Advanced Topics in Science and Technology of Concrete
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Environmental impact and life cycle assessment (LCA) - Part 1

Thank you for joining me while I discuss some of the environmental benefits and the use of life cycle assessment in the context of recycled concrete aggregates. I am Ravindra Gettu from the Indian Institute of Technology, Madras, IIT Madras in India. So, some of the benefits of recycling are obvious. We are using material that is being thrown away to make new structures. So, it is clear in that sense that we should recycle. There are other benefits to the planet, to the environment and to the society when we recycle.

Construction and demolition waste comprise more than a third of all the solid waste generated. So, one can imagine the amount of construction demolition waste that is being produced. As we construct more and we have to clear up the land, we are going to demolish more and more. Further, our infrastructure built in the 50s to the 70s have become old and may need to be replaced soon.

This means we are going to demolish those structures and build more. So, as we progress, we are going to have more and more demolition and we have to do something more than just dumping in landfills. About a fifth to a third of all construction and demolition waste is concrete, old concrete that is coming from structures that we have demolished. The most important aspect that we will have to consider when we are looking at construction demolition waste and particularly concrete waste is the avoided burden of landfills and dumping. Landfills are often sites that are designated by administrative bodies.

However, when we use these landfills, we are wasting land that could be used for better purposes. Often these areas are near cities, which are prime property for further development and to put up services that are of better use, more important to the society than just having a place where we are dumping material that is coming from demolition. Further, there is a lot of possibility of leaching of chemicals from the construction and demolition waste. This could end up contaminating groundwater. Depending on what has been used in the construction, the material that can leach out of the concrete could end up in groundwater.

There is also a lot of dust because the demolition, the attrition, the degradation of the waste produces dust and this ends up in the air and causing allergies, causing disturbance and just being unsightly. Further, what happens when you have a landfill and permit allow the disposal there of construction and demolition waste, be it concrete or other waste, there are also other materials which could be of hazardous nature like asbestos and some chemicals which can be together with this construction and demolition waste, mostly non-hazardous, but some could be hazardous and this could be dumped there in the same landfill. So, this means that we would not be able to control what happens to such material and this is there in the landfill, this could get out of the landfill as leachate or as dust or by some movement it can leave the landfill and contaminate the environment. Very importantly, in several regions of the world, India is a notable example, we have a lot of illegal dumping, that is construction and demolition waste is taken to some low-lying area, some riverbed, a swamp or even stormwater drains and just dumped. This is often done overnight, it is difficult to find out who did it and this remains so.

So, we can imagine the disturbance this causes to society, to the environment, if a stormwater drain is blocked by construction demolition waste, one can imagine the disturbance, this could lead to flooding and stagnation of water and so on. So, all these are very important effects of recycling construction demolition waste and not sending such waste to landfills. One technique that is used to go further and see what are the environmental benefits or demerits of any technology or product is called life cycle assessment. Life cycle assessment can quantify the environmental impacts of a product or service. This can be done with different indicators, I am going to take two indicators, the carbon footprint that we talk about a lot and embodied energy and you will see that in most construction related activities, we talk about these two indicators, the carbon footprint and the embodied energy more than anything else.

And even in the research done on construction demolition waste, when we are analysing, comparing different techniques, technologies, we use this life cycle assessment to compare different products or processes. Now, life cycle assessment studies can be done, performed for various scopes or systems. What is a system? A system is a group of processes that we consider for the assessment. So, in terms of construction and construction demolition waste, there are three categories that we can think of. One is cradle to gate, cradle means the mine, the material coming out of the ground, all the raw materials from their extraction stage until the material is leaving the gate of the factory or the plant.

So, this is the cradle to gate system. So, this is something that would require us to know where the material came from. The material is not only that which we are going to construct with or recycle, but also the fuel, the electricity needed for the processing of this material. So, if we start from, right from the beginning, that is from the mine, ground upward up to the product leaving the factory or the plant gate to be used is the cradle to gate system. The gate to gate system is basically what happens within the plant.

And later, I will show you a case where we are just looking at crushing. We are just looking at the crushing of waste to make them into aggregates. So, only what happens in the plant, if we want to compare one, what happens in one plant to another, irrespective of the transportation, irrespective of where the electricity came from, what was the source of electricity, which also impacts the cradle to gate system. The gate to gate system looks only at what happens within the plant. The cradle to grave system is the more complete system.

If for many products, we can do the cradle to grave system, because we can start from the beginning and follow the product through until end. An example would be soda bottle. We know how the glass was made. So, we can start from the cradle from the beginning and we can go up to the end of the use of the glass, whereas again made into a new bottle or it is put into some other use. So, if we can trace, if we can understand or need to understand the entire process from the beginning till the end, then we could use a cradle to grave approach system, where we look at everything from the raw material processing extraction until final disposal.

Now, for construction, this is very difficult. We can do it in principle, but it is very difficult to get reliable values. One can imagine that when we are talking about the structure, a structure could last several decades, if not centuries. Now, to understand how that structure would be disposed of, we are speculating on how this structure is going to be disposed of after several decades or a century. So, most analysis that is relevant, useful is either cradle to gate or ground to gate or gate to gate, where we can compare different materials, different processes, not having to speculate a lot about what is going to happen much after the structure has been built.

We can however bring in the aspects of maintenance, the usage of a structure, but the final demolition since is going to be happening much, much later. We will not, we do not

know now what technologies will be used 100 years from today. It is difficult to do a cradle to grave analysis for civil engineering structures and applications. So, we use this life cycle assessment for the analysis of cement and concrete systems. So, we have done a lot of such systems at IIT Madras.

The process of LCA follows the ISO guidelines, where we have first the goal and scope, we have to understand why we are doing the LCA, what is it going to be used for, what is the purpose of doing the LCA. In the scope, we have to define the system that I just talked about a few minutes back. In the case of cement and concrete, the goal and scope is basically to choose a concrete system that has a low environmental impact. We want to see how to develop new technologies, we want to be able to compare different products, so that we can choose the one that has the lowest environmental impact. And for this, we have to decide the functional unit, whether we are looking at a ton of material, a cubic meter of material or a building in its entirety, what is that we are going to compare.

So, that will define the functional unit and that has to be same throughout the comparison. Then we have to define what is the system we are looking at. Like I mentioned before, is it going to be ground to gate that is cradle to gate, where we are looking at everything that comes from the mine up to the gate of the plant or are we just going to focus on what is happening in the gate, within the plant itself that is gate to gate. Both have different implications and I will show you some examples in a few minutes. Then what we do is we do the inventory.

We first collect the inventory and then analyse the inventory. So, the inventory is all the inputs and outputs to a particular process or in and out of a system. So, this would include all raw materials that are needed for the product or process, the electricity and other energy that is required to keep all this functional and then all emissions or products that are coming out. So, that is the what is needed in the inventory, what comprises the inventory. So, in our case, when we are talking about cement and concrete, we have to look at data from cement plants, from aggregate plants and from concrete plants.

We will have to know what goes into making cement, what is the energy required for the aggregates and how the concrete is produced and then we calculate all the inputs and outputs, put them all together and that is the inventory. Then we have to assess the impact of this. So, from the inventory, we have to convert the values to certain indicators. There are many indicators which could be relevant. For cement and concrete, the most important are the carbon footprint that is the carbon dioxide emissions and the embodied energy or the energy consumed.

The carbon footprint tells us what is the impact on greenhouse gas emissions on global warming. So, if we know the carbon footprint, we know what is the global warming potential and we can compare and choose which is the one which has a lowest global warming potential. Embodied energy is also very important because when we decrease the embodied energy or the consumption of energy, we are going to use less fuel, we are going to use less electricity or we are going to have less transportation requirement. Energy also means raw materials and cost. If we decrease the embodied energy, the energy consumption, that means that we are decreasing the cost of a process and we are most probably going to use less raw materials.

So, these two are the important indicators when we consider concrete and other structural systems. Once we have this, then looking at all these, we look at how to interpret and come up with the best materials, the best systems and we can conclude and make recommendations on how to go further with this process of improving the construction and the construction sector. So, this is how we apply life cycle assessment to cement and concrete systems. So, let us look at some examples or typical cases that we have worked on. So, let us start with cement because we know that cement has the most carbon emission out of all the materials that we use in concrete.

So, here I have a typical case of a cement plant. So, we go to a cement plant and then we find out all the processes that are involved. Say this is a cement plant that produces ordinary Portland cement. So, OPC stands for ordinary Portland cement and PSC is for Portland slag cement. So, Portland slag cement would have about 50 to 60 percent of GGBS that is ground granulated blast furnace slag.

So, this process map here looks very complicated, but this is something that has to be done. So, what does it have? We are calculating here or we are putting together all the materials and processes involved for calculating one ton of these materials. So, one ton becomes the functional unit. So, one ton becomes the functional unit and now what we have is all the materials that are going to form the cement. So, you have here the different materials that are going in to making the cement, mostly limestone.

Limestone comes out of a quarry, so we have to see what is the process involved in the quarrying, in the extraction, the distance that the limestone is travelling, the electricity required for the limestone processing that is needed for the cement. In addition, we have other raw materials. In this plant, they use flue dust, red mud and laterite and this travels a certain distance. The distance is important because that is also consuming energy. Transportation has a significant carbon footprint and embodied energy and we need to know it.

So, all this goes in to making the raw meal required for cement and you can see here all these are the quantities that are required, which go in for a ton of material along with the limestone. So, this is limestone and you see that other minor quantities of other materials are also going in. For all these processes, we need electricity. So, the electricity could come from the grid or it could come from a dedicated power plant in the cement plant itself. If it comes from the grid or from any other source, we would like to know what is the source of the electricity.

Is there a mix of electricity from different sources or it is all coming from one place because the source and the process of generation of electricity has a different carbon footprint from some other way of getting the electricity. So, we will also have to know what is the carbon footprint of 1 kilowatt of electricity that is used. Then for heating the concrete, heating the raw meal to make clinker in the rotary kiln, we need fuel. So, in this case coal is used and pet coke is used. Pet coke is commonly used in many plants in India and you will see that this is a common ingredient that comes up in the analysis when we do the life cycle assessment of cement.

Here in this plant, lot of other waste material is also used. They use carbon black, pharma waste and other waste. There could be other alternative fuels also being used like broken crates, packing material and so on. So, all this goes into the kiln and finally we get clinker.

So, with this process we can analyse what is the carbon footprint and the embodied energy of clinker and within concrete this is the most important in terms of the life cycle assessment.

We find that the biggest part of the carbon footprint and the embodied energy comes from the clinker. So, as an aside less clinker in the concrete is always going to be more environmentally friendly. So, clinker is combined with gypsum. Again we have to see where the gypsum is coming from in this particular plant. They are using a combination of natural gypsum that comes from the Middle East via boat and phosphor gypsum which is a waste product.

So, both of these in certain proportions travels over a certain distances and comes to the ball mill where it is ground along with the clinker. And the product is ordinary Portland cement which is packed and sent out of the plant after blending with certain performance enhancers about 5% can be blended into the ordinary Portland cement before it is it comes out as a marketable product. So, in this case the values come out to be about 855 kilograms of CO2 per ton of cement is the carbon footprint and this is for the analysis of gate to gate. The same values for Portland slag cement where some amount of GGBS is also ground in is about 500 kilograms per CO2 of CO2 per ton of cement. So, here as I said before about 50 to 60 percent of GGBS is incorporated in Portland slag cement and therefore the carbon footprint and the embodied energy comes down significant.

So, this is what we will do for cement and let me give you some examples of what we have. So, in the ground to gate system say in this particular plant if I am going to make a ton of ordinary Portland cement I would have more than 900 kg of CO2 emitted for every ton of ordinary Portland cement. Suppose it is Portland pozzolana cement where I have lot of fly ash 25 to 30 percent of fly ash the value comes down the CO2 emission comes down by a substantial amount from 900 to less than 700. In Portland slag cement I have more substitution of the clinker and then you see that this is even better.

It comes down to about 550 kg of CO2. LC3 is a new type of cement that we have done a lot of work it stands for limestone calcined clay cement where we have 50 percent clinker, 30 percent calcined kaolinite clay and 15 percent limestone and the limestone could be waste limestone we are not removing or we are not using limestone that is meant for cement production. And here we have again the calcination of the clay so there is some impact of the calcination of the clay and that is what you see here in this red part of the bar diagram giving us a carbon footprint of about 600 kg of CO2. So, this is also lower. So, what we will find and what we find is the main culprit in having a high carbon footprint of cement is the clinker and in the clinker the most of the carbon footprint is from the limestone because calcium carbonate converts to calcium oxide and CO2. So, anytime we convert limestone into calcium oxide we are going to give out CO2.

Other than that we have the fuels. The fuels are being burnt because we have to heat the material to 1500 degrees in the kiln and this is going to emit CO2. So, in this case pet coke and other fossil fuels are used. So, the clinker this is the clinker part the gray part of each of these bars is clinker and we see that as we decrease as we decrease the clinker we are going to reduce the carbon footprint. Similarly, we can look at the energy consumed or the embodied energy. This is again for a ground to gate system and I am looking at the four different cements that I just discussed ordinary Portland cement, Portland pozzolana cement.

So, the PPC has fly ash, PSC has slag and the LC3 has calcined clay and limestone powder. Again, the grey part is coming from the clinker and in the clinker the embodied energy is mostly coming from the fossil fuels, pet coke and other fossil fuels. The electricity, so this is the electricity consumption, electricity also is used a lot. So, that has its own embodied energy content for the production of electricity not just the electricity itself but the embodied energy of the electricity. Consequently, as we decrease the clinker content we find that the overall energy requirement also decreases.

Similar to what we saw before from 5900 in the case of OPC, PPC the value comes down to 4600, PSC 4100. For the case of LC3 it will be more than the PPC and PSC because we also need energy for the calcination of the clay. It is less than that of clinker because the temperature is required for calcination of the clay is about 700 to 900 degrees Celsius instead of 1500 that you would have in a clinker in kiln. So, this gives an idea, an illustration of how life cycle assessment is done and what do we get as indicators that we can use for comparing different materials for choosing the right material for certain application.