Advanced Concrete Technology

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Lecture – 34
Shrinkage: Drying Shrinkage

Good morning everyone. We will continue our discussion today on shrinkage. We were talking about different means of measuring shrinkage in the last class and we saw that the primary measure of shrinkage should be in the restrained condition because that is what generates cracking and if you have to really study the influence of fibers, there is no point in studying the free shrinkage because that may not be too different as compared to regular non-fibre reinforced concrete.

So for really understanding the impact of fibers better, it is always better to do a restrained shrinkage experiment which is done with the help of the restrained ring test. You have a concrete ring which is restrained by a steel ring from shrinking and when this restraint leads to a stress that is exceeding the tensile stress of the concrete, there is cracking in the concrete and this cracking obviously is the time of occurrence of the cracking as well as the width of the crack are both altered significantly whenever the concrete is reinforced with fibers.

Nevertheless, most shrinkage studies in concrete mix design as well as recent studies with concrete are done using the free shrinkage measurements where you simply prepare prismatic specimens of the concrete and subject it to drawing environment and measure the length periodically.

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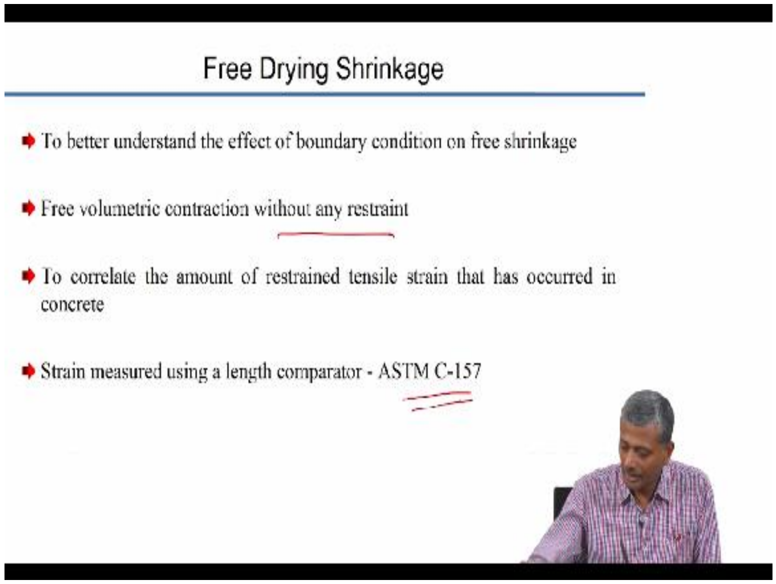

So essentially, this is free volumetric contraction without any restraint. That is what you mean by free drying shrinkage. So again, this is useful to correlate the amount of restrained tensile strain that has actually occurred in the concrete and usually it is done with the help of a methodology that is prescribed in ASTM C-157. Of course, this is standard methodology, most codes have a similar methodology. It is not much complicated.

You need to prepare prismatic specimens. You need to store them in regular moist-curing conditions until the age at which you want to start the exposure to drying. There is no predetermined age. You can decide it based upon your site conditions. For example, in some cases, you can cure for 7 days. In other cases, you may cure for 28 days, yes and then beyond that, you expose it to the drying environment, typically at 50% relative humidity, that is what a typical drying environment is.

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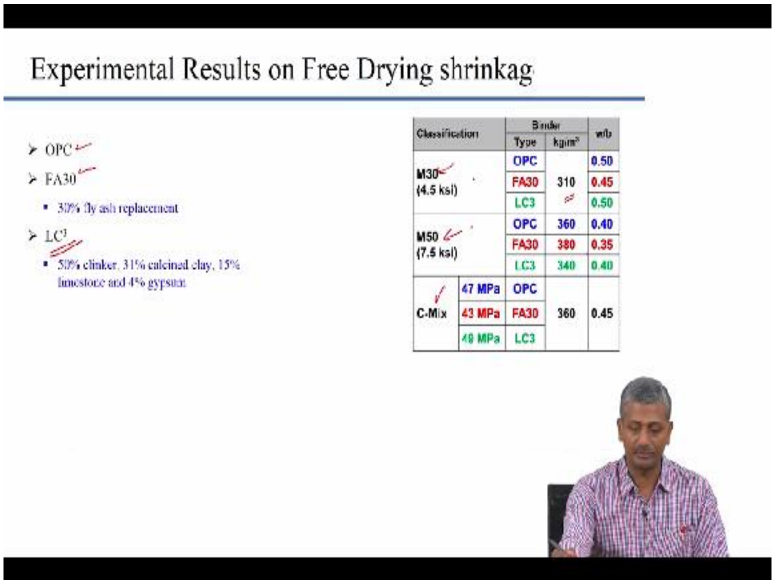

And then you monitor the length change periodically. I am just going to show you some experimental results, on free drying shrinkage, on 3 different sets of binders. Remember, we have talked about limestone calcined and clay cement and this is being compared against OPC and a mix which has 30% fly ash as a replacement of OPC. These are the mix designs on the right.

We have a M30 concrete and M50 concrete and a common mix which has the same binder content and water-binder ratio for all 3 mixes. So these concretes are specially designed concretes where the water-cement ratio and the binder content may differ for the different types of binders that are being used. Because ultimately, their designs based on the achievement of the strength at 28 days.

So some of the results that you are likely to see as far as these concretes are concerned, may also be attributed to the fact that these mixes have different binder contents and water-binder ratios. So obviously the paste content in these mixes can be different because of the difference in binder content and water-binder ratio. Whereas this common mix, all the pastes will be of the same volume.

Oh, I am sorry, not the volume, the same mass. Why not the same volume? Because the concretes which have LC3 or FA30 binders will have slightly higher paste volume as opposed to OPC because of the lightest specific or the lighter density of the fly ash as well as the LC3 components.

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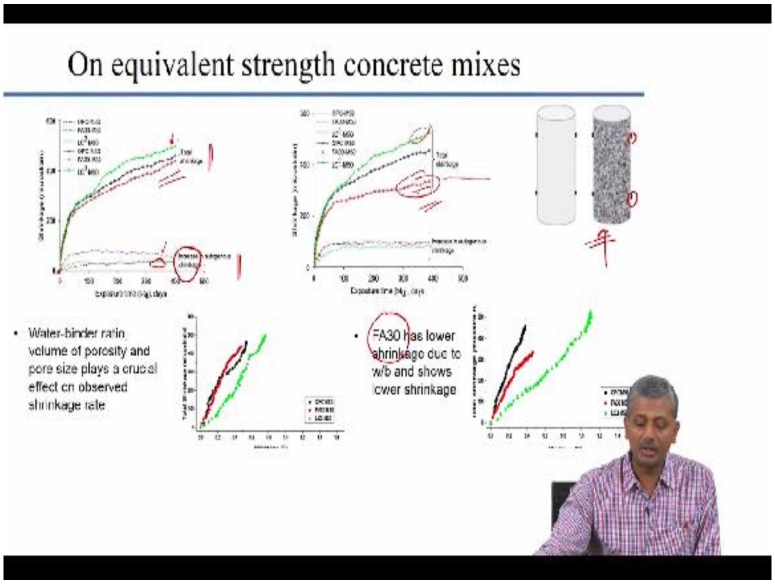

So let us look at the evolution of shrinkage. So here the shrinkage was actually measured on cylindrical specimens, again by placing palettes on the surface of the cylindrical specimens and measuring the deformation between the palettes using what is called a DEMEC gauge, just like what we did for the creep experiment that we did previously. Now what you need to understand is?

If you have a specimen that is under load and is also subjected to drying at the same time, the deformation is not just because of creep, it is also because of shrinkage. So whenever you do a creep experiment, you are supposed to also carry out a shrinkage experiment on the same type of specimens, that is the cylindrical specimens of 150 mm diameter and 300 mm height. So on these specimens we can see the differences in shrinkage here between the different binders.

So we did some sealed specimens. So there, we could measure the autogenous shrinkage and we also did some unsealed specimens where we are actually measuring the total shrinkage which is composed of autogenous plus the drying shrinkage. So here, please note that the result is expressed in terms of increase in autogenous shrinkage. Now why is it like that? Because we have no control about what is happening within the mould.

When the concrete is within the mould, I explained earlier that there is a lot of self desiccation already going on inside the concrete but since we are not able to measure the length when the concrete is inside the mould, we do not have a very clear answer to what the actual autogenous shrinkage is. So what we are doing is measuring from the time that the concrete is actually exposed to the drying or from the concrete that the; from the time that the concrete is taken out of the mould and sealed.

From that point onwards, we are measuring the length and what is expressed here is the increase in autogenous shrinkage. So when you compare the different types of binders, you see that the autogenous shrinkage increase for OPC and LC3 are nearly similar. For fly ash mix, it is slightly higher. As far as total shrinkage is concerned, the LC3 mix shows a marginally higher total shrinkage.

This is for an M30 grade of concrete. Again for M50, the differences are little bit more pronounced where OPC and LC3 mixes are showing slightly higher free shrinkage as opposed to the fly ash concrete mix. So please look at the time axis here. This is data up to 1 year or little bit more than 1 year. So again you see that these graphs are not entirely stabilized. You do not see a perfectly horizontal sort of a system here because there is continuous drying that is actually happening in the system.

That means there is still drying which is continuing in this process. So again the lower shrinkage that you see with fly ash 30% replacement mixes is primarily because of this effect that you have a lesser water content in the system. Because the fly ash mix had to be designed with the 0.45 water-cement ratio to obtain this 30 Mega Pascal grade. Whereas the OPC and LC3 mixes could be designed with higher water-binder ratios. That means you have lesser water available in the system in the fly ash mix. So naturally the shrinkage is lower.

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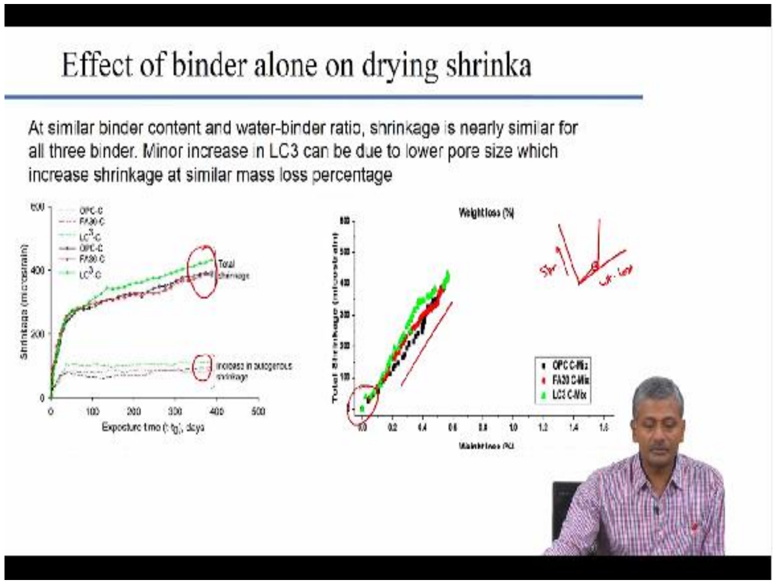

Now in terms of the common mix, the total shrinkage that was observed was not much different for the 3 different types of concretes. That means that irrespective of the binder type, when you have the same binder content and water-binder ratio, the shrinkage is not all that different. Again, autogenous shrinkage increase is also on the same lines for all 3 different types of binders. Again, on this side, the shrinkage is plotted against the weight loss and you see a fairly good linear relationship between the shrinkage and weight loss.

Of course, what I had earlier told you is, mostly you will get a bilinear relationship. In the first part, the weight loss will be more and then you have a constant weight loss based on the shrinkage, extent of shrinkage. So in the early part, the level of shrinkage will be very small as opposed to the amount of weight loss but I guess, we are not capturing that part very well in this case.

So what we are actually seeing is a start of the second phase almost immediately. So the binder effects on drying shrinkage need to be worked out every time when you do a concrete mix design because when you change the binder, you are affecting different characteristics of the concrete. First of all, you are changing the paste volume because the binder that you adopt instead of OPC, may have a slightly different specific gravity leading to a different paste volume.

And you know that paste is the component that is subjected to shrinkage, not the aggregate but paste volume is not the only effect. What happens to the characteristics of the paste, what happens to the interfacial transition zone, what happens to the overall stiffness of the concrete, all that will go into determining what happens when the concrete is subjected to drying? So this has to be worked out experimentally.

Shrinkage models are available which can help you predict shrinkage but then very often we find that there is a lot of discrepancy between different types of models. You must have talked about different prediction models and these prediction models are widely varying from each other and the experimental later usually matches with 1 or 2 of the models and not all of them.

So again, this goes to show that whenever you are designing concrete and where shrinkage and creep are going to be a concern, it is always better to actually study these properties before you go into the actual construction process rather than just relying on an estimate of workability and strength. So in many of the high rise buildings for instance, when you have 70-80 stories, you can imagine that the extent of creep that you can expect from concrete can be tremendous but then we also use high strength concrete in such applications.

So when you use high strength concrete, what happens? Can you still use the same creep coefficients that are prescribed in your course or do you need a modification for that? What about the levels of drying shrinkage, do you get the same drying shrinkage or should you start accounting for autogenous shrinkage separately? So these are questions that need to be answered by additional testing to be done at the time of mix design.

It is not as simple as just putting up something together and getting workability and strength. So we need to have sufficient amount of time before we can actually prescribe the mix for a given situation. Now when you come to regular concretes, M20, M30 concretes which are used on a day-to-day application like residential buildings, your regular column and beam filling concrete and so on, there the issues of shrinkage and creep can be very well controlled by what provisions we already have in the course.

You do not probably need additional testing for that. But then when you are designing special applications, for example high rise buildings, dams, water retaining structures where crack width could be a very important factor, all those considerations need to be taken into account for designing the concrete mix appropriately.

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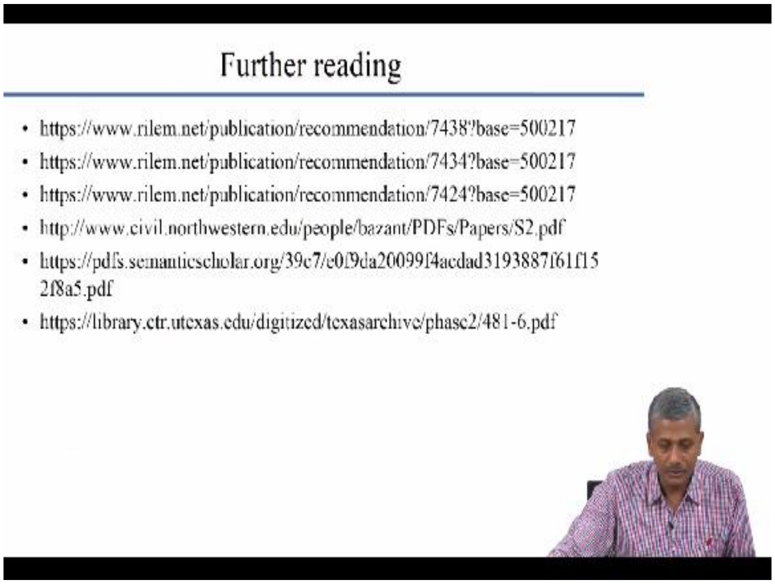

So there is a lot of recommendations of further reading. Many of these are actually RILEM reports. RILEM is an international organization which is similar to your American Concrete Institute or Indian Concrete Institute. Here there are a lot of research reports that have been published by several technical committees that have worked within RILEM and these reports are available for free on the RILEM website.

So I would suggest those of you who are interested in further understanding this subject to go and take a look at these reports that had been published in the website. Some of these may not be directly downloadable. You may have to write to the organization to actually get permission to access these documents but they are free. They are freely available.