Advanced Topics in Science and Technology of Concrete

Prof. Alexandar S. Brand
Department of Civil & Environmental Engineering
Virginia Tech, Blacksburg

Week - 03
Lecture - 12

Effect of moisture condition on the microstructure and design of RCA concrete - Part 1

Hello everyone, and welcome to this presentation on the effect of moisture condition on the microstructure and design of concrete with recycled concrete aggregates. I'm Alexander Brand from Virginia Tech, and I'll be talking today about some of the work that we've been doing on assessing how the moisture condition of these aggregates really can dramatically impact the microstructure and perhaps how we may consider design considerations accordingly.

So what is recycled concrete aggregate or RCA, as it will be defined throughout this presentation? Some people may have different definitions. In my view, I will call RCA basically a cleaned version of construction demolition waste, right? So construction demolition waste can contain a lot of additional materials such as, you know, brick, mortar, tile, glass, in addition to concrete, right? So when it's a stockpile of all these mixed materials, we may consider that CDW, construction demolition waste, or in my view, a cleaned version of that where we're only looking at concrete. That, for my purposes in this presentation, will be what RCA is. So pretty much, your aggregates now, again for this presentation, are only concrete.

There are no sort of deleterious or additional materials in that stockpile, right? So of course, here are just some images of an RCA stockpile. Right on the right, you'll see a lot of the steel, right? So, you know, as you're crushing the concrete, there'll usually be a magnetic separator to pull out the steel, just in additional ways to sort of clean up that material and only pull out the concrete. So in the U.S., the government doesn't necessarily keep track of pure RCA, but they do have the history of CDW in the U.S. This is through the EPA, the Environmental Protection Agency of the U.S. government. So you can see in 2018, roughly 24% of all CDW was landfilled. These are sort of the latest statistics, but 76% was used in other applications, right? Predominantly in aggregates, right? Now of course, here we're talking about CDW. In the case of the EPA, how they'll define CDW is basically the demolition and consolidation of steel, wood, drywall, brick, asphalt shingles, concrete, and asphalt pavement. So sort of all of it combined here. So again, concrete is just one part of this.

Now, some of the numbers that you can find just for concrete in the U.S. it's about 140 million tons and this is now what's recycled, right? So we're not really even keeping track here of what has been landfilled, so we don't necessarily have those numbers. But you can see here each year an estimated 140 million tons of concrete does get recycled. The vast majority of it does get used as aggregate base. You can see where we have very little other use, right? Only 6% of that is used as an aggregate in concrete. It's a fairly low number. I would like to see that number go up of course, then of course also seeing it as an aggregate in asphalt concrete as well, in addition to fill and riprap. So RCA I would say, you know, is under some consideration in parts of the U.S. Is it important everywhere? Probably not necessarily, but certain regions of the U.S. have a significant issue with access to quality aggregates. So this is an image from the USGS, the US Geological Survey, and these highlighted areas on the map of the contiguous U.S. are areas where high-quality aggregates are not as readily available, right? So they may be perhaps a lower quality or deleterious aggregate, marginal aggregates, maybe it's highly porous, right? So some other issue. So the question in those regions is what do you do, right? How do you accommodate the need for high-quality aggregates for whatever application that is, whether that's bases, aggregate in concrete, aggregate in asphalt. So of course one option is to ship it in from other regions, which of course starts to become fairly prohibitively expensive. So perhaps it's a bigger consideration of reusing more of what we do have readily available, and that would be things like recycled aggregates, right? So of course, this is a problem that is not limited to just the United States. You'll find this in a number of countries around the world where high-quality aggregate is a premium, particularly sand is becoming quite an issue in certain parts of the world, but it's the same with coarse aggregates as well.

Okay, now a number of reports from the American Society of Civil Engineers, ASCE, does publish the report card for the American infrastructure. You can find that online. Basically, what that report card shows is the US has an aging infrastructure that requires significant repair and rehabilitation, something like trillions of dollars of investment to get a report of an A, right, in the US for the infrastructure. And the numbers are for aggregates to meet that goal, right, to invest and rehabilitate and repair all of America's infrastructure, we need a 70% increase in area production to do that, right? So again, therein lies the problem where if you

look at this map and you see that there are regions where quality aggregates are not necessarily readily available, if we need 70% more aggregates in those regions, again what is there to be done?
If you look at the density for the oven dry in the top left, you know, ranging from 2,000 to almost 2,700 kilograms per cubic meter, right? Again, some of this variability has to deal with just the grade of that concrete and the formulation of the concrete, the age of it. Is it damaged? Does it have micro cracking, right? All of these things will affect that performance. Also things like percent of aggregate versus adhered mortar in a given RCA particle, right? There can be quite a bit of variability here. And in that same study, they, you know, showed that some things can have a correlation, right? So sort of the lower the density of the RCA, perhaps the higher porosity is, the greater water absorption it can be. All right, so that's where you can see as you move left along the x-axis, right, we move vertically along the y-axis, so you know lower density RCA tends to correlate with higher absorption.

Again, that probably mostly has to do with with things like porosity, right? But still there's quite a bit of scatter here, right? So you can't necessarily use one metric to predict the other. All right, here's another study that was useful. I just put this in here just to show you the range of some of these values. This was a study where they tried to use machine learning to predict mechanical properties of concrete with RCA, right? So I'm not going to that study at all. I just wanted to show this slide, this table from that study, right? So they collected 607 unique data sets from a total of 87 publications, right? And if we just look at some of these line items, whoops, laser pointer, there we go, right? So if we just look at the density of the RCA, right, kind of the very similar variability that we saw in that previous study two slides ago, but water absorption is a much larger variability than what we saw in the in the previous slide.

I heard the previous slide was something like 0.5 up to 10. Here they're showing up to you know 12.7. You know in my research we've definitely found RCAs with with moisture absorption or water absorption capacities as high as 12 percent, which is you know fairly staggeringly high, right? Oh then of course you know now they're looking at different mixture proportions, but I want to also show the bottom here, right, compressive strength.

So this again is just the range of the data from this total set of 607 data sets, right? And so that you can see that they found research for compressive strength ranging from 6 MPa all the way to 104 MPa, right? All right again that's a fairly staggeringly large distribution, right? And so the question is, right, is all of that variability just due to, or sorry, is that range in strength only due to the mixture proportioning, or what role does the properties of the RCA play into that, right? There's just some things to note here. So really what I want to focus on today and what the main focus of most of our work has been is looking at the the moisture condition of the RCA and understanding how that affects the microstructure and the properties of your concrete, okay? You know so again the the moisture absorption capacity can be as high as 10 percent. The previous slide up to 12.7 percent. We've done studies up to 12 percent, right? These are dramatically, dramatically higher than natural coarse aggregates, which tend to be right around less than two percent.

Again there's of course different variability just due to the lithology of of the aggregate, right? But you know granites can be maybe as low as half a percent absorption. You might have some porous limestones that will be much higher, right? So of course there is variability in natural areas as well, but it appears to be not nearly as dramatic as the variability in RCA, okay? So just just to go through through some definitions here for these different moisture conditions as we'll be discussing in this presentation, all right? So this is just a classic textbook definition of of these moisture states, all right? So if you you have an arrogance, right? You're given area will have surface pores, it will have interior pores, right? It will have surface texture, right? You will have these surface pores that are permeable on the surface, all right? So if we have a completely dry dry aggregate, I'm going to be calling that oven dry through the rest of the presentation, right? So if you put your aggregate in the oven at 105 celsius for probably more than 24 hours, dry out all that moisture, you have no water in any of these permeable surface voids or pores, right? Interior pores, right? Those are we're going to assume those are are impermeable, all right? For at least the time frames that we're looking at for the surface absorption, right? So as those surface pores start to absorb moisture, right? We can have some condition where that you know that that pore is partially saturated but not fully saturated, such that if it is just sitting in the ambient environment, it may just absorb some moisture from the atmosphere, right? We can call that air dry. We then have a condition called saturated surface dry. That is where the pores are fully saturated, but the surface of the aggregate is not saturated. So there's just enough moisture in that aggregate to fill those voids, to fill those pores, and the aggregate is not going to absorb any more water into those pores, right? Then of course if it's oversaturated, now you have you know some water adsorbed to the surface, maybe as a fairly thick film.

For our purposes, for the next you know number of slides, we're going to be looking at this saturated surface dry condition, this oven dry condition, and then another condition in between that for our purposes is roughly 80% of the SSD condition, right? So roughly 80% of these surface pores are saturated or filled with water, okay? So why are we talking about this? Why is this important, right? It relates back to that absorption capacity, right? If that of course capacity can go as high as 10%, how is that going to affect our performance if the aggregate is in one of these different conditions, right? So you know let's think about an RCA that can absorb 10% of its weight in water. How is it going to affect the concrete if you add it in if it's completely dry, so oven dry, versus saturated surface dry? And that's really something that we're going to be looking at here. So one thing to think about along those lines is something known as the effective water cement ratio, right? So of course we have a design water cement ratio, right? Where we account for the moisture that the area will absorb, okay? So if our aggregate is at pure SSD condition, it is not absorbing any more water from the fresh concrete, right? And it's probably not giving any water as well, okay? So we're not adjusting our mixing water when we have SSD, but if we have an oven dry condition, we are going to adjust the mixing water to add additional water knowing that the RCA at oven dry is going to absorb, you know, x percent of water from the fresh concrete.

However, this process can be slow, all right? So here's just one example from one study where Butler looked at an RCA that had a 7.8% absorption capacity, and that took eight hours to reach full saturation, or SSD, right? So what you should consider here, right, is if we do have an oven dry RCA, and let's assume it's going to absorb let's say 10% of water, so we add additional mixing water as we're mixing the concrete, as we're batching the concrete, that additional mixing water is not immediately getting absorbed by the RCA, not by any means, right? If it's taking multiple hours to reach full saturation, and our setting time is perhaps only a few hours, we may now have a problem, okay? So we discussed this known as the effective water cement ratio, because now it's going to be different than the design water cement ratio at least locally, right? So that oven dry aggregate is not uniformly pulling in water from the entire mix, right? You still have to wait for the water to sort of diffuse through, so locally around your RCA is now where you're going to have a different water cement ratio, all right? So now we have the risk of possibly having a gradient, let's say, of water cement ratio as a function of distance from that RCA, okay? And how is this going to affect our properties, right, and microstructure? This is exactly what we're going to be talking about in the coming slides.

So this is just another important consideration from another study, and this is a nice showcase of how these different moisture conditions will affect just your workability. Okay, so here's a study where in this case I'm showing the data for the mix with 100% RCA. Of course RCA, they blended two different RCAs, the absorption capacity was, you know, around 6 to 7.6%, and they looked at an air dry, oven dry, and SSD condition, and so what you should note here, right, is that the oven dry for freshly mixed concrete, oven dry had the highest slump, which is no surprise because we've added that additional mixing water, right? So our effective water cement ratio now is high, so no surprise we have a higher slump, but of course as that oven dry aggregate starts absorbing more and more water, you can see that we start to lose slump fairly quickly, right? So oven dry has the fastest slump loss, but the highest initial slump, right? And that can become a big issue if, let's say, you have a long haul to your construction site, right? These are things that you should probably, may need to consider.

All right, so the remainder of this presentation will pretty much consider recycled concrete for that application. My research group does look into a number of different recycled aggregates as well, but for our purposes today, we'll just be talking about RCA. So here we have a nice micrograph of a virgin aggregate that's either a limestone or a dolomite compared to, you know, an aggregate from recycled concrete, right? If we put on the laser pointer here, there we go. So of course, you can see the, you know, that this limestone or this dolomite is fairly homogeneous, right? Of course, there's some pores, there's some grains. Contrast that now to the RCA, very different, right? We'll see, of course, pieces of aggregate. So here we have maybe part of a coarse aggregate, maybe these were fine aggregates, right? Then, of course, you'll see all of this adhered mortar as well, right? We'll see that in the next slide as well. Here's another fairly nice one, right, where we have again part of an aggregate, right? Maybe this was a larger coarse aggregate that during the crushing process broke off, right? Or maybe this was all adhered mortar here beforehand. It's kind of impossible to know at this point, but of course, you'll also see pores. So it looks like this concrete was air-entrained, which would make sense from where this RCA was sourced from. They use air entrainment quite frequently, but of course, you'll also see cracking, right? So is that cracking existent from the original concrete? Is it there due to the crushing process, or is there some other issue at play? But again, what you want to see here is just there is this residual adhered mortar on the RCA, which you will commonly hear referred to throughout this presentation.

So why should we be considering using RCA in this case as a concrete aggregate, right? So kind of rid of what we've been talking about there. There is some question of material availability. Again, high-quality aggregates are not readily available all over the U.S. or

even all over the world. Also, the question of sustainability, right, as you do, you know, move to more urban environments, as you produce more construction demolition waste, what to do with that material, right? So of course, you can just landfill it, but that's not always economically viable, and there's not always land space to do that, right? There's also questions of economics and cost, right? Again, if we're thinking of an urban area, maybe it's a lot more expensive to ship that material out of a city to landfill it somewhere, right? Or maybe just in general it's cheaper to use RCA than, let's say, shipping in a high-quality area from another region. Performance is going to be the question here. We're going to be talking about that in this presentation a bit. You will have studies that show that RCA can meet equivalent performance to virgin or natural aggregates. Other studies may not show that, right? So this is going to be sort of a question we'll talk about a little bit in this presentation.

All right, one of the driving factors as to why we may or may not have equivalent performance to natural aggregates is the material variability, all right? If you already just want to consider the vast array of different formulations of concrete that can be used, even in the same region, right? So comparing the concrete we would produce for a sidewalk versus a pavement versus a high-performance bridge deck next to the seawater, right? All completely different formulations, different design lives, different risks of damage, right? And deleterious performance, durability concerns, right? So you know when you're collecting RCA, unless you know where it came from and what the condition of that parent concrete was, you may not necessarily know if it has chlorides in it, for instance, which could be a concern for corrosion, of course, right? Or maybe it was a concrete damaged by alkali silica reaction, right? Has that reaction stopped or is that going to continue? And how would that affect your new concrete? So you know lots of variability here we have to think about, right? So kind of for our purposes today we're going to be assuming that the aggregate that we're using, well at least in the studies that I'll be showing here, were all let's say higher quality RCA, right? We knew where the material came from, it wasn't necessarily damaged, didn't have any durability concerns. We'll talk about that in a few minutes here, right? So again, risk contamination, we've kind of already talked about that.

We don't necessarily know what the long-term performance of concrete with RCA will be, right? And some of that has to do with the material availability, right? So of course there are plenty of existing structures, you know, that have been around for decades that have successfully used RCA and are still performing, right? But that's, you know, not necessarily guaranteed in the long term, okay? Particularly if we have a highly variable material, right? Again if it's damaged or contaminated, these are all concerns for what the long-term performance would be. Contrast that to natural area concrete, right? That we've been using for, you know, decades and decades, right? So if you have a concrete producer who has produced producing the exact same concrete mix for the past 30 years and never had a problem, right? It's a question of why change it, right? If we know this is a successful mix with this natural aggregate, now we change up that aggregate, it's now a question of, you know, will that long-term performance be guaranteed? Another big concern here is it may not be allowed, right? So there could still be regulatory issues, you know, and this is a problem in certain states in the U.S. and probably certain countries around the world as well. That concrete, or sorry, RCA may not be allowed to be used in certain applications, right? Some of that has to do with some of these questions of variability and performance, but that is something to always be considered as well is if you can actually even use the RCA for a given project.

And then of course, as I already said, with an advantage, right, RCA can have equivalent performance to natural area concrete, but of course a number of studies have also shown that it may not, right? So how do you plan for that, right? So just look at some of the variability here. This was a nice review article. You can see the reference there on the side that looked at quite a number of references in the literature and basically plotted that the properties of various course RCAs reported in the literature, and then you can see that they tried to fit some normal distributions to this. So if we already just look at this variability, let's just look at water absorption there in the bottom left-hand corner, right, ranging from maybe something like half a percent all the way up to 10 percent water absorption. That's a fairly large distribution, right? Same thing with the density.

If you look at the density for the oven dry, all right, in the top left, you know, ranging from 2,000 to almost 2,700 kilograms per cubic meter, right? Again, some of this variability has to deal with just the grade of that concrete and the formulation of the concrete, the age of it. Is it damaged? Does it have micro cracking, right? All of these things will affect that performance. Also things like, you know, percent of aggregate versus adhered mortar in a given RCA particle, right? There can be quite a bit of variability here. And in that same study, they, you know, showed that some things can have a correlation, right? So sort of the lower the density of the RCA, perhaps the higher porosity is, the greater water absorption it can be. All right, so that's where you can see as you move left along the x-axis, right, we move vertically along the y-axis, so you know lower density RCA tends to correlate with higher absorption.

Again, that probably mostly has to do with with things like porosity, right? But still there's quite a bit of scatter here, right? So you can't necessarily use one metric to predict the other. All right, here's another study that was useful. I just put this in here just to show you the range of some of these values. This was a study where they tried to use machine learning to predict mechanical properties of concrete with RCA, right? So I'm not going to that study at all. I just wanted to show this slide, this table from that study, right? So they collected 607 unique data sets from a total of 87 publications, right? And if we just look at some of these line items, whoops, laser pointer, there we go, right? So if we just look at the density of the RCA, right, kind of the very similar variability that we saw in that previous study two slides ago, but water absorption is a much larger variability than what we saw in the in the previous slide.

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So this again is just the range of the data from this total set of 607 data sets, right? And so that you can see that they found research for compressive strength ranging from 6 MPa all the way to 104 MPa, right? All right again that's a fairly staggeringly large distribution, right? And so the question is, right, is all of that variability just due to, or sorry, is that range in strength only due to the mixture proportioning, or what role does the properties of the RCA play into that, right? There's just some things to note here. So really what I want to focus on today and what the main focus of most of our work has been is looking at the the moisture condition of the RCA and understanding how that affects the microstructure and the properties of your concrete, okay? You know so again the the moisture absorption capacity can be as high as 10 percent. The previous slide up to 12.7 percent. We've done studies up to 12 percent, right? These are dramatically, dramatically higher than natural coarse aggregates, which tend to be right around less than two percent.

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