Admixtures And Special Concretes

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Lecture -52

Life cycle assessment of concrete - Part 3

Case studies- Clinker/ Cement production:

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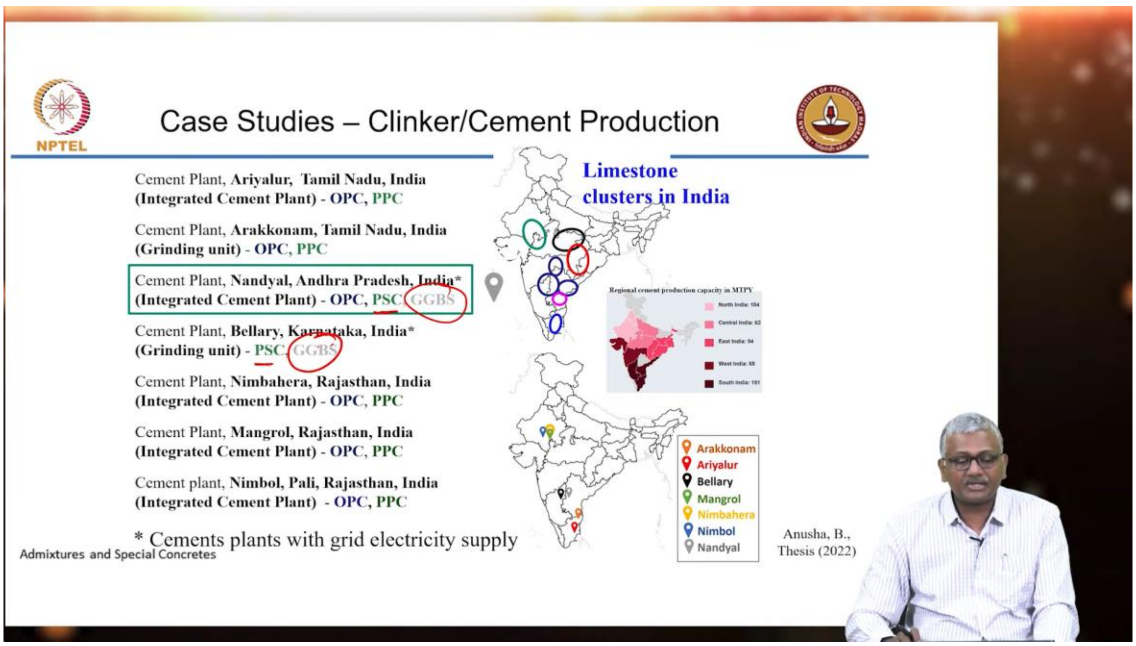

So, here Anusha in her work actually visited several cement plants to collect some real time data on all of these processes from various different cement plants. So all of these plants were actually visited, the Ariyalur, Arakonam is a grinding unit, Ariyalur was the integrated cement plant, Nandyal in Andhra Pradesh was also an integrated cement plant and Bellary had a grinding unit, similarly in Rajasthan, Nimbahera, integrated cement plant and couple of more integrated cement plants from Rajasthan itself. So, the type of cements that are produced by these cement plants is also given, most of these produce OPC and PPC but in Nandyal and Bellary you are also producing Portland slag cement and there is also because it is Jindal has their plant there, so they are also producing slag itself as a mineral admixture. They produce slag cement, they also produce slag as a mineral admixture. So these are the different locations which have been actually studied. So here this example is with the data from Nandyal in Andhra Pradesh.

Cement production:

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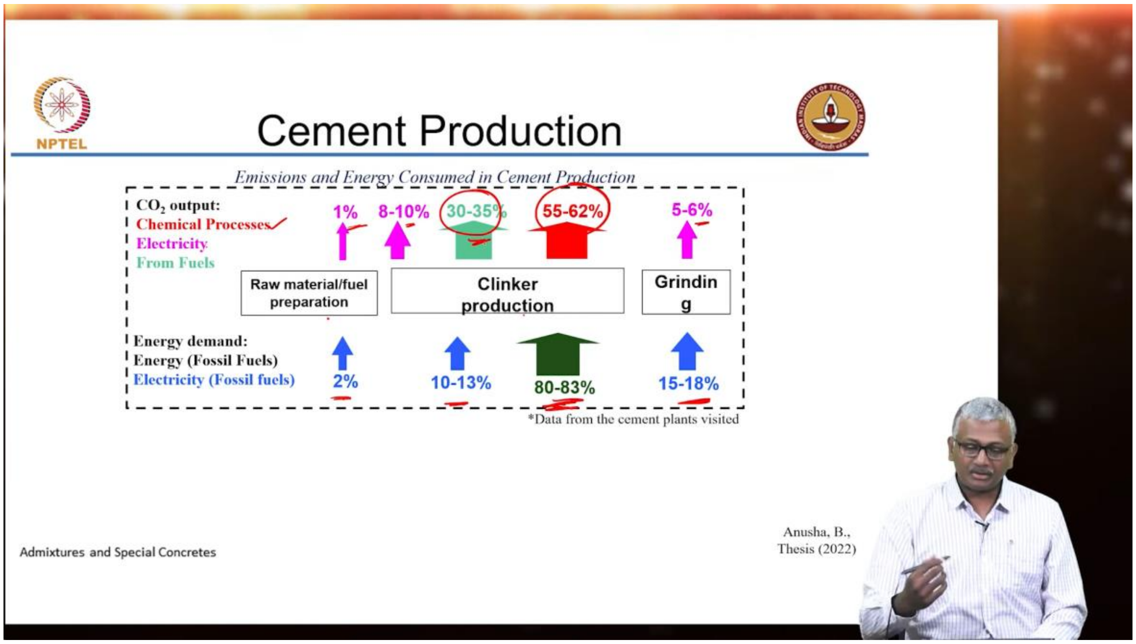

So, again what is the energy and emission involved in the cement production? So let us look at the energy first. Now your energy in the form of electricity from fossil fuels is about 2%. Energy going into the, so, this 2% is going into the raw material and fuel preparation. The energy that goes into the clinker production is 80-83% from fossil fuels like coal for instance for this particular plant.

Energy from, electricity from fossil fuels is about 10-13% that goes into the clinker production. So, electricity is basically involved in the rotation of the rotary kiln. So, you need to provide electricity to cause the rotary kiln to rotate. You also have electrical controls that are operating all the raw material discharges into the kiln. So, all that is electrically controlled.

So about 10-13% is from the fossil fuels. For the grinding process about 15-18% is the electricity from fossil fuels. Now in terms of CO_2 output there are 3 different things that are contributing. One is chemical processes for instance the calcium carbonate giving out CO_2 when it is heated beyond 900 degree Celsius. The electricity when you utilize electricity associated CO_2 of the electricity is also impacted.

If the electricity is coming from coal-fired thermal power plants the CO_2 impact is more than if electricity is coming from solar or from water hydro sources. So, that is also calculated here. And the CO_2 output from fuels is also given here. So, you see here that the electricity-related CO_2 emissions are rather small as compared to the chemical process-related CO_2 emission. That is something which is not possible to get avoided at all.

Because to produce clinker you have to burn $CaCO_3$. CO_2 will be evolved in that case. You can obviously put in a system where you can capture that CO_2 and take care of it in other processes but in most of our cement plants that is not being done. A process that is otherwise known as carbon sequestration. That is not something that we are doing actively in cement plants yet.

So, 55-62% of the energy of the CO_2 output is just coming out from the chemical process involved in clinker production. But what you can have a control of is this fuel-related CO_2 output. That is about 30-35%. Given that you have lot of carbon or coal-bearing sources that are getting fed in. So, if you go more for alternative fuels the fuel impact of CO2 will also come down.

You get my point. When we start using alternative fuels this net impact can be brought down also. So, this is something that cement plants are continuously striving to do is that they are trying to burn alternative fuels as far as possible to really have an impact in the production. The CO2 released based on electricity is not really that significant a component. So, most of the components that are significant are related to the clinker production in the kiln.

The part on limestone decarbonization you cannot do anything about because that is the causes that leads to cement production. But the fuel part is something where you can actually start playing with alternative fuels and get a clear estimate. So critical aspects obviously are clinker content, fossil fuels, alternative fuels, electricity generation and sources.

Case study for Foreground Data:

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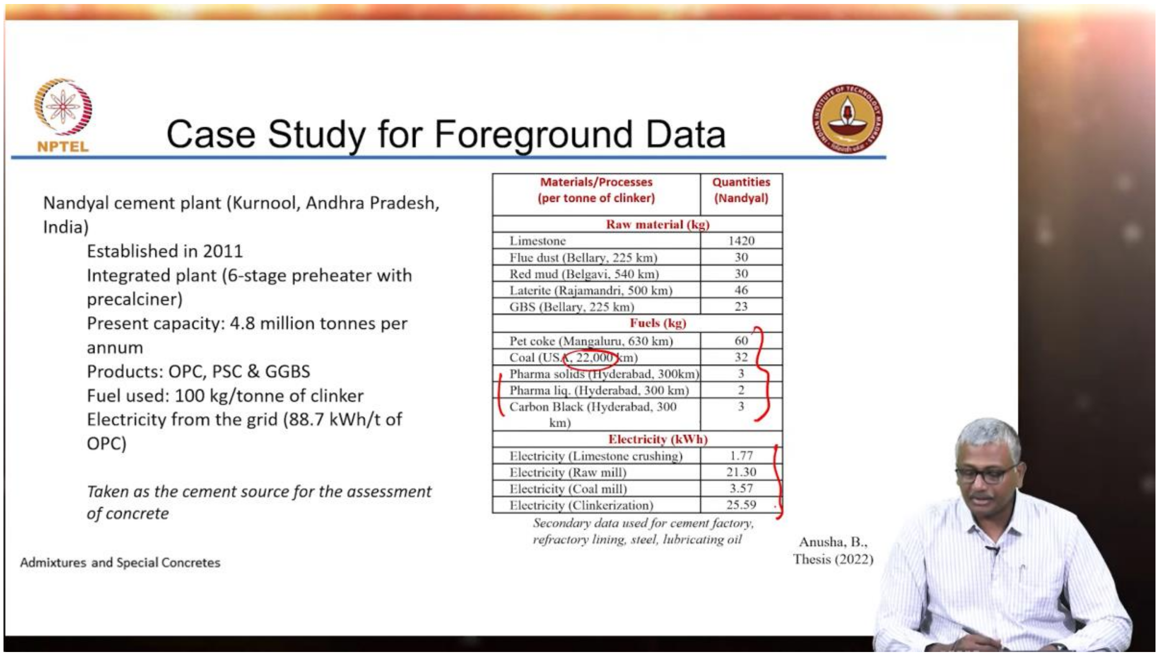

So, again this Nandyal cement plant just some data is provided here. It is an integrated plant which has a 6-stage pre-heater with pre-calcina.

This part comes before the rotary kiln just to ensure that there is sufficient heat energy given even before the material comes to the kiln so that you can actually shorten the length of the kiln. Present capacity of this is about 4.8 million tonnes per annum and it produces OPC, PSC and of course because it also has a slag source coming they also manufacture slag for mineral additive purposes. The fuel used is 100 kilograms per ton of clinker and electricity from the grid is about 88.7 kilowatt hour per ton of OPC that is produced.

So, this is the cement source that is taken for concrete production later on. But how do we get an estimate of the quantities? Again all of these were obtained directly from the cement plant to produce 1 ton of clinker, these are the compounds that are actually going in. As I said 100 kilograms fuel per ton of clinker. What is also given is where the material is coming from. Interestingly some coal is also coming from USA.

It is very interesting to note that because the shipped coal is very often cheaper as compared to the coal that comes from roadways. So, economics of coal can really be quite surprising. And because of that the kind of burning that you get, the kind of mixtures that you get are quite different. So, these are alternative fuels that are used in the system. Petroleum coke is an impure form of coal which really burns with a lot of impurities which has a lot of other sulphur-bearing emissions.

So, sometimes pet coke in some locations may actually not be allowed beyond a certain level also. But nevertheless, it is quite useful for cement plants to use. Electricity from the grid, it gives you an indication of what are the different stages involved and where this electricity is getting consumed.

Selection of conversion factors:

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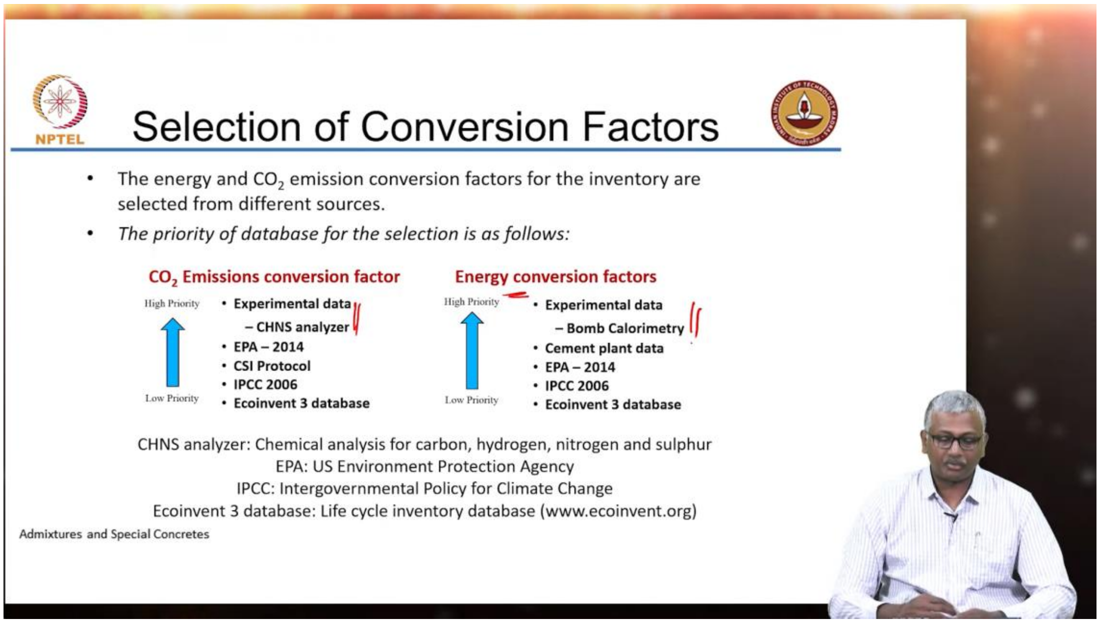

So now the conversion factors are absolutely important. How do we convert the amount of this for instance when we have 3 kilograms of carbon black, how much CO_2 is that going to give out? So, for that we need conversion factors.

So, we need CO_2 emission conversion factors and also energy conversion factors. And there are several databases that help us do this. Alternatively, we can also get from experimental data. Calorimetry to get energy and CHNS analyzer to get CO_2 emissions which are possible from a given fuel source. So, in this project a lot of data was collected experimentally but for some we had to resolve to actually go to sources which had some data. The eco-invent database is quite useful in this regard.

Conversion factors used:

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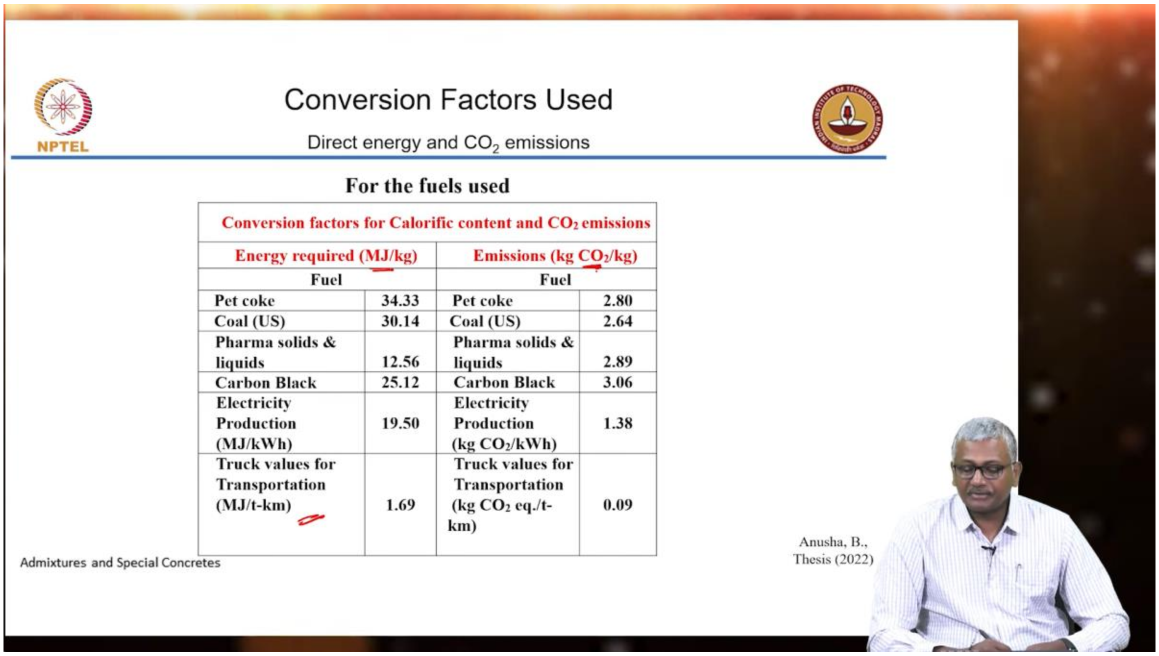

So, these are the energy factors or conversion factors that are used for energy and emissions. So, you can see as far as the million joules per kilogram of energy required. So, per kilogram of pet coke that is 34 million joules, for coal 30, farmer solids and liquids about 12.5, carbon black about 25 and so on and so forth.

Also truck values for transportation are given for every kilometer of transportation you are expending about 1.69 million joules of energy per ton. Similarly, electricity production per kilowatt hour of electricity so many million joules are being spent. Then kilogram equivalent carbon dioxide per kilogram of cement or per kilogram of clinker is again you see different values given for different types of raw materials or different types of fuels. So, conversion factors are required for the fuels.

Impact of clinker (Ground-to-gate):

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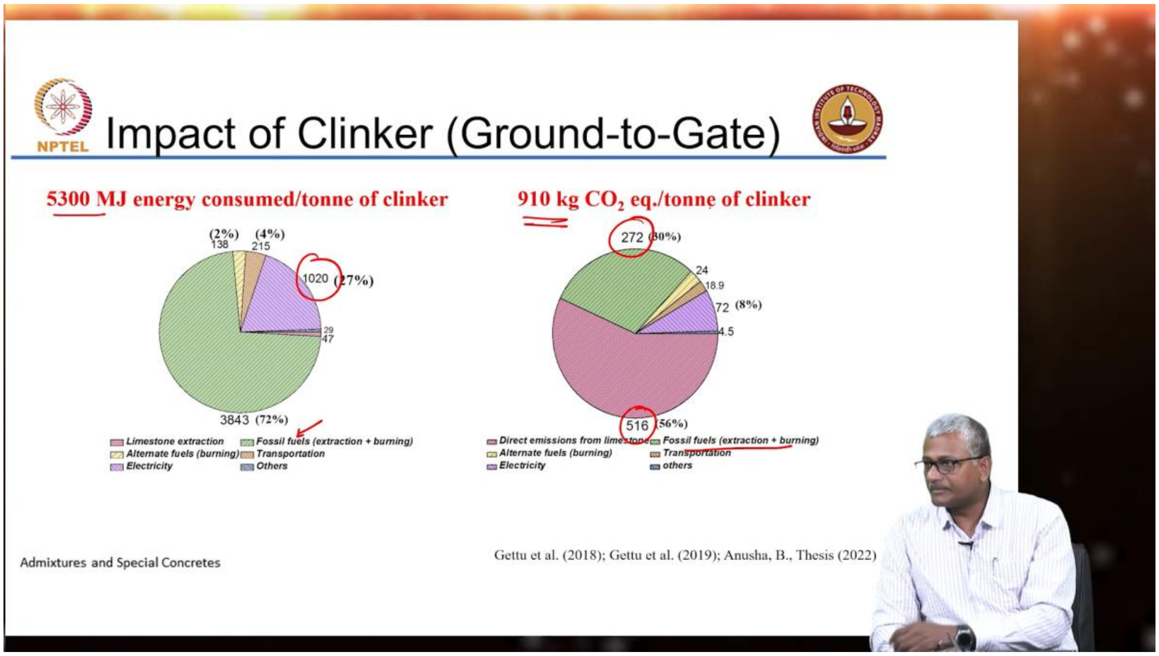

Now based on this data the impact of clinker in a ground-to-gate process was being calculated. So, you can see here per ton of clinker production the total energy that is consumed is 5300 megajoules or million joules. Look at what is contributing to the maximum energy consumption is basically the burning, the extraction and burning of fossil fuels. So, you have a large way to cut down on that. The limestone extraction is not that much of a laborious process it does not consume so much energy but electricity also is the other contributor to the energy consumption.

So, again fossil fuels, alternative fuels are a great way to reduce the extent of energy that is embodied in 1 ton of clinker. Similarly in terms of CO_2, 910 kilograms CO_2 equivalent per ton of clinker. So to produce 1 ton of clinker we are evolving nearly 910 kilogram equivalent of CO_2. So, almost like 1 ton of CO_2 per 1 ton of clinker. If you take it on cement basis it will be 1 ton CO_2 per 1 ton cement.

So, here 516 out of this 910 is contributed by direct emission from limestone. So, that is something we cannot really do much about except in concrete when we use less of OPC that means the impact of this becomes lesser. What is the second bigger component? 272 from extraction and burning of fossil fuels. Again that gives us a scope for reducing the CO_2 there. But keep this figure in mind 910, so we will compare this with other cementitious systems.

Cement production: Nandyal Cement Plant

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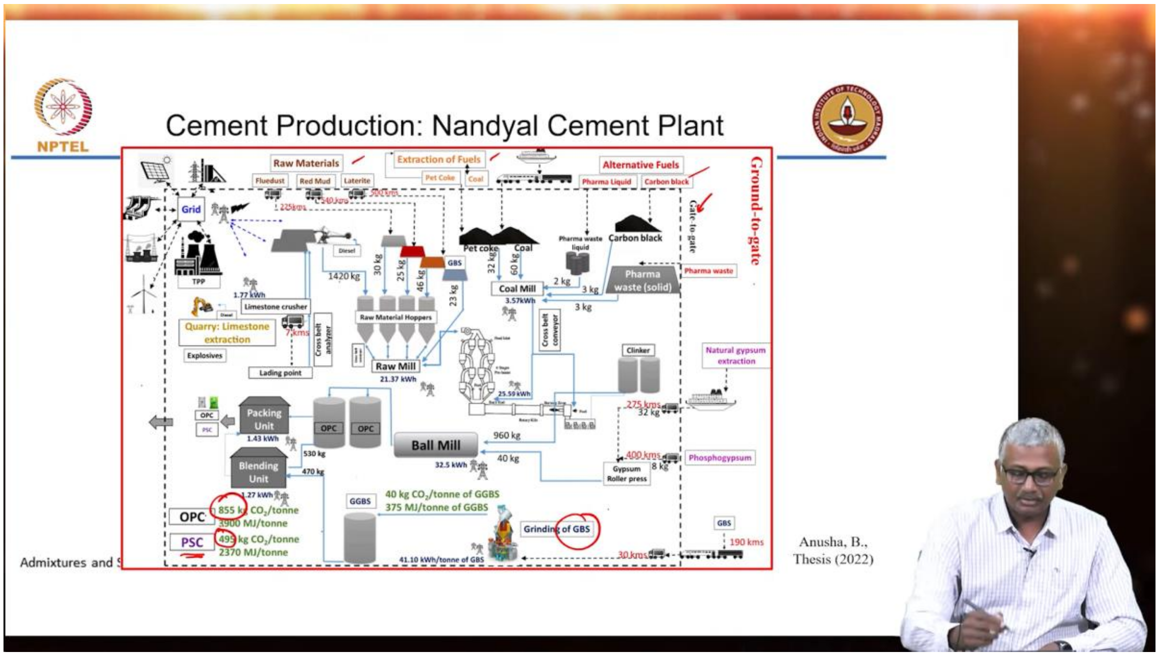

So, again here the ground to gate analysis of the Nandyal cement plant involved obviously the extraction of raw materials and the fuels and the alternative fuels. This is a scenario I already showed you earlier and grinding of slag was within the plant itself because slag it was actually an integrated plant which involved slag also. Now, so this was the overall process that was considered of course if you are doing gate-to-gate it will be a much smaller unit you will not be considering the extraction of the raw materials into the system.

Cements- carbon footprint:

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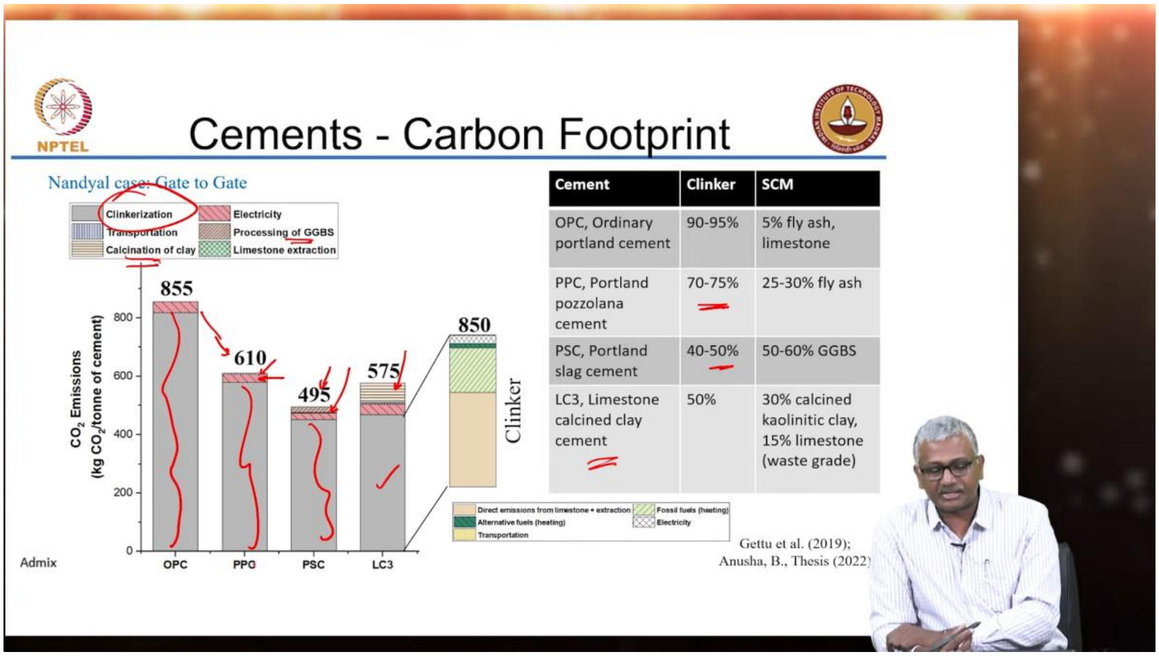

Now when you convert these clinker values, so this is for 1 ton of clinker. So when you are producing your PPC what will happen? This amount of energy and CO_2 from clinker is going to be there.

In PPC, how much clinker is there? Portland Pozzolana cement how much approximate clinker value will be there? How much fly ash is there typically in PPC? Sorry? 5? 5 percent is a normal cement. In ordinary Portland cement, you only have about 5 percent as performance improver, limestone or fly ash. In PPC, fly ash is typically around 30 percent you are allowed up to 35, but typically it will be 25 to 30 percent. So, remaining about 70 percent is clinker, so 70 percent of 0.7 into 910 will be constant for all PPCs.

Now you need to add the energy and CO_2 that is coming in because of the fly ash. Now because fly ash is considered as a waste material the part that contributes to CO_2 and energy is only from the transportation of fly ash to the cement plant. That is it. That is what we are considering as far as fly ash is concerned. So when you do PPC you are automatically coming down, sorry I missed one aspect here, when you convert this entire system into OPC the clinker value is 910 CO_2 per ton of clinker, but per ton of cement it is 855 kilograms equivalent of CO_2 per ton of cement.

Because cement has some performance improver and some gypsum that does not involve the same level of energy for processing. So, overall impact comes down in terms of cement quantity. For Portland slag cement where 50 percent slag is used this is coming down to even 495 kilograms equivalent of CO_2 per ton and that is what is seen here. In PPC when we use 30 percent fly ash or if you have 70 to 75 percent clinker we are coming down from 855 to 610. In slag which has nearly 50 percent of GGBS we are coming down to 495.

But what is constant is the fact that this energy is contributed by clinkerization. The formation of cement clinker in the kiln contributes maximum energy in the case of all of these cements. PPC or PSC maximum amount of energy is because of the clinkerization of OPC. We are assuming almost zero cost for the fly ash or zero CO_2 energy for the fly ash. The only part that is contributing this small bar that you see here is the transportation of the fly ash to the cement plant.

This part is obviously dealing with the electricity required for all the processes put together. As far as slag is concerned you have an additional component here which is related to processing of slag. We need to grind slag. This is actually an integrated cement plant set up next to a steel production unit. So you get the slag directly from there and you are now processing it.

Some energy is involved there or some CO_2 is also involved there. But maximum component is coming from clinkerization. The main thing to notice is the lesser amount of clinker that you use in your cement, the lesser will be the sustainability impact. The CO_2 and energy impact will be reduced if you use lesser cement clinker in your system. Now what about LC3? In LC3 you have your clinker which is still producing or clinkerization process is still producing maximum amount but apart from that you also have this calcination of clay that is leading to some level of CO_2 output.

It is not from the clay obviously. What is the CO_2 coming from? Clay may have some calcium carbonate as an impurity but calcination of clay is producing CO_2 because of burning of the fuel. The fuel that is getting burnt to calcine the clay that is releasing some CO_2. That is the CO_2 coming from calcination. But your part on electricity involved in the process and some level of transportation is still there. But that is minimal as compared to the clinkerization. So, large component is still your clinker.

Cements- Energy Demand:

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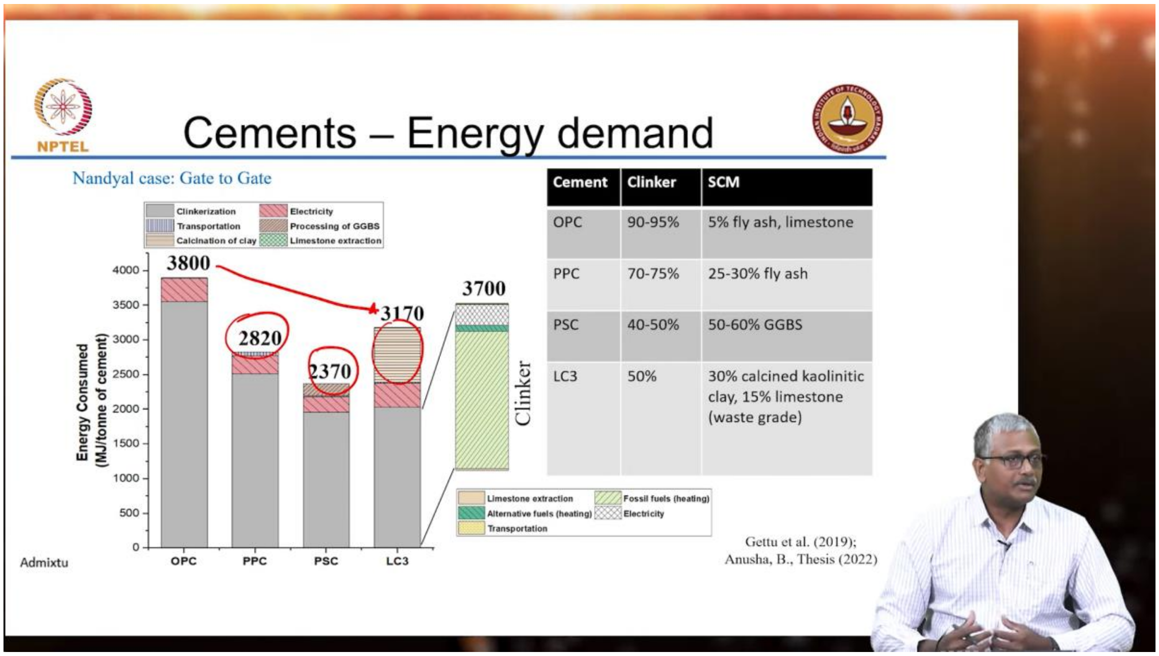

So, large component is still your clinker. When you consider the energy once again the large component is the clinker only thing that happens is the energy required for calcination of clay could be quite substantial because you are still burning at 800 degree Celsius. So, that calcination can still account for a significant bit of energy. So, there even though the system is still better as compared to OPC you are not really matching with your PSC or PPC. In CO_2 emissions it was even better than PPC but in energy it is higher than PPC. So, the part to remember is that your clinkerization process is leading to maximal impact in terms of CO_2 and energy.

All other processes are only minimal. So clinkerization if you can do something. So, today alternative fuel source people are even looking at using hydrogen, green hydrogen as an alternative fuel source for calcination of cement and that is a project that is going to be undertaken by the energy consortium here in IIT Madras.

Case study- Aggregate production:

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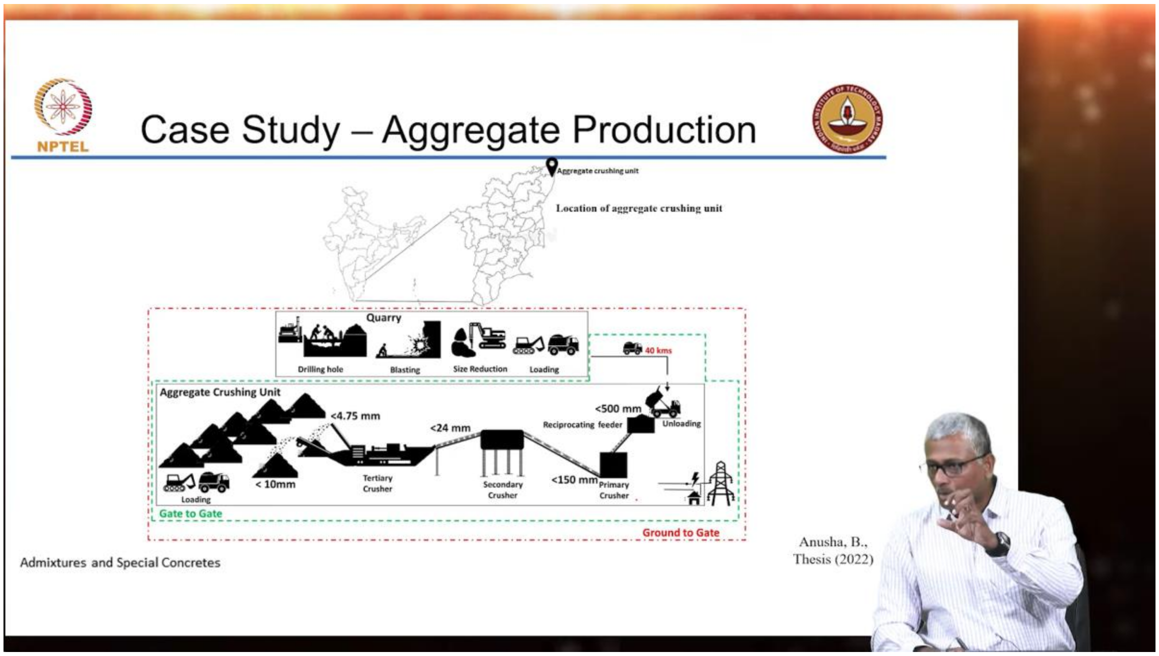

Now all that is good now what about concrete? So, concrete also requires aggregate to be brought to this concrete plant. So there are several processes involved in producing aggregate including quarrying which includes drilling, blasting, size reduction and then loading on to back of trucks then they are brought to the crushers you have a primary crusher, secondary crusher and sometimes you have a tertiary crusher. In the case of fine aggregate usually there will be a tertiary crusher which we also call as a vertical shaft impact crusher, VSI crusher which ensures that the particles are more uniformly sized rather than being angular.

So all of these aspects need to be considered when we talk about aggregate.

Case study- Batching plant (RMC)

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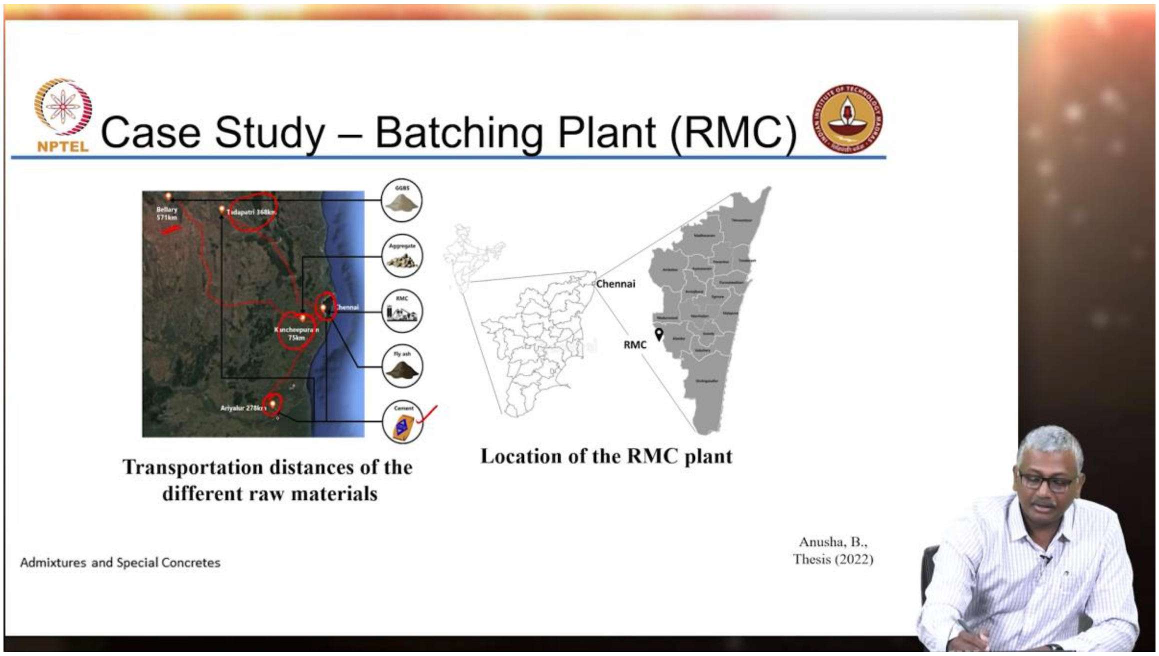

So, to do a case study of concrete production a concrete plant in Chennai was chosen and what we are assuming here is that the cement is coming from Ariyalur which is about 280 kilometers south of here, the GGBS is coming from Belarry and the fly ash is being brought in from Tadipatri and aggregates are from Kanchipuram, 75 kilometres away. So, imagine the process is quite complex when you have a material in a given location it does not mean that it is local exactly there, local here means nearly 200, 500, 300 kilometres away. So, all of that has an impact on the overall. So that is why I was saying always that to be sustainable one has to be as local as possible.

If a source is available locally then that is what you want to use. Sorry, fly ash is locally available, it is from Ennore thermal power plant, not Chennai. Tadipatri was used for the cement, Ariyalur and Tadipatri both were used for the production of cement that was supplied to Chennai.

Concrete:

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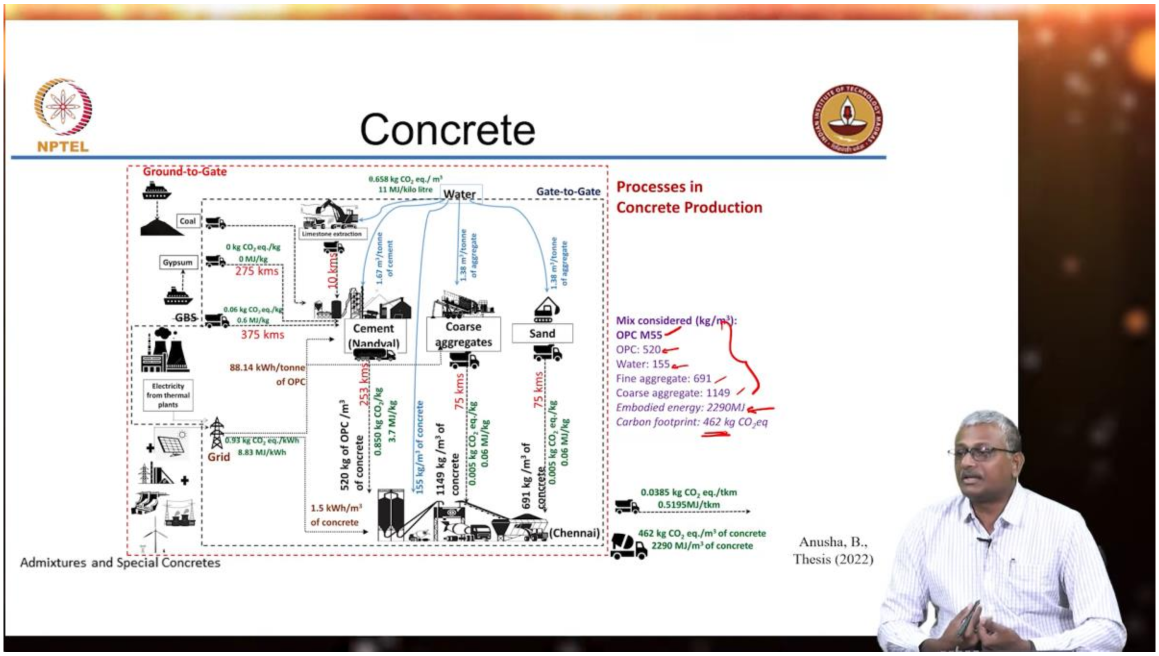

So again you need to define a system boundary as far as concrete is concerned. You can have various processes in concrete production starting from extraction of cement or extraction of limestone to produce the cement or extraction of your coarse and fine aggregate and so on.

So, all of that and the transportation associated with the process is going to contribute to the CO_2 and energy of the concrete itself. So to make things short a simple mix design of M55 grade concrete is considered with OPC of 520 kilograms, water of 155, fine and coarse aggregates as given here in terms of kilograms of cubic meter. This results in an overall embodied energy of 2290 million joules that means one cubic meter is having an embodied energy of 2290 million joules and carbon footprint of 462 kilograms equivalent. One cubic meter, how many cubic meters are used in the world of concrete? About 10 billion cubic meters of concrete are used around the world. So, one cubic meter produces 462 kilograms equivalent of CO_2.

10 billion cubic meters you can just keep multiplying by how many zeros I do not know. So, construction contributes, concrete contributes nearly 8 to 10 percent of your overall CO_2 emission.

Concretes with different dosages of SCMs

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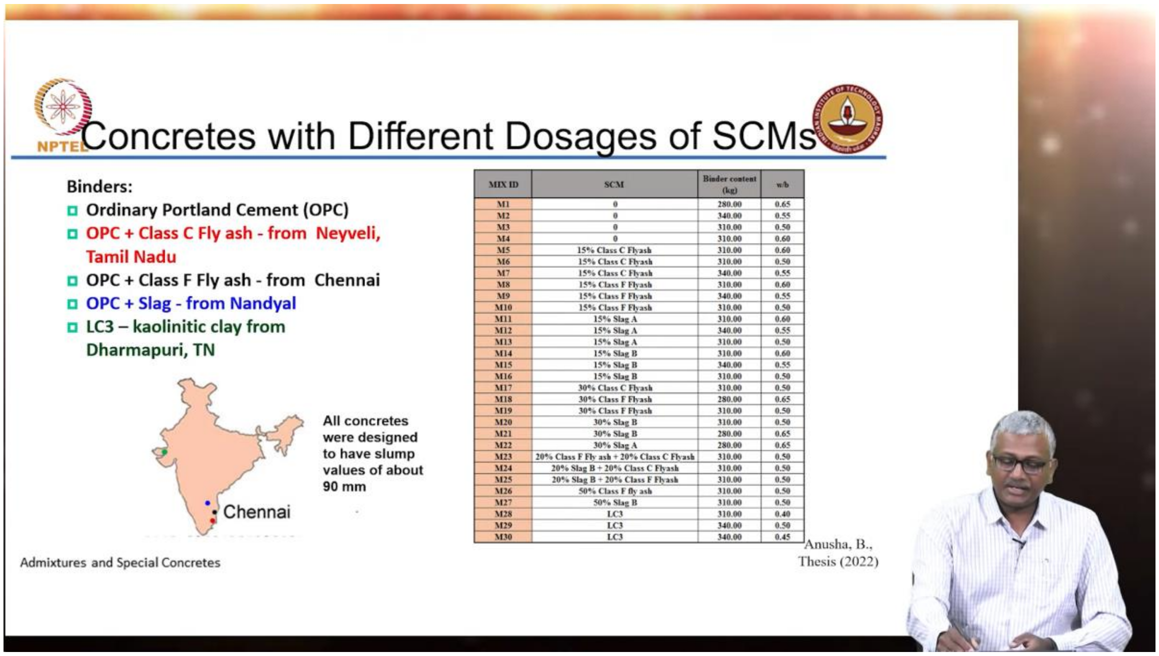

Okay, so now what we did was we had a large database of concretes with different dosages of supplementary cementing materials. We had class C fly ash, class F fly ash, two different types of slags, we had LC3 and so on and so forth. So, all of these concretes were designed to have a slump of about 90 millimeters.

So, workability was kept constant. So, we had to obviously alter the mix with use of super plasticizer to achieve that workability.

Impact assessment of concretes with different dosages of SCMs:

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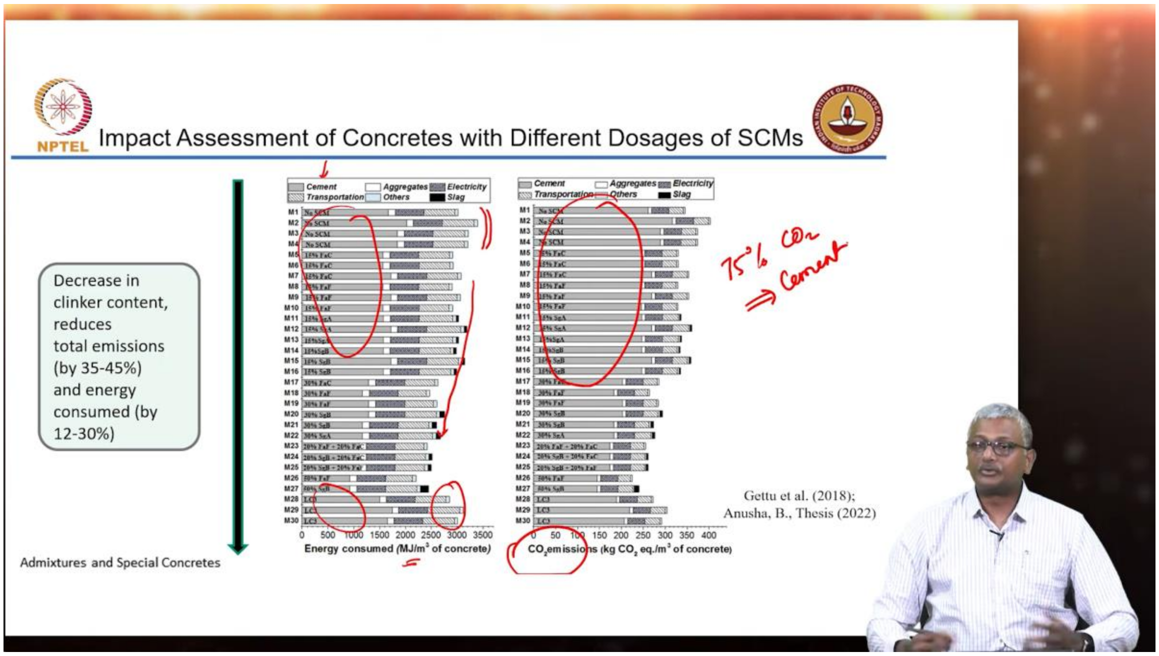

Now for all of these mixtures we did an impact analysis in terms of CO2 and energy. So you can see here the energy consumed million joules per cubic meter of concrete is given here. For concretes without supplementary cementing materials these are the four concretes. As you use increasing dosage of supplementary materials your energy is coming down, expected.

With LC3 you really do not see too much of a decrease because of the fact that calcination of clay has contributed to extra energy being utilized for production of LC3. But what is important from here is that the part played by cement has the largest role to play in the energy consumption. The part played by cement that means the cement input into concrete has the largest role to play. Your aggregates and electricity required is only a smaller component but not so small it is about half. So half is because of cement and half is because of your aggregate and electricity involved in production of the concrete.

What is interesting to look at is the CO2 emissions. Look at what is happening here. Nearly 75% of your concrete CO2 emissions is because of cement. 75% of CO2 emission because of the cement that is being used. So if you have to reduce the CO2 impact of concrete you have to use less cement. If you have a type of cement it may be used less cement but within cement use less clinker, use more substitute materials.

So that is what is the approach that was done. In this case there is actually a very good paper which is available for you to read.

Sustainability indicators:

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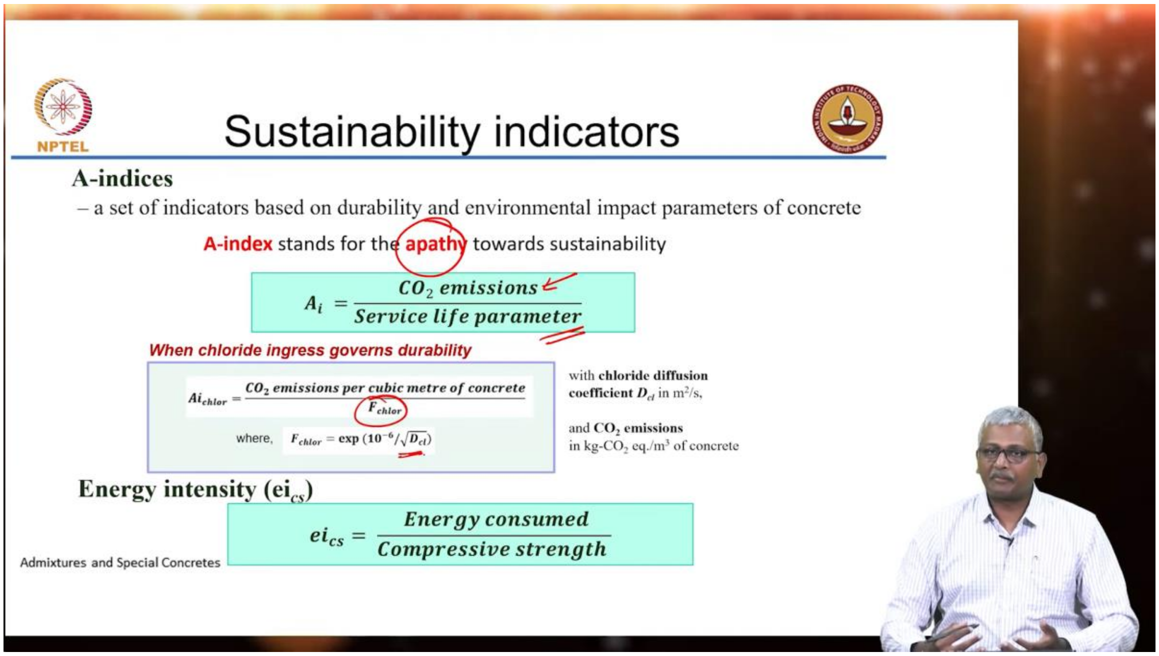

Now it is important for us not to just stop there. What is the point of, let us say I use 50% fly ash and it is reducing my CO2 and energy input significantly but my structure is only going to last let us say 10 years as compared to 50 years. What is the point? So I need to have some definition of durability also into my sustainability.

So, for that sustainability indicators were proposed. This is called A index or apathy index. Apathy means you do not care about something. So, A index being high means the apathy towards sustainability is very high that means you do not care about sustainability at all. ‘A index’ being low is good for you. So, what does ‘A index’ is doing is calculating the CO2 emissions as a fraction of the service life parameter.

For instance, let us say chloride diffusion coefficient, okay, can be the service life parameter we define or carbonation rate can be a service life parameter. Right, so, that is basically the definition of ‘A index’. So, when chloride ingress governs the durability, the Ai or apathy index for chlorides is given as CO2 emissions per cubic meter divided by this factor which is the service life parameter. So, we want the apathy index to be low that is why the service life parameter is defined in terms of an exponential function which decreases with increasing chloride diffusion coefficient. So, what we are simply doing is normalizing the CO2 emission per unit of durability of the concrete.

You also can do an energy normalization, energy consumed per unit compressive strength of the concrete. Now what does this mean? This means that I can start designing concrete with much higher strength for my application. Right? For my application and reduce the overall quantity of concrete that I use. But my energy consumed will depend on the raw materials that go into the making, the cements and the production of that concrete. So, energy intensity factor here is defined as energy consumed per unit compressive strength.

Sustainability framework: Chloride attack

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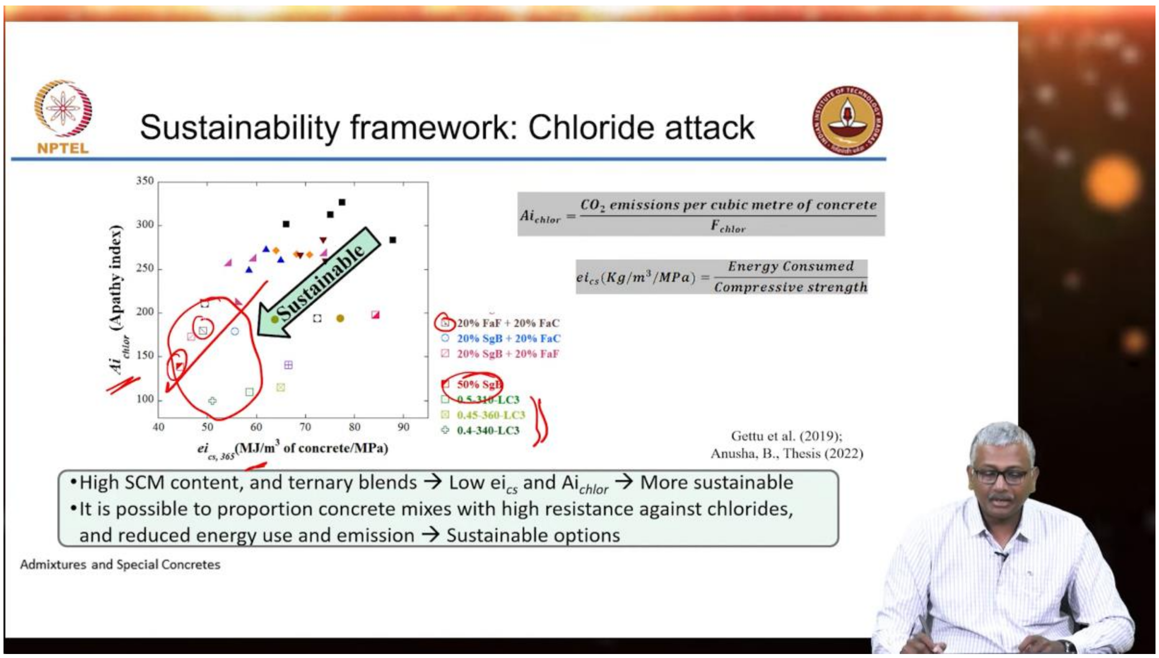

And what we do is sustainability framework that was generated by Anusha and her studies said that if you plot the apathy index versus the energy consumption per cubic meter, you will now get some sort of a rational way to select mixes that are going to be sustainable. So let us say for a chloride attack scenario, you want as low an apathy index and as low as an energy intensity factor that is possible.

So you want to select the mixtures that are located somewhere here. So from this segment what you seem to indicate is that the systems with LC3 all of them are really falling in this low apathy, low energy index category. The systems with high amount of slag are also falling there, the systems with large amounts of fly ash are also getting, so this fly ash F and C combination is also falling within this category. So, now you have a rational means of looking at what is actually sustainable. Sustainable is something which is not just low CO2 or low energy but also durable.

So, all of these factors need to be considered together. So when you go to the bottom left corner, you become more sustainable.

Conclusions on Life cycle assessment:

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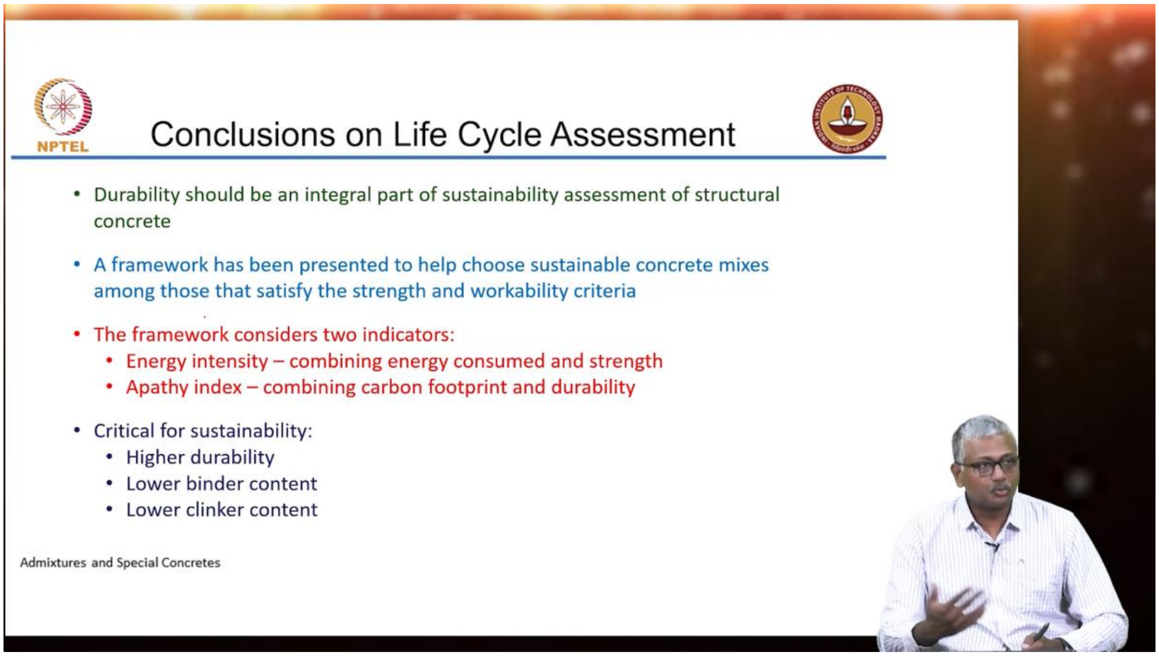

So, in general as I said durability has to be an integral part of sustainability assessment. Here what you saw is the framework was presented to choose sustainable mixtures with satisfying a particular strength and workability criterion. So here energy intensity factor and apathy index are 2 possible ways of looking at how impact of strength and durability can be taken in along with CO_2 and energy. So, obviously higher durability, lower binder content and within the binder lower clinker content.

So, make concrete extremely durable, use less cement in the concrete and in the cement use less clinker. So this is the mantra for durable and sustainable concrete and that is where mineral admixtures have a large role to play.

References:

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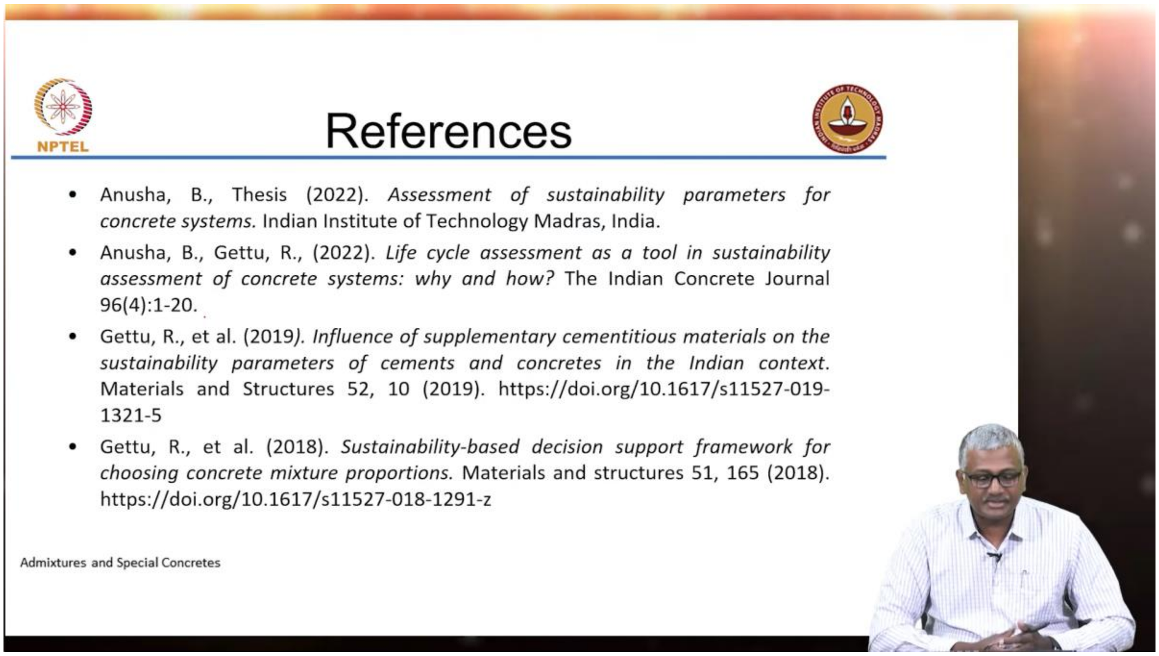

I think we will finish with that, there are some references that are provided here.