Concrete Technology
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Lecture - 41
Special Concrete Concrete & Sustainability

Welcome to module nine, lecture six – the last lecture of this module, and also the last lecture of the series – concrete technology series. And we shall be discussing about some more special concretes in this lecture, and also talked about sustainability.

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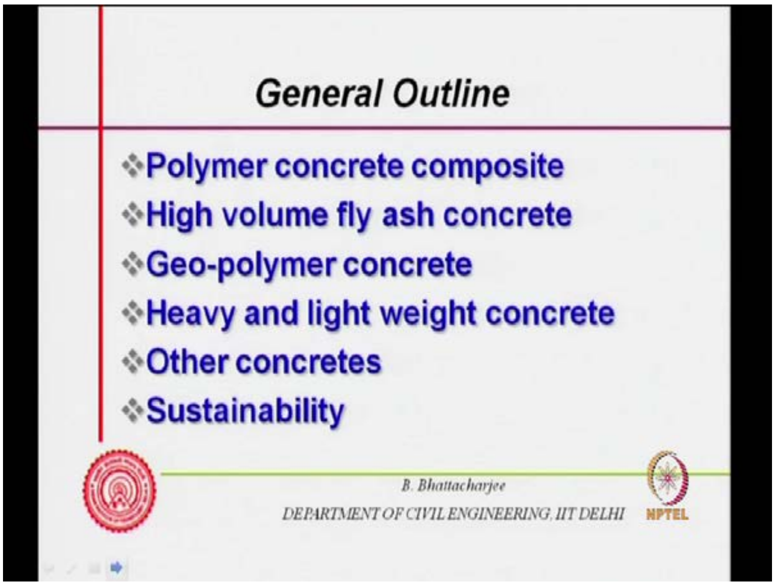

Polymer concrete composite is the first one that we look into. Then, we look into high volume fly ash concrete; geo-polymer concrete; heavy and light weight concrete; and, other concretes; sustainability. That is what we look into. So, this is the sequence of things that we are going to look at. The 1960s, when the 50, 60s development in polymer science and technology took place; and in the mean time, concrete science and technologies were trying to enhance the strength of the concrete. Now, the strength of the concrete is restricted by the cap it is the finally, the water-cement ratio that we have understood that it is a water-cement ratio, which governs the strength.

And therefore, there is an inherent porosity, capillary porosity in the concrete system. And therefore, its strength could not have gone beyond 40s those days. So, the other alternative was remove the hydraulic cement altogether. Polymer science and technology had developed by that time. Therefore, why not remove the hydraulic cement bind here altogether. This gives to polymer cement concrete composites actually – polymer concrete composites.

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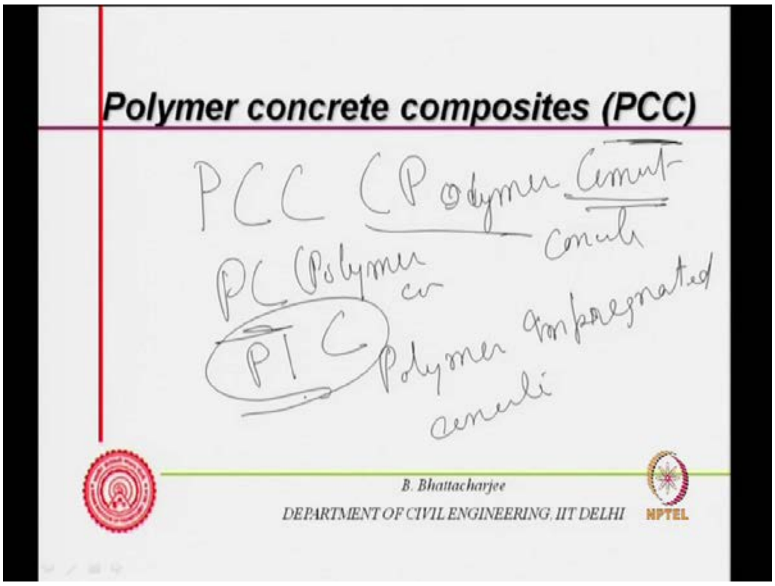

Out of this, there are three of them; one we call as polymer cement concrete. Then, there is another one – we call it polymer concrete. A third is a polymer impregnated concrete. So, this is polymer cement concrete, polymer concrete, and polymer impregnated concrete. Now, you see in this one, polymer cement concrete means the attempt is to remove the hydraulic binder. Here this is actually we do not remove the full thing. In fact, we add some component as an admixture almost – 5 percent, 6 percent and then use together with the… So, in the part of the cement system, we use the polymeric material. And, PC is one where actually hydraulic binded is completely removed. And, polymer impregnated concrete is already an existing concrete where we impregnate with polymer. So, this is what it is – polymer concrete composite.

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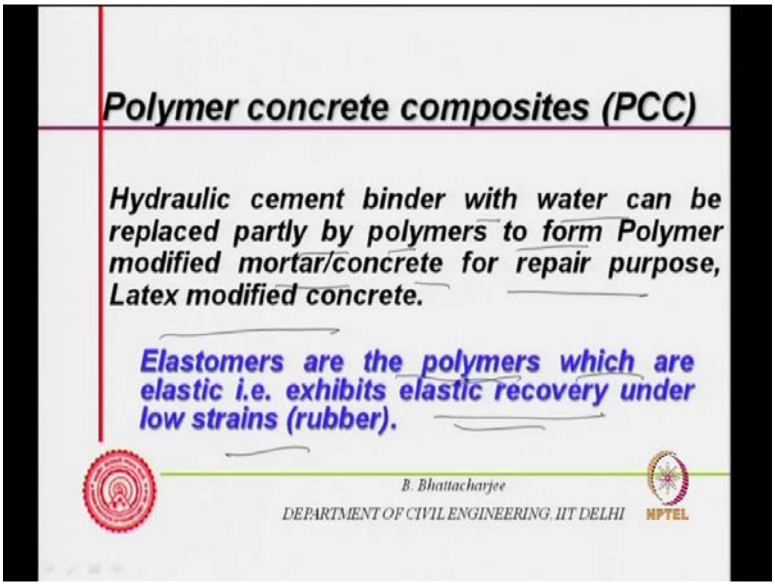

First one is the polymer cement concrete. We just had about 5, 6 percent. Hydraulic cement binder with water can be replaced partly by polymers to form polymer modified concrete, mortar concrete for repair purpose – latex modified concrete. Rubber latexes are what are used here mostly. And this rubber latexes – they are actually elastomers. Now, I am sure most of you are familiar with what is a polymer. A polymer is a material, which is actually produced from monomers, repetition of the monomers.

So, there are varieties of polymers like thermoplastics, thermo sets, elastomers – the classes on materials. So, thermoplastics are the one which can be remoulded after heating. Thermo sets are one which cannot be remolded; they are usually cross-linked polymer system. I do not have time to go into the details of these ones that could be form of other materials course that you might have done.

Now, the elastomers is another class of material, which can be there, can be thermoplastic elastomers. But these materials are another kind of polymers, which are rubber, because we understand they have elastic recovery under low strains. So, elastomers are polymers, which are elastic exhibits recovery under low strains.

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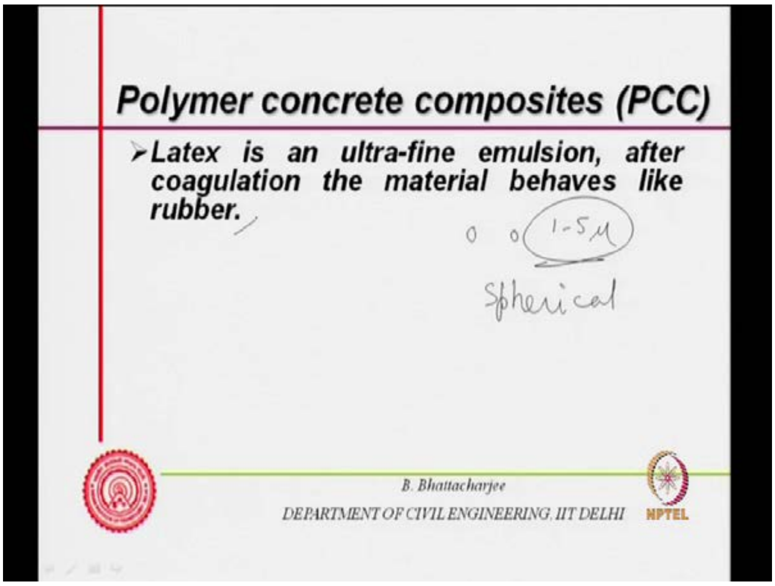

So, latexes are actually elastomers. This ultra-fine emulsion after coagulation; and, the material behaves like rubber. So, these are small particles – 1 to 5 micron. I suppose these are the kind of sizes; very small size; have a latex spherical particle actually. This is added to the cement concrete and they behave like rubber and they get polymerized – solidified polymerize. So, when polymerization occurs, the mass increases – molecular mass increases. And therefore, it solidifies. And when it solidifies within the concrete system, cement system; 1 to 5 micron means, they will go into the interstitials of the cement themselves. And thereby, they actually increase the strength of the… So, they act as filler; then, solidifies, reduce down porosity somewhat.

And therefore, they increase the strength. So, strength enhancement could be 1.5 times. Strength enhancement ratio as it is called; the strength of same water-cement ratio of concrete; so, strength of the polymer modified concrete divided by strength of the same water-cement ratio ordinary concrete non-modified could about 1.5, 1.6 times. So, good concrete can be prepared with this.

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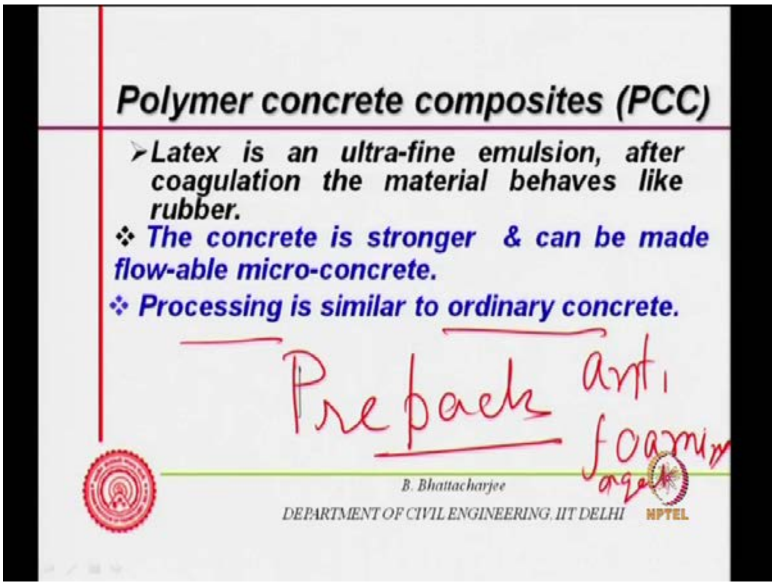

But this is costly. Therefore, remain as a repair material. One can make them into flow-able micro-concrete; then, use extensively for repair work. Processing similar to ordinary concrete only one point, because if you are trying to… They come as prepack materials. They usually come as prepack system. Manufactures apply them as prepack system. So, they give you prepack kind of mortar for example. So, everything is mixed. You mix water; and, the material is made; then, all the construction chemical companies who supply them – they give you prepack. But if you are making yourself, then when you are doing this processing almost similar, you must have some kind of antifoaming agent, because these fine particles – very fine spherical particles – they tend to generate a lot of foams.

So, you must have antifoaming agent. Some plasticizers and other admixtures could be there. But, antifoaming agent is very much required. So, one can actually use these rubber latexes; prepare their own concrete also. But then commercially, prepack materials are available and very useful in repair works, because they can be free-flowing; they can be flow-able. So, before self-compacting concrete came, this was very much flow-able material. And, even after self-compacting concrete has come, this is used as an extensive (( )) repair material.

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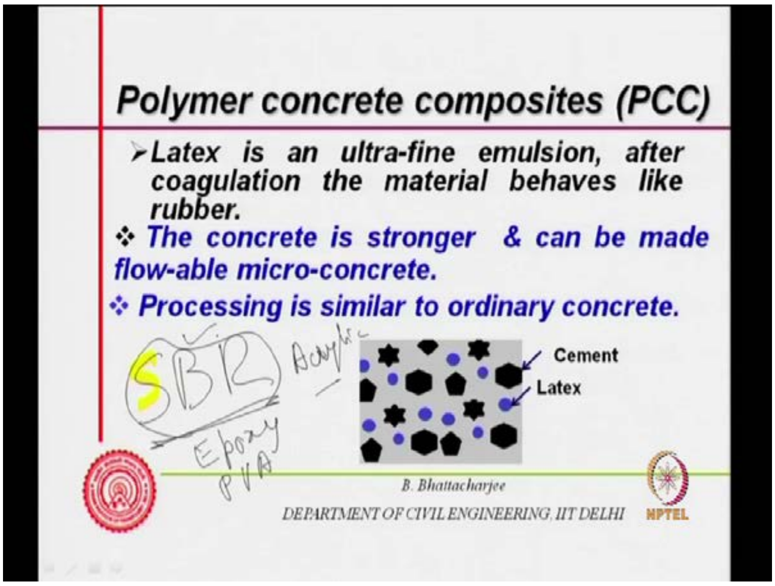

Something like this. So, this is the material; you can see the cement and the latex. So, they go inside the system and actually polymerizes. Once they polymerize, they will actually get inside and the cement hydrates. Cement will also… Hydration of cement… So, cement hydrates will be there. This will also polymerize, solidify. And therefore, the bond to make it better concrete as (( )) So, this is the polymer cement concrete; this is polymer cement concrete. You have all kind of latexes such as basically SBR – styrene-butadiene rubber. It is not easy for concrete technology and cement; I mean civil engineers to remember this polymeric name.

But styrene-butadiene rubber is SBR; system is very popular; SBR is very popular; you can have epoxy latexes, polyvinyl acetate – PVA latexes; you can have acrylic latexes acrylic, etcetera, etcetera. There are various kinds of system. But this is very very popular. Butadiene is a rubber – styrene-butadiene rubber system. So, this is basically kind of latexes, which are used and they make the polymer concrete. So, this is one type.

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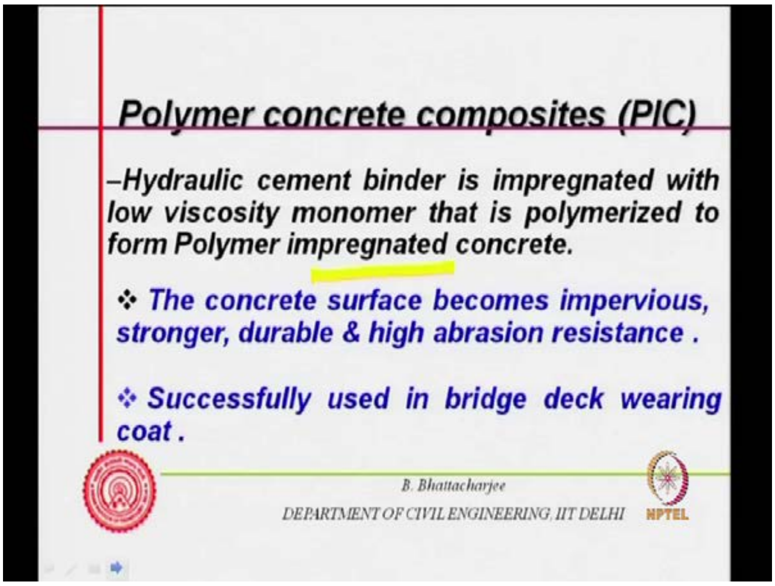

The next type is polymer concrete – polymer impregnated concrete. So, polymer impregnated concrete – you have got hydraulic cement binder. And this is impregnated with low viscosity monomer that is polymerized to form polymer impregnated concrete. Let me see if I have a diagram; I will come back to this later on.

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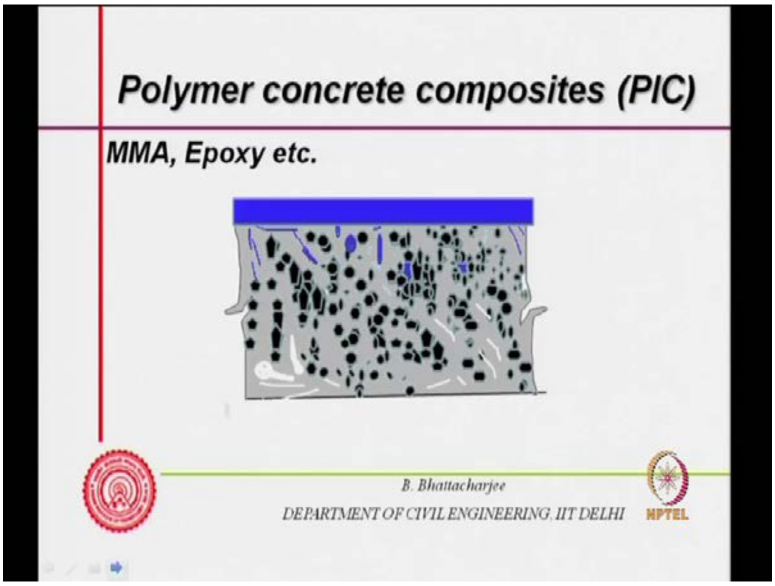

Just let us look at this. This is the ordinary concrete; this is the exiting concrete; and, you have pores. This is the pores as I have shown – the blank white spaces. This is the pores. So, these are the pores; originally, they are the pores actually; they are the pores actually.

Pores are available. So, what you do, you actually… Impregnation means put the material – the monomer with accelerator, etcetera, etcetera, because polymerization would be through an accelerator or by radiation technique or by thermal technique. So, what you do, you actually put some heating system. So, you just… Impregnation injection is under pressure; impregnation is just putting it on top, flooding it; and then, the impregnation would occur; the polymer will get inside; polymer will simply get inside and block the pores on the top. And, this is polymer impregnation concrete. So, polymer impregnation can be done from the top on a flat surface. And obliviously, the bottom pores are still reaming. But the top pores are there. So, this is the process of polymer impregnation.

Originally, you must have a good concrete. Low viscosity monomer – that is actually impregnated into the concrete and then polymerized to form polymer impregnated concrete. Now, this polymerization can occur because of the radiation. But, that is a health hazard. By thermal techniques, thermal polymerization, radiation polymerization or by using chemical polymerization with kind of a hardener system… If you are familiar possibly araldite, which is of course an epoxy; these are various kind of glues – two components glues or epoxy – is one material which is very popular. Now, you have two components or three components. So there is a resin; there is a hardener and maybe an accelerator.

So, one of them would be a catalyst or another material, which will finally make it to polymerize. And, there is acceleration – accelerates this process. So, you can have monomer mixed up with those materials altogether, which will polymerize it. And, they get inside and then polymerize it. So, successfully used in bridge deck actually. The concrete surface becomes impervious, stronger, durable and high-abrasion resistance. Their durability is very good. Strength improvement ratio can be as good as too in this kind of material when tested in laboratory cylinders.

And, successfully used in bridge deck wearing coat, because wearing coat – what happens is, they actually tend to get actually damaged and distressed during… because of abrasion of the wheels and so on. So, what you got to do? After some years, you have to put another wearing coat. Now, if you go on putting in that manner, the thickness would go on increasing and dead load will increase. Also, the people what they thought – they initially thought that, they will replace the wearing coat after a given number of years, not replace, put another layer over a number of years. Replacing is very difficult. But, it so happened that, the traffic increased significantly, the automobile technology improved – more automobile, cheaper automobile; automobile market actually increased. And therefore, traffic increased in the system.

And, when the traffic increased, the wearing coat actually gave off much earlier. Therefore, you have to put in another wearing coat. So, repetition, the frequency of putting in wearing coat increased. So, what you do? You cannot go on putting weights after weights on top of it. Polymer impregnation actually did a very good job there, because once you put that, the wearing coat last much longer, its abrasion resistance increased, durability increase. And therefore, it will also protect the inside structural element longer. So, this was polymer impregnated concrete. Methyl methacrylate, epoxy – many of those polymers – they have been used for this purpose. So, that is what we showed earlier.

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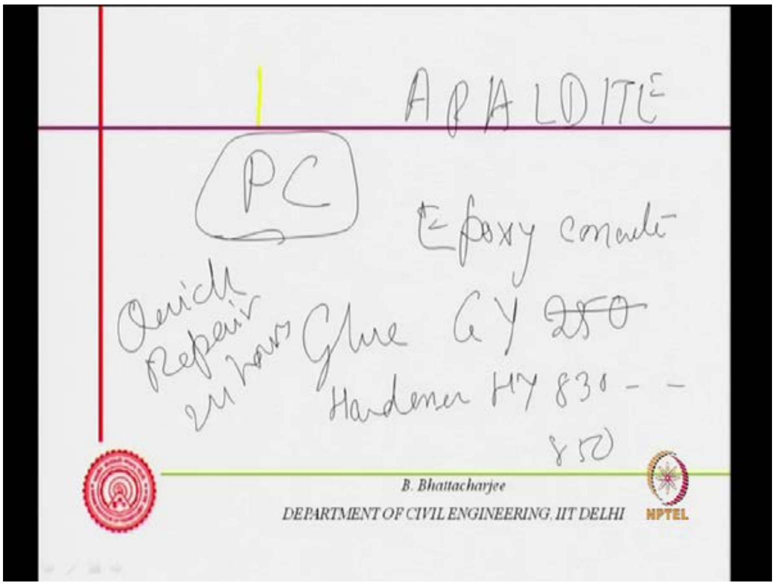

Polymer concrete is simply you replace hydraulic binder completely with polymeric material. So, epoxy concrete – also used for repair material – epoxy concrete used for repair material. So, you have a glue… Like for a epoxy concrete, for example, GY 250 or 230 – these are brands earlier available; hardener glue and hardener HY 830, 850. etcetera, etcetera are series. And, there are third component another. So, we will have this one; you mix the monomer or resin with the hardener system and put sand into it.

Now, just simple example; you can take example of araldite. You take example of araldite. It has got a glue and a hardener. Now, you put some sand together in this araldite. It makes you an epoxy mortar. But, only thing is the difficulty is that, the mixing process, the viscosity of the system, stickiness of the system is such that it is not easy to make them. So, you have to have special kind of ones. At the same time, you may have to have a spray. For example, you might have a silicon spray as a demoulding agent. So, normally, one would not be using them for regular concrete, because it is so costly; you can understand small araldite tube cost you how much.

Even today, in Indian scenario, even if the cement prize is high, 50 kilo would cost… Let us say if 50 kilo costly than 500 rupees, it is only 10. But today, it is not 500 as yet; it is 10 rupees a kilo. But, epoxy will cost you… Araldite small tube cost you – few grams cost you 10 rupees or 20 rupees, 25 rupees. The cost is astronomical compared to concrete. So, this kind of concrete cannot replace our conventional concrete. But, can actually do very well as far as repair is concerned; so, quick repair. It will set within 24 hours. So, if you have prestressing – let us say prestressing anchor, it just gave in.

Then, you have the system is all locked up. Unless you do the prestressing, in bridge, it can happen or similar kind of elements it can happen; that if you do not do the prestressing, you cannot remove the support system. So, everything gets locked up. And, in such situation, you want to quickly get the concrete repaired. Epoxy can be a solution there, because it will develop the strength within 24 hours; curing time is relatively less, but extremely costly.

Of course you have jet cement today. Jet cement I mentioned earlier. They can quickly set; I know that. So, airport runway repairs – particularly during the odd time, could be such jet cement. Epoxy is costly. That is why it is not used. But epoxy have similar kind of properties; quickly, epoxy concrete. You can have polyester concrete, PMMA – polymethyl methacrylate concrete. All these concrete have been used; the strengths are much higher, because the capillary – inherent capillary porosity business is not there. But the cost being higher, not used for conventional structural element, only used for repair. So, these are the polymer cement concrete; these are the polymer cement concrete system.

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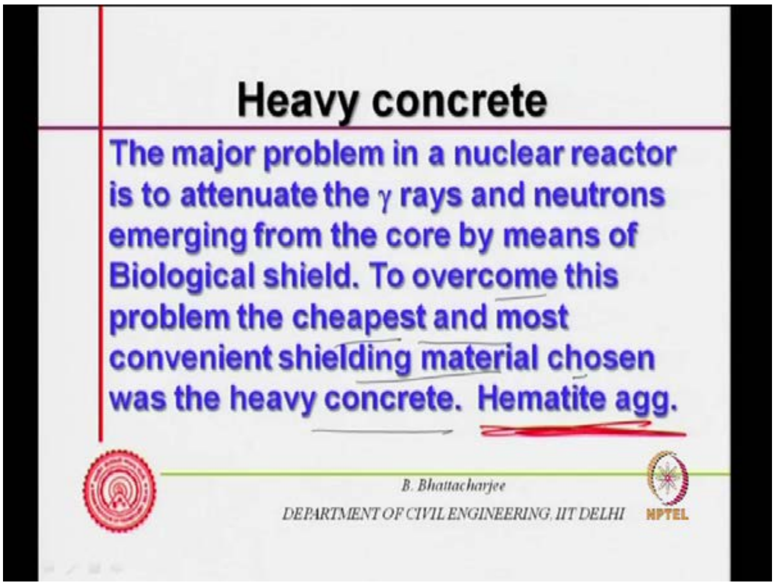

Let us look at new concrete called heavy concrete used for radiation shield. The major problem in a nuclear reactor is to attenuate the gamma rays and neutrons emerging from the core by means of biological shield. This should provide a kind of a shield for biological shield. So, you do not want gamma rays and neutrons must be going out. This is overcome; you have the cheapest way. And, most convenient material chosen is the heavy concrete. And, what you do in this one? You have heavy aggregate – hematite aggregate, barite aggregate – the aggregates, which are very strong. So, this is called heavy concrete.

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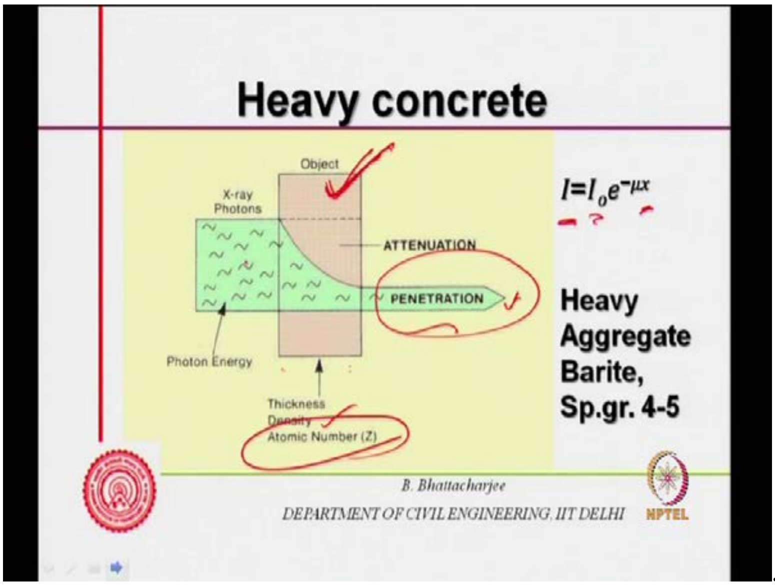

Quick introduction to this material; essentially, you have x-ray photons – photon energy, etcetera, etcetera; the after attenuation you know; this is the thickness… Basically, this should be the concrete. So, when it passes through the materials, some object, which has got a thickness, a density and there is atomic number, actually, it will attenuate. And, if this radiation is allowed, this is fine. So, heavy concrete is based on this (( )) I – the radiation that you get is I 0 – that is incident radiation and e to the power of minus mu x. So, this mu depends upon density, thickness etcetera, etcetera. x is the thickness; mu depends upon… Among other things, it depends upon the density. There are few other factors. Therefore, heavy aggregate – we use barite or hematite; and, their specific gravity is 4 to 5. So, this is the concrete.

Obviously, here the mix proportioning is not different from the conventional concrete. Finally, it will be the water-cement ratio and all other properties of the aggregate; whichever govern the strength of concrete, it will be the same. So, heavy concretes are used for radiation shield.

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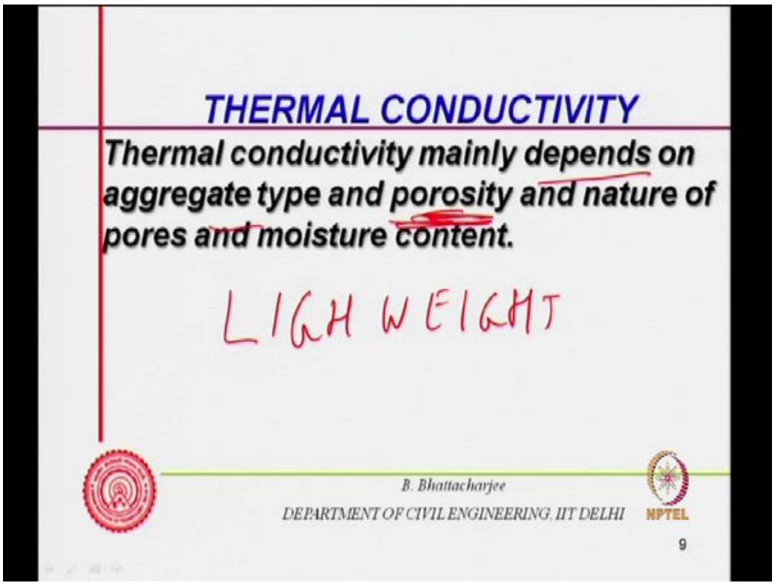

Light weight concrete on the other hand, we use for insulation purpose. Now, you remember, thermal conductivity; thermal conductivity mainly depends on aggregate type and of course the porosity of the aggregate and nature of pores and obviously moisture content – moisture content effective. Now, this means that, the density – it will depend upon density. So, thermal conductivity has become more important than ever before because of what you call energy efficient, building design and so on, so forth; operational energy consumption in condition building. So, thermal conductivity is very important; thermal insulation is very important from that point of view. And, the concrete – thermal con… – concrete that can provide these are actually light weight concrete. How light weight? Essentially because high porosity means light weight. So, thermal conductivity depends on aggregate type of course and the porosity. Aggregate is the one which conducts, which has got the conductivity of its own. But the porosity is one which governs it. And obviously, nature of the pores also govern somewhat.

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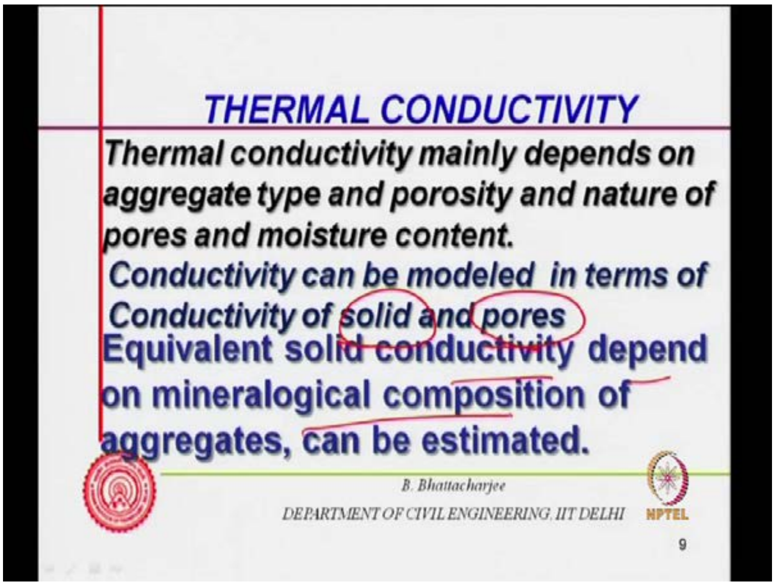

But, I think I am not interested in telling you about what is the kind of nature of the pores and so on, so forth. So, it depends upon conductivity of the solid and pores. And, the solid conductivity will depend upon mineralogical composition of the aggregate. For example, quartz or quartzite has got very high thermal conductivity compared to other type of aggregate. So, light weight concrete will depend upon… is basically because of the porosity; low porosity means high density; high porosity means low density. Now, light weight aggregates were the other kinds of aggregate, which is generally not available much in India. You have something called cinder concrete, not a structural concrete.

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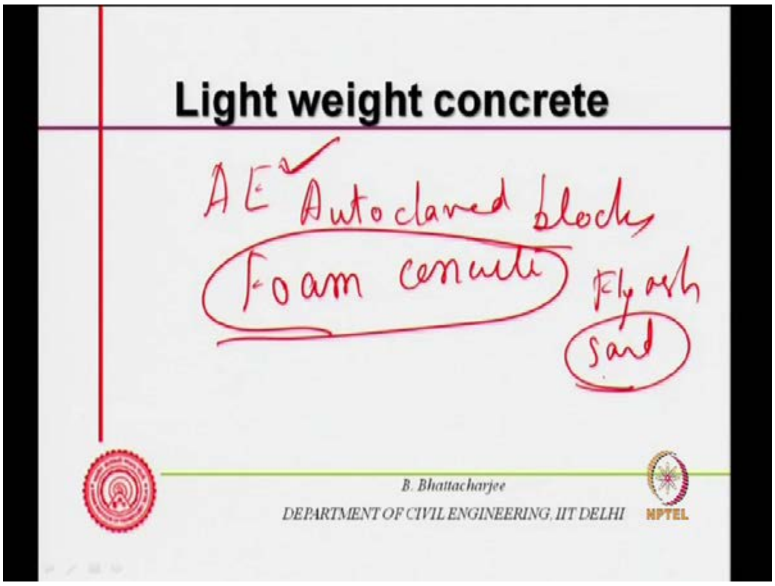

But, cinder or overbound bricks – they will give low density; lower density would give you somewhat good thermal conductivity. But in India, it is aerated concrete – autoclaved aerated or foam concrete – these are the ones, which are used as light weight concrete. So, you have got aerated concrete actually, autoclaved blocks, foam concrete. The foaming agent you have; some sort of foaming agent, aluminum powder; or, there is even organic foaming agents these days. So, you make foam and put it into the concrete or mortar that you make; and, you can make foam concrete.

There are some agents, which you can add in the concrete right in the beginning. They will be go into the concrete system and generate lot of foam or void system – gases. And, this entrapped gases can give you aerated concrete. Now, curing of this one, one can do the autoclave. So, using fly ash sand, one can use even reverse sand on those ones. Fly ash sand and part cement – one can actually then use autoclaving. At high temperature, blocks can be generated. And, that gives you fly ash or various kinds of blocks in the concrete there. There are… Even in foam work also, you can produce actually the foaming agent aerated concrete. So, these are particularly used for thermal and acoustic insulation particularly for thermal insulation. Also, they serve as light weight. So, they can serve of course… By the porosity at the (( )) they can reduce down the… provide you some kind of sound insulation. Sound insulation actually is function of the mass of the wall; larger mass, more insulation. But, absorption property is the function of the surface. So, if you have porous surface, that absorbs more.

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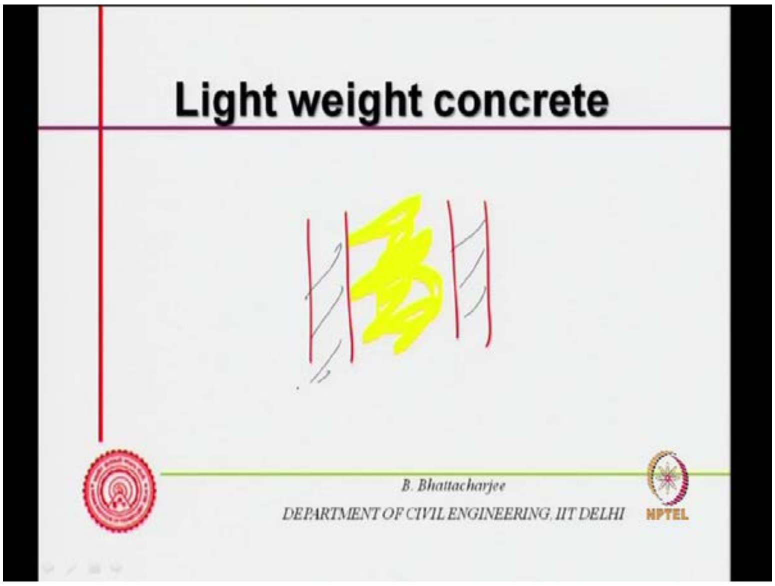

So, light weight aggregate concrete – also, if it is used as a core in a sandwich panel… Sandwich – you have two: this is one; this is another panel. And, you have a third sandwich material here. So, that is a sandwich one. So, these are the ones. This material will take the load let us say. And, inside material can be light weight material, which will act as thermal insulation; whole system can give you good acoustic insulation also, because lead system gives you good acoustic insulation as well. So, these materials are used for such functional purpose.

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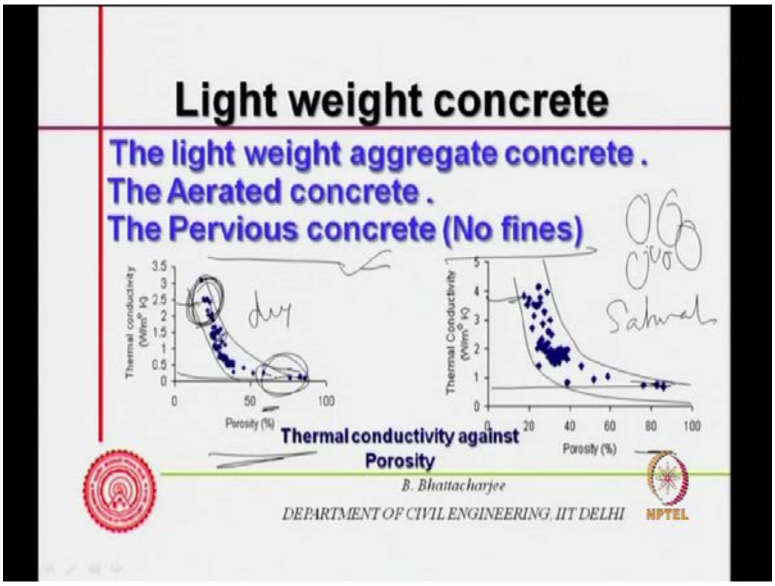

And, light weight aggregates are of course not much popular in India, because they are not available. Natural light weight aggregates are available elsewhere in the world. But, you can have light weight aggregate generated from fly ash by sintering process. So, you can have synthetic light weight aggregate coming from sintering process. And, aerated concrete I have already mentioned. A variety of another concrete is no fines concrete, which is pervious concrete. But, I will come this; just before, let us see the thermal conductivity is a function of porosity in dry state and it is also a function of porosity in saturated case. This is saturated; this is dry; this is the thermal conductivity. So, as the porosity increases, thermal conductivity reduces; significantly, porosity increases.

Now, here is the (( )) concrete somewhere; very small – 0.02 what meter degree centigrade. Even in saturated condition, they will be 0.4 or 0.5 while normal aggregates are here. This is for concrete actually. This normal aggregate would be somewhere there – 2.5; and, its saturated condition – 4, etcetera with quartzite aggregate. Other aggregates might show you somewhere here. So, you see you can actually light weight concrete here; but, even normal concrete, their thermal conductivities of these varieties, orders are known to us. Saturated conditions with moisture – they give you higher conductivities. The pervious concrete allows water to percolate through it; no fines.

Now, you can actually have only the… You have to also find out the strength is sufficient. So, no fines; there will be voids in the system and interconnected voids in the system. For water harvesting, they could be a useful thing. The pervious concrete could be useful for water harvesting. But, they can serve also as good insulation. They can also serve as good insulation provided you are able to make them and put them in the right kind of place, where you do not want moisture to percolate, because if you put it in the roof top, the water percolates; then, it is going to be no use. But, they can also depending upon the situation. No fines concrete – you leave voids; basically, you will have system like this – aggregate system and paste will go; do not put in sufficient paste to fill-in all of them. Or, even if you put that, it has to be controlled; otherwise, the cost would high. So, one has to see that. People are also trying with kind of polymeric balls or polymeric hollow aggregate system, plastic aggregates and so on.

There are several other attempts are being made to get actually light weight concrete. And, these are all at those stage. But, aerated concretes are reality. And, light weight aggregate concrete elsewhere in the world are also reality. The strength actually reduces down; you cannot get very high strength concrete with them, because aggregate becomes the weak point. So, this is about light weight concrete; heavy weight concrete to light weight concrete.

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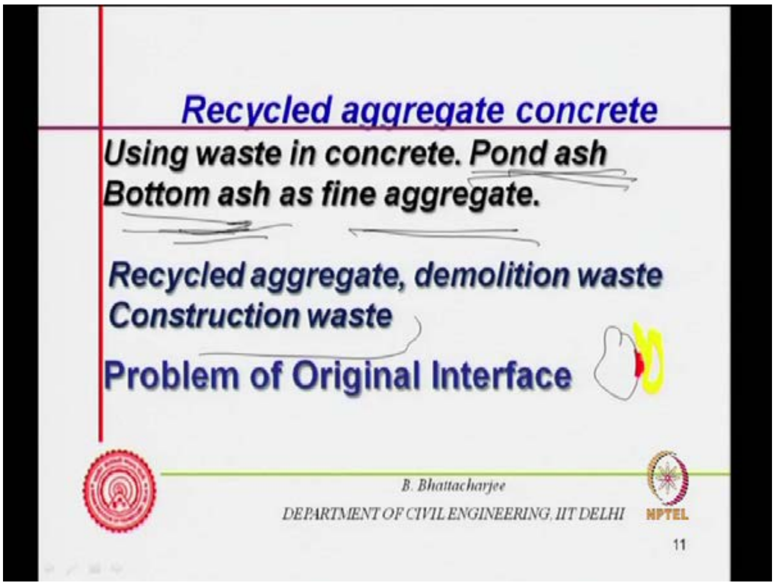

Recycled aggregate concrete – using waste in concrete of varieties kind. For example, people are trying all kinds of wastes that are available for other industries to use, because sand is a problem; availability of the fine sand; sand has got fine aggregate is a problem. On the other hand, you have got huge quantity of pond ash, bottom ash as fine aggregate. This you can use as fine aggregate. There is a huge quantity of pond ash available, bottom ash available as fine aggregate; pond ash available, bottom ash available as… And, that you can use as fine aggregate. But, one must design the mix; characterize this material and design this mix. One must characterize this material and design this mix. One can use them successfully; there is no problem.

Bottom ash has got other advantage. If you are collecting directly from the thermal power plant, they can actually give you good thermal insulation as well. However, these materials are to be seen and designed, because there are components of spherical particle there and hollow spherical particle. And generally, density is lower. But, strength can be higher. Therefore, pond ash, bottom ash as fine aggregate. This pond ash is nothing but the bottom ash and fly ash mixed together. They are pounded for disposal purpose, where variation – they vary from point to point in the ash pound. But, they can still be. The sizes are similar to fine sand. Therefore, one can use them.

Recycled aggregate, demolition waste, construction waste – they have to be crust and make into (( )) These are in research state, still have to be used. But, these are possibilities. People are attempting them. One problem associated with this one is whenever you take the aggregate, recycle aggregate crush them; you will have original mortar layer adhering to it. The interface – the original interface remains. So, when you will add now, new mortar, fresh mortar – they would again form an interfacial transition zone. So, original interface remains and people are trying to solve.

Now, you have to increase the strength. Therefore, there one has to see limitation of the strengths would be there; good lot of research are going on to look into this material; grade them. First, crush them; get them graded; get the packing density and obtain the system as it should be. So, this is the recycled aggregate. There are lot of research being done on this right now.

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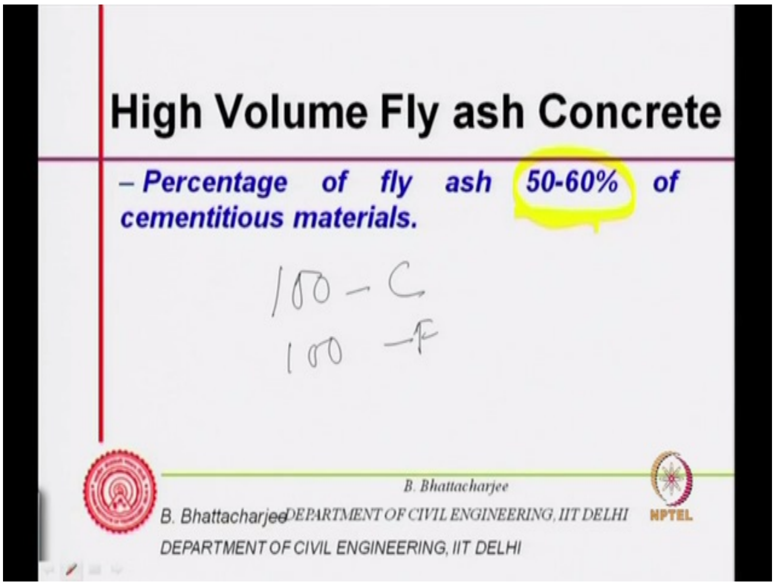

Another concrete is high volume fly ash concrete. Percentage of fly ash can be as high as 50 to 60 percent in this one of the cementitious materials. So, you have 100 kg of cement or maybe you just have 100 kg of cement; develop largely North America, Canada and United States. 100 kg of cement; maybe you will have 100 kg of fly ash or maybe more – 120 kg of fly ash. So, this is the material you use.

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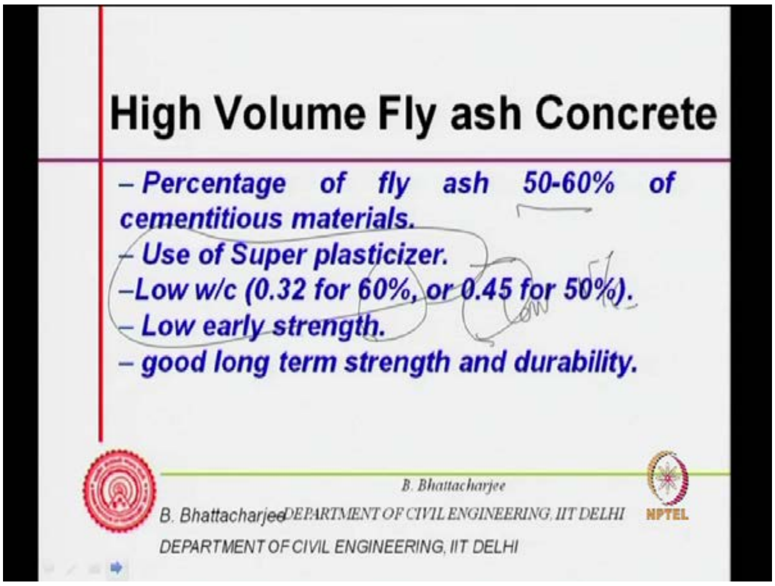

Now, whole sole idea is to use… Whole sole idea where you do not want too much of strength wanted, is not very large; where, you do not wanted very large strength; but, you want to use a lot of fly ash. Then, this material (( )) Afterwards, fly ash is a waste and you are saving on to the cement. We will come that in short while. And, in such situation, you can use this material very well. But, how do you use this? To get structural guide of concrete – 20, 30 MPa, 40 MPa concrete. Use super plasticizer to cut down on to the water. And, use low water-cement ratio; low water to cementitious ratio. Therefore, initial strength will be given by the cement.

So, 0.32 for 60 percent fly ash; 0.45 for 50 percent fly ash. So, use low water to cement ratio; use a plasticizer to get the workability. In fact, fly ash can improve the fly ash actually, because its spherical shape as we have seen earlier, it actually water… that is like somewhat like a water reducing agent; it cut downs to water demand. Therefore, both fly ash… And when these are used judiciously, normally, we use low water-cement ratio for high strength in normal concrete.

But here I am using low water-cement ratio super plasticizer, but using large quantity of fly ash. So, the strength may not go high, but it will be normal strength concrete, but large quantity of fly ash I will be able to utilize. Low early strength because I am using fly ash – low early strength. And then, good long term strength and durability I will obtain. The question of reinforcement – if it is there, then the issue of carbonation – these are to be looked into. So, high volume fly ash concrete has been a development largely; it will give us… It can make it to be a sustainable concrete, because cement saving would be there.

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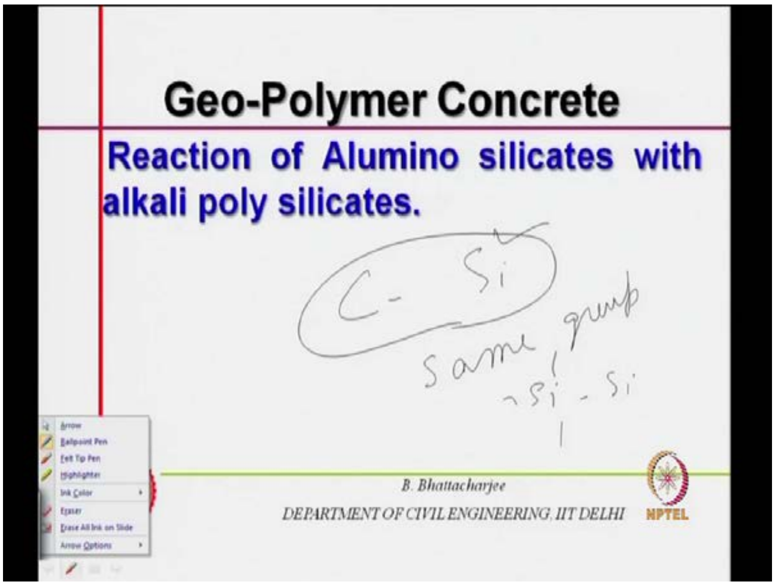

Then, there is another concrete of the similar kind called geo-polymer concrete. Now, this does not use cement at all. That was high volume fly ash, but no cement. High fly ash, less cement; but now, no cement; fully fly ash. Basically, it is carbon; and, silicon belong to the same group in periodic table. Therefore, this silicon also shows polymerization tendency. It can form bond with silicon to silicon – SiO Si-Si bond possible. 4 valance is… So, this also… It can show that, similar properties as carbon. So, it can be polymerized limited extent.

So, this is reaction of alumino silicates with alkali poly silicates; utilizes poly condensation of silica and alumina and high alkali content for strength; basically, poly condensation. Condensation reaction is a polymerization reaction, where all the products – they actually react living no byproduct to make a polymer. So, poly condensation reaction is that. So, everything goes into it in high alkali. And then, this is because of polymer, solidifies, and therefore, it gives you strength. So, basically, initially, plastic; then, polymerizes becomes solid and it can give you the strength. One problem has been curing temperature is 60 degree centigrade or so; so far, as understood.

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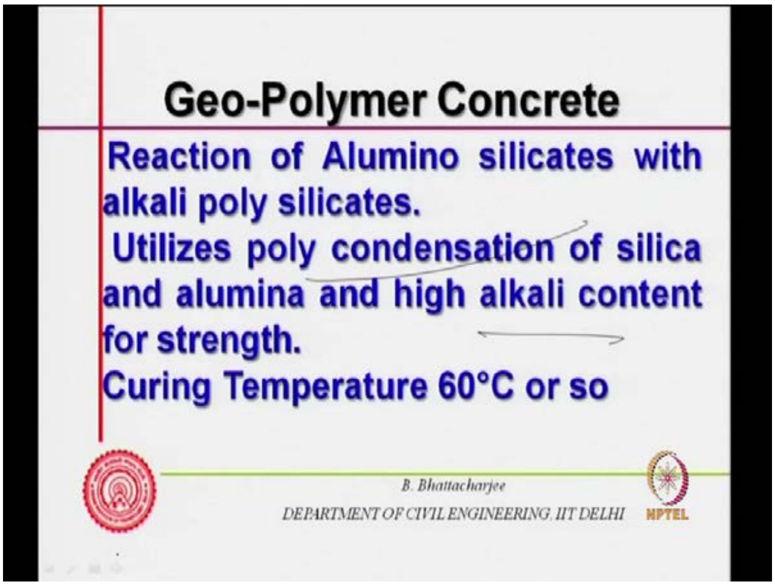

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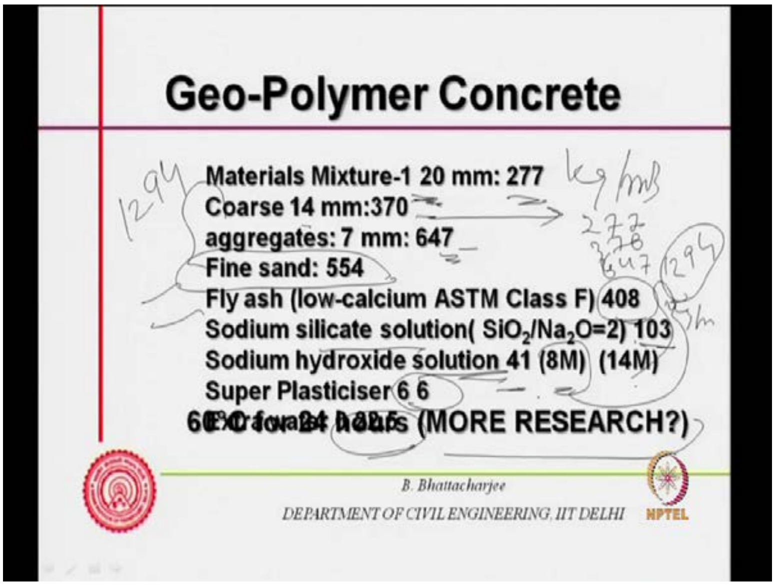

And therefore… But remember, it does not use any cement altogether. A typical mixture of this geo-polymer concrete would look like this. 20 mm aggregate – about 277 kg per meter cube of concrete; coarse aggregate – 40 mm. This is the second coarse aggregate – 370 kg; and, 7 mm – 647 kg. So, you have actually 277, 370. It will depend upon packing densities – 647 – would make it something like 1200. So, 14, 9 – 1294 kg of coarse aggregate. Fine aggregate is 554 – say fine sand. Then, use fly ash – low-calcium, because these are the binder now. This is 408 kg per meter cube. This is the binder together with sodium silicate and sodium hydroxide – 103 kg; this is 41 kg. So, silicon to sodium oxide ratio should be equal to 2.

Actually, the concentration is very pretty high – pretty high; it is rich. For example, this is 8M; that was 14 molar concentration; this is 8M concentration; this is 14 molar concentration. So, high concentration sodium silicate solution, sodium hydroxide solution. Then, use a super plasticizer to actually disperse the system; and, you might add extra water – 22.5 kg etcetera, etcetera per meter cube. So, this will have some water in the system itself plus this water.

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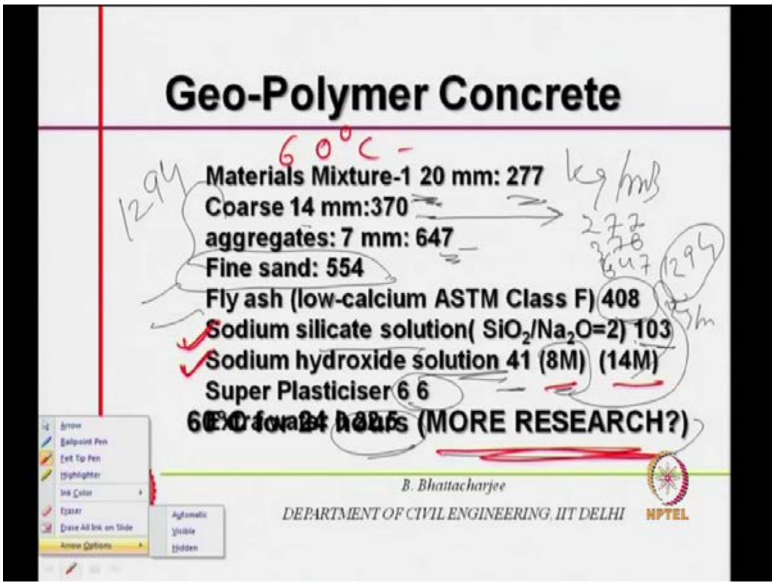

So, what you were using; you were using fly ash, sodium silicate, sodium hydroxide end of the coarse. Rest all is like concrete only. And then, you make this concrete 60 degree centigrade curing temperature; curing temperature is 60 degree centigrade. 60 degree centigrade is the cue temperature. That is only the problem that is there. Curing temperature is 60 degree centigrade and that is somewhere around that. And, that is actually the problem besides the problem of purity of this one. This molarity and this molarity; such strong concentrated material; pure (( )) material you got to use. And therefore, the cost is high; cost is not yet… It is not… So, more research is required. You require more research in this. But one successful – it may actually do away with the lime-based cement altogether. There could be something new coming in – magnesiabased cement coming in in the meantime and several other things are actually being worked on.

Now, so far, what we looked; we looked into all the types of concrete, varieties of concrete. And remember, we talked of so many types of concrete right in the beginning in the first lecture, which had normal concrete, high strength concrete, and high strength and high performance concrete, high strength matrices, roller-compacted concrete, self-compacting concrete. And, as I know, whole lot of them we discussed actually.

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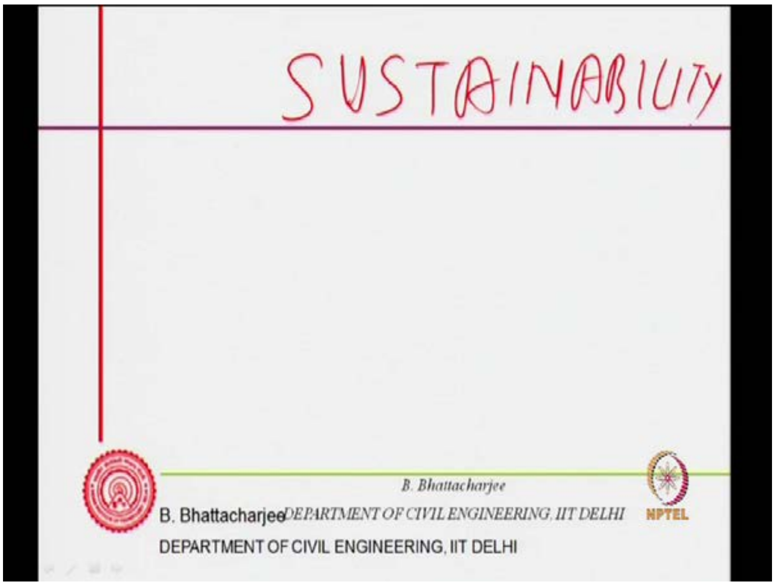

But, one issue of concrete we got to look into called sustainability. It should sustain. What is sustainability? To use the resources – currently available resources in such a manner that, it does not affect the use by future generation. So, that is it. Use all materials, energy, everything in such a manner that it does not affect. I am not going to form a definition of sustainability now in this last lecture, because I have other things to talk about. But, this has a whole set of (( )) which are available on this issue. But, it is relevant to a concrete very much.

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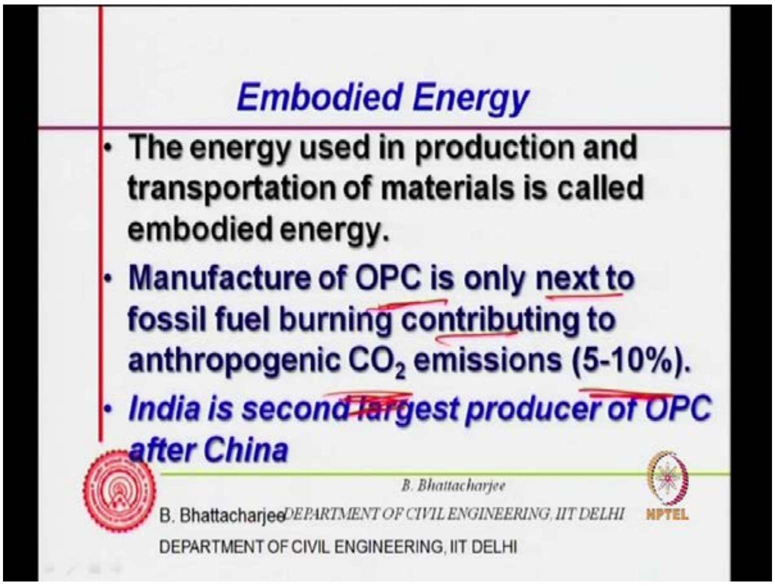

And, first thing in this issue is of course the embodied energy. Cement production uses energy; also, emits carbon dioxide, because you are calcining calcium carbonate. So, it emits actually carbon dioxide. It uses some amount of energy. Therefore, that energy, which is used in cement production, it is called embodied energy. It will include the transport of raw material; you can go further down below. There are other concepts such as exergy and so on are so many things. I do not we are going into this. But, embodied energy is the energy that has gone into the materials from production up to the construction in our case. So, the energy used in production and transportation of the material is called embodied energy. This is therefore, cement. Aggregate may require… If you have crossed aggregate, may require some energy for production, mining and then…

Today, in future, surely, it will be mined only – opencast mined as they are in many of the western countries. Quarry – even if you are taking out from the quarry, you are crushing it. There are some energy going into it; then, transportation. Therefore, similarly, fine aggregate, transportation as well as energy required in production – they make the embodied energy.

And then, OPC produces carbon dioxide. And, it is actually next to fossil fuel in production of carbon dioxide, which is a green house gas as you know. What is the green house gas? A green house gas is one like carbon dioxide, methane, etcetera, etcetera, water vapor. What is a green house? For example, if you have glass house. which you might have seen in hill stations; the glass allows shortwave radiation to pass through it. So, it allows sunlight to come through it. But does not allow longwave radiation to pass through it. So, it is transparent to shortwave radiation, opaque to longwave radiation.

As a result, in a green house, temperature is maintained house high if there is sun's radiation available. So, in cold countries, it is very important. Even in hill station in India, the plant rooms, where you have the small plants in nurseries, you have green houses; where, actually the glass or some transparent material, which allows shortwave radiation on solar radiation to come in. But, opaque to terrestrial radiation, which are longwave radiations. So, carbon dioxide layer formed on top of the atmosphere is almost acting like that. And, that is causing solar radiation to come in, but getting trapped.

Normally, within a year, whatever radiation comes in from the sun, it actually gets dissipated to the atmosphere in some manner or other by radiation back; evaporation, (( )) so many mechanisms; we are not going to this. But, if the carbon dioxide is there, it does not allow radiation to go back. So, it is trapping. And, that is causing global warming. So, this is a concern. So, cement is the next to fossil fuel in terms of this carbon dioxide production – anthropogenic carbon dioxide – 5 to 10 percent. And therefore, it is very important to look into this. In India, of course, it is the second largest producer of OPC; and, it is OPC only. So, OPC after China. And therefore, this issue is very important for us.

And then, if you look at this, the volume of concrete we use, because we have set concrete is a very economical and many other advantages are there. So, because of it, volume of concrete used is very large. The cement is the material used by mankind next to water. Water is maximum; then, you use cement or concrete.

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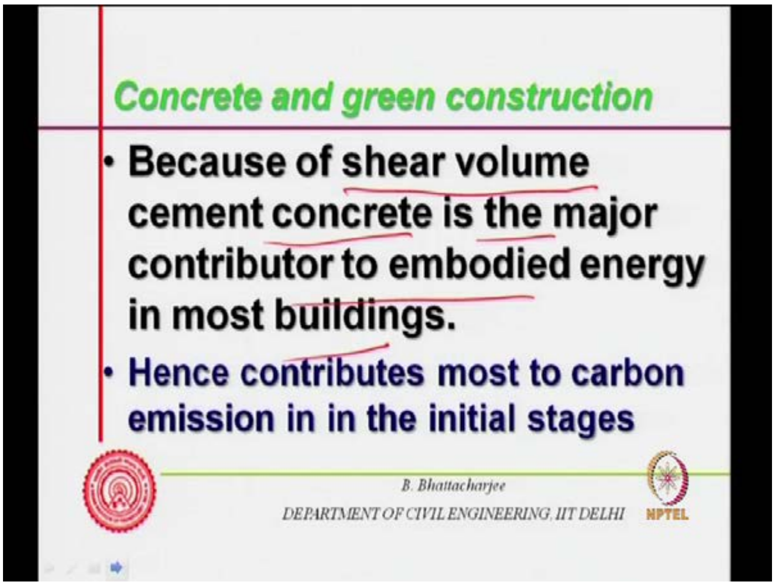

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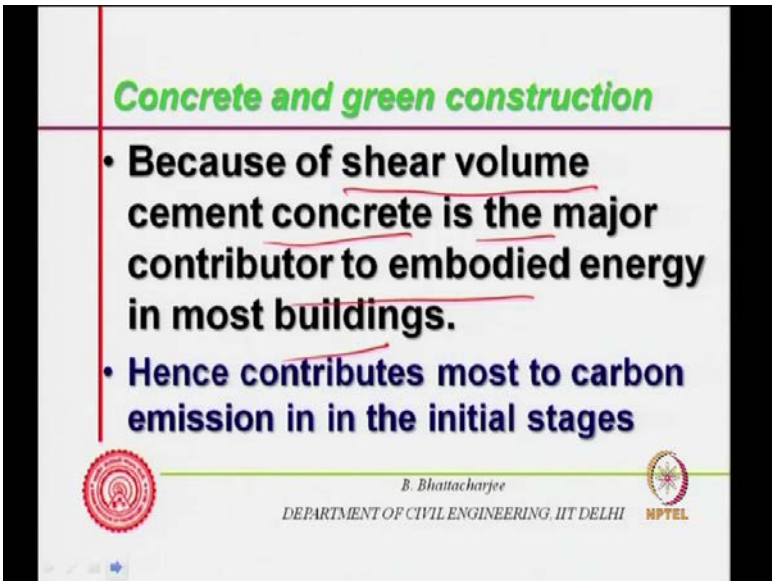

So, per capita concrete consumption in the world is increasing also astronomically. Need not go into that detail at the moment. But because of shear volume of cement concrete is the major contributed to embodied energy in most of the buildings. But it is also a major contributor to carbon dioxide in the atmosphere. So, that is why, 5 to 10 percent. Hence, contributes most to the carbon emission in the initial stages. In its initial stages, it actually contributes maximum to the carbon. Therefore, concrete and green construction – this is very very important. So, we should see that, how concrete reduces. And, one of the culprit is of course the OPC clinker production. And, that is why this high volume fly ash concrete came by; geo-polymer concrete is being looked into; magnesium based cement is being looked into; and, several other issues are being looked into. Now, major contributor to embodied energy in most building; and, as we said, it is next to the OPC cement.

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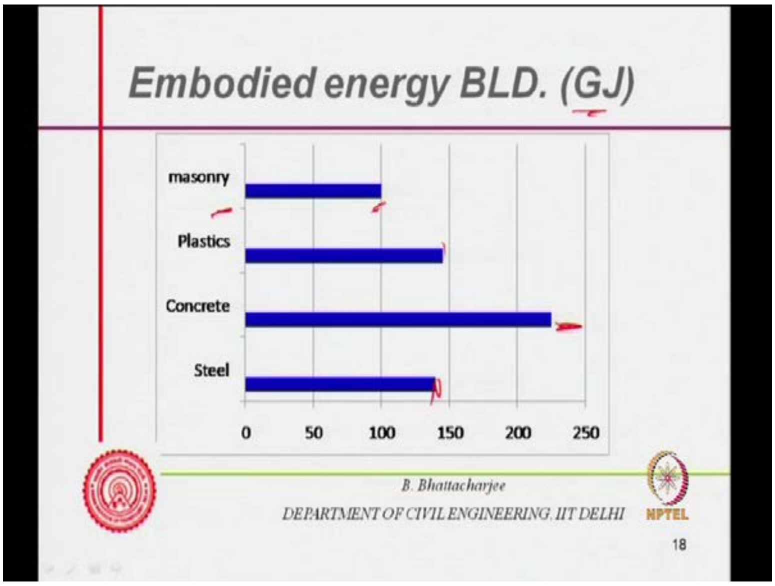

Typically, if you see it in buildings; in a given building, because of the quantities used, masonry would be embodied energy – giga joules if I look at it. Typical in a building, masonry will be there; steel will there. Although steel per met ton – metric ton; per metric ton embodied energy produced by steel is much more; plastics. But, concrete being shear volume, it is actually the largest contributor to embodied energies building. So, one issue is embodied energy.

The other is of course the operational energy in buildings. And, of course infrastructure embodied energy itself is good enough; concrete is not going to add to the or save the operational energy in any manner. So, one must look at lifecycle energy implications in all cases. Lifecycle green house gas contribution that one should look into as far as concrete sustainability is concerned. And, contribution to natural resource depletion other than those used as fossil fuel, because fossil fuel is already taken care of there, for example, sand.

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Today, in India, sand – you cannot get reversal; environmental problem – you have created pond, pits in the river; changing the river by taking sand from the river actually disturbing the system of the river, ecological and environmental system of the river. So, you cannot take sand from there. Therefore, depletion of the natural resource – this has already occurred. But, you should not deplete it more right now further, so that future generation gets more affected by various manners – by notable to use the resource for themselves, but environmental concerns all put together. So, natural resource depletion is an issue.

Similarly, coarse aggregate resources – they are not increasing; they are decreasing. Therefore, one has to keep that into mind. So, natural resource depletion is what one should see. And, that must be taken in. So, sustainability performance of concrete should take into all these issues. And that is why, you have high volume fly ash, geo-polymer concrete, magnesium – geo-polymer concrete and magnesium based cements. And, these are being thought about. Minimization of the cement consumption is very very important, because durability – it should be more durable, maintenance free. If you do more maintenance, lot of cement again you are going to use; where, OPC might contribute. If you are using polymer, there also again, polymers also – they will contribute to some kind of energy (( )) and so on. So, this issue as to be looked into. And therefore, sustainability performance – one talks about concrete; one must look into all these issues put together.

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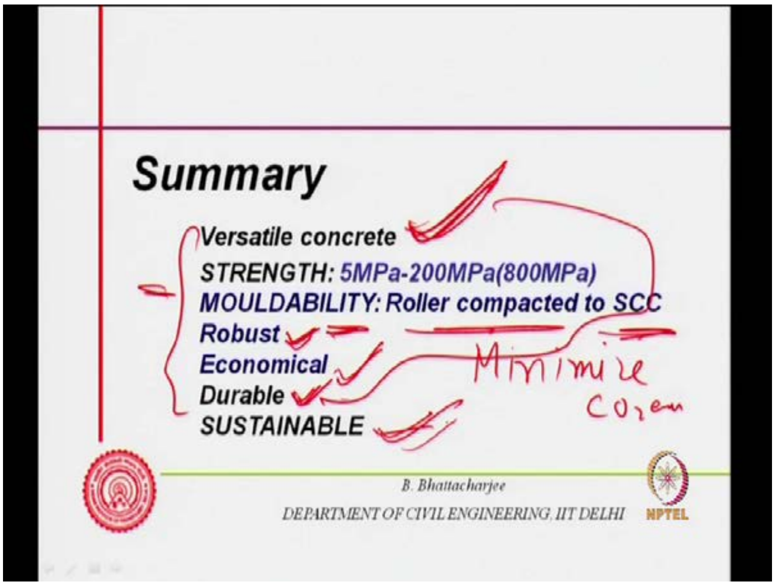

And therefore, let me summarize these lectures altogether one by one. And, I will take a few minutes in this summarization slide. You have looked into concrete. From the last one we looked is that it is sustainable, it can be sustainable. Now, how it can be sustainable? Minimize carbon dioxide emission; that is you know reduce the use of OPC clinker as they are produced now. How can you do it? Use of supplementary cementitious material. Surely, use of high range water reducing agent – particularly, supplementary cementitious materials like fly ash, which is actually otherwise a problem of storing from environmental concern. They would create environmental disturbances.

So, use this material in concrete, even in structural rate of concrete, if you have good structural rate of concrete, if you are not using high volume fly ash concrete. So, they should be used. And, so is the water reducing agent, because water reducing agent can reduce the use of water, and hence for same water-cement ratio, you can use less cement. It has got its implification on economy also.

Attempt to use recycled aggregate – recycled aggregate as much as possible or recycled material as much as the possible. At the moment, coarse aggregate may not be very easy to use. But surely pond ash, bottom ash and waste from let us say marble industry and other industries (( )) they characterize properly and a research properly – they can also be used. So, to make concrete sustainable, these are the thing. First is the… And also, its thermal properties if you are using in building. So, one must look into, because concrete can store energy. It has got what is called thermal mass; it can store energy. So, these issues are looked into. Then, radiation – rejecting the radiation – this depends upon what is called emissivity of the surface – longwave emissivity, so the color. And, of course now, people are using nano technology. For example, titanium oxide on concrete might produce or various kinds of admixtures and so on a concrete, which is self-cleansing concrete. And several other attempts are being made. So, these are trying to make concrete sustainable. So, this is the last one I looked into in the summarization.

But first of all, all through our 42 hours of discussion, what we have observed? Concrete is versatile. Where does the strength range from? 5 MPa to 200 MPa, maybe 800 MPa cement-based composites. So, it is really versatile very very versatile material; it can show you… You can design it for strength as you want. Put fiber into it; you can get right kind of ductility that you desire. But if you do not get it, tensile strength improvement is not as much; you can obviously use reinforced concrete or pastures concrete. But, tensile strength also can be enhanced perhaps in future.

If you look at mouldability, roller-compacted concrete zero slump to self compacting concrete. Again, it is versatile; very high range. The tensile strength and ductility of course remains problem for normal concrete. But then, we do not use concrete as such in most of the cases; we use that as the composite as reinforced concrete or we (( )) it obviously providing reinforcement. It can provide robustness, massivity; a mass concrete dam – you can make it concrete. Or of course, good old days could have been with masonry. But largely, concrete provides that answer. You cannot use most of the other material. For example, you cannot use a plastic, polymer to really make a robust gravity dam. But, concrete can provide you that.

It is economical; it is cheap. That is why it is used so much. It is relatively durable, more durable than many materials; and you can make it more durable. But, many understandings are yet to be developed; lot of things are still non-empirical stage particularly with reference to this. So, researches are required and they are being done. Development has taken concrete to a new height in last one or two decades – last two decades of a twentieth century and following it up. Therefore, it has actually given you, real versatile material is available in terms of concrete. And it can be made sustainable. And, there are of course more kind of attempts are being to make it more and more sustainable.

So therefore, with this, we can conclude the concrete is a versatile material and can be used. And, in our discussions right from the first to the last lecture, we have tried to look into all those aspects of concrete.

Thank you very much for hearing.