Advanced Topics in Science and Technology of Concrete

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Overview and generation of recycled concrete fines

Hello everyone, this lecture is about recycling concrete fines. I am Priyadarshini Perumal, a senior researcher working at the University of Oulu in Finland. Before going to the lecture, I would like to introduce my research group, Fibre and Particle Engineering Research Unit. Here in this research unit, we try to utilize industrial site streams or the by-products into useful cementitious materials and aggregates to produce concrete-like materials. We start with identifying the material by characterizing their reactivity, physical, chemical, and mineralogical properties and then deciding what kind of processing it may need to improve its properties or specific applications. The treatment methods could be mechanical, thermal, or chemical methods, and we also design the binders.

It could be alkali-activated materials or supplementary cements, ettringite-based binder, and several other non-conventional binder materials. We also study the properties of the end products, which could be in aggregates, a mortar, a concrete, and in many cases, it is also for stabilizing heavy metals for those industries which produce by-products that are high in heavy metal content. The purpose of today's presentation is about sustainability and circularity in construction, and then I will be explaining a bit of construction and demolition products, recycling concrete, and some of the pre-treatment methods that are already existing in these types of materials. The main focus would be recycling fines which can be in high-value application or in high-volume application which I will explain in the later slides and then we will touch upon a bit about the findings from these studies and what could be done as next steps. When we consider sustainability and circularity in construction, it is heavily emphasized in recent days.

Before going to the broader picture, let's see what it means in definition. So, these findings define us meeting the needs of the present generation without compromising the needs of the future generation. So, it stands in three major pillars, economic, environmental, and societal. In most of the cases, construction materials depend on the natural resources, for example, the minerals mined, rocks, sand, wood, and so on. Creating sustainability in these kinds of environments when the material is heavily dependent on natural resources, we should rely on the 3R principle which is reduce, recycle, and reuse.

Coming to the circularity in construction, it mostly is defined by knowing the end of life scenarios. When you see this picture, this is how it looks about construction materials in recent days. If you consider steel in the right, you can see it is almost 93% recycled whereas 6% is reused and only 1% goes to the landfill. Coming to the concrete, you see 75% is downcycled whereas 20% is recycled and 5% goes to landfill. Considering timber, almost 58% goes to landfill.

So, what we learned from the past generation, we had an abundance of resources wherein 100% of raw materials were used from the natural resources, we made the buildings and then new buildings were formed also in the same way whereas the old buildings went off mostly to the landfill and we never know how much of the material were reused, recycled, or recovered because that was not the main criteria in the past because we had enormous of the raw materials. And in the present generation, when we feel the heat of so much of natural resources has been used already in the past generation and we need the sustainability to be maintained for our future generation to have their own resources, we are emphasizing so much on the secondary raw material usage which should be a minimum of 70% according to EU regulations, EU waste framework directive which is coined in 2008. However, 30% of the raw materials are normally recycled into the new buildings in the present situation. So, what we see as our future is 96% of circularity in the construction industry. So, the European environmental agency has estimated 96% of at least the mineral residues from the construction and demolition waste can be recycled.

So, is the future generation able to keep the present material flow considering also the need for infrastructure and the increasing industrialization? This is a big question, do we have the enough resources for the future? So, in that, I would like to give an overview of the situation of construction and demolition waste in Finland. Finland is a country with a population which is roughly around the same amount as the city of Chennai. So, if you consider the construction and demolition activities in this country, you see a total waste of 13.5 to 15.5 metric tonnes were generated every year out of which 15% is construction waste, 27% is demolition waste, and the major portion 58% goes to renovation waste.

Here, we should also see the point that more than demolition or construction, there is a lot of renovation happening. So, it is not necessarily all the time we should focus on recycling or reusing, we can also think about reducing the use of raw materials that is by extending the life of the buildings or the construction materials, we can also try to increase the life of these building materials that wherein we can reduce the amount of material that has to be used in the future. If you see the situation of recovering the minerals from construction and demolition waste in Finland, it improved over the years. When you consider 10 years before, in 2013, you still had almost half a million tonnes of construction and demolition waste going to the landfill. But when you consider in recent years, most of them were used in energy recovery or material recovery and it seems that none of it goes to the landfill as such.

So, there is continuous improvement in the processing method and also the emphasis on nothing goes to the landfill has been created over the years. And here in this lecture, we are emphasizing so much on concrete, though we have shown also there are other construction materials like wood and steel. Why? Because you can see the graph over here to the left, you see there is an increase in the population over past years, which is showing the world population. And there is also some increase in the amount of steel that has been consumed or produced in these years. But it also shows the consumption or production of cement, which exceptionally or exponentially increased from 1990 to 2020.

And it still grows in the same way or follows the same trend also in the recent years. The global cement production is 3.8 billion tonnes per year. And normally the concrete has just 15% of cement. And the remaining material is made of rocks and sand.

So, if you consider the concrete has sand gravels or the rocks and also the cement materials. And when we do think about demolishing this material, you will also is throwing up all these resources into garbage. This is why we are today talking about recycling concrete. Now, I have also given a brief introduction, what are the ingredients that goes into the concrete like the sand, gravel, or the rock and also the cement. So, when you talk about recycling the concrete, you will also end up with these materials, but in a bit different physical, chemical, and mineralogical form because of the reaction it would have underwent during the formation of concrete material or as it has undergone some wear and tear over years.

Ideally, we should expect the same material that we put inside this concrete as a raw material that is coarse aggregate fractions, which are mostly bigger than 4.75 mm in size, finer aggregate fraction which

is less than 4.75 mm, whereas powder fraction which is less than 75 micrometre. Now, we are clear about the type of material that we could expect when we are recycling concrete from construction and demolition activities. So, let us go one by one.

First, let us look into the aggregate fraction. So, like I explained in the previous slides, we have the sand and the coarser material that is rocks or the gravel that go into the concrete, which we call it as aggregate. Normally, these days when you crush these recycled concrete, the coarser fraction or the aggregate goes to an application like road sub-base or earth construction, which is nothing but in backfill application in several places. It could be like an embankment or other such applications. So, this is why we call it as downcycling because for these applications, you do not need that quality of aggregate that we have already used in the concrete.

We can use several other materials for these backfill application or the road sub-base. So, the intention these days is to upcycle this material to be back into the concrete production. But why not this is possible at the moment? Why the direct utilization of these materials which is actually coming from concrete is not going back into the concrete? It is because of reasons like the quality of this aggregate is spoiled in the process of making the concrete in the initial stage. For example, you are mixing these stones with the cement fraction and when you are crushing it back to the stones, the cement fraction is still left over there. So, you see there is old matter surrounding these stones which is hindering or which is making a layer surrounding the stones which is a weak zone creating issues for the new concrete.

So, this also causes strength and durability problems for the new concrete. Hence, the value of these aggregates are reduced and mostly used in downcycling or low-value applications. So now we understand that this old mortar is creating issues for these concrete aggregates to be used in the production of new concrete materials. There are several treatment methods proposed in literature like through mechanical treatment where you abrade this mortar layer and remove that old mortar creating better aggregates or the stones. And you can also do thermal treatment wherein you are applying high temperature where your thermal expansion of the cement paste compared to the stone material is different which creates a thermal shock and the mortar layer cracks and falls off compared to the stone that stays intact at that temperature.

And it also then helps in removing this old mortar from the surface. And there are chemical treatment where you use acids to remove this old mortar layer. There are also some technologies in recent days like electrodynamic methods, hydraulic pressure using water those things are applied to remove the old mortar from these surfaces of the aggregate. Here is one example which is a mechanical treatment wherein you can see the concrete rubble goes to the jaw crusher where this is crushed into small pieces of aggregates and then there is magnetic separator to separate the iron scraps that could be in the demolition waste and then it goes to the mechanical scrubbing action which is mechanical treatment to remove the old mortar and there goes to the screen where it can be separated into finer and coarser fractions. Wherein this is a typical processing method for the recycling concrete to produce aggregates.

So there are also different crushers which could be used to modify the shape of the aggregate or the quality of the aggregate like impact crusher or eccentric shaft rotor and such crusher technologies that could also help in improving the material. In thermal treatment in addition to this crushing operation you can also see that there is a rotary cling which is heated at 700 degrees which helps in removing this mortar material and by impact of the aggregates within itself like the different aggregates or the aggregates impact created by heating each other helps in removing this old mortar and then this goes to the screen and later saved into different size fractions wherein you now see this new fraction that comes up which is powder fraction which is less than 75 micrometre most of the times. So this is one such method so heating and rubbing which is I said like impact created by rubbing each other and then heating and shorting. So these are some of the methods where you can use to treat the aggregate to remove the mortar. So this is some examples that helps you understand that it is possible to further improve the aggregate quality by treating them in different ways.

So this aggregates can be again used in the new concrete production. However, we now know that these aggregates which are coarser and finer fraction can be used back into the concrete production. There are also this other fraction which is less than 75 micrometre which is powder which is expected to be a cement powder but then during the course of action of crushing the concrete you may also expect some of the aggregate fraction is powdered and also mixed with this fraction of less than 75 micrometre. Moreover, these are hydrated cement so these are not the actual cement that we mixed it has been hydrated and it is different in chemical and mineralogical composition at this point. So we cannot directly use them as a replacement for cement material.

So what we do with this concrete fines this is the main focus of this lecture. Like I said in the content slide we will be focusing on both high-value and high-volume application. In the high-value application I will go only with the literature studies because there are like numerous work happened in this direction. In high-volume application I will show some of the results from my lab where we try to develop some application to use high volume of this material. In high-value application the main focus is to use this material as cement replacement because these are technically cementitious materials which are hydrated.

So supplementary cementitious material is one application that could be a possibility for high value. So like I said this is hydrated so we have to find a way to make it reactive. So there are several treatment methods already used for other type of material like mechanochemical activation, thermal treatment and carbonation activation. In mechanochemical activation what you do is like you mill this material and make it into a much finer fraction which also activates the material because you are actually distracting the crystal structure or the mineralogy of the material making it amorphous. So with the increase in amorphous content this material also becomes reactive.

So this is the concept behind the mechanochemical activation. So here you see that you have this recycled concrete powder which is again milled using ball mill and it is said that the reactivity is improving by reducing the size of this material which is expected to be because of distracting the crystalline structure of the products hydrated products from the old cement. And however when you see that when this is replaced with the Portland cement in this mixes there is a decrease in the compressive strength. So still it is not equivalent in performance compared to the actual cement that we are using in recent days. Next comes chemical treatment wherein they are trying to use tannic acid.

It is not necessarily tannic acid but in this case in this study tannic acid has been used where it is said to produce some submicron particles of reaction products that provides nucleation sites. So it produces more of the reaction products and fill the pores thereby improving the properties of the materials. This is one study on chemical treatment. When you consider thermal treatment what we are trying to do is to dehydrate those reaction products. When you dehydrate we expect that it goes back to its original form of the cement so it becomes reactive.

So first we can also assume that this reduces the particle size by physical disintegration when you thermally treat it to 400 to

500 degrees or even more than that. So it will eliminate the water, evaporable water and the bound water and then it will dehydrate ettringite, gypsum, your CSH and aluminate hydrates and at certain case it also forms lime to portlandite and then dihydroxylation also happens in this stage around 600 degrees. So these are thermal activation by which we can dehydrate and produce a reactive fine fraction which can be used as a supplementary cement. Another interesting way to make this material reactive is by carbonating them. So there are several ways of carbonation that can be used like wet carbonation where you mix it in a wet condition or semi-dry and dry condition and the efficiency of carbonation is said to be different in different conditions or humidity temperature you can apply it to the material.

Temperature you can apply together with the carbonation that also affects the efficiency of your carbonation. The final result that has been seen is the calcium hydroxide that is left out in your hydrated cement turns into calcium carbonate that's one thing. Another thing that was observed in the studies is your silicon alumina becomes reactive gel that helps in improving the reactivity of these carbonated recycled concrete fines which then can be easily used as a supplementary cement.