Admixtures And Special Concretes

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Lecture -55

Special concretes - High strength concrete - Mix designs, strength and durability

Okay, so good morning, we were talking about how particle packing approaches which are typically used to design compacted powder mixtures could be also used to design concrete mixtures for high performance concrete or high-strength concrete. So, the idea is to design concrete mixtures with the view of providing a system that has the least voids. For that we need to select particles which are of the right sizes that can be proportioned in such a way that they fit into the gaps offered by the next higher size. So, overall we then come to a more compact system which requires less water to provide the given workability. So, if you are considering a mixture of all the aggregates we provide minimum paste that fills up the spaces left behind by the packed aggregates and whatever excess space is there is able to provide the workability that carries the concrete when we do the compaction. For this modern systems tend to utilize particle packing models that are little bit more sophisticated as compared to the maximum density gradations that were employed in the past. There was not that much attention given to maximum density gradations in the past and we have been following a very archaic system with respect to understanding how best particle packing can be done with aggregates.

Modified Andreassen Model:

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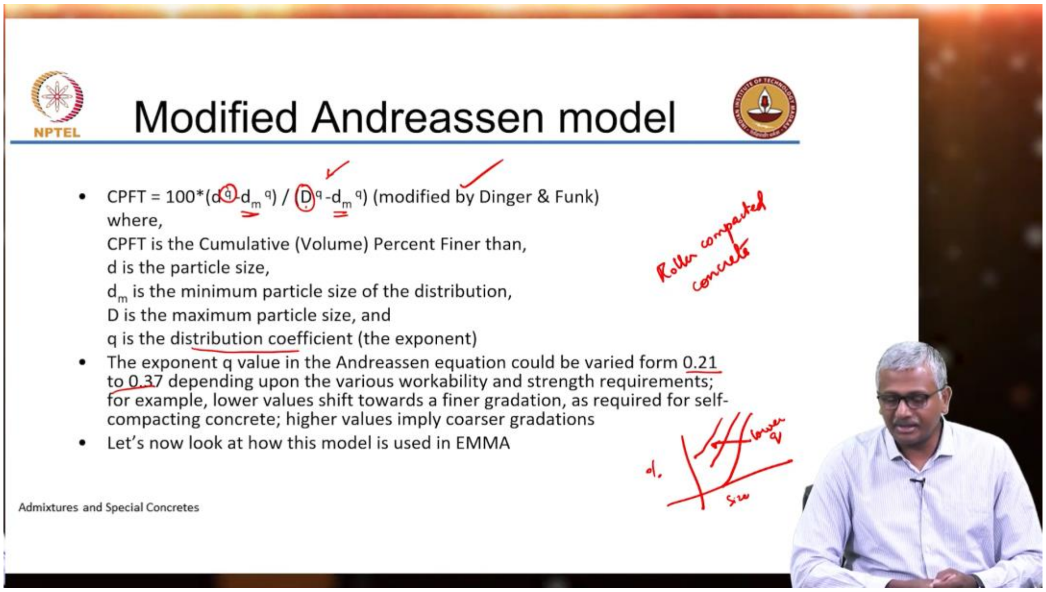

So, in order to move forward with this people have looked at various different approaches and in concrete science a lot of people have adopted approaches based on the Andreassen model which was later modified by Dinger and Funkum sorry, Dinger and Funk and this essentially describes the model in terms of a distribution coefficient. The very idea is that when you change the distribution coefficient you are moving your system to more finer sets of particles. The idea is to locate an ideal Q value for the specific concrete mixture that you design.

Step 1- Input material PSD:

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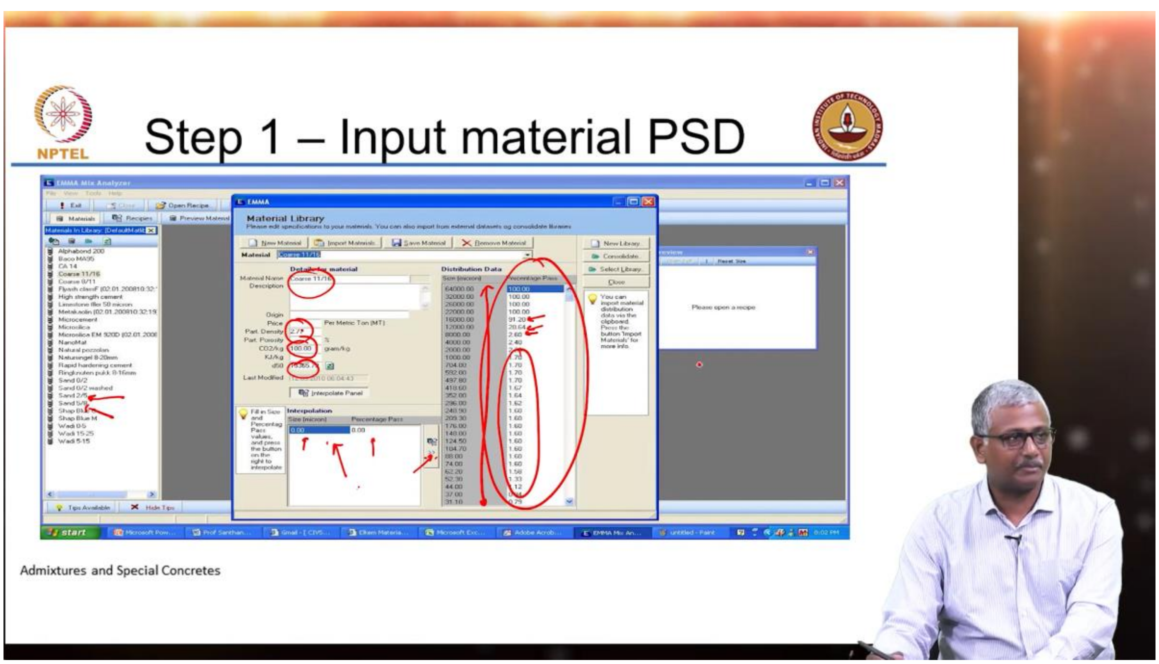

And I also took you through the steps in the software which is titled as EMMA, Elkem Materials and Mixture Analyzer which is available from the site of Elkem for download but I think lately there has been some difficulty in actually downloading it but the idea is you can as well set this up in a excel macro.

You can actually do an Excel macro and calculate the ideal gradation that is required from the set of the ingredients that you are actually putting into the system.

Step 2- Preliminary recipe:

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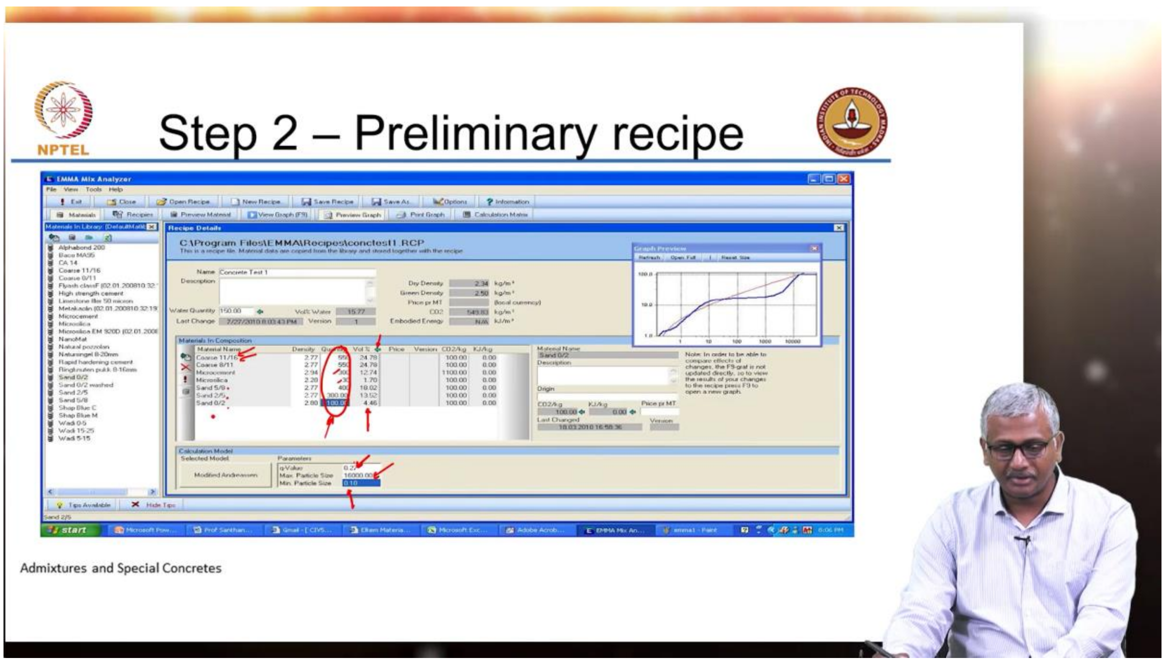

Step 3- View graph- and adjust recipe:

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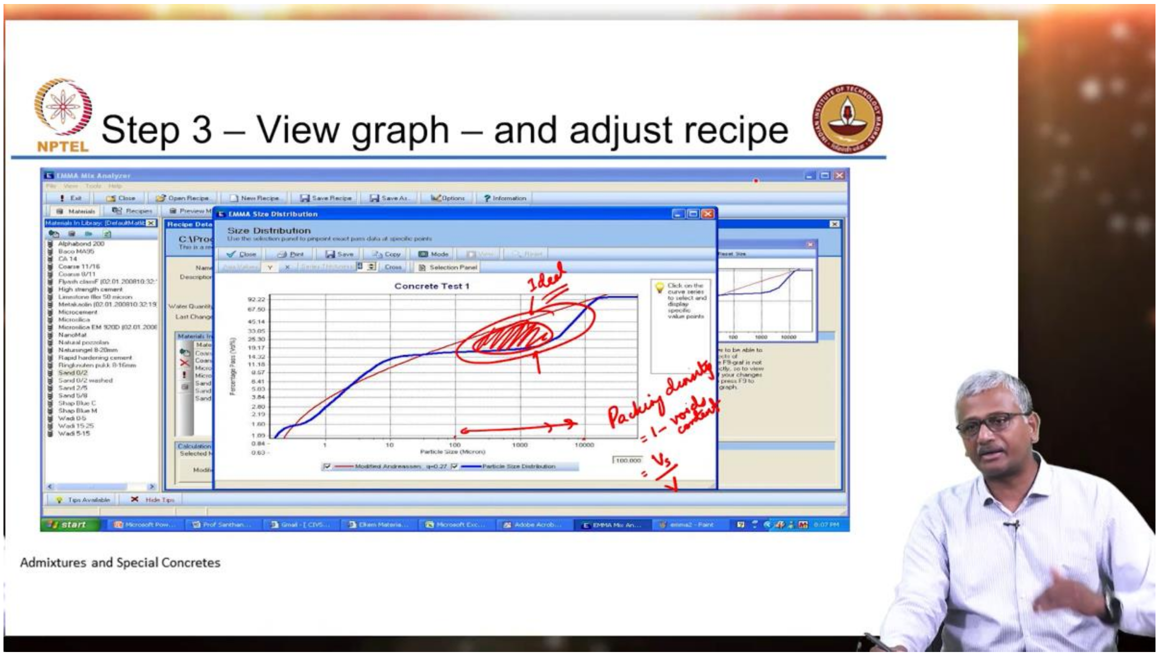

So, idea is to bring the combined particle gradation as close to the ideal gradation as possible with the assumption that particles that are packed ideally will give you the maximum strength and will also help you design the concrete for appropriate levels of workability.

Particle packing for producing HPC with low cement content:

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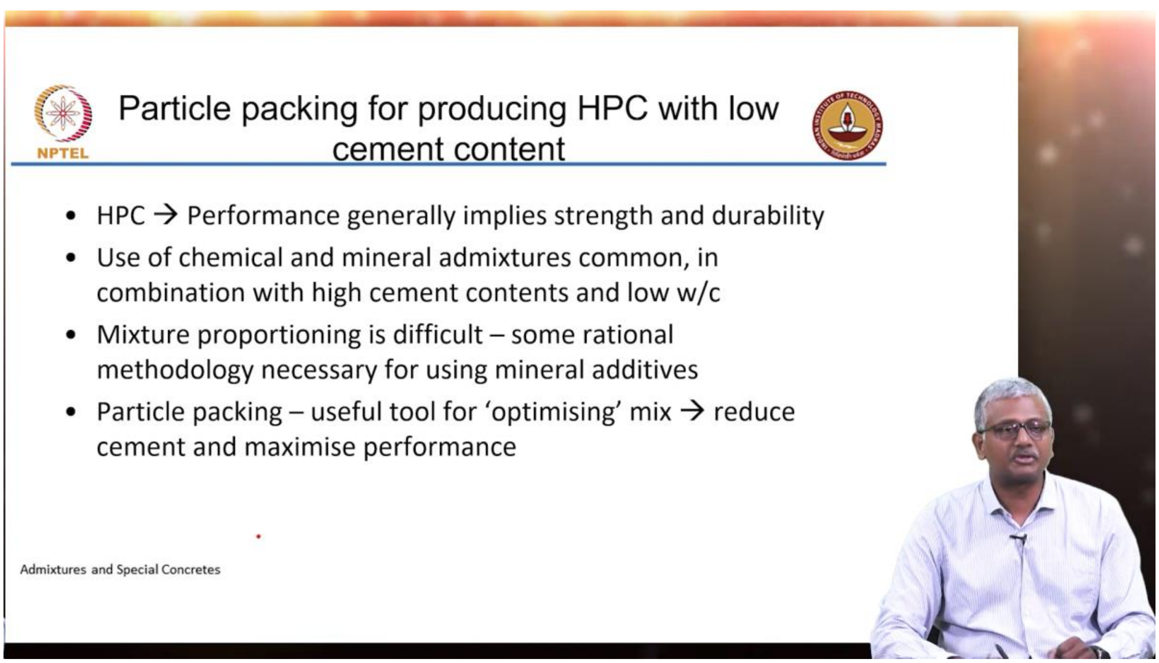

So, let us look at an example of how this approach was used to produce high-performance concrete with low cement content. Now, generally high performance means high strength and durability as I said in many instances people interchangeably use HSC and HPC but truly speaking performance should imply more than strength it also means durability. Generally we always have high cementitious contents, we have mineral admixtures and chemical admixtures always in the design of high-strength concrete and high-performance concrete.

So, here the idea was to use particle packing to cut down the number of trials required to get the required workability and strength and also from the opinion, from the perspective of actually minimizing the extent of cement that was used to produce the high-performance concrete because we want to cut down on the cement usage.

Mix Designs:

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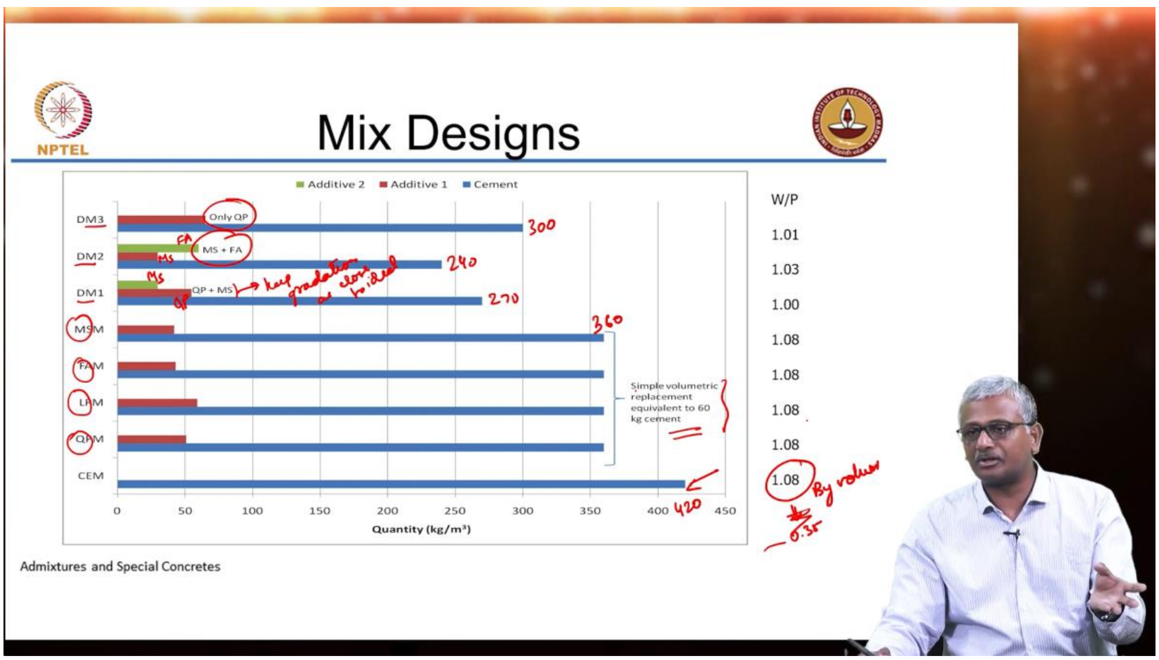

So, here these are the mix designs, this is the control mix which was used. The control mix had a cement content of 420 kilograms per cubic meter and water binder ratio of 1.08- this is by volume. This is presented by volume, water to powder ratio by volume.

To get the actual water-to-powder ratio by mass, you need to convert that volume of cement to an equivalent mass and then obtain the water-to-powder ratio by mass. So, 1.08 will approximately correspond to 0.35 or so by mass. Typically, we express water to binder ratio and water-to-cement ratio in terms of mass, mass of water by mass of cement or mass of binder.

So, if you do that in terms of volume it becomes around 1. So, the next strategy was to look at a typical design approach where we are simply replacing one part of cement by the mineral admixture. So, we talked about the fact earlier that in most cases we would be replacing a certain mass of the cement by the mineral additive. But here we chose to replace, so in a normal case when we do mixture design with mineral admixtures we replace a part of the cement mass by the mineral additive. In this case, what we did was we replaced a certain volume of the cement by an equivalent volume of the mineral additive.

So simple volumetric replacement equivalent to 60 kilograms of cement was done implying you remove 60 kilograms from the mixture and put an equivalent volume of the mineral admixture that is corresponding to the volume of 60 kilograms of cement. That is what is called as volumetric replacement. So, here volumetric replacement was done by quartz powder, limestone powder, fly ash and micro silica or silica fume. So, you can see that the quantities of quartz powder were about 50 kilograms, limestone powder which is denser than quartz powder we could fill in close to 60 almost similar to 60 kilograms of cement, fly ash and micro silica are less dense so you need less mass to fill up the same volume. So, this is basically a simple volumetric replacement.

This is what you do in a typical scenario. But now to adopt a particle packing approach what we looked at was how the particle gradation of the combined granular particles that means aggregates, cement and mineral additive combined together how was it different compared to the ideal gradation as prescribed by the modified and recent model. So, in this case we came up with 3 mixtures, we named them as design mix 1, 2 and 3. So, here the design mix 1 had a mixture of quartz powder and microsilica. It was proportioned in such a way so as to keep the curve as close to the ideal gradation as possible.

I will show you those curves in the next slide. So combined to keep gradation or keep the combined gradation as close to ideal. Similarly, second design mix had micro silica and fly ash which were proportioned in such a way so as to get a gradation which is as close to the combined gradation as possible. Now of course, when you use micro silica and fly ash the smaller quantity is micro silica, the larger quantity is fly ash and quartz powder plus micro silica, larger quantity is quartz powder, the smaller quantity is micro silica. We cannot obviously use too much micro silica that is expected to make some problems for your mix with respect to initial workability and so on.

In the third design mix we thought okay let us only look at quartz powder, let us see if we can fill in a mineral filler without any reactivity just to optimize the size as much as possible because you are not getting the advantage of the sizes of micro silica from the quartz powder. Quartz powder is of a fineness which is slightly less in cement but not to the level of micro silica. Micro silica average size is about 0.3 microns 0

1 to 0.3 microns whereas quartz powder will be around 5 to 10 microns, cement is about 15-20 microns. So you are not getting that level of advantage but we wanted to see how far can we go with just removing some cement and putting a mineral additive to fit the gradation as close to ideal as possible. We are not going to fill up all the gaps but let us see how much we can do. What you need to notice here the cement content is only 270, here it is 240 and here it is 300 as compared to 420 here. So here in all these 4 mixes is 360 because we have removed 60 kilograms of cement and put an equivalent volume of the mineral additive.

Now water powder ratio is more or less in the same range because this is presented by volume when you compare with the densities of the cementitious phases that are involved they will work out to the same water-to-binder ratio by mass. This is by volume that is why it is different by mass it will work out to the same level.

Combined granular gradations for all 8 mixes:

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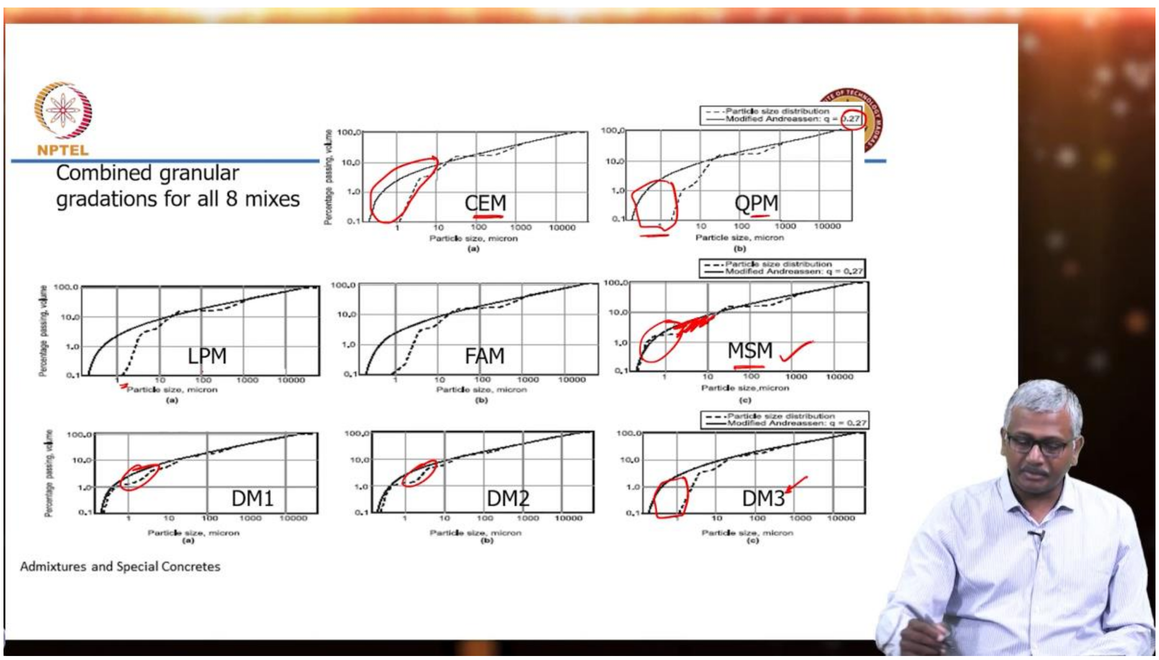

So, let us look at these gradations and how far they are from the actual gradation. This is the control mix with only cement. You clearly see that there is a deficiency here with respect to the ideal gradation.

An ideal gradation here is done with a Q value of 0.27. A Q value chosen was 0.27. When we replace the cement by simple volumetric replacement using quartz powder you see that we are not really changing the system very much because we don't, we cannot get the advantage in this particle size.

We are talking about less than 2 to 3 microns. Quartz powder is not able to supply particles in that range. So we are not really filling it up. Limestone powder maybe a little bit improvement was achieved here but not really too much. Fly ash mixture again the same.

With the micro silica mixture simple volumetric replacement also led to a condition where almost all the particle sizes in this sub 1 micron size range were filled up and the curve got close to the ideal curve. But what you are missing is this region here. You are not able to fill up that particular region because it corresponds to a size that is not given by microsilica and is at the lower end of the cement sizes. So let us try quartz powder. It sort of fills up that space a little bit.

Fly ash also tends to fill up that space a little bit. So when you combine quartz powder and micro silica fly ash and micro silica you are getting the curves as close as possible to the ideal curve. Now in this case when we simply used quartz powder and tried to optimize the combination of cement and quartz powder by minimizing cement as much as possible to get this as close to the ideal curve you still see that there is a big gap left here in the small particle size range because there is no particles to fill up that size range. Now what do you expect will be the result of this? If our assumption is true that a curve as close to ideal should give us higher strength which of these should give you highest strengths? You should get very good strengths with micro silica mix, your DM2 mix, and the DM1 mix and that is exactly what happened in the case of strengths.

Compressive and flexural strengths:

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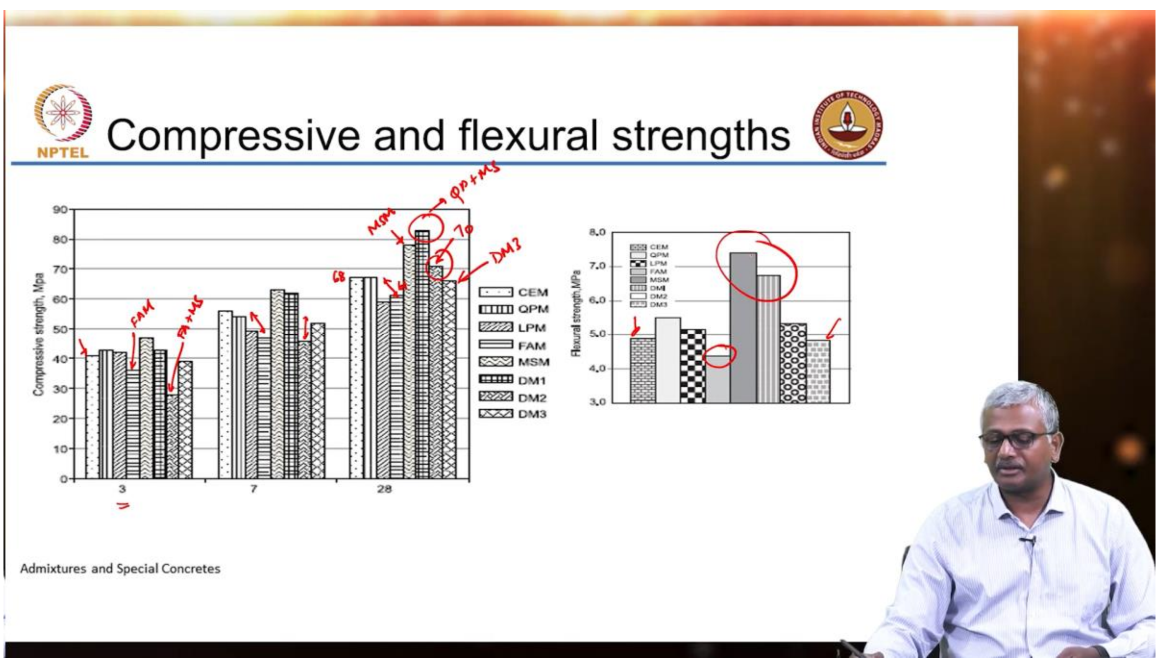

So, all of these mixtures are presented here together. At 3 days, if you compare with the plain cement mix, the fly ash mix gave a lower strength expected at 3 days you are not getting any contribution from fly ash. The mix which had a combination of fly ash and micro silica which had much lower cement content that gave a lower strength. At 7 days, this gap was still there but by 28 days the gap is not so much it is 68 MPa here it is about 61 MPa here so 7 MPa difference at 28 days is not really a big deal. Interestingly this concrete with fly ash and micro silica has come up to 70 at 28 days. So, you are getting the synergy of the pozzolanic reaction of fly ash and the good particle packing afforded by the mixture of fly ash and micro silica.

So, very clearly what you are seeing is you have replaced cement content from 420 to about 240 or 270 and you are able to get such excellent strengths, especially this mix here with quartz powder and micro silica is able to achieve a strength level of more than 80 MPa. So, clearly this goes to show that by choosing particle sizes appropriately you can maximize the extent of strength.

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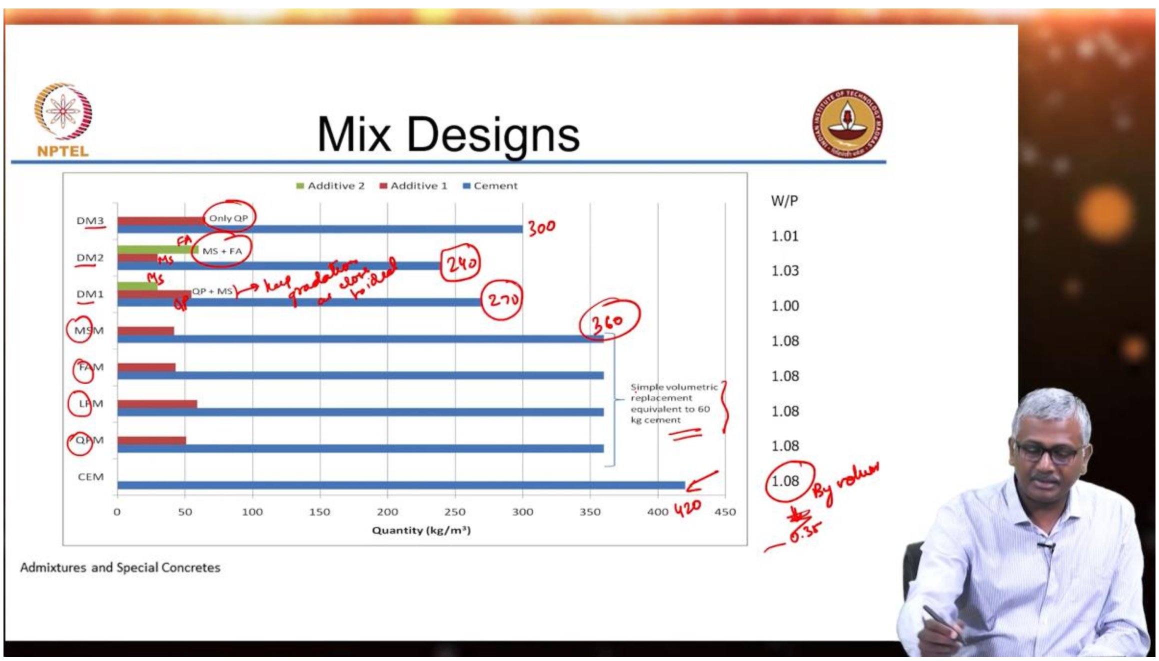

Now here this is just the plain micro silica mix you are able to get nearly 78 with just replacing cement with micro silica but please remember the cement content there was 360, the cement content there was 360. Whereas in these mixes cement contents are down to 240 and 270. So very clearly particle packing approaches help you bring down overall cementitious materials content, especially the overall cement content. If you go back to our previous understanding, we said that not all of the cement hydrates some of it simply sits as filler.

If you can use approaches like particle packing to identify how much of it is needed as a filler you are automatically getting there. That is made very clear by this DM3 example which has only quartz powder but it is reaching the same level of strength as a cement 420 cement mix. This has only 300 cement you have simply cut down cement by 120 you have added a little bit of quartz powder that may add some cost but it is simply a filler it is able to produce the same strength as your plain cement mix. What about flexural strength same trends flexural strength also you have the same trends. The fly ash-based mix is slightly lower but not really too much 4.9 to 4.5 it is not really that much of a drop but your micro silica bearing mixes are significantly high.

Durability properties:

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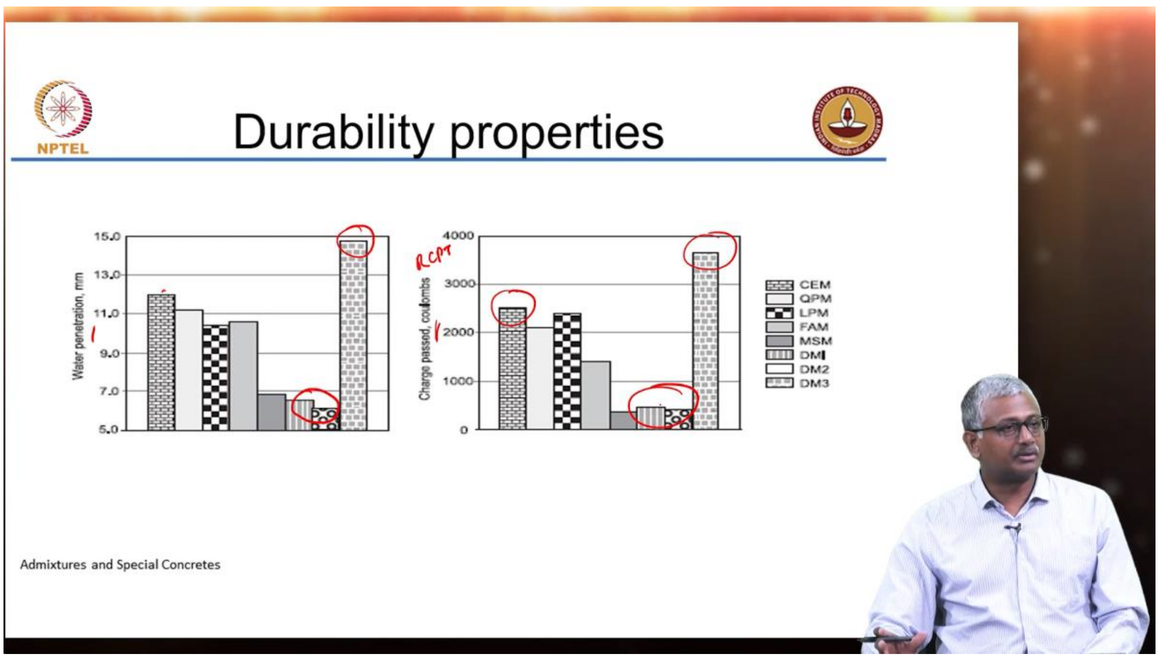

In terms of durability, the water penetration under pressure in millimeters is presented here and the charge passed in coulombs in the RCPT test is shown in this case. This is interesting so now you see that when you do a optimization of particle packing with a non-reactive filler like quartz powder your durability seems to have worsened with respect to the plain cement mix which had much higher cement content. But all your mixes which were designed with ternary packed systems with silica fume plus quartz powder or silica fume plus micro silica plus fly ash you are able to get a much better durability than the plain cement system. Same concept in rapid chloride penetration test also here 2500 here it is 3500 you have less cement in your system there is much lesser ability to fill up porosity to the extent that would reduce the charge passing through your system.

Whereas your systems with reactive silica which is micro silica fly ash and so on are able to produce charge passed of less than 500 coulombs. Again particle packing works well in the case of prediction of good strength properties for your mixtures but for durability, it is important that the materials with which you do the packing have some reactive properties so that they are able to perform better in durability experiments. So when you do particle packing your end goal has to be properly defined. If your end goal is to produce strength and durability it is better to have mineral ingredients that are reactive. If your end goal is only strength you may as well choose an inert material to replace the cement.

But what you are seeing here is that there is tremendous potential to drop the cement content significantly and that results in a concrete mixture that is much more sustainable.

Summary:

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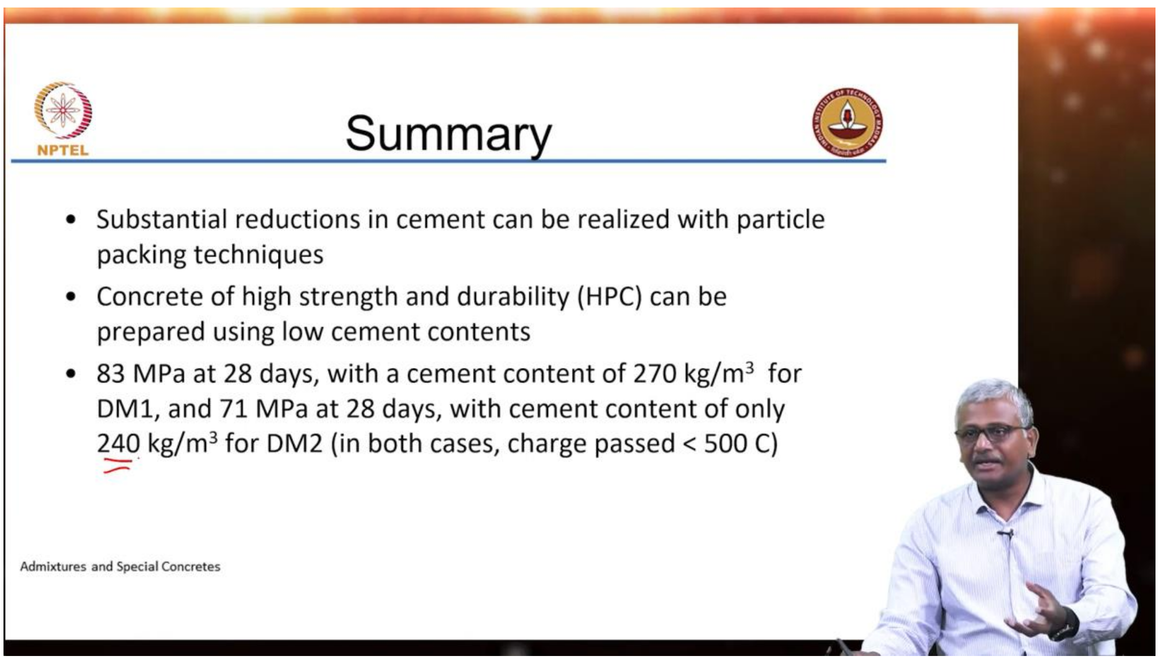

So essentially here you are capable of reducing your cement content by nearly 150 kilograms per cubic meter. That is a large amount of cement reduction or even in the case of the DM2 180 kilograms per cubic meter of cement was reduced and an equivalent amount of fly ash and silica fume is used. Assuming fly ash is absolutely no contribution to CO2 assuming in the way that it is usually calculated silica fume also is obtained as a waste but because of the way that it is processed, it may have some contribution to CO2. So you can then lead to a much more sustainable mix if you utilize the methodologies to actually do the life cycle assessment.