Shape Deformities in Recycled Concrete as a Substitute Aggregate in Concrete

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Concrete is a universal material that is used widely across the construction industry. Within a standard concrete mix, a fine aggregate and a coarse aggregate are added to the mix design to help with solidity and compressive strength in the mixture. The admixtures, additives, slump, and mix ratios will differ based on the compressive strength you're trying to attain. This paper directly reflects the results of the differences between shapes in recycled concrete used as a coarse aggregate substitute in concrete mixes. As the construction industry grows, so does outreach towards sustainability and reusing materials anywhere the industry can. Testing concrete re-batched in a new mix is sustainable but seemingly broad. The results found in this paper will shed light on the compressive strengths of re-batched concrete but centralize the focus on the differences in rounded versus jagged pieces. The research found will educate the industry on how applicable recycled jagged concrete used as coarse aggregate could be and help continue more extensive research by industry professionals to allow for potential applications in the real world.

Keywords: Concrete, Recyclable, Coarse Aggregate, Rounded, Jagged

Introduction

The shape within aggregates can be an outlying factor when considering the overall make-up of the compressive strength within a mixture. Identifying where the compressive make-up comes from in a mix-design is beyond the sizing but more focused on ratios, shapes, and material thrown into the batch. With so much concrete being produced annually, batch plants can begin shifting their focus toward sustainability within their mixes rather than constantly pumping out new material to be used and trashed later on. As our world begins to shine on sustainability within a built environment and focuses on an eco-friendlier space, the reduction of material usage and increase in recycling is ideal for the construction industry. Now, the big question of interest when considering this topic is, of course – will recycled concrete material still hold an operable compressive strength?

As you can imagine, the construction industry uses a lot of different materials throughout specific projects and most of these materials aren't reused once the lifespan of the building is up. To put this into retrospect, the construction industry is responsible for 50% of natural raw materials used (Bradford, 2015.). An example of a lack of renewable materials would be a wood-framed building that stands tall for 100 years (if it makes it that long), the new owner then decides it's time to demo and remodel – there is no chance the owner is going to reuse all that lumber to re-frame the new building. Now yes, lumber is a very specific and small portion of material used in the construction industry. But the point being made is what if we could take specific materials heavily used in the construction industry and reuse them? What if we could take the 100-year-old building and recycle it in ways that would hold its structural integrity all while saving money? Concrete is one of the few materials that will allow us to do that. Concrete demolition being as common as it is, it raises the question of why the construction industry hasn't made more of an effort to try and implement a system where it can be reused. With aggregate being the largest portion of a concrete mix, it wouldn't take a construction genius to look towards the idea of replacing the aggregate with what was originally a concrete slab or foundation. Though prior studies show the replaced concrete aggregate would not hold the same compressive strength as true coarse aggregate, my studies conducted on the shape and makeup of the concrete mix give insight into what could potentially be a breakthrough in the industry.

The studies conducted below show a compare and contrast between rounded and jagged concrete aggregate recycled back into a batch. The research conducted shows that if concrete were broken down into jagged pieces and thrown back into a mix – replacing the coarse aggregate ratio, the mix design would still hold an operable compressive strength and could ultimately be re-poured on a construction site. However, the same statement does not stand true for rounded pieces thrown back into a mix. The theory behind the results conducted is that the more jagged pieces allow the rest of the "mud" to bind to something when under compression. Whereas the more rounded pieces have no rigidity for the "mud" to bind or hold against, which ultimately forces the concrete to break a lot easier when under compression.

Literature Review

During my literature review, my primary focus was on size, shape, and sustainability within the material. I was able to break each prior study down based on exactly that. Being able to identify prior studies that were similar to mine was pretty easy, the sources provided below allowed me to specifically base my research around them. Though they are not the same as mine, the characteristics and points provided in the literature gave me insight into what to expect from my study. The different studies on sizes, shapes, makeup and sustainability qualities in each of these papers gave my study exactly what it needed to attain the correct information and provide results for future research.

Aggregate Size

The standard concrete mix contains the same ingredients: water, cement, fine aggregate, coarse aggregate, and admixtures. The ratios and percentages of these mixtures will vary from mix to mix but stay relatively similar. However, if we begin changing the sizes of the granular composition, that is when we will begin seeing efficiency differences within the concrete when put under compression. Though we may see differences, there is typically a purpose behind why the aggregate sizing may be bigger or smaller, the "standard" aggregate size we see in mixes is 1" in diameter. The aggregates and basic materials used in a mix haven't changed since originally used. The study behind size differences in aggregates ranging from 1"-3" in diameter gives us some insight into the overall makeup and how shape could then play a role in the overall compressive strength. (Tsiskreli, 1970.)

Sustainable Additives

Recycled material is something that is becoming progressively more common within the construction industry. Many studies have been conducted on specific materials put into a concrete mix to serve as a "filler" whilst allowing the concrete to still hold an operable compressive strength. Adding plastics and glass that hurt the environment will allow positive impacts on trash pollution in our world while still supplying a concrete product that holds the necessary strength for smaller projects. This, however, does not mean that we should add these products to every concrete mix, it just gives useful insight that shows we can take recyclable materials and re-batch them in a way that still allows the concrete to serve a purpose. Though these "sustainable" mixes may not be used for high compressive projects, like columns, concrete decks, etc. they can be used for everyday pours such as curbs, sidewalks, benches, and smaller projects. (Lynch, 2017.)

Aggregate Shape

Particle shape characteristics of the aggregate affect the workability, strength, and durability of the concrete produced. The shape of the aggregate you use will determine the properties within the concrete in both its fresh and hardened states. In this study, the elongated aggregate was tested against flaky aggregate to see which held a better compressive strength. These studies confirm that the shape of aggregate used in a concrete mix is a very important parameter that helps determine the overall characteristics/ properties of a specified mix. Flaky aggregate showed to hold a higher compressive strength than the elongated pieces due to the rigidity of the particles having more friction to bind to the mix. The aggregates not only make concrete more economical by occupying more volume but also ensure stability and increase durability. (Oluwasola, E. Afolayan, A. Ipindola, O., Popoola, M., and Oginni, A., 2020.)

Greek RCA

Greek recycled concrete aggregate (RCA) is a way Greece has implemented the recycling of concrete, more specifically focusing on Greek specifications for recycled concrete used as aggregate. The findings in this study focus primarily on the general attempt to go "green" and develop more sustainable infrastructure during our time. The use of natural raw materials used in concrete (granite aggregate) is decreasing the availability of natural resources, which is almost always sub-graded. The purpose behind the Greek specifications of using RCA is to cut down on material usage and sustainably use large volumes of concrete already constructed into something else, instead of wasting it. Greece is known for its large, old buildings that are well past their lifespan. Demolishing these buildings would only create more unnecessary demolition waste. This study focuses on different types of recycled concrete used as aggregate (masonry, concrete, and recycled aggregate) and how they are re-introduced into new mixes. Though the shape is not a topic of concern for this study, it does allow me to gain knowledge on the possibilities behind recycled concrete like material put back into a concrete mix. (Oikonomou, 2005.)

Methodology

To first test my hypothesis, I researched different ideas on how to use recycled concrete as a replacement for aggregate within a concrete mix. I found that the study of broken down concrete re-batched in a mix has been conducted, but nowhere did I find a study on how the shape and makeup of the recycled concrete played a role in the overall compressive strength of the new batch.

At the beginning of this study, I was anxious that the shape of the new "aggregate" wasn't going to play a role in the compressive strength of the new mix and that all batches would hold similar PSI during their respective tests. Though I was anxious, I was almost certain that my hypothesis on rigidity within the aggregate would ultimately add friction and help with "binding" to the rest of the mix. As shown in the results in Table 1, my hypothesis seems to be correct. The jagged pieces added to the mix show a much stronger compressive strength than the rounded pieces throughout the 7–28-day tests.

As written (Lynch, 2017.), "*Recyclable Waste Material as Substitute Aggregate in Concrete*" – adding, replacing, and manipulating concrete with materials that may contribute to sustainability within the industry creates a gateway for potential findings thought to be undiscoverable. For my study, I wanted to conduct something similar to this paper but more specifically focus on sustainability within concrete instead of other materials. After I realized what I wanted to do for my senior project, I began reaching out to different professors seeking permission to access the concrete lab. Once permission was gained, it was time to start separating the broken-up concrete into its respective shapes. Broken-down shapes can be seen in Image 1 below.

Round **Both** **Jagged**

Image 1. Discrepancies of “Jagged” versus “Rounded” Recycled Concrete Aggregate.

There was a lot of planning, coordinating, and physical work that went into the preparation of being able to successfully mix and batch all three different types of concrete. The three types of concrete that needed to be mixed were a standard mix with the jagged pieces replacing the standard coarse aggregate, a mix with the rounded pieces replacing the coarse aggregate, and a control group with the standard coarse aggregate. All weights and ratios for each group can be seen in Table 1 listed below.

After I managed to separate both aggregate types into their buckets, I weighed them to make sure I had enough material to successfully replace the standard coarse aggregate (90 lb. for each group). I then weighed out all the rest of my additives and began mixing – weights shown in Table 1. Perfecting the consistency of the concrete in the drum was the most challenging part. You will see in Table 1 that the weight of my water differs in all the mixes. This was my fault, in the first batch, the drum was not lowered enough so to get the concrete off the back of the drum I sprayed it down with extra water. Thus, resulting in a higher water ratio which could have been a small factor in the overall compressive strength of that mix. Once each mix was completed, I conducted a slump test and poured the rest of the mud into multiple 6”x12” concrete cylinders. Based on ASTM C39, I took a metal rod and rodded (compacted) the concrete inside of the cylinder to fill any potential voids or air pockets. Once everything in my cylinders was complete, I labeled each cylinder cap with a specific identification. “J” for Jagged, “R” for Rounded, and “CG” for the control group, along with the numbers 1-4 to show which week they were to be broken at over the 4-week (28-day) break span. I then submerged each cylinder into the water tub and let them sit until it was time to break them. Every week for the next 4 weeks I pulled the three different cylinders out of the tub and broke them in the concrete lab. My findings were accurate to what I had expected and desirable for future research.

Results and Data Analysis

As stated, this study was based on 3 different test groups. The first being 90 lb. of rounded concrete aggregate, the second was 90 lb. of jagged concrete aggregate, and the third was the control group with 90 lb. of standard coarse aggregate. The weight for fine aggregate and Portland cement remained the same, as shown below. Water content varied based on the three groups due to clumping and build-up on the bottom of the mixing drum. To test the consistency of the mixes, a slump test was conducted for each of the three studies using ASTM C1437 standards. To measure the slump, each batch is inserted into a conical mold put on a level surface and compacted with a steel rod at three different lifts (1/3 the size of the cone each time). Once the three lifts have been completed, the conical mold is removed and the height difference from the top of the cone to the top of the mix is recorded. Below you will find all of the results conducted during this study, including final compressive strengths for each of the three groups over the span of 28 days.

Fine (lb.)	**Coarse (Recycled) (lb.)**	**Cement (lb.)**	**Water (lb.)**
70	**90**	**40**	**20**

	PSI	SLUMP	NOTES
Round (7 Day)	**2428.4**	**6”**	**Added 6lb Water**
Round (14 Days)	**2517.1**	**6”**	^
Round (21 Days)	**2830.1**	**6”**	^
Round (28 Days)	**3112.4**	**6”**	^

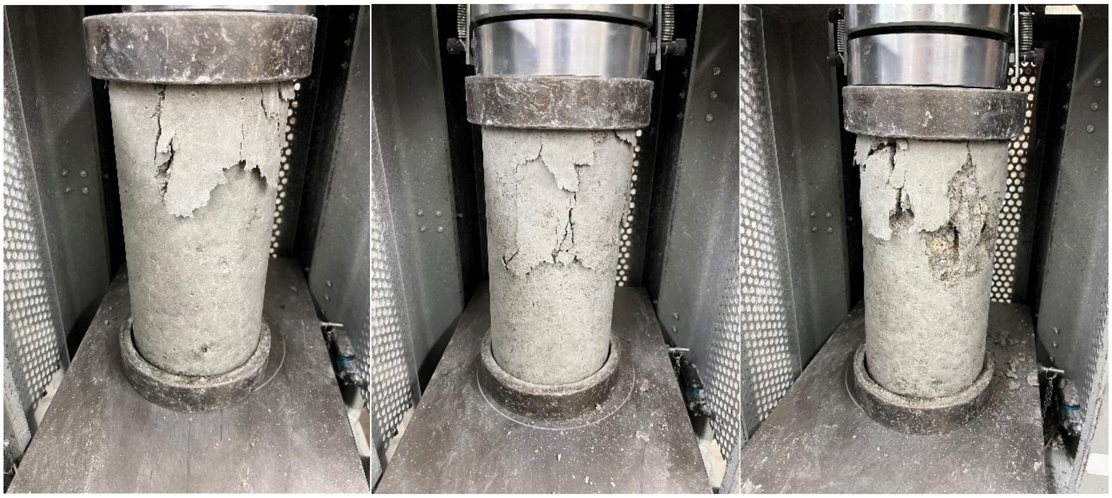
Jagged (7 Day)	**3129.3**	**4.5”**	**Added 4lb Water**
Jagged (14 Days)	**3393.5**	**4.5”**	^
Jagged (21 Days)	**3400.6**	**4.5”**	^
Jagged (28 Days)	**3452.6**	**4.5”**	^

Control G. (7 Day)	**3202.3**	**5”**	**Added 5lb Water**
Control G. (14 Days)	**3294.2**	**5”**	^
Control G. (21 Days)	**3634.7**	**5”**	^
Control G. (28 Days)	**4143.7**	**5”**	^

Table 1. Shows the mixes and their correlating results.

The final results were very comparable to what I expected. My theory leading up to testing my cylinders was that the rounded pieces had less friction or “rigidity” to them, so they weren’t going to bind as well with the rest of the mix. As stated in my literature review conducted by Oluwasola, E. 2020., I already had prior knowledge that rigidity and friction played a huge role in the binding of a mix. I don’t believe there was an anomaly in my test results and that the 4 different tests I conducted (7,14,21,28 Day) accurately represent each mixes overall strength. Assuming that there may have been a random anomaly in my test groups, each group still held a relatively strong compressive strength to be used somewhere in the construction industry. Yes, the rounded pieces only broke over 3000PSI one time, but that doesn’t mean this mix can’t be implemented in projects with specifications asking for 2500PSI or similar. That being said, the test results from all three groups were consistent with gradual strength increase throughout the weeks and prove that recycled concrete broken down into aggregate-like pieces, can be re-batched into a mix and used again.

The process for breaking each cylinder was quite simple. To properly record an accurate test on the concrete compression machine, the plastic which encapsulated the concrete was broken off. Once the concrete cylinder was safely removed, a top pad and a bottom pad were put onto each side. It is then put under the compression ring and the machine gets tared and set to zero. After everything was safely set and ready to go, it was on me to operate the machine and make sure the compression ring was dropped at a consistent rate. With help from the CAED shop personnel, we were able to keep the dial at a steady range which allowed us to get consistent numbers that properly reflect the compressive strength of each cylinder. This process was repeated once a week for 4 weeks until all results were captured. Pictures of cylinders once they reach failure can be seen below.



This senior project explored deliverables to enhance and contribute to sustainability within the construction industry whilst trying to test fundamentals to help improve the knowledge of a specific material. This experiment, along with the 12 different cylinders used, gave insight into what could someday be the future of our concrete/ construction industry. The finalized test results conclude that jagged concrete pieces used as the coarse aggregate hold a much more desirable compressive strength than that of the rounded concrete pieces added to the mix.

Conclusion

I chose this senior project because I have always been fascinated with concrete and all the different things you can do with it. The different strengths, uses, colors, additives, enhancements, etc. have always been incredibly interesting. Working with concrete during summer internships and taking CM 113 at Cal Poly only enhanced my desire to establish new knowledge of concrete and conduct research that'd benefit the construction industry. Being able to create a custom mix that holds standard compressive strength while sustainably giving back to the industry is ultimately what my desired topic came down to. After some research, it quickly came to me that shape and makeup seemed to be heavily researched, but nowhere did I find a study on shapes within the recycled concrete aggregate. It seemed like a detail that was incredibly interesting and could benefit the industry. As assumed, this "detail" was much more significant during its study than some may have originally thought.

The biggest lesson learned was that the size and shape of the aggregate within a mix do make a difference to its compressive strength. This research was primarily focused on the strength behind the makeup and shape of recycled concrete used as aggregate. Rather than focusing on the material of aggregate used, it can be said that the shape of the aggregate is truly the determining factor of the strength within the mix. As I look back at the test results over the 28 days, it is pretty interesting how the concrete within all 3 groups consistently saw growth in its strength as the days went on. The biggest thing that sticks out when reading the test results is how skewed the rounded particles test results were compared to the jagged and control groups results. After the first two tests, I wasn't sure if maybe the mix was just wrong, but after the last two rounds, it became apparent that the rounded shape just isn't meant to be used as aggregate in a concrete mix, it's just too weak. Now, the control group was the strongest group of the three, but it just comes to show how much of a difference some rigidity within the aggregate can make to the overall strength of a mix. There's a reason the granite coarse aggregate hasn't been replaced with anything over the years - because it does its job.

Though the standard mix with coarse aggregate was the strongest, the results conducted in the test show that jagged concrete pieces can be used as a replacement for the standard coarse aggregate and still hold a desirable compressive strength. Although this one test may not be enough evidence to convince a rubble yard to start selling their jagged pieces of broken concrete to batch plants for reuse, it is a step in the right direction. If that's one day the case, the first step towards implementing this in the real world would be to start on smaller projects. Sidewalks, benches, curbs, small walls, etc. would be a perfect starting point because none of these items will need to hold an unattainable compressive strength. After a few years of this implementation, the real-world feedback and tests will be a true testament to see if it is worth taking the next step and trying to replace all coarse aggregate with jagged pieces of recycled concrete. More extensive research by industry professionals would need to be conducted with this type of mix before building tilt-ups, bridges, and other large concrete/masonry buildings that require a much higher compressive strength.

Future Research

This senior project only conducted the comparative strength qualities between rounded pieces of concrete versus jagged pieces of concrete. In the future, it would be interesting to see if there is a material out there that's cheaper and stronger than concrete that can be broken down into an aggregate and put into a concrete batch. Instead of recycling concrete, what if future students conducted tests on steel particles that acted as the aggregate within a mix? I'd imagine if you grind down little pieces of steel, they will remain pretty jagged, comparable to my test – but may perform at a much higher strength value. Another idea for future research would be to conduct my exact test over again but be exact on how much water you add into the three different batches. As you will see in Table 1 above, I had to add water to each batch in different ways due to the way it was binding in the mixer. Since I had to add the most water to the rounded group, I am curious to see if that was the reason behind the significantly lower strength values.

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