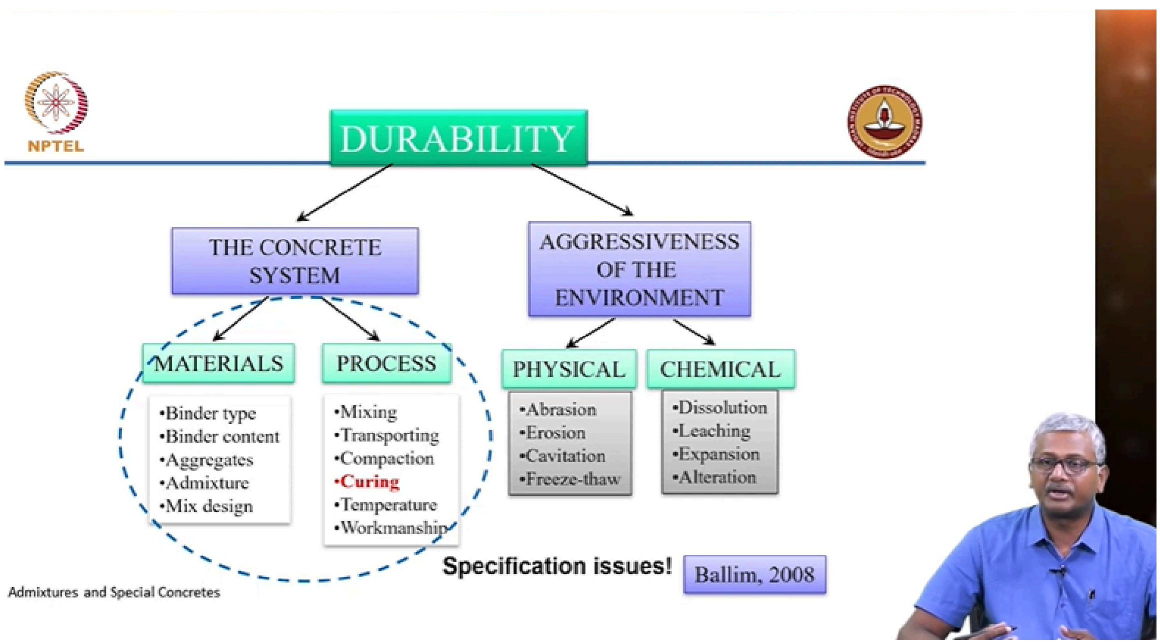

Today we will talk about the final part of the chapter that is curing compounds. Now to understand curing compounds one has to understand what impact curing has on the overall durability of the concrete. Now if you really think about durability you can separate that out into two aspects, one is the concrete system itself, the other is the aggressiveness of the environment. Concrete has to be designed specifically to undertake or to perform satisfactorily in different environments. You can have a chloride exposure environment, carbonation environment, sulphate environment and so on and so forth. Several different mechanisms can make these aggressive agents attack concrete and deteriorate concrete in one way or the other. The concrete system itself is composed of your materials, that is the different types of binders, amount of binder, the aggregates that are used, admixtures, and mix design and so on. But then you also have the process of actually manufacturing the concrete or putting it in place inside a structure that involves your entire process from mixing, transportation, compaction and curing is absolutely an important strategy to ensure that you are able to produce concrete of the right strength and durability inside the structure. It is not just enough to have good quality concrete in cubes that you store in ideal conditions but the actual concrete in the structure should also have the right kind of mechanical properties and durability properties.

Curing:

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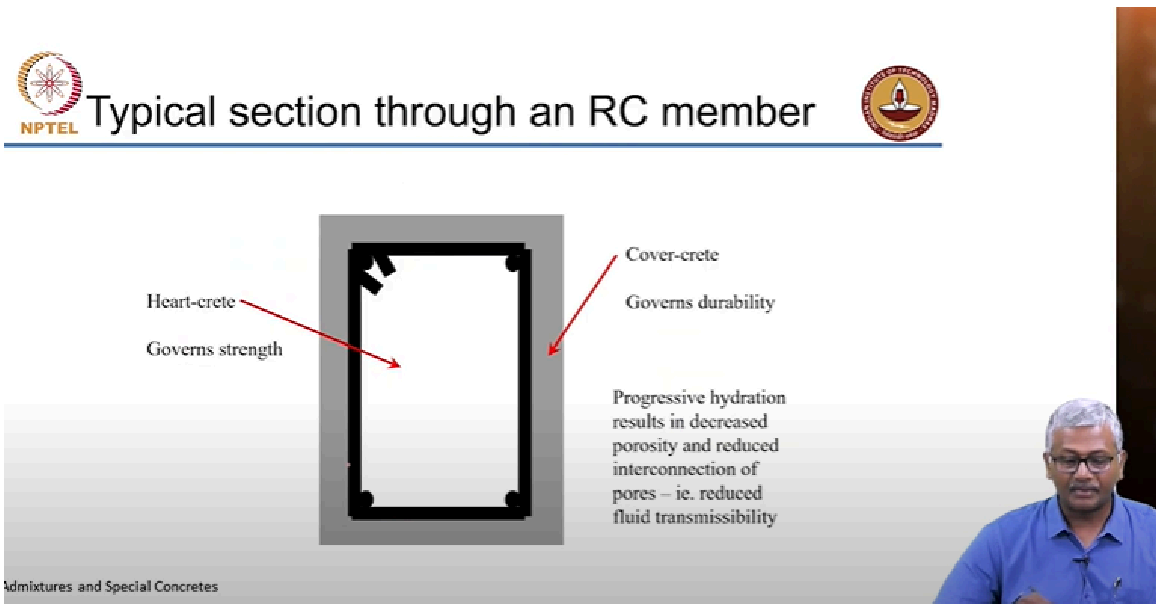

There are other aspects that can also affect the concreting that is temperature and workmanship but here our focus is on looking at curing. If you think about a typical reinforced concrete member like a reinforced concrete column for instance which is primarily working from the principles of compression. So the concrete is contributing significantly to the overall compressive load carrying capacity of the column. Now the steel also contributes to some extent but more likely the steel is there to help with any bending that may happen because of eccentricity of the load.

If the load is completely axial it is obviously concrete which is bearing most of the compressive load that is happening on this column. Now if you think about separating the concrete out into two parts, the part which is inside the steel and part which is outside the steel. The part that is outside the steel we commonly call as our cover and the cover concrete is otherwise termed as covercrete. The part that is inside is the bulk of your concrete because your cover typically depending on the environment could be as high as 30 to 75 mm but what is inside if you have a 200 x 200 mm column let us say a large chunk of the concrete will be inside the reinforcement and that you can term as hardcrete. So most of the contribution to the strength is coming from this hardcrete what is inside what is present in the large quantity and so on that is contributing maximum to the strength of your concrete structure or the column in this case.

The external part which is protecting the reinforcing steel is protecting it from corrosion so the durability is contributed primarily by the covercrete. Now when you do curing it is the quality of the covercrete that you are trying to improve. You are not curing to increase the strength of this internal part of the concrete because you cannot imagine a condition in which the water from inside will dry out. It is not going to happen because there is a sufficient amount of concrete on the outside; the hardcrete is perhaps not going to get subjected to any drying. The external chemicals that are entering the concrete are going to deteriorate only the cover region and not really the inside part.

So truly speaking if you do not do curing you are more likely to impact the you are not likely to impact the compressive strength as much you are likely to impact the durability because this is the zone the covercrete is a zone which is concerned with drying when drying of the concrete structure happens the water from the cover zone is basically trying to move out. If you do not do good curing you do not result in good hydration of the concrete on the surface. If hydration does not happen you are not going to have deduction in porosity and permeability that is typically associated or accompanied with hydration. So very important curing is done to improve quality of the cover concrete and that is the message that you have to take wherever you go many people think curing is done for several reasons if you go to the site people talk about curing being done for strength, at least that makes sense many people say curing is done to reduce the heat of the concrete. Now if concrete is hot you are pouring water in it you are doing damage because it is going to crack the concrete it is not to reduce the heat it is to ensure that concrete has a moist environment so that water inside concrete can interact with the cement and lead to hydration right. So all kinds of reasons people give you outside but the primary reason that is important from an engineering perspective is the fact that you are protecting the cover concrete making the cover concrete less permeable and that will lead to an improved durability of a concrete structure.

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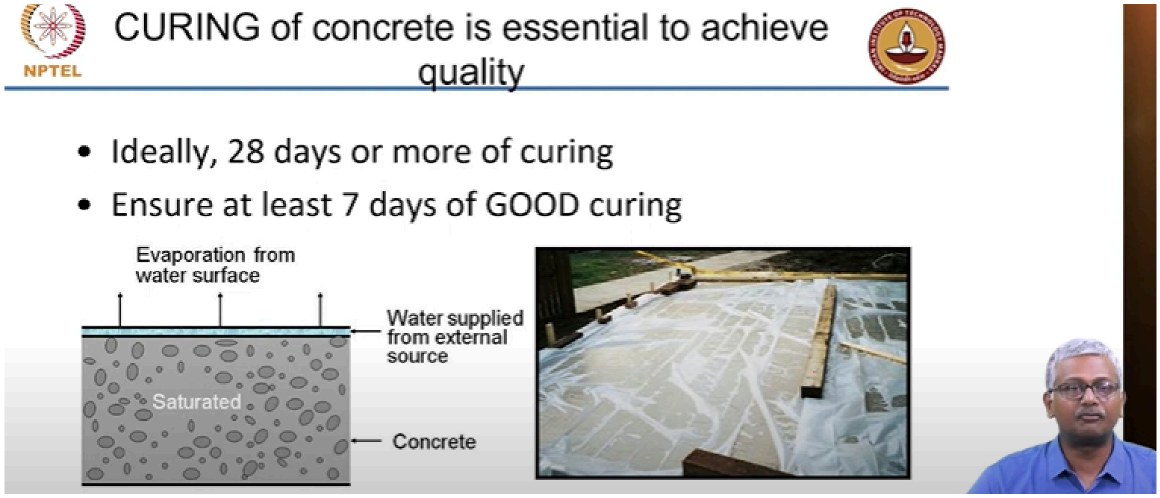

Now ideally we want as long a curing as possible 28 days or more. We do ideal curing for 28 days in the lab but in the field it is simply not something that is achievable so at least we should ensure 7 days of good quality curing right. Good curing for a slab implies you are ponding the top surface like having a water pond maintained at the top of the slab so that the evaporation will happen only of that water the water inside the concrete will not evaporate or alternatively you can cover the surface with the polythene sheet, but early on in the life cycle of the concrete structure when the concrete is not going to be water cured because concrete has just been placed or finished after that to protect the water from drying out you are not going to be pouring extra water because that may tend to wash out the surface because concrete is not fully set or hardened yet but still at this stage you can still protect the concrete by covering it with a polythene sheet very often for slabs this is a very important thing to do to protect against plastic shrinkage cracking.

Quality Curing:

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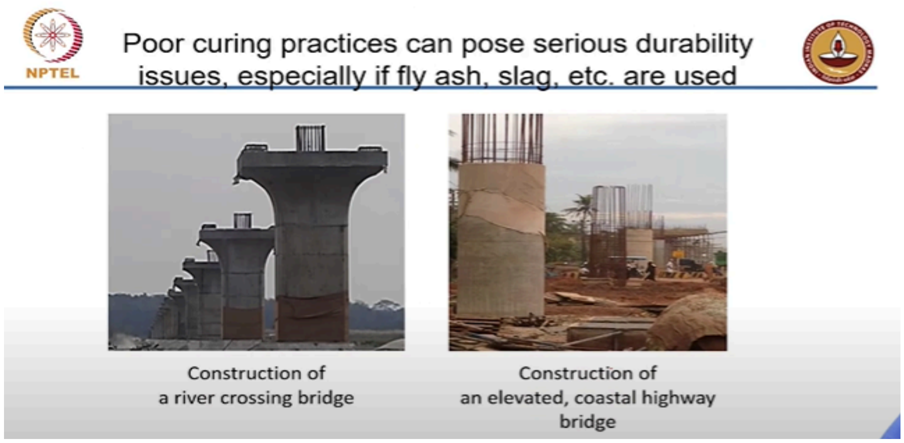

Now you can see on our sites curing quality is typically very poor you see this hessian that is covering the concrete surface but it is not at all wet it is dry completely dry and you can imagine that if it is dry there is no water supplied from the outside environment so water is going to start drying out from the concrete and you are going to get very poor curing again same story here. So when you are using hessian or jute cloth covering on the concrete surface it has to be kept wet all the time only then it will protect the concrete and provide sufficient curing to the concrete.

Long-term Curing:

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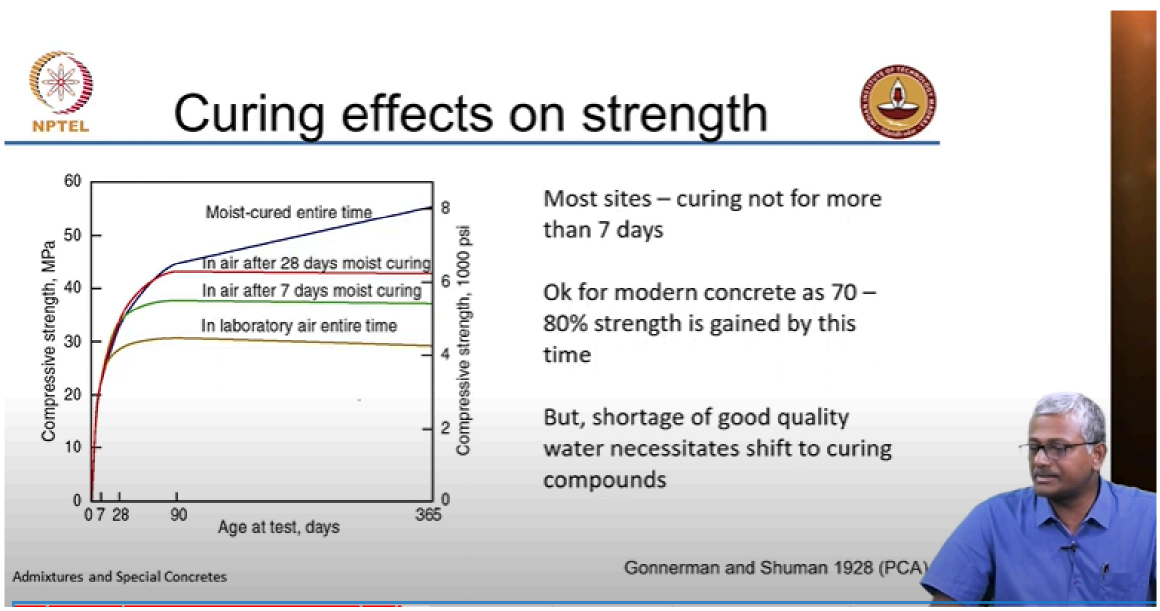

So there have been several large scale studies undertaken mostly by the Portland cement association the US and these articles are available for everybody to see and very clearly it shows in laboratory studies when you do long term curing so if you do moist curing for the entire time the strength continues to increase for any concrete because hydration will continue to happen the strength will continue to increase so marginal enhancement will happen over 28 days it is not going to be very large after 28 days. So in air after 28 days of moist curing you have achieved a strength at 28 you still increase a little bit and then there is not much of an increase that you see after that.

If you cure for 7 days you at least reach a certain level of the 28 days strength and then you can see that the marginal enhancement only is there but if you have curing which is done in air, the entire time that means without any supply of external moisture you do not develop that same extent of strength. These are in cubes but if you take the same example I showed you earlier of a concrete column maybe your column capacity is not going to be severely impacted if you do not cure it as far as strength is concerned. Your column capacity which depends a lot on the hardcrete may not get significantly affected but nobody is going to listen to you on site if your concrete cubes are not getting cured. People are going to obviously say that it is not acceptable. So you need to ensure that you provide a curing system which can take care of concrete at least until 70 to 80 % of strength has been gained by the concrete. So we typically follow site curing for 7 days because most concrete that are designed with modern cements tend to gain up to 70 % of their strength by that time.

Problem is when you start using mineral additives like fly ash which slow down the reaction your strength gain may not be achieved in 7 days up to 70 % so you may have to prolong the curing by a few days and that is very important as an engineer to understand because it is affecting your productivity and economy for sure but the investment of this longer term curing for mineral additive based concrete is going to extend your service life significantly and that is something which we will talk about later.

But these days water obviously is not available because of lack of water, good quality water because what is the requirement for curing water in terms of its composition or in terms of its purity. Curing water there is no special requirement is the same as mixing water which is potable water, water that can be drunk basically. Potable means water that can be kept in a pot for drinking that is exactly the type of water for curing also. That good quality water is not easily available on sites these days. So we have to increasingly shift towards curing compounds.

Water footprint:

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So the other aspect that you will come across a lot more in the future is this water footprint. Water footprint is going to be a reality in the future just as carbon footprint is becoming a reality now. So materials will have to be evaluated for the amount of water that they take up during the construction. Now here again use of water reducers is a great option to reduce the amount of water in your system and obviously the use of curing compounds is important from the perspective of reducing curing water.

So how much I mean where do you think more water is used for mixing or curing? Possibly in curing you need much more water during curing. So the amount of water saved during curing will be tremendous. Now with curing compounds one has to be very careful about the type of chemical that is there as a curing compound. You could get different types of compounds one is wax based, you can get resin based or water based. The efficiency of these curing compounds will vary depending upon the type of curing compound that you have. Interestingly the type of test that you do to assess the efficiency can also affect the result. I will talk about that in just a minute. Most commonly you will find that the efficiency is only about 70%. What do you mean by that? Curing compounds are only producing 70% of the properties that water curing does. But that is only because application strategies are not properly devised and people often do not follow the recommendations of the curing compound manufacturers.

What would be a good value of efficiency you think for curing to be justified to be used with curing compounds? More than 90% yeah. If you have 90% or more you should be satisfied. You cannot get 100% obviously it is not possible. But anything more than 90% should be good. So you need to ensure that you have the mechanisms and the methodologies in place to measure this efficiency.

So here you can see this spray is being applied on the surface curing compound. There is also this roller which is actually applying curing compound on the surface. So different ways of doing that you can either brush it, roll it or spray it various ways of actually applying curing compounds.

Curing compounds:

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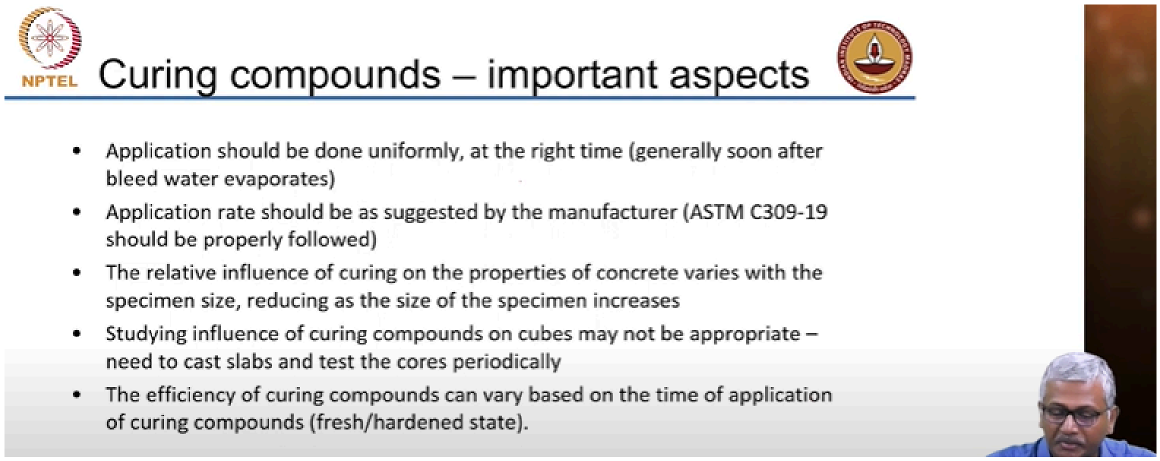

Application has to be done uniformly obviously because it has got to cover the entire surface. It has to be done at the right time. If the concrete has the surface sheen of bleed water your curing compound is not going to be affected. It needs to have almost a drying surface, not a completely dry bone dry surface but a drying surface. So the bleed water has to evaporate and then you apply your curing compound on top and that will stick to the surface well. Application rate has to be as per the suggestion of the manufacturer. Sometimes not just in one coat but you may have several coats of the curing compound to be applied.

There are guidelines in ASTM C309 which need to be properly followed while applying these curing compounds. Now when you cure small specimens versus curing larger specimens the efficiency of curing is quite different. In large specimens where volume is huge the surface area to volume ratio is quite small. In small specimens like cubes, the surface area to volume ratio is going to be high. So the curing efficiency if you are testing on cubes versus testing on a slab for instance your answers may be quite different. So you have to be careful about how you check the curing efficiency. The relative influence of curing on the properties varies with the size of the specimen. Influence of curing reduces as the size of specimens increases. So be careful about how you establish this efficiency. That is why if you use cubes it may not be accurate to assess the curing efficiency.

For instance if you take a cube and one day you demould take the cube out we typically put that inside a moist curing chamber or under water until the age of testing. Instead of that, take the same cube and start spraying the curing compound on all sides and then store it in the air dry condition then use it for 28 days. That will be the efficiency test done on cubes. But if you do a slab for instance if you have a large slab that you cast and you spray the top surface of the curing compound your drying is only happening through one surface all the other parts of the slab are protected. In a cube all six surfaces drying is likely to happen. So the amount of surface available for drying as a function of the volume in a cube is quite different as compared to what you have in a slab or a beam. So in such a case you need to be extremely careful about how you take those results, how you compare those results.

So it is easier or probably more justifiable to cast slabs and test the cores periodically. So you cast a slab, cover the top surface using curing compounds and then use cores from time to time to assess the strength of the concrete. That may be a better approach. Again the efficiency will depend not just on this aspect but also on the type of compound that is being used. And efficiency can also vary based on time of applications. In most cases what you find is on sites people disappear after finishing the top surface and they come back only the next day to start spraying water or curing. By that time usually it is already too late if you are looking at the modern concrete which has a lot of tendency for plastic shrinkage cracking. So applying curing compounds early enough is absolutely essential.

Studies:

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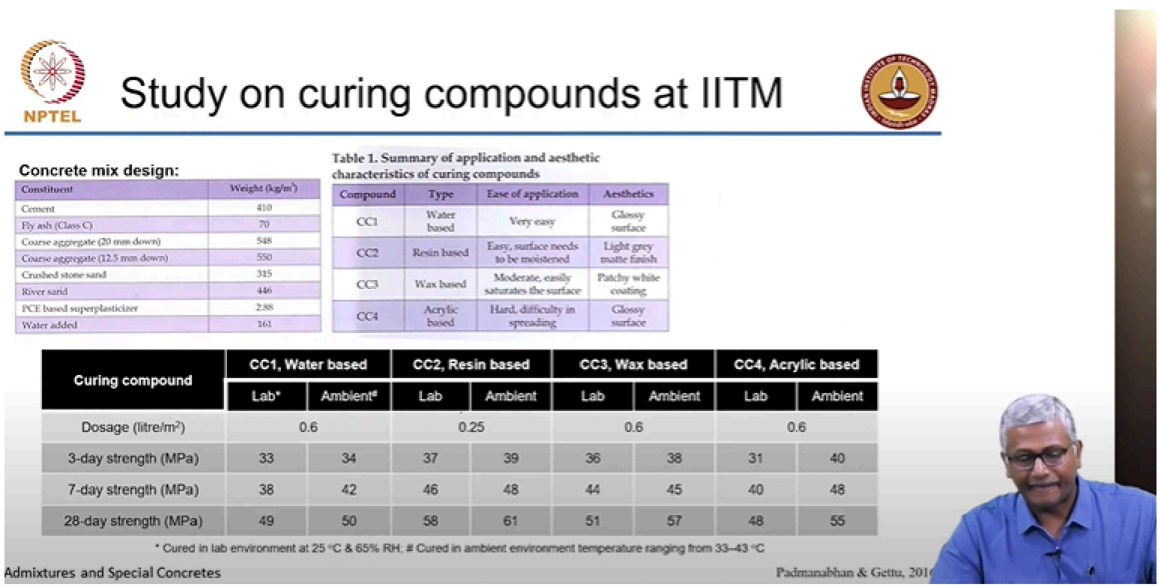

So we have done several studies in curing compounds. So there are two studies that are reported here in this slide deck. One is the study done by a student where they looked at the use of curing compounds for tunnel segments.

These were tunnel segments that were being looked at. So here cement weight is about 410 kg, fly ash is 70 kg and you see that the water cement ratio is roughly 160 kg/m^3 by about 480 kg/m^3 so about 0.33. So these are concrete that are intended to develop significantly high strength. Four different types of curing compounds were used. One was water based, resin based, wax based, acrylic based. Now what happens is your ease of application also varies depending upon the type of curing compound you have. Water based curing compounds are easy to apply and sometimes you also need to worry about the aesthetics, what kind of surface texture or what kind of surface sheen is provided when you use these curing compounds. So those were also compared in this case as you can see from the table here.

Interestingly based on the application, what you saw here is that the lab application or curing in the lab versus ambient curing as you can clearly see after application of the curing compound, the difference here is that the lab is at a temperature of 25°C control temperature and 65% relative humidity. Ambient environmental temperature is varying between 33 and 43°C, much higher temperatures. What you do see is actually the ambient is producing a higher strength increasingly in all the cases and that is just the effect of the external temperature because lab temperatures are lower, external temperatures are higher so you get higher strengths. Now look at the strengths achieved at 3 days with the 4 different types of curing compounds varying to some extent.

At 28 days 49, 58, 51, 48 MPa. So here the resin based compound certainly is the one that leads to most effective water curing. Efficiency has not been reported here but the efficiency essentially compared to water curing for the resin based compound which was used here was nearly about 75 to 86% that is what is reported in this study.

Application:

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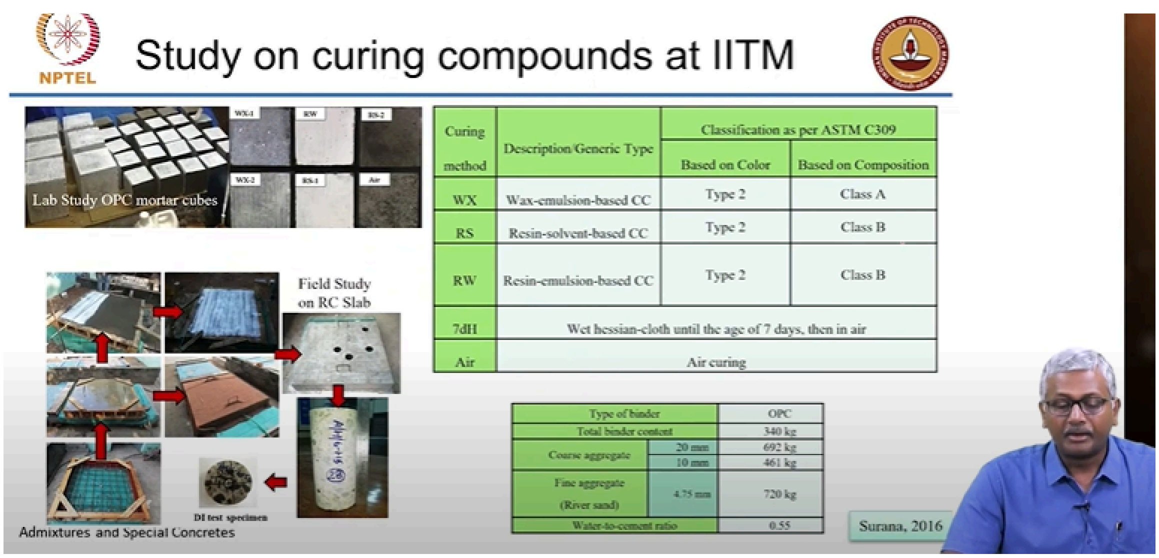

Curing method	Description/Generic Type	Classification as per ASTM C309	
		Based on Color	Based on Composition
WX	Wax-emulsion-based CC	Type 2	Class A
RS	Resin-solvent-based CC	Type 2	Class B
RW	Resin-emulsion-based CC	Type 2	Class B
7dH	Wet hessian-cloth until the age of 7 days, then in air		
Air	Air curing		

Type of binder		OPC
Total binder content		340 kg
Course aggregate	20 mm	692 kg
	10 mm	461 kg
Fine aggregate (River sand)	4.75 mm	720 kg
Water-to-cement ratio		0.55

In the other study we studied both applications. One was a study on mortar cubes where we applied the curing compound on the cubes. We then extended the study to concrete where we actually studied reinforced concrete slabs, only the top surface curing compound was applied and then concrete cylinders were cored from the slab at different ages for the testing.

These are the different types of curing compounds used wax, emulsion based, resin solvent based and resin emulsion based curing compounds. And we also had a site based curing that is 7 days with wet hessian cloth and then exposed to air and then also just air curing right after finishing completely air cured. And you can see that the water binder ratio is very high 0.55, binder content is 340 so expected strength is about 25 to 30 MPa that range strength.

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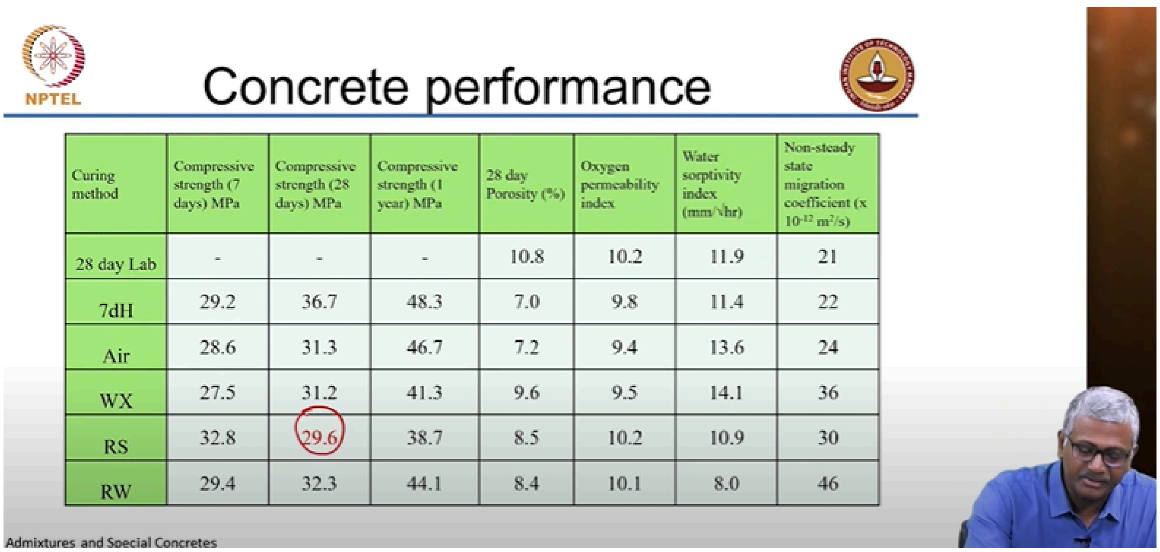

Concrete performance

Curing method	Compressive strength (7 days) MPa	Compressive strength (28 days) MPa	Compressive strength (1 year) MPa	28 day Porosity (%)	Oxygen permeability index	Water sorptivity index (mm/√hr)	Non-steady state migration coefficient (x 10^{-12} m^2/s)
28 day Lab	-	-	-	10.8	10.2	11.9	21
7dH	29.2	36.7	48.3	7.0	9.8	11.4	22
Air	28.6	31.3	46.7	7.2	9.4	13.6	24
WX	27.5	31.2	41.3	9.6	9.5	14.1	36
RS	32.8	29.6	38.7	8.5	10.2	10.9	30
RW	29.4	32.3	44.1	8.4	10.1	8.0	46

So in this case the comparative data is provided for the strength and for durability. Of course there is some problem with this one data point here for some reason we were not able to really figure out why that happened but if you look at the 7 days strength comparison the air curing is at 28.6, the 7 days hessian curing is at 29.2 not a major difference. Wax based curing compounds are not producing a strength which is similar to the resin based solvent or resin based emulsion. So there are differences at 7 days.

Interestingly at 1 year you see a very different performance of this resin based system. You are only reaching 38.7 in this case, 41 MPa in the case of the wax based compound. The resin based emulsion seems to be producing a strength which is almost comparable to what you get in air curing and 7 days hessian cloth curing. The interesting part here is that just doing the air curing did not seem to affect your overall strength so much.

But what about durability properties? Again interestingly in this study the durability properties are again not that badly affected when you do 28 day lab values versus the 70 day hessian or only when you see air curing the water sorptivity is increased tremendously, the chloride migration coefficient is also increased but not significantly.

All the curing compound applied concretes seem to indicate a much higher migration coefficient indicating poorer durability. I do not know what would be the reason for this is a very difficult thing to understand because if you look at the water sorptivity they are seemingly producing a better concrete as compared to your air cured material but in terms of chloride characteristics you are producing much different results.

Now of course there is a lot more detail that is required to be understood here with respect to the type of test that is done and what kind of specimen conditioning actually is done to get the test method. In many instances you need to dry the specimen before doing the test, in other tests like the migration coefficient test you need to actually saturate before you do the test. So there are various different conditions or preconditioning regimes that are used for durability testing and because of that it becomes difficult to ascertain the overall impact here of the use of curing compounds. So again this study was essentially not very conclusive and that is what you will find in many of the field studies also. When you get reports from your sites they will also tell you all kinds of results with curing compounds.

So this is one aspect of research that still needs to be done to some extent to really get truly accurate data which can reflect the efficiency of these compounds. Application strategies have to be worked out, application has to be done properly at the right time, and you need to also use the right type of elements to be prepared to check the efficiency of these compounds. Again not going too much into these results because they were not really giving a clear indication of what the expected performance could be. So very brief treatment but again something that you have to keep in mind because these days increasingly we are having to rely on curing compounds. So some methods of understanding efficiency on site are absolutely essential.