Admixtures And Special Concretes

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Lecture -70

Special concretes - Lightweight concrete - Lightweight aggregates, aerated concrete

Application of Lightweight concrete:

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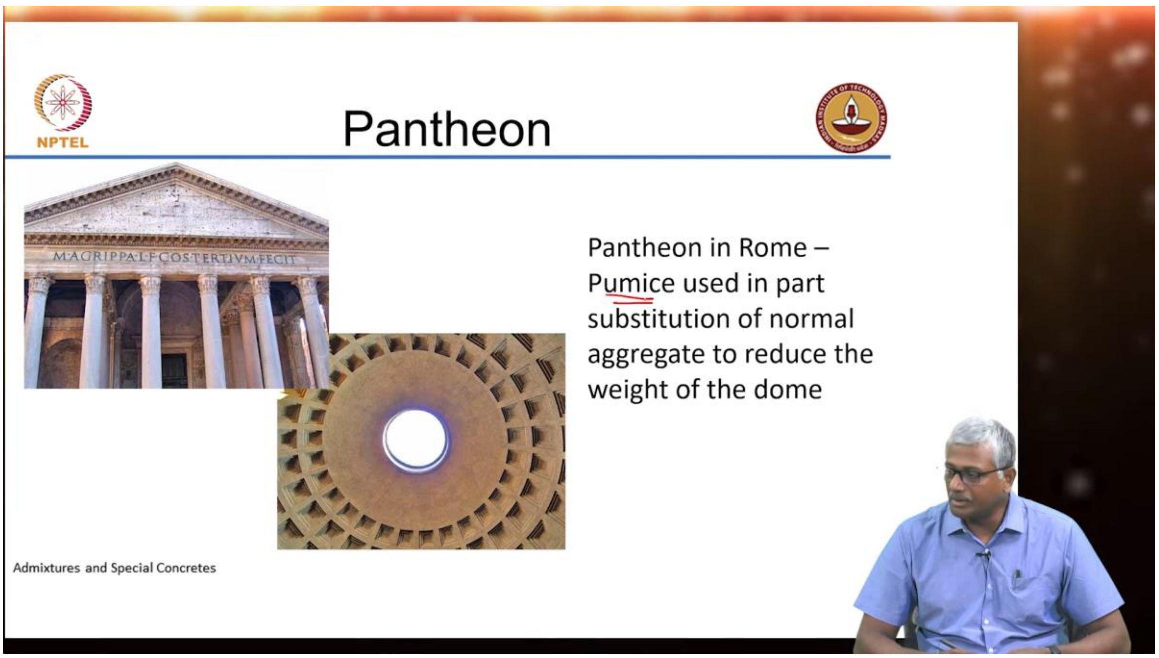

Now, of course, one example of lightweight aggregate concrete is the dome of the Pantheon, where the naturally occurring pumice was used as part of the substitution of normal aggregate to reduce the weight of the dome. So, you know that there is no reinforcement in the structure, this is a concrete dome and it was built, in 500 AD or something, not sure, not clear about the period but yes, there is a usage of low-density or lightweight concrete in the dome of the structure.

Synthetic Lightweight aggregate:

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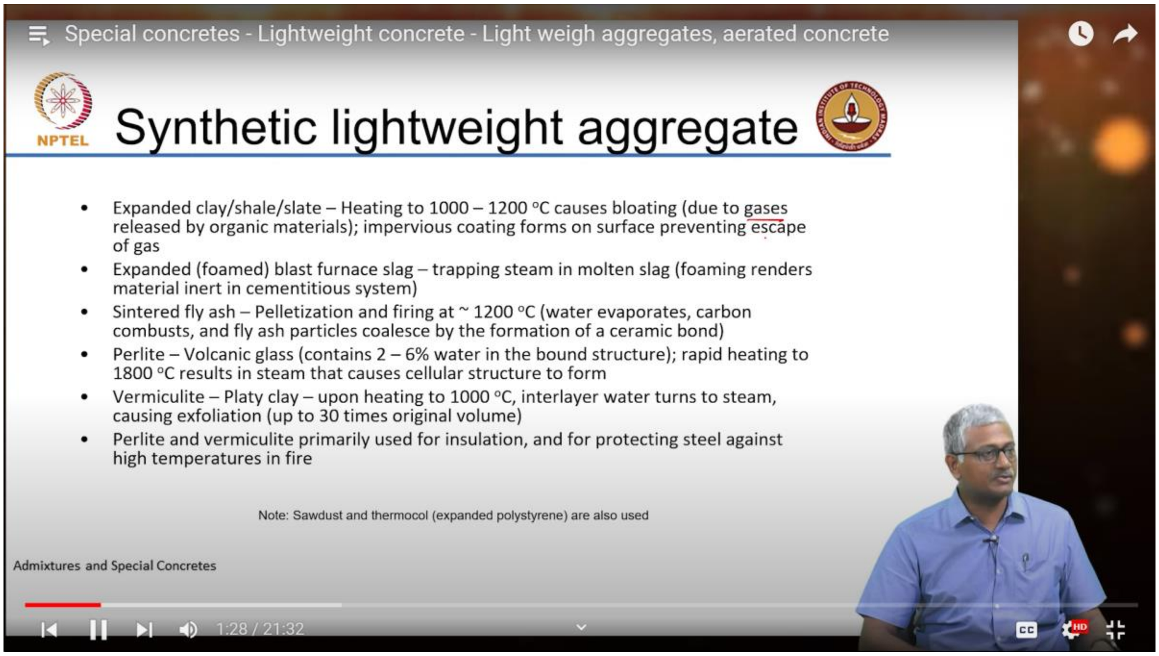

Synthetic lightweight aggregate includes expanded clay or shale or slate. When these materials are heated to a high temperature, it causes bloating, basically, the air is entrapped in the system because of the layered or foliated structure and the possibility of even gases that are released by organic materials that are present already in these shales. There will be organic deposits when you extract shale and when you heat that to a very high temperature, the gases will form, and get entrapped in the system which leads to a higher porosity, causing the material to become lightweight. Then the process also leads to an impervious coating forming on the surface which prevents the escape of this gas which means the bloated structure is maintained when you do this heating process. So, you still need to provide energy to get this lightweight aggregate, you are forming after the provision of a high amount of energy. Expanded slag as I said, you trap steam in molten slag, the steam generates high-pressure vapor inside the system, and that leads to the foaming of the system.

Now because of the steam, apparently it renders the material inert in a cementitious system which means it is not going to be reactive anymore, it is going to be just an expanded slag as an aggregate, and it will not be as reactive as blast furnace slag which is quenched. Sintered fly ash, as I said is caused by the pelletization of fly ash particles, you have to bind the particles together typically using clay or cement, or like bentonite can be used to bind the fly ash particles together. The pellets are formed to aggregate size and then these are fired in a furnace to a temperature that leads to the sintering like the formation of a brick for instance. So, water can evaporate, carbon combusts and fly ash particles coalesce by forming the ceramic bond between the silica and the alumina.

Perlite is essentially volcanic glass; it contains 2 to 6 % water in the bound structure and again this has to be heated rapidly to 1800 degrees Celsius which results in steam that encapsulates air inside the system. Vermiculite is a foliated platy clay, the interlayer water basically turns to steam and causes exfoliation, and separation of these individual plates, and then overall material as an aggregate becomes extremely light in weight. Up to 30 times the original volume can be obtained by doing this process of heating to 1000 degrees Celsius.

So, as you primarily see all these systems are formed by supplying a significant amount of energy to heat. That is why using lightweight aggregate is not always very sustainable from the point of view of using something natural versus making something lightweight by enhancing or rather providing heat energy to it. At the same time, there are applications that we cannot do without lightweight aggregate. If you want extremely low-density concrete then using lightweight aggregate if it is available at a cost that can be justified is a good idea. Otherwise, you must deal with using air entrainment or foaming or aeration to get the low density which is possible.

Perlite and vermiculite are primarily used in insulating concrete and for protecting steel against high temperatures in fire. So, when a fire happens obviously the concrete is a protecting layer to the steel and when you have a system that provides a very high insulation, the heat conduction to the concrete is slowed down significantly. So, the longer the heat takes to reach the steel the longer the structure will be stable. So, insulation also helps against fire damage that happens in buildings.

You can also use thermocol or expanded polystyrene which is another way of reducing weight. Sawdust is again a filler-type material that could be used to make lightweight concrete.

Properties of Lightweight concrete:

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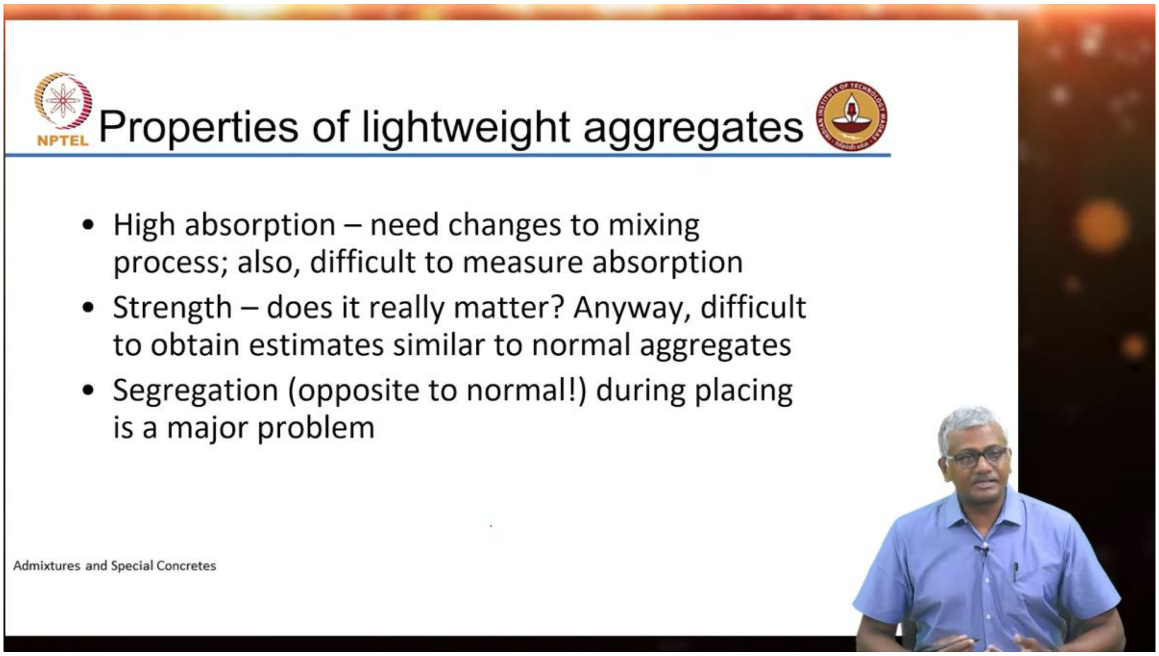

Now lightweight aggregates have high porosity so obviously they will have very high water absorption. You need to change the mixing process because if you put the lightweight aggregate in a dry fashion inside the concrete mix it is going to absorb all your mix water and you really do not know how to then control your workability. So generally, when lightweight aggregates are used there is a pre-soaking that needs to be done. You pre-soak them and make them saturated surface dry before you utilize them in concrete.

In some cases, it may be difficult to measure the absorption because the porosity in these materials is so much because to measure absorption you need to get the aggregate in a saturated surface dry state. What is saturated surface dry? When all the pores of the system are filled with water but there is no water sticking to the surface, that is very difficult in a system that is very porous because as soon as you remove from the water the pore water also will start draining out. So, getting SSD condition is not very easy so measuring absorption is also not easy. Now the strength of the aggregate, how do you determine the strength of an aggregate? What kind of experiment do you do? You do the impact and the crushing test. Essentially you take a sample of the aggregate and you have this hammer that drops and then you measure how much of the aggregate is still retained beyond a certain size.

So that is the strength of the aggregate. When you use it in concrete how does the strength of the aggregate affect the strength of the concrete? Does the strength of the aggregate affect the strength of the concrete? It does how? In what type of concrete? If the concrete is of low strength what will happen? Will the aggregate come into the picture? Yes or no? No, because in low-strength concrete, the cracks pass through the ITZ (Interfacial Transition Zone). When you make the concrete stronger and stronger the ITZ becomes strengthened and then the cracks can pass right through the aggregate. We discussed this. When you do high-strength concrete your cracks are passing through the path of least resistance and that happens to be the aggregate in the case of high-strength concrete and that causes the failure to be highly brittle, explosive and that is something that you can also expect will happen when lightweight concrete is used or lightweight aggregate is used because lightweight aggregate will in general be much weaker as compared to the paste phase.

So, in such a case, your concrete will fail through the aggregate. But the crushing test or impact test that you do for normal aggregates you cannot really do for lightweight easily because unless your lightweight aggregate is of the type of sintered fly ash or expanded clay and all which may have some strength in it all other aggregates may just get crushed to powder when you do the impact test or crushing test. So, you need to adopt the test carefully for lightweight aggregate. Now segregation can happen in the opposite direction because if you are using perlite or vermiculite as aggregate for instance this can start floating to the top. In normal concrete, aggregate settles, and paste floats to the top. Here opposite can happen. So, you need to design your concrete mix well for that purpose.

Types of Lightweight Aggregate:

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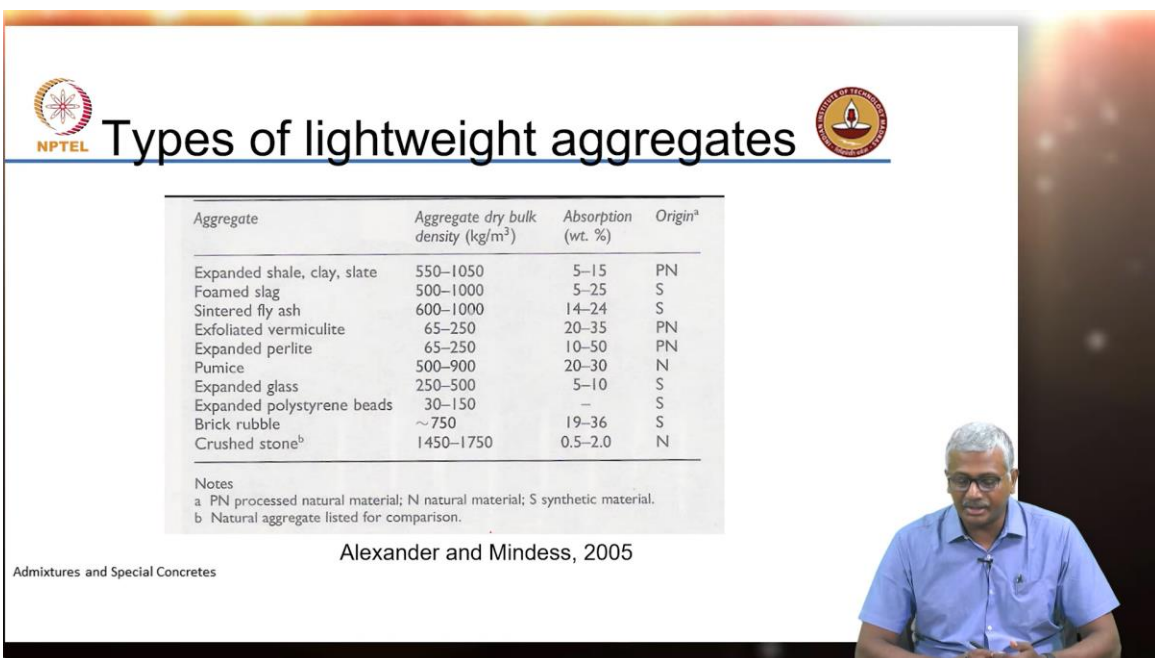

So, some properties of lightweight aggregates are given here. So, the densities and the absorption levels that you can get and how the aggregate is obtained. Origin- Pn is processed natural, S is synthetic, and N is natural. So, pumice and crushed stone is natural.

Crushed stone is just listed for comparison of the properties. The bulk density of the crushed stone which is typically of the order of 1500 to 1600 kg per cubic meter and absorption of crushed stone is usually less than 1%. Most granite limestone will have an absorption of less than 1%. But as compared to that, you can see the extent of absorption of some of these aggregates. For instance, perlite 10 to 50%, you can get up to 50% water absorption in the system.

So varying properties of these materials are there. You need to choose your material carefully to design the concrete with lightweight aggregate. That is why lightweight aggregate concrete is a lot more complicated than producing foam concrete or aerated concrete. Aerated concrete is something we will talk about; we do not discuss that yet.

Fly Ash aggregate:

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Just an example of fly ash aggregate.

So, you have these pelletized fly ash which has been then fired inside a furnace at very high temperatures to cause sintering. That is why these are rounded because they are pelletized. The pellets are nice and round. You can see that there is also a commercial product called Lytag, that is available for sintered fly ash aggregate and this is available in the market. But then again it is produced by pelletization and sintering both involving energy imparted to the process.

So, is it really worth putting in that much to obtain fly ash as an aggregate? As I said most of these lightweight aggregates are produced by imparting a significant bit of energy. So, you cannot do a complete LCA analysis to really get a clear picture of whether it is justified to go with lightweight aggregates at all. But for certain applications as I said you do not have any other choice. You have to go with lightweight materials.

Methods to produce synthetic light weight aggregate:

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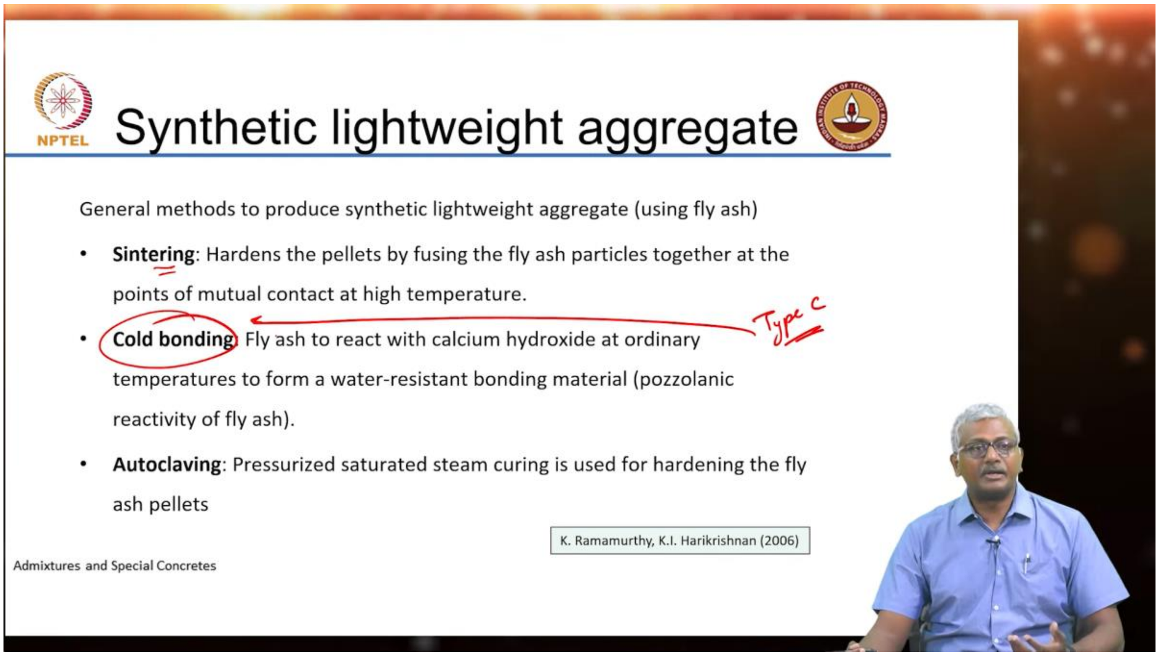

Now fly ash aggregates can of course as I said you can form by sintering.

You can also form the same by cold bonding. If the fly ash is reactive, extremely reactive, it can react with calcium hydroxide at ordinary temperatures to form CSH because fly ash is after all reactive silica. If it is highly reactive it can react as well you can make a mix with calcium hydroxide, do the pelletization with calcium hydroxide and just cure the material that will also form hardened aggregate because of the reaction of fly ash with calcium hydroxide. Alternatively, if you have type C fly ash, what will happen when you have type C fly ash? It will exhibit much higher reactivity because of the higher calcium content present in the system. So, with type C fly ash often cold bonding is a realistic solution.

Now this is good because now the energy is only for pelletization. The remaining process is just natural curing. There is no high-temperature sintering involved. So that is one thing which you need to consider. Can you process the material without the provision of the high-temperature sintering and that is what you can do with cold bonding if the fly ash is reactive.

Now often, to increase the rate of this reaction you can also do autoclaving. Autoclaving implies putting the material in a chamber where pressure and temperature can be increased to increase the degree of reactivity that you find in your system. So, it is almost like steam curing but at high temperature or steam curing at high pressure. Steam curing is normally done at atmospheric pressure but autoclaving means steam curing at high pressure. You also pressurize the chamber while doing the curing.

Sintered Fly Ash Aggregate- Influence of Binder

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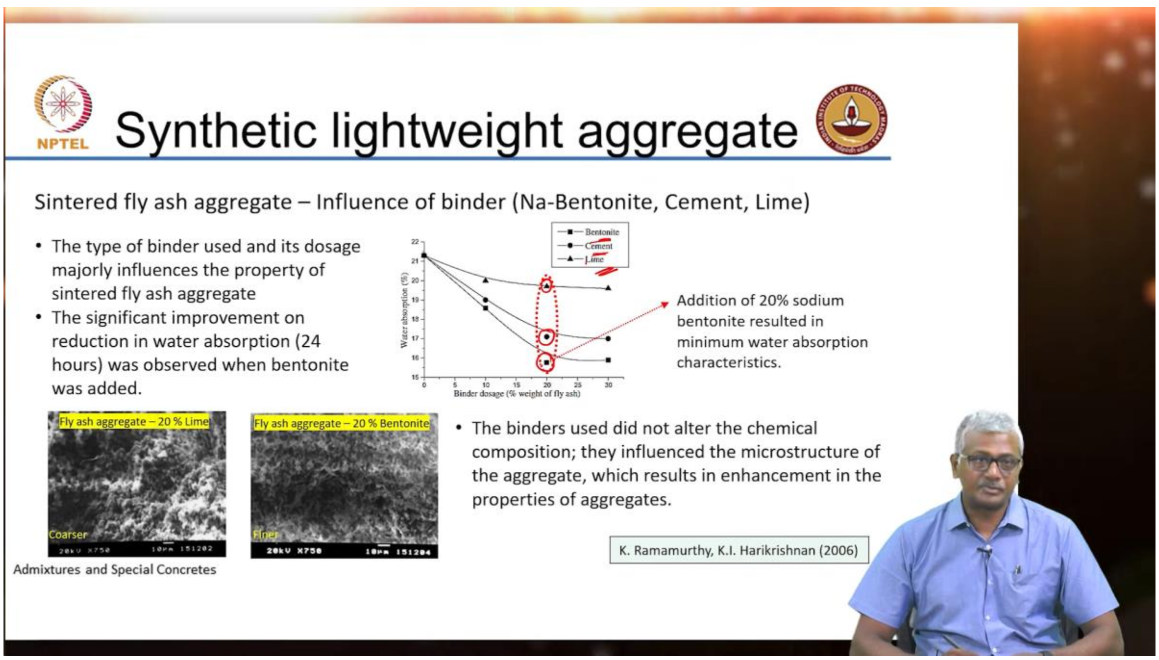

There is an influence of the different types of binders that are used for sintering the fly ash aggregate or to pelletize the fly ash aggregate. Depending upon the type of binder that you use either bentonite or cement or lime, the resultant sintered aggregate that you produce will have a different property. For instance, if you use lime the resultant sintered aggregate still has a fairly high water absorption. If the binder is cement, you are lowering it to a certain level but bentonite seems to work quite well in terms of water absorption characteristics. You are adding about 20% sodium bentonite to the fly ash and then causing pelletization and then sintering this material and that leads to a significantly low water absorption.

So, the type of binder that is used to pelletize is because you need some glue to keep the fly ash particles together to make the pellet and then these pellets are sintered and then you get the properties of lower water absorption.

Cold Bonded Fly Ash Aggregate- Influence of Curing Method

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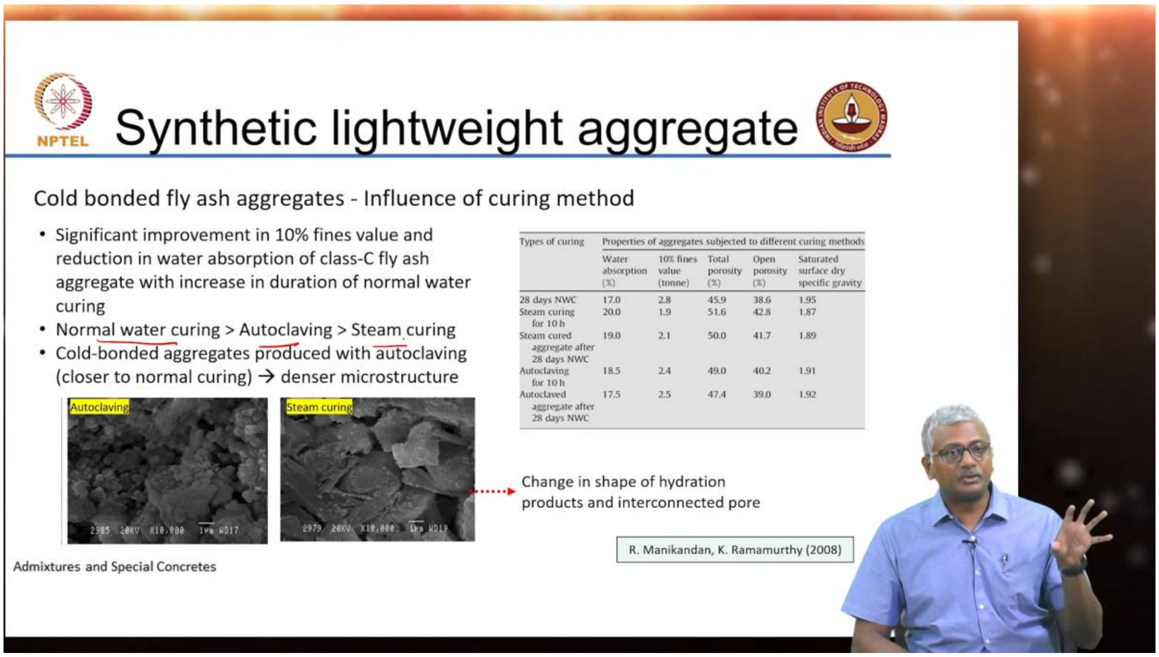

Types of curing	Properties of aggregates subjected to different curing methods				
	Water absorption (%)	10% fines value (tonne)	Total porosity (%)	Open porosity (%)	Saturated surface dry specific gravity
28 days NWC	17.0	2.8	45.9	38.6	1.95
Steam curing for 10 h	20.0	1.9	51.6	42.8	1.87
Steam cured aggregate after 28 days NWC	19.0	2.1	50.0	41.7	1.89
Autoclaving for 10 h	18.5	2.4	49.0	40.2	1.91
Autoclaved aggregate after 28 days NWC	17.5	2.5	47.4	39.0	1.92

As I said cold bonding can be done with fly ash aggregates that are reactive. So again, depending upon the type of curing method, you can get different properties. If you are willing to wait for long normal water curing is the best. The next best is autoclaving and the last is steam curing.

Natural bonding happens over a long period of time but then you get a property of water absorption that is much lower as compared to what you get from autoclaving or from steam curing. So generally, what you end up with normal curing is that you get a much denser microstructure that forms. We discussed this when we talked about steam curing and its effects on the long-term development of strength. When you do accelerated curing what ends up happening is you introduce more coarse porosity in the system and that is what exactly, you can think about cold bonded fly ash as a hydrating cementitious system. The same thing, if you subject that to high-temperature curing it will gain strength fast but it may not have a long-term property that matches that of normal low-temperature curing.

So same concept here also. So, this is just some data that is presented from the work of Manikantan who worked on his PhD here with respect to fly ash-based aggregate system. Now the interesting part about the work that has been done here is that this is not just based on the fly ash that you get from the ESPs, it is also based on bottom ash and other low-quality fly ash that is usually dumped in power plants. In most power plants they have these ash ponds where they dump the fly ash that has not been collected by cement companies to make blended cement. A lot of that extra fly ash is just dumped and now tons and tons of this fly ash is available and Professor Ramamurthy's group has worked with this low-grade fly ash also to a large extent and ended up producing very good quality lightweight aggregate from the system. .

Aerated concrete

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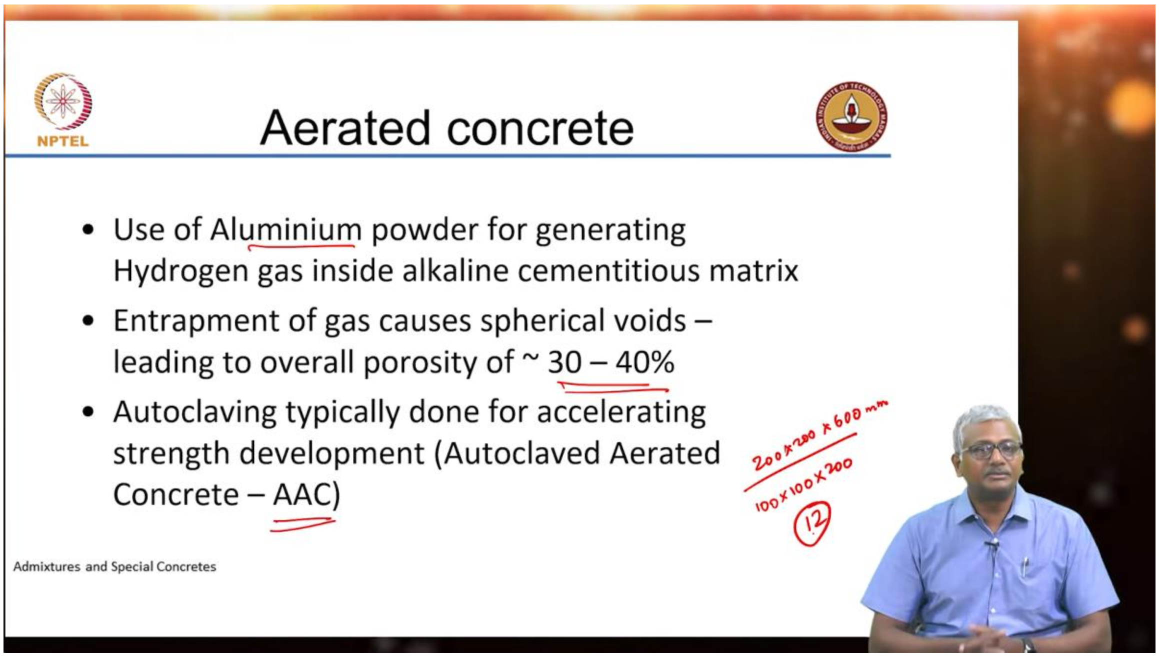

So finally, the other part of lightweight concrete is aerated concrete. Aerated means you just generate air in the system or entrap gas in the system. So here what we do is we use aluminium powder for generating hydrogen gas. So, in an alkaline system when you have calcium hydroxide present in the system, the presence of aluminium, not aluminium oxide, the aluminium oxide will be mostly inert, it would not do anything but aluminium itself as an element if it is present it will react, and lead to the generation of hydrogen gas and if that happens the gas gets entrapped in the system and that leads to the aeration of the system. It is almost like baking a cake. What do you do? You add, what do you add to aerate the bread? You can add baking soda or natural materials, yeast is also there which you can add to bake and then when you add this and cure it at a high temperature you create a system where the air is entrapped inside the dough.

So, bread is aerated flour, that is what bread is, aerated cured flour. That is exactly what we do in the case of aeration of concrete also. So that is why we do not want to use aluminium pipes to transport concrete. Aluminium pipes will be much lighter in weight, easy to handle but you cannot use them because if concrete is pushed through aluminium pipe, you start generating hydrogen gas and that will block because when air voids are present you cannot really pump the concrete well. So, the exact same reason why we do not use aluminium pipes is the reason that we use aluminium to generate hydrogen gas inside the system.

So, what you do by entrapment of this gas inside the system is generate a porosity of nearly 30 to 40%. Significant porosity can be generated. To accelerate the strength development and to increase the productivity of making these blocks you can do autoclaving and high-pressure steam curing, and the blocks that are produced are called AAC blocks or autoclaved aerated concrete blocks. These are today perhaps the most used concrete blocks everywhere in construction. As I said you can have a block of typically 200mm by 600mm, that is the typical size of these blocks. What is the size of a brick? So essentially 100mm by 100mm by 200mm.

So now you can see how many blocks are there, y 12 bricks per block, volume of 12 bricks comes in one block and this block is light in weight because of the lightweight concrete nature. So, you can have one worker put this in place, in a single mortar joint. So, it increases productivity significantly. Instead of lifting 12 bricks now you are lifting one block.

Factors affecting aeration in aerated concrete:

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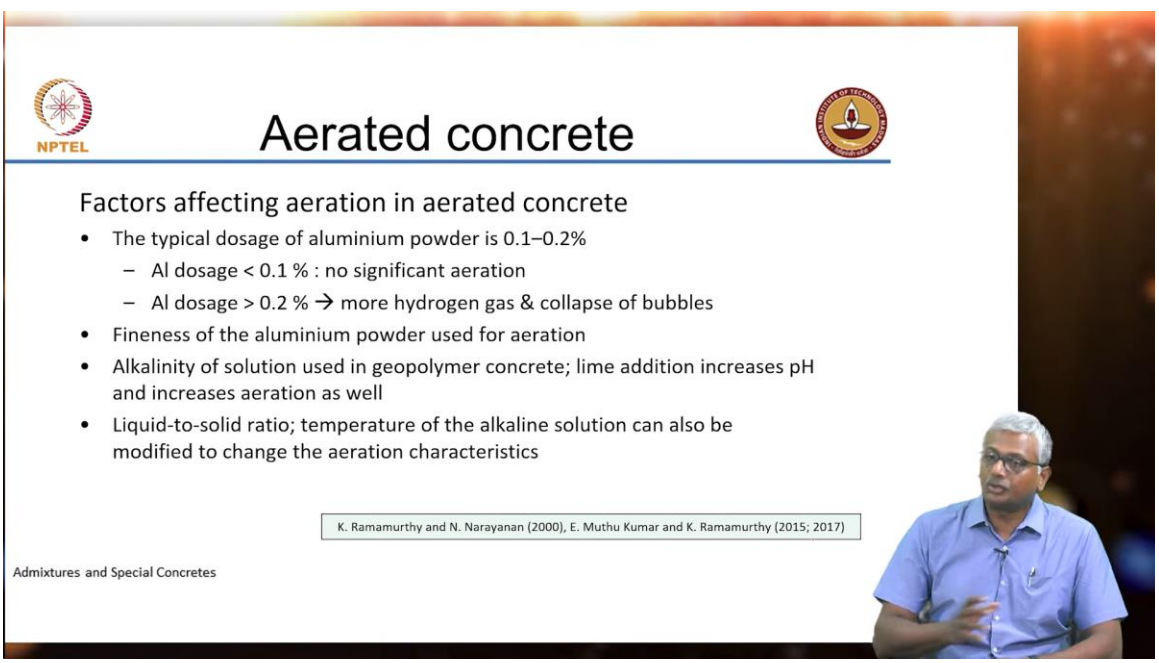

So again, you need to pay attention obviously to the magnitude of the aluminium that you add if you have a dosage less than 0.1% you do not get variation, and dosage of more than 0.2% you generate too much air in the system and if you generate too much air in the system the bubbles are not going to be stable, they will start breaking. The bubbles have to be of a proper size to be properly entrapped and remain stable in the system.

The air generation will also depend on the fineness of the aluminium powder that you use and the alkalinity of the solution. Higher alkaline solutions just like in the case of foam concrete, higher alkalinity also help in the case of stabilizing the air void system in this aerated concrete. So, the temperature of the alkaline solution and liquid-to-solid ratio overall for the concrete mix can also affect the aeration. So, several different factors most of which are well covered in the literature produced from IIT Madras