Sustainable Materials and Green Buildings
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Lecture 17 – Modern composite concrete

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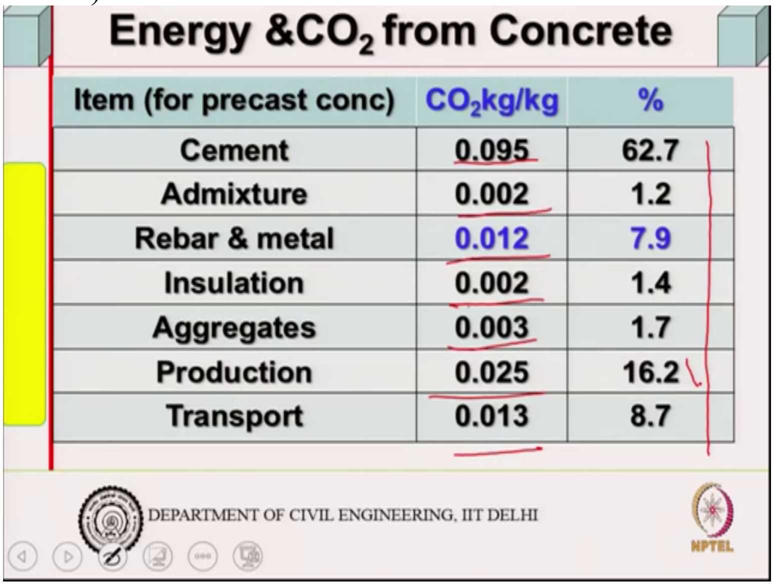
Energy & CO_2 from Concrete

Item (for precast conc)	CO_2kg/kg	%
Cement	0.095	62.7
Admixture	0.002	1.2
Rebar & metal	0.012	7.9
Insulation	0.002	1.4
Aggregates	0.003	1.7
Production	0.025	16.2
Transport	0.013	8.7

So if you recollect, last class we were looking at energy from, you know energy and carbon dioxide from concrete, we stopped somewhere here. So if you see the energy contribution for each one them individually, cement it will have, cement will have, cement will have this much 0.095 carbon dioxide per kg of concrete which is about you know and similarly, admixtures, then rebar, metal, reinforced concrete you are looking at. Insulation, if it is a building panel; aggregates, production and 0.013. So the proportion of the energy if you look at it, cement is again the, I mean carbon dioxide is the largest, rest all do.

So, remember we said that there are when we look couple of glass black, basically we are looking at flowchart and we, as far as the concrete is concerned and we said there are additional you know material which are produced like dust and nitrogen oxide and all those. So if you look at the contribution of now the carbon dioxide part from construction, admixtures and all, there the rebar and metal is the next, highest is the cement. So, there is a kind of and there is a kind of actually and production process because you will be, will be running machines et cetera, their contribution is around. So, it is for precast concrete for which recording can be done easily, recording can be done very easily.

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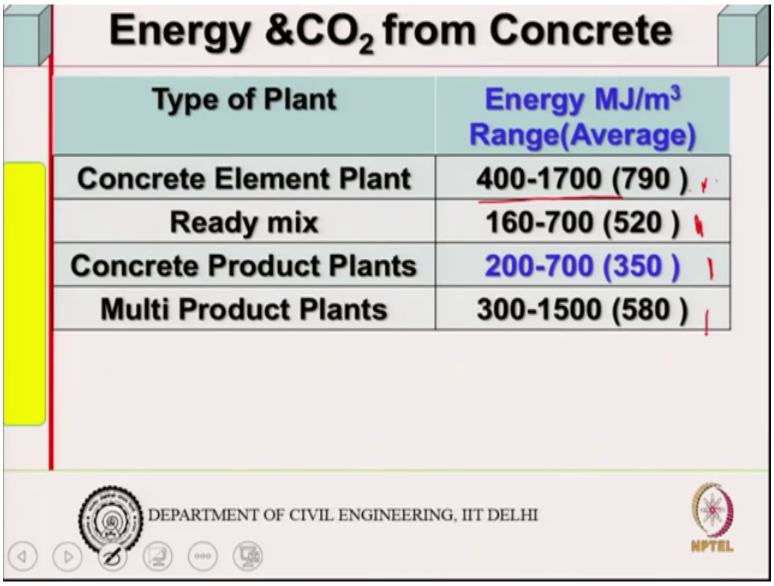

And if you see energy mega joules per meter cube of concrete on an average basis, so concrete element plant, what is element plant? Element plant is because if I have a precast plant I will be producing walls maybe hollow core, hollow core slabs or maybe linear element like beam, columns which are then joining to make the building itself. So this precast plant if I look at, now the energy per meter cube of concrete varies from 400 to 1700. So there can be large variation depending upon the process that you are adopting and something like this would be average. Right, not absolute average but weightage volume multiplied by you know, that is why possibly it will not work out. 2100 divided by 2 is 1,000 but this 790 shows that volume of concrete which is produced, there is a weighted average.

Ready mix plant will have something like 160 to 700 mega joules per meter cube of concrete and concrete product plants something of this order. And multi product plants for example if you are producing not only the wall element, multi products you know several products you are producing in that case this is something of this kind. So you can see energy and carbon dioxide that comes out from concrete. So if you can reduce down the volume of concrete, you can in fact cut down on to the all these, both energy and carbon dioxide production.

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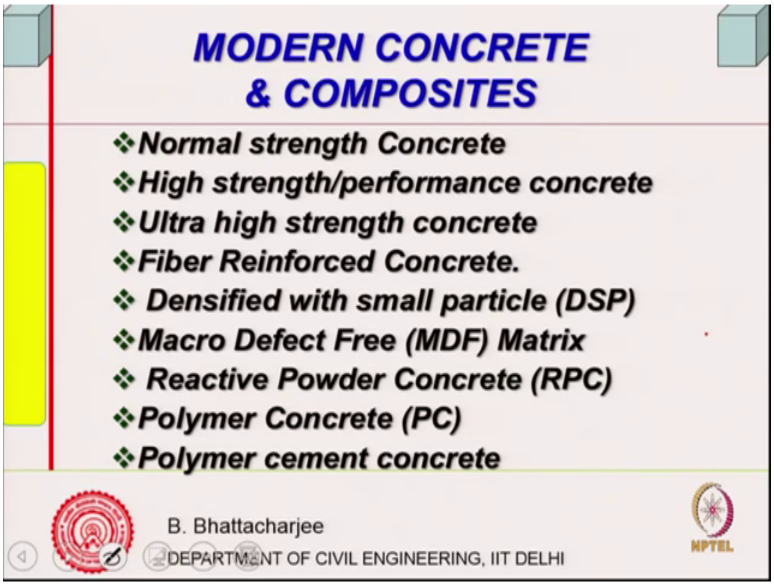

Now concrete today is not the single component, I might have given this somewhere else in some other class but it can be thought of, modern concrete can be third of concrete composites actually. So you have varieties of concrete system, it is a cement based composite if I may call it. So normal strength concrete is only one of them but then you have high strength concrete or high performance concrete, then ultra-high strength concrete, ultra high performance concrete, Fiber reinforced concrete. There is something called DSP which is a very high. Excuse me. DSP is very very you know relatively high strength material, generally not used for cement concrete structure or cement concrete but for ceramic base, base for electronic substrate you know and such things.

So then there is something similar called macro defect free matrix. Then there is something called reactive powder concrete which is actually ultra-high strength concrete you know. And polymer concrete where cement you do not use but instead use polymer as binder. Polymer cement concrete were partially cement as well as polymers are used together.

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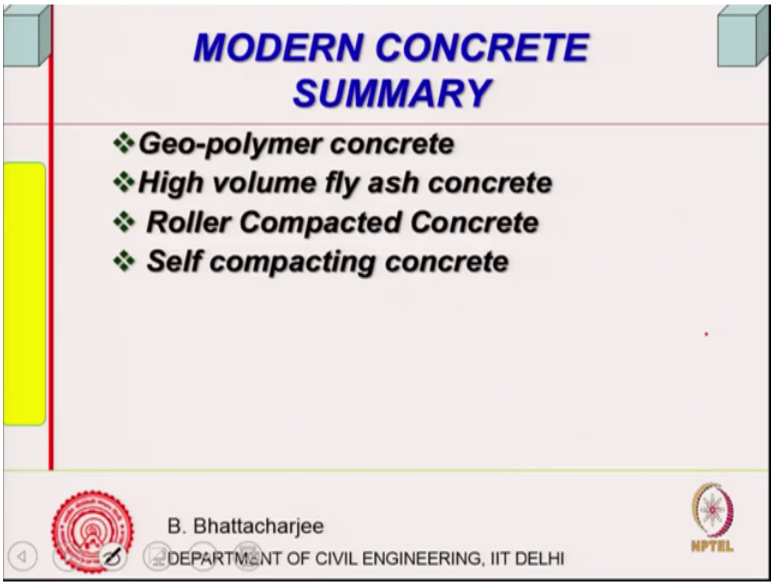

And Geo polymer concrete is the other which I already told you about alkali activated cement, so that if you can use in concrete. High volume fly ash concrete, roller compacted concrete. High volume fly ash concrete use about 50 to 60 percent, fly ash in the cement ashes and roller compacted concrete is used largely in dams and pavements.

You can make pavements out of them and they are efficient in pavements in the sense that pavement you do not require very high strength. 25 MPa, 30-40 MPa around that MPa you require for rigid pavement and that you can construct using road rollers or equipment that you use for. Self-compacting concrete is other one which does not vibration.

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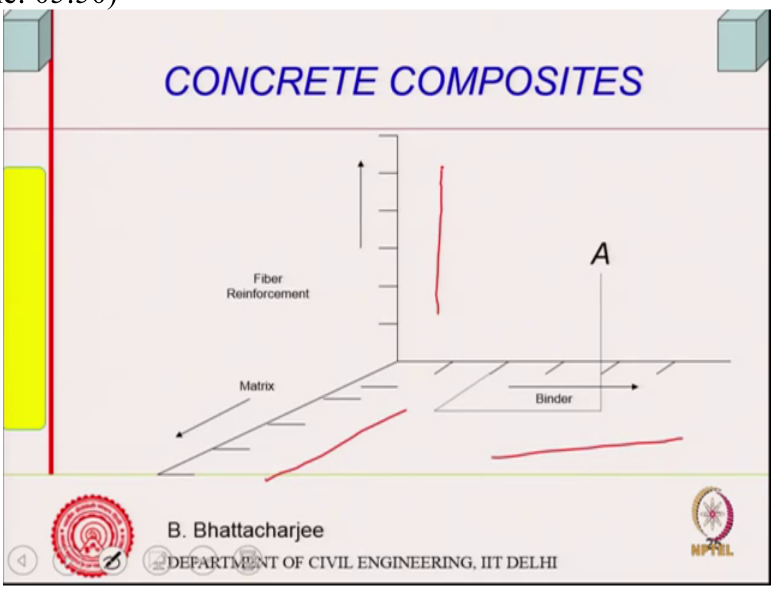

So you see concrete composite system is something like this, you have different types of binder, different types of matrices you can have. Binder means either polymer or cement of varieties of kind and I can have fiber reinforcement of various kind, hybrid fiber for example, steel plus polyester or costly one like carbon fiber etcetera, etcetera to enhance the property. So here your scope of reducing down the size of the element and therefore material consumption you can reduce down if you use the high end material. Obviously for mass concrete system you may not be using them.

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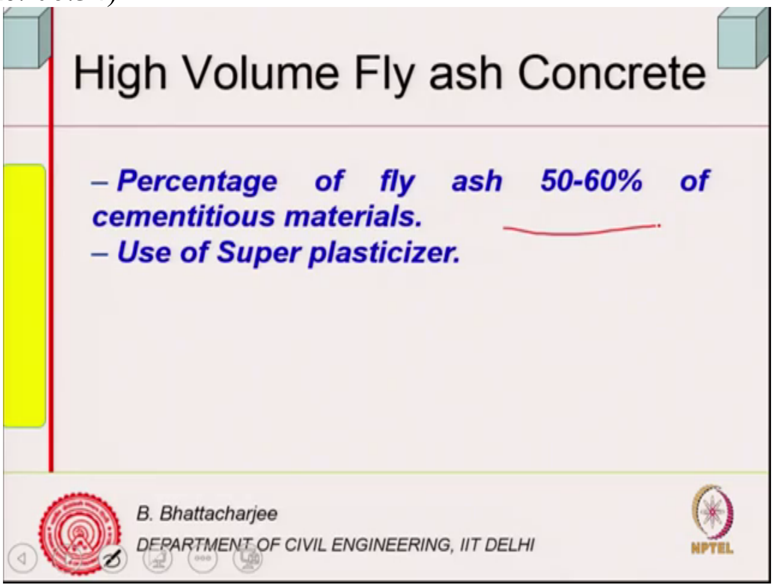

So high volume fly ash concrete for example is the percentage of fly ash is 50 to 60 percent of cementitious material. Now I will just come to this a little bit. You see how do I, I do get high strength concrete. If I have to get high strength concrete, how do I get it? Very relatively the higher strength.

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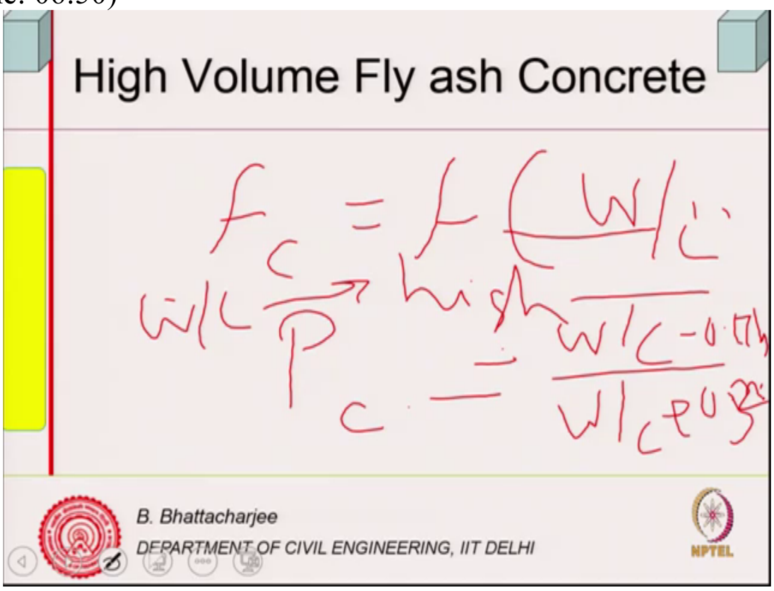

Normally the concrete as you know the strength is a function of if you call it Fc cube strength is a function of w by c to a large extent. Obviously you must have sufficient paste content in in the system, so this is the large one.

So now the reason is, reason, what is the reason? reason is essentially higher w by c you will have more p capillary porosity, pc capillary porosity, so w by c high, high means capillary porosity will be higher. And if you recollect there is a formula which I might have given you in some other class, it was w by c minus 0.17 h divided by w by c plus 0.32 something of this kind. You know something of this kind you can calculate this out, so as your water cement ration increases porosity, also pore sizes increases.

Gel pores they do contribution to strength reduction to a much limited extent. They are more responsible for shrinkage and creep and similar properties you know shrinkage, creep properties, similar properties. So they are more responsible for that kind of properties. So they are responsible for more to more like that kind of properties actually.

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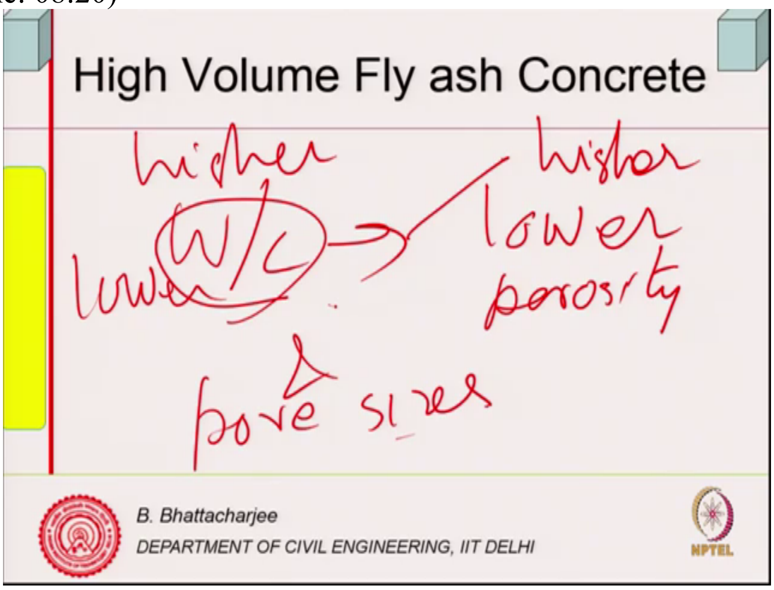

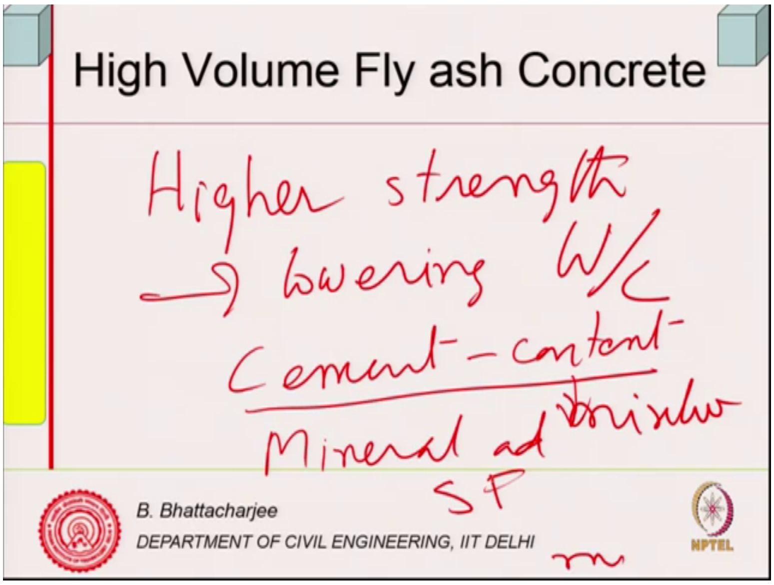

So water cement ratio strength, water cement ratio results in lower porosity. Higher water cement ratio, higher porosity and lower water cement ratio, lower porosity and pore sizes. So this is related to strength, I think I have some slides just to give you introduction to how it affects. Possibly I have in one of those once. So strength is a function of water cement ratio, higher water cement ratio lesser will be strength. Because water around a cement particle is more now, so hydration product has to fill in as I was talking of segmentation in one of the classes.

So you know if too much of water is there even after full hydration of cement particles they may not be able to fill in. So capillary porosity will remain and then you know we have seen that 0.7 water cement ratio, it may not get segmented at all, so this is one thing. Now to get there for high strength you must reduce down the water cement ratio. So higher strength is obtained by, higher strength is obtained by, higher strength lowering w by c, but if you lower w by c right, then you got to use very high cement, cement content will be high. If you want to maintain the paste content same, paste volume of same, volume of paste if you want to maintain same, cement content will increase.

Therefore you could not have you know earlier before supplementary cementitious material came, you could not have had high strength concrete, those are restrictions. You could not go below certain water cement ratio. So one thing is cement content will increase, so replace part of it by some other mineral admixtures. So replace some of it by mineral admixtures especially fine mineral admixtures like silica fume, like silica fume that is one thing. Second thing is use high range water reducing agent or what we call superplasticizer or you know hyperplasticizers. So use those which will cut down which will disperse the system.

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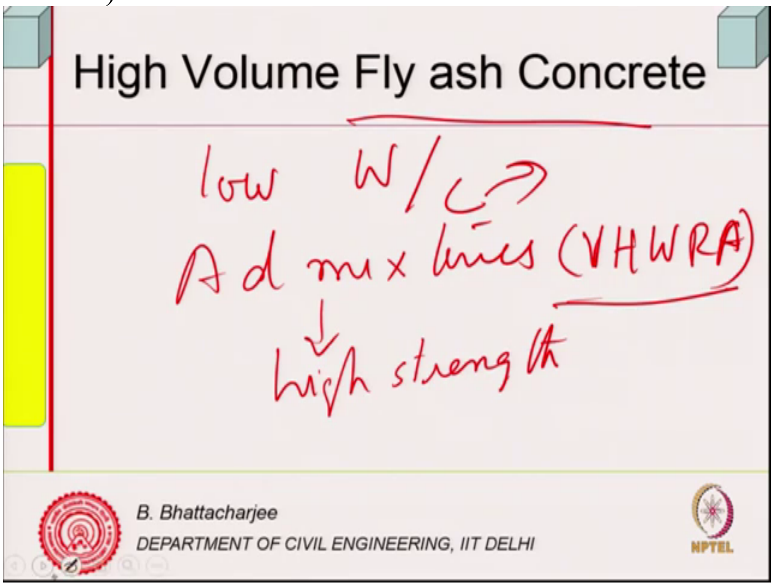

So use of water cement ratio, water cement ratio, low water cement ratio, admixtures, that is you know high, very high range water reducing agent, VHWRA. Using those I can get together with an appropriate proportioning system I can get high strength. Because I can lower down the porosity at different level, right. So that is how I get high strength. Now supposing I decide I do not want high strength, I do not want high strength, I want strength to be relatively lower what I can do is, I can cut down onto the cement consumption, use very high range water reducing agent so that water cement ratio is low but water to cement and fly ash may not be as low.

So the principle is similar, only thing is if I do not want high strength then I can reduce down the cement instead I can add lot more fly ash, principle is same. So high volume fly ash concrete the principle is the main, main thrust here is to use as much as fly ash as possible, cut down on clinker consumption.

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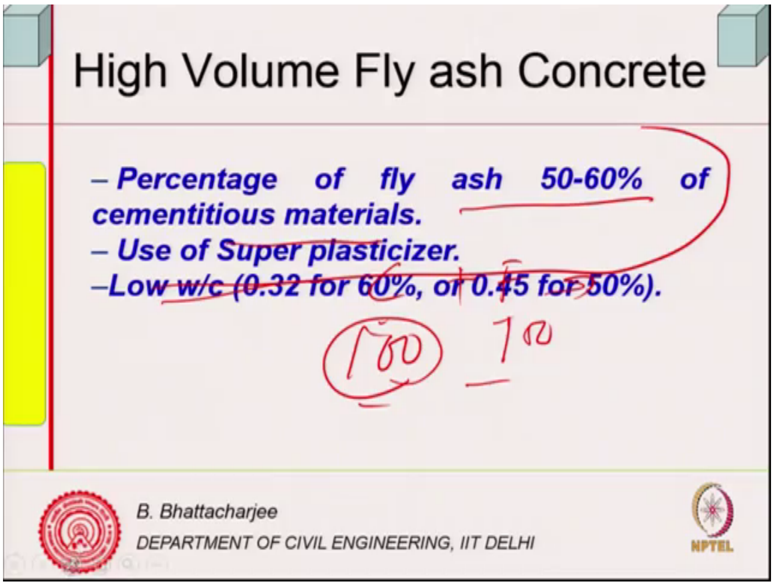

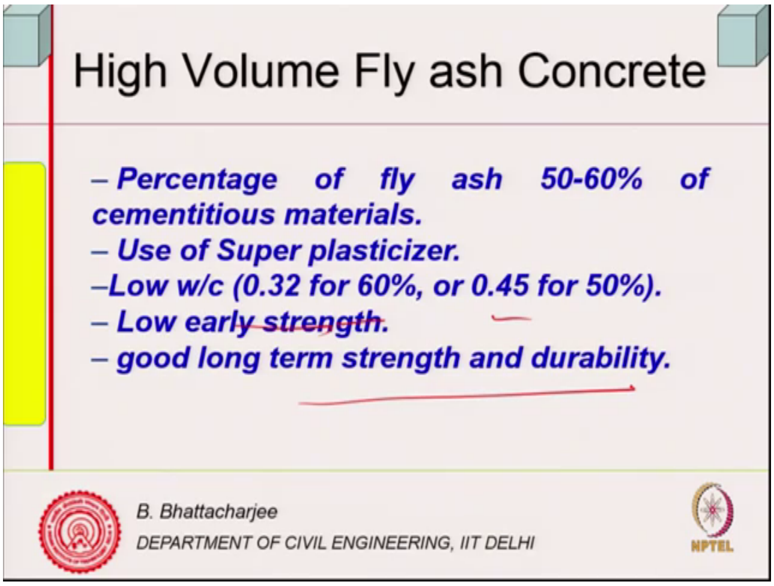

So idea is that what you do is you have fly ash percentage is 50 to 60 percent of the cementitious material. That is if you use C plus F you know then C plus F these are almost similar. Mass of C and mass of F, so 100 kg of C, it could be another 100 kg of fly ash. 50 percent, 50-50 in the whole mixing system. Now this with the water is of course relatively high water cement ratio. So they are, this gives me somewhat initial strength. But in the long term there is a pozzolanic action, so I get somewhat higher strength. The mixing problem is taken care of by adding large amount of I mean not large appropriate amount of superplasticizers.

So here we use lower water to cementitious ratio, uses water to cementitious I am saying. Use high range water reducing agent but in the cementitious I use large quantity of fly ash, some of it will not react, remain in the system to fill in the, make the paste. Remain in the system as inert, make the paste. But rest of it will react, give sufficient strength, give sufficient strength. Because we have seen the upper limit of you know of fly ash addition depending upon percentage of you know how much you replace we have calculated this out, one time we did calculate it out. We said because 185 grams of CH will react with 100 grams of S to produce CHS. Therefore calcium hydroxide which comes from the cement hydration, that limits because you may not have sufficient calcium hydroxide to react.

Cement is reduced so calcium hydroxide produced will be less. So fly ash if you added extra beyond that point, it will remain in the system, contribute to the paste only. So I am actually reducing down the reacting material in the system. And therefore I will not get high strength, higher strength but my paste content is sufficient and no compaction for because I have added extra fly ash. So these two together so for example I have water to cement ratio, in water to cement ratio could be 0.32, for 60 percent 0.45, for 50 percent and low early strength but good long term strength and durability because I have added sufficient paste content and whatever my cement and fly ash is there they would react by cementitious and pozzolanic reaction to fill in the voids.

But I am not getting very high strength because binder content will be relatively less, so obviously I will have some amount of weak point in the excess fly ash that is there which are in the system not very strongly you know bonded in that manner as would have been the case if I was using. And pores would have been reduced but the size of the pores may not be as low as if I was using silica fume which I used for high strength. So idea here is to use as much as fly ash as possible, so therefore make it more sustainable and it has been used in pavements, blocks and things like that, roller compacted system also something similar to that. So this is one thing. So this is what I was mentioning.

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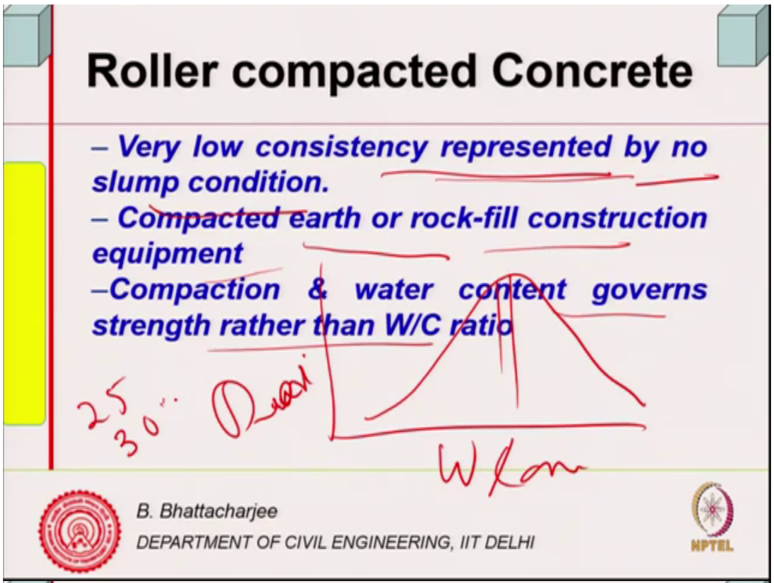

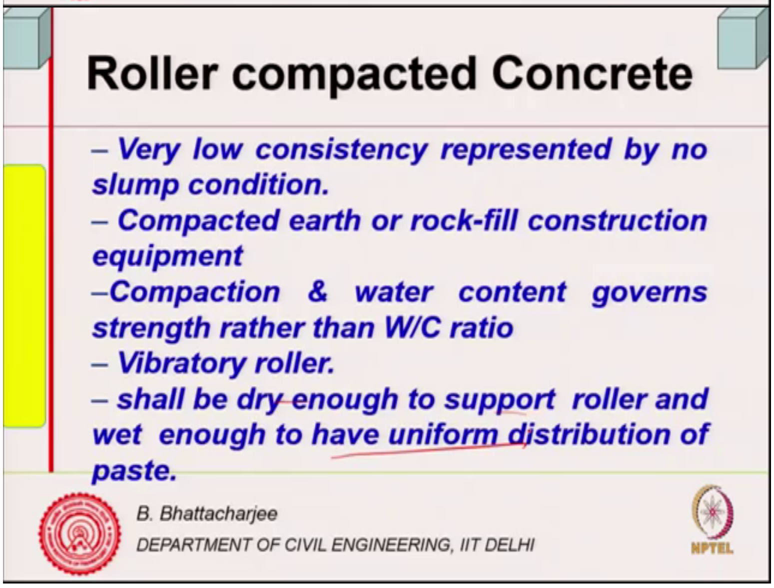

Here you can use a lot of fly ash, low consistency you know in case of roller compacted concrete I do not need any water otherwise my roller will simply sink in the concrete. So it is zero slump concrete as we call it, no slump or zero slump concrete. It is like your sub-base material or you know normally the other than anything other than your top, black topping whatever you produce there is a water bound make item, you put in water and then compact it with road roller. But then water is not so high that actually the roller sinks there, so this concrete is something of the similar kind, it is relatively dry what we call no slump concrete.

So my roller weight, by its own weight it should not sink into the concrete. So that is one of the extremes. Other is the self-compacting concrete as I was mentioning, compacted earth or rock fill construction equipment that is what we use. And compaction and water content governs strength rather than water cement ratio. Here the strength required is not very high again, so it is actually Proctor's compaction. So you know we go by the principle is not water cement ratio reduction of the porosity but cut the material in such a manner so that you get the maximum Proctor's density. So it is actually design through Proctor's test, Proctor's density. Remember that if you add water you know water content if you have increased, moisture content or water content if you call it and you will get at certain point the density if you plot you know density, Proctor densities high at some points, right.

So you use this principle what is used in soil in order to compact it and design the mix proportion as well. And you get around strength around 25, 30 MPa easily you can get if the packing of the system is proper, your design is proper. Even 30 MPa, even people have recorded 40 MPa as well as reducing something like 50 percent GGBFS and certain 30, 40 percent fly ash is not a problem because here it is a packing of, is a major issue actually. So this concrete is another one which is more sustainable, then using some vibratory rollers are used and shall dry enough to support the roller and wet enough to have uniform distribution of paste, that is what you require. So this is another one where you can use lot of fly ash or GGBFS.

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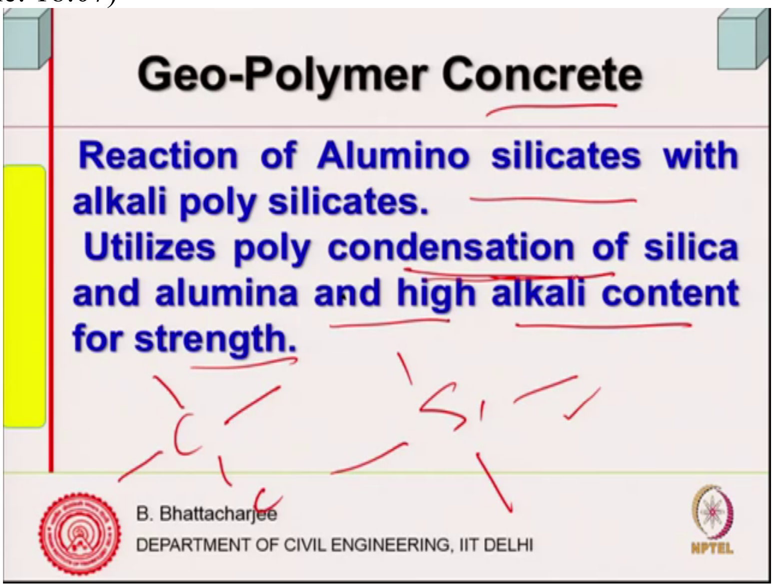

I already said about alkali aggregate, alkali activated fly ash, this has been prime and has been relatively successful in making blocks et cetera, et cetera, geo-polymer concrete. Alkali activated fly ash, I think I talked about that sometime earlier when I was talking about alkali activated cement.

So poly condensation of silica and alumina and high alkali content for strength, this is yet to be understood fully, the cementitious system you know the chemistry behind it actually, what really happens, degree of polymerization etcetera, etcetera where still lot of work to be done. So it uses the idea because silicon belongs to same group as carbon. Carbon has got four valencies, they are in between not the metal, not non-metal, in fact this is a semiconductor. So this has got conducting property, property in some allotropes like graphite is a conductor, something else is not a conductor. So this is because of you know their position in the periodic table. So this shows some degree of polymerization also. SI was system can also show some degree of polymerization.

So condensation reaction is where everything get combined you know there is no residue left and polymerization occurs. So this is condensation, in polymer chemistry they use this kind of terminology. So in high alkali, alkali is activated and people are again trying lot of varieties of this one.

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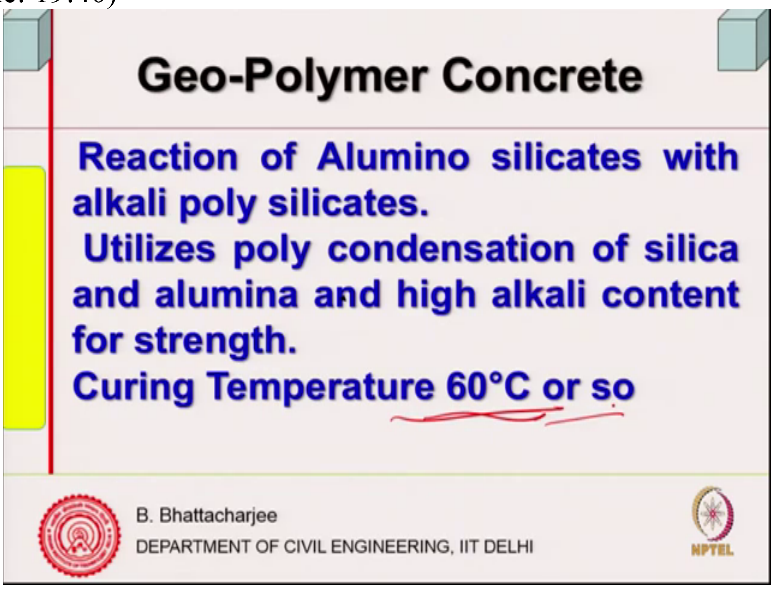

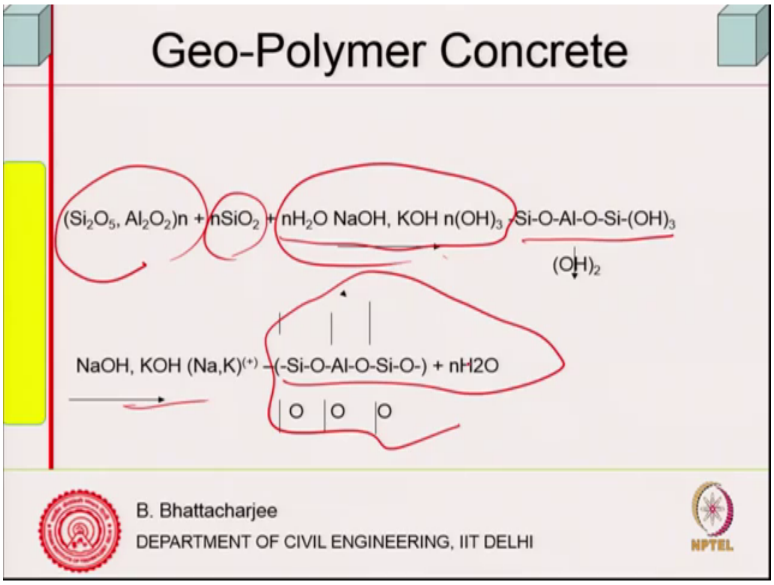

But one problem that has been there for say it is partially solved, the curing temperature required is high, 60 degree or so. Normal geo-polymer concrete system we have to heat curing, heat cure it for the reaction to occur and therefore this eats away the benefit that you would have got because you have to set up the plant for you know heat curing, heat curing. So this is kind of reaction I do not really want you to remember this but this is a kind of you know this is a n, n number of molecule, n sodium hydroxide, potassium hydroxide etcetera then this is, this is what will form in presence of sodium hydroxide and potassium hydroxide something like this. I have not given you the full formula because it is not easy to remember.

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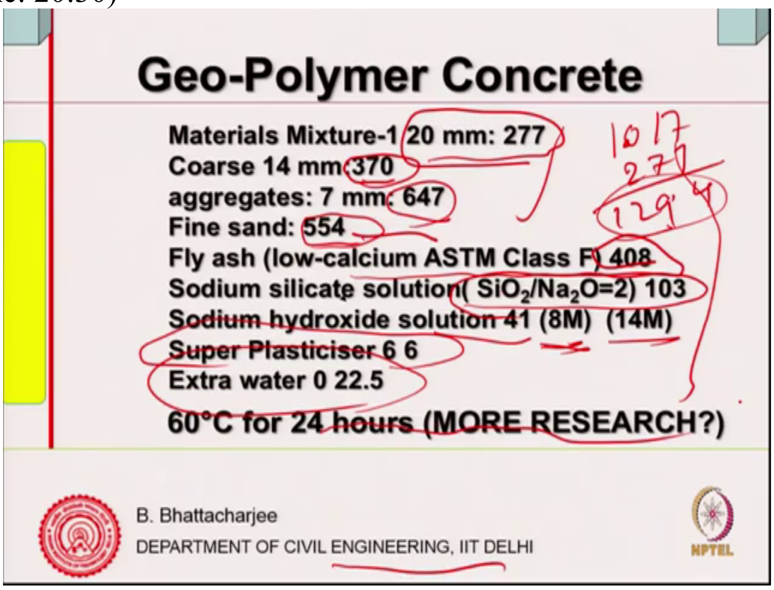

But geo-polymer concrete is one of them, typically a mixed proportion, there is improvement over it, you can look into the literature. There are lot of things will be available, this comes from the people who really work quite a lot in Australia originally originated in Ukraine. One professor, David (())(20:49) I think this name I am not sure I am able to pronounce it properly. He was you know kind of popularizing it and then in Australia there are lot of people who worked on it. Now so typically if you will see 20 mm aggregate, 277 kg, they use 14 mm aggregate, 370 kg, maximum 14 mm. 7 mm aggregate, 647 it may not match with the IS sizes. Fine sand, 554, so if you add this up you get 600, 300, 900,000, 1,017 plus to you know something like 277, this aggregate content.

This is typical of a normal concrete as well. You know similar to that, normal concrete will have 1100, 1200 kg of course aggregate, fine sand is slightly less here. Well, similar to our normal concrete, normal concrete will be about 1,100, this will increase to about another 1,000 or so. Then low calcium fly ash, for geo-polymer reaction to occur you do not need calcium system but even in presence of cement geo-polymer reaction do occur. So, people are thinking I mean the reaction process is to be understood as yet. So fly ash, 408, sodium silicate, the purity of this one creates the problem. You need highly pure sodium silicate and sodium hydroxide solution. So this purity is again is a cost issue is there.

If somebody can use industrial byproduct as this which have been attempted but has to be, has to be attempted has to be you know confirmed then one can use. So order of this you can see is 8 molar, 14 molar. Ratio of silicon to sodium should be 2, sodium oxide should be 2 and then you use some superplasticizers, some extra water, that is what is a mix proportion. So it is like normal concrete, you do not see any Portland cement clinker in the whole thing. That means if this is successful Portland cement clinker utilization would be much, much less. But also the other carbon dioxide issue and all that, but you know one has to see that. This needs lot more research, so this is one thing and then 60 degree for 24 hours, so therefore the more research is needed and is going on and you know.

Some countries for example, they do not have fly ash at all. Europe, Canada, even United States of America, they have very less amount of fly ash available because they utilize it cement and other. India we have plenty of it, so thus you know this if one can utilize then it would be definitely.

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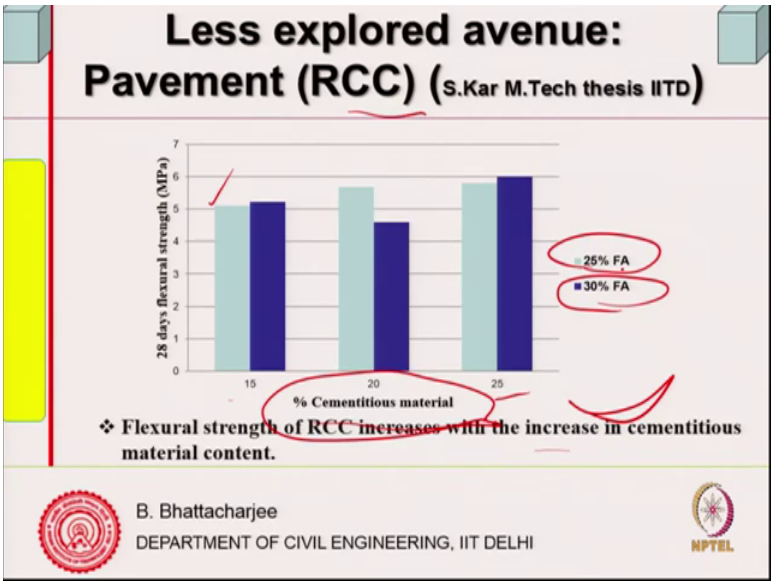

So as far as the roller compacted concretes are concerned, you can see that pavement you have cementitious material, total cementitious material, 30 percent fly ash, 25 percent fly ash. The order of strength I am not interested but you can get that 28 days flexural strength. Flexural strength is required for pavement. Pavement design is based on flexural strength of concrete because this you know wheel load causes local bending, so flexural strength is important.

So flexural strength of the order of around 5 MPa, 4 MPa etcetera you can get what is required for pavement. So depending upon the cementitious content material you can get it this way.

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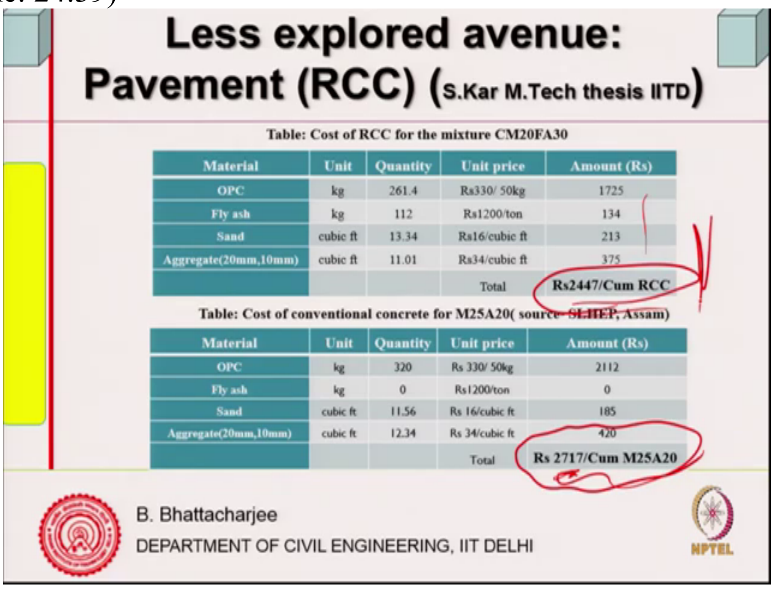

Table: Cost of RCC for the mixture CM20FA30

Material	Unit	Quantity	Unit price	Amount (Rs)
OPC	kg	261.4	Rs330/ 50kg	1725
Fly ash	kg	112	Rs1200/ton	134
Sand	cubic ft	13.34	Rs16/cubic ft	213
Aggregate(20mm,10mm)	cubic ft	11.01	Rs34/cubic ft	375
			Total	Rs2447/Cum RCC

Table: Cost of conventional concrete for M25A20(source SLHEP, Assam)

Material	Unit	Quantity	Unit price	Amount (Rs)
OPC	kg	320	Rs 330/ 50kg	2112
Fly ash	kg	0	Rs1200/ton	0
Sand	cubic ft	11.56	Rs 16/cubic ft	185
Aggregate(20mm,10mm)	cubic ft	12.34	Rs 34/cubic ft	420
			Total	Rs 2717/Cum M25A20

Then cost, slightly costly at the moment. So if you see this is the cost OPC, fly ash, sand, aggregate etcetera, etcetera, the cost would be something of this order and a conventional concrete if you see, it would cost you yeah slightly higher, 2717, sorry this is higher, conventional concrete is higher and this concrete is much lower, am I right? Yeah. So cost-wise roller compacted concrete is, it can be work out. If you design the system properly, it can work out actually. So this is a possibility.

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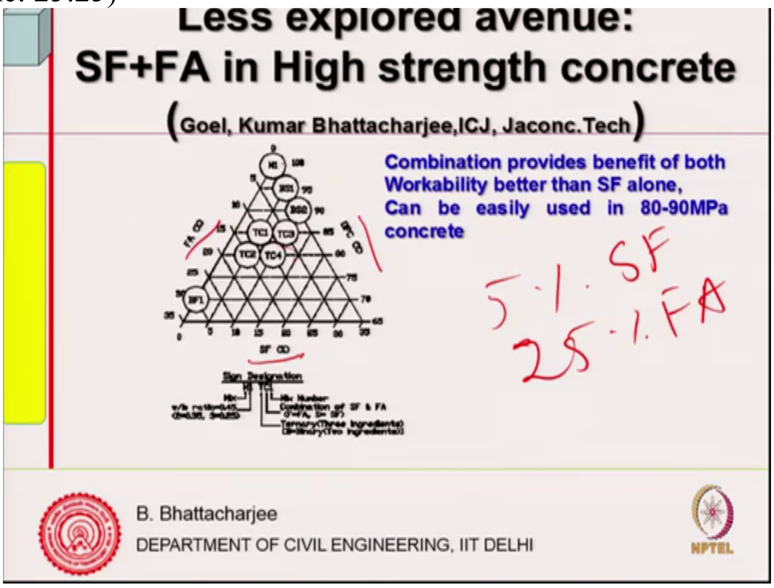

Also using fly ash and silica fume together or maybe fly ash, GGBFS combination in concrete. I mean one way is to composite cements but you can add yourself by design. And if you look at it you get best of the both world. Silica fume gives you early strength, fly ash improves the workability. And so if you want to compromise the little bit on the strength, early strength, but use so something of the order of 5 percent silica fume, 25 percent fly ash, this makes good sense actually. So this gives advantage of both somewhat improvement. So for example there are varieties of this concrete can be possible with fly ash and OPC and silica fume combinations and combines once can give benefit of both.

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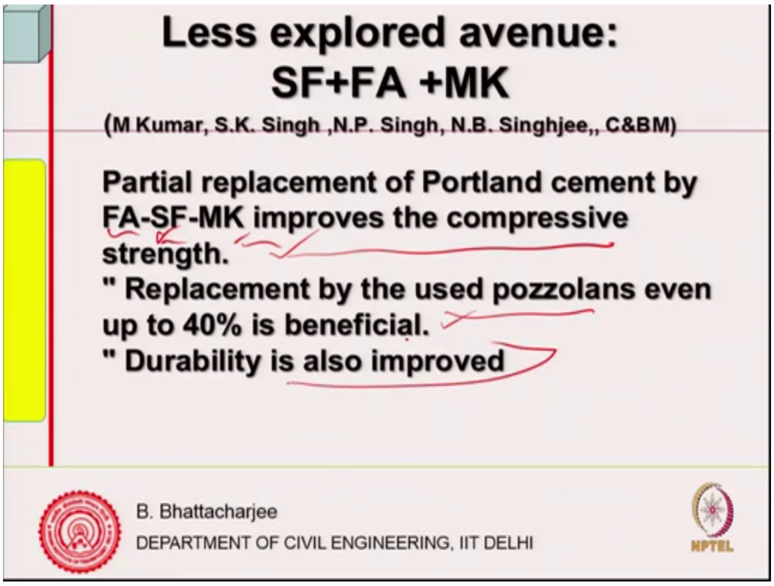

So partial by silica fume improves also, if you look at fly ash, silica fume, metakaolin, all put together it improves replacement by use of pozzolans even up to 40 percent is beneficial. But then silica fume, metakaolin both are very fine material. Sizes might differ, structures might differ a little bit, so one has to see how do you use them. So combinations gives you much better performance, you get both. Fly ash gives you more to us, you know like waste material which we are using and it improves the workability side of it, function and things like that. This can give you somewhat strength related things. So some, lot work has been done along this line.

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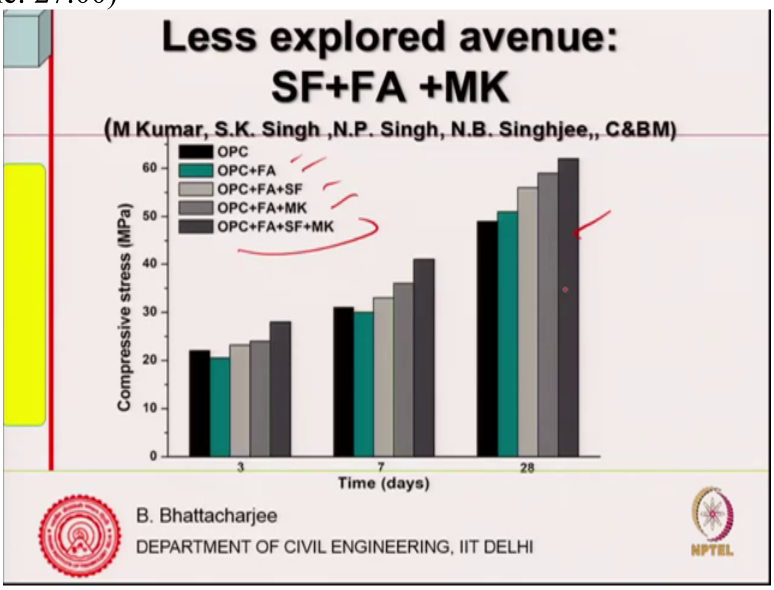

So this is what it is, just OPC, OPC fly ash, OPC fly ash, silica fume, OPC fly ash, metakaolin combinations, you can improve the system by design . So therefore there is not one, you can add, I am in class, call you later, so you can improve, so all combinations are possible. So saving the cement clinker is possible. This is also being attempted.

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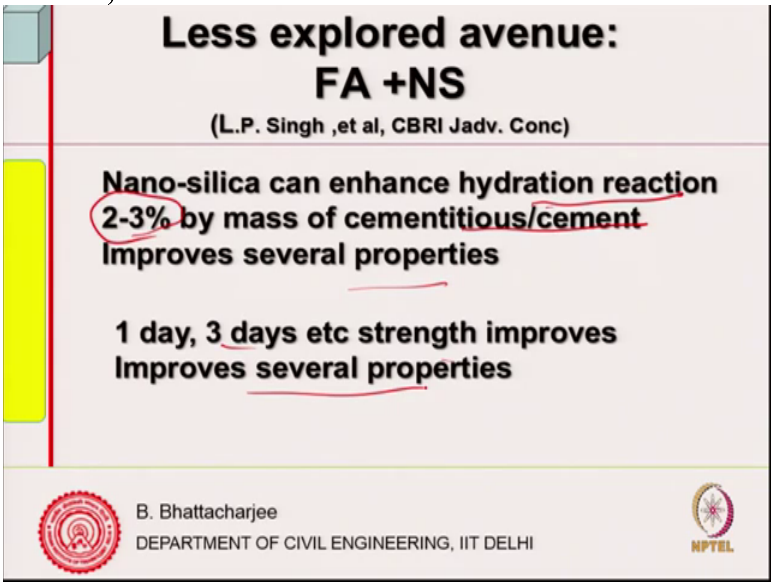

This nano-silica can you know produced by sol-gel technique as they call it, there are different other techniques available. So, there is a fine level and they can enhance the hydration reaction by forming nucleus, nucleation points. So when you are using fly ash, supposing you add small amount of nano-silica it is seen that the early strength development which was a concern for fly ash cement you know fly ash cement system, this get improved but the quantity is very small, required is very small because this is also costly.

So 1 day, 3 day strength improves and improves several properties. So what you can see is there is a whole plethora of possibilities of the cement based system both in terms of cement improvement, concrete improvement etcetera, etcetera. So far we have looked into really cement first, we looked into the water and the quality control system and water reducing the water consumption etcetera.

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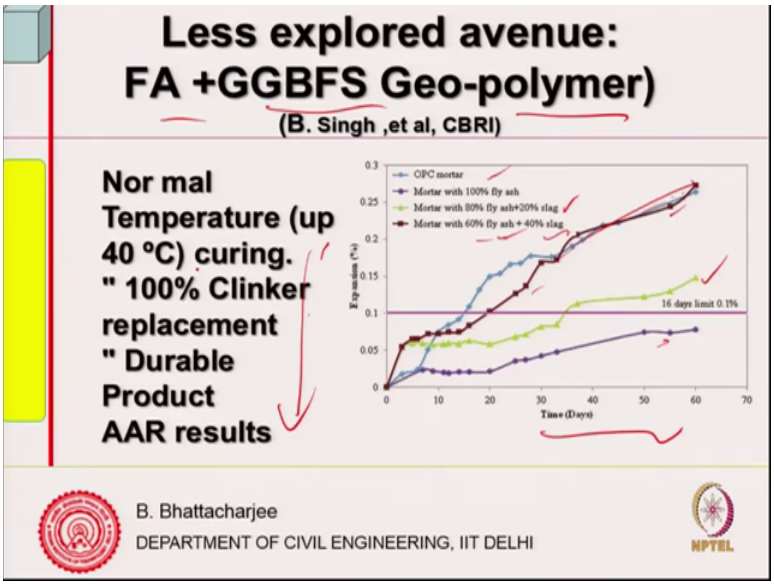

Next, we will like to look into, after this we will try to look into aggregate system. Because aggregate is also a scarce now, so recycled aggregate is another one that is being looked into. So you can see that fly ash, GGBFS, geo-polymer again 40 percent temperature curing can be reduced. Curing temperature they could reduce it down, so somewhere OPC mortar, somewhere 60 to 40 percent slag. These boxes are slag and this is OPC is the, blue is the OPC mortar, mortar with 100 percent fly ash. So, with age the strength you know mortar is 80 percent, fly ash and 20 percent slag. So, some of them are comparable actually, mortar is 60 percent fly ash, 40 percent slag is comparable with OPC in terms of strength development.

So geo-polymer concrete with just OPC concrete it can be comparable but as I said bringing to the concrete requires lot more some more research actually. And then they have gone up to 40 degree curing, one can do at lower temperature curing as well.

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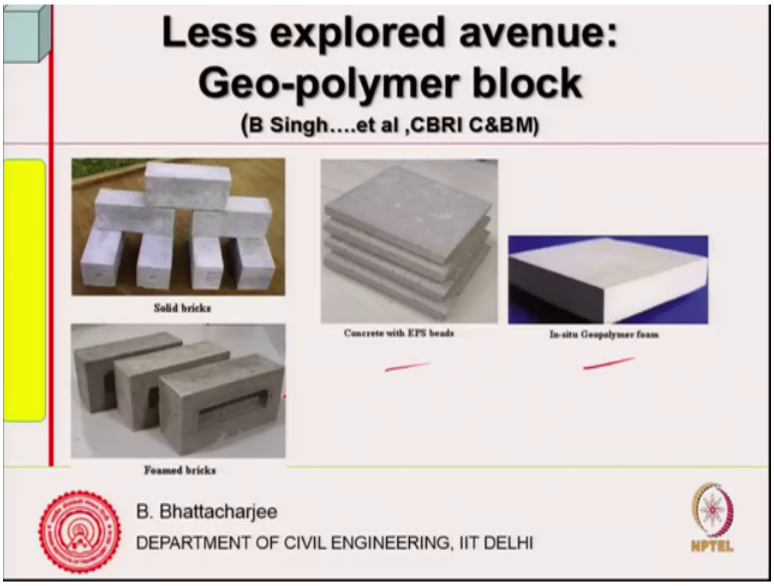

These are the blocks, these are the blocks one can produce. So blocks are fine, structural concrete still some research. Blocks you can manufacture by various combinations. Okay.

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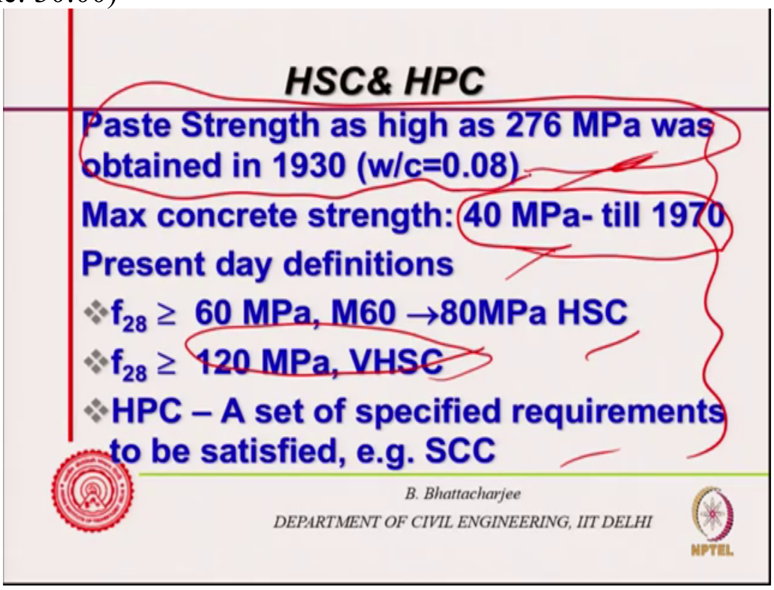

This is what I was talking of, this is what I was talking of earlier, the strength you can go very high, right. So historically 1970, 40 MPa and very high strength concrete more than 120 MPa and when I talk of high performance concrete, we set a specified requirement that means durability, shrinkage, early shrinkage and all those. So performance is something more than the strength. Like limit state design, you talk of serviceability limit together with the safety limit.

So that is what it is, so strength can be high and this is what is possible with low water to cement ratio I was just mentioning, I will possibly continue with that a little bit more after this and high strength concrete stems from the fact that you can go to water cement ratio, very low. Here he used (())(31:08) or something of this kind by putting pressure onto your paste. So 0.08 water to cement, we took just paste, water to cement put pressure and compacted it. Because this compaction would have been difficult, so historically it is something like this all you know varieties of concretes are possible today to make concrete reduction in ordinary Portland cement consumption, then reduction in natural resource consumption because we said that consumption of natural resource is also a problem. So we will look into that, just we will address few questions.