A Study of Recycled Concrete Using Nondestructive Testing

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Abstract

Research was conducted on multiple concrete samples that contained recycled materials by using nondestructive testing methods. The purpose of the research was to determine if the use of recycled materials as a component of concrete maintains the strength of the concrete, which in turn can lead to the reduction of carbon emissions. A direct current resistance test was used to determine the probability of corrosion and a rebound hammer test was used to measure the hardness and compressive strength of the concrete samples. Four concrete samples were compared – a-controlled sample, a recycled aggregate sample, a sample containing fly ash, and a sample with both fly ash and recycled aggregate. The controlled sample with no recycled material showed the best results in regard to both corrosion and hardness, with values of 63.7 ohmmeters for corrosion and reaching an average rebound hammer R-value of 30.58. Samples containing fly ash showed high likeness of corrosion with lower strength compared to samples without fly ash. The sample containing recycled concrete in its mix showed higher likeness of corrosion compared to the controlled sample. The rebound hammer test has an error value of two R-values due to the reading scale present on the device. The Direct current test has an error value .05 volts due to the changing voltmeter readings while running the tests. In conclusion, the test demonstrated that concrete samples with fly ash were more likely to corrode and have less strength in their samples making them a questionable method for replacing current concrete mixes. The sample with recycled aggregate posed a liable solution as its strength level reached similar values to the currently used fly ash sample while also maintaining better values for corrosion. The recycled aggregate mix did not reach the same values of hardness and corrosion as the controlled sample but still reaches values that have potential to be used in the concrete industry to help reduce carbon emissions.

Introduction

Concrete has been used since the Roman times and continues to play a significant role in modern construction. Concrete is present in all urban environments in the United States and the majority of the world. It is used in many different building properties such as bridges, houses, roadways, and much more. It is also often used in small home improvement projects as well, adding to the amount of total usage. The industry is the second largest industry in the world, and according to Statista, the United States alone produces 88.5 million metric tons of concrete. On the global scale, China is the leader in concrete consumption. Globally, approximately 2.4 billion metric tons of concrete is used in a single year (2018). The concrete industry is a dominate industry, leading to alarming environmental impacts as well. This industry is one of the leading producers of carbon dioxide emissions. It is extremely problematic as the amount of concrete needed and used around the world is increasing.[3] An 80-pound bag of cement and aggregate mix can only produce around 0.6 cubic feet of concrete. The concrete industry which includes the creation of cement, mining for aggregate, and production and use of concrete itself, accounts for approximately 5% of the world's carbon dioxide released into the environment. [2]Within the industry, about 50% of the emissions come from the chemical process of making concrete and 40% from burning fuel for production and mining of aggregate. On top of this, concrete is not largely recycled, leaving the material waste to fill landfills as buildings or roadway are demolished for repaving or rebuilding. Recycling concrete and using recycled material in concrete poses a viable and environmentally sound solution to reducing the carbon footprint. Aggregate makes up a large percentage of concrete, ranging from 60%-75% of a concrete mix depending on the use of that mix. Aggregate is generally mined in rivers or by crushing quarry rocks or boulders which takes energy, resources, time, and money, while also adversely impacting the environment. By recycling old concrete, the need to mine for new materials is eliminated, and reduces the need for landfill space by recycling old concrete from demolitions. There is also the option to use fly ash. Fly ash is a byproduct of electrical power plants created from burning coal. Fly ash is normally stored in ponds as it contains mercury and cannot be placed in regular landfills. Fly ash can replace parts of cement, as it has the same bonding abilities as cement. This material has been used by the concrete industry increasingly in recent years. Fly ash is a cheap and efficient substitute to replace cement. Using fly ash benefits the coal industry, the environment, as well as the concrete industry. By using fly ash, the need for as much cement is reduced in the concrete mixes. By reducing the amount of cement used, the total carbon dioxide output from the concrete industry is subsequently reduced. To test these types of mixes, nondestructive tests were used to prevent the need to damage concrete samples while testing. This method provides information about already placed concrete to understand and measure its properties for safety. Nondestructive testing is extremely beneficial to construction companies as they could quickly run tests on a sample to tell if the concrete is up to standards. These tests can also tell other properties such as corrosion possibility and water permeability and estimated strength. It is often hard to tell the strength of concrete just by observation, and as of now, the most reliable method is the destructive test called the compressive strength test. This test often uses a hydraulic compressor that pushes down on the top of the concrete until it fractures or breaks. The measurement is then taken in megapascals to estimate the total strength of that concrete sample. This test can give the best value for the strength of concrete but cannot be used by industries who want to check concrete for safety after the concrete has been set. This is why nondestructive testing proves to be beneficial to many industries that work with concrete. By using these tests, we are able to determine much more than just the strength of concrete, as there are many important properties of concrete that also need to be assessed for safety and use. Using electrical tests and other nondestructive tests make it less burdensome for companies to run quick testing without damaging their products or structures. These nondestructive tests are being used to help us research multiple properties of concrete on one single sample. Being able to run different tests on the same sample helps eliminate the error of having to use different samples to run each test, another important benefit of nondestructive testing.

Cement mix procedure

Material	Sample one	Sample two	Sample three	Sample four
Aggregate	44.90%	42.30%	43.10%	42.60%
Cement	44.90%	44.30%	32.35%	31.90%
Fly Ash	0%	0%	10.70%	10.65%
Water	10.10%	15.30%	13.70%	14.70%

Figure 1: *Material Chart for the samples. Sample one: control; Sample two: recycled aggregate; Sample three: fly ash; Sample four: recycled aggregate and fly ash.*

Figure one displays the amount of material used in each sample by percentage. To make the concrete samples, ASTM C 387 quickrete concrete mix was used. This is a premade cement and aggregate mix that can be used for roadways, setting posts, small projects etc. and is often used by smaller companies or for someone to purchase and make their own concrete for projects. This is an extra strength quickrete mix that can cure to 4500 psi after a 28-day curing process. This mix was used for all of four of the samples. This research contained four samples, sample one is the controlled sample that added no recycled material to it or any other additives to the premade mix. Sample two is the sample with cement and recycled concrete as the aggregate. Sample three had parts of cement and parts of fly ash with no change or additives to the aggregate. Sample four contained both parts of fly ash, cement and recycled concrete as its aggregate. To make the samples, cylindrical tubes made of plastic with dimensions of 15.5 cm in length, with a diameter of 10 cm were used. These cylinders were put on top of wooden boards with the bottom edges sealed down with silicone to prevent any leakage from the base of the cylinders when pouring the wet cement. The concrete was measured by weight, then adding water to the quickrete to be mixed in a plastic bucket. calculating the weight based on the cubic footage that the cylinder took up (0.043 cubic feet). 9 pounds of the mix for the controlled sample was used (sample one). The entire bag of 80-pound quickrete could make up to 0.6 cubic feet of concrete which allowed for calculation of the amount of water it would theoretically take the 9-pound sample that was used. The manufacture of quickrete contained instructions for water to weight ratio. The manufacturer approximated that about 16 ounces of water for the controlled mix would be needed. Some water measurements had to be changed to ensure that the cement had enough water to mix properly as the water recommendations provided by the manufacturer did not allow the concrete to mix properly or would still have dry cement in the mixing bucket. Tools were used to help mix the concrete thoroughly until ready to pour. The wet concrete mix was then poured into the plastic cylinders that were created from the plastic pvc pipe. To transfer the wet mix from the bucket to the cylinders, a small gardening shovel was used. While pouring the concrete, it was poured in layers. The mix was poured to fill the cylinder about a third of the way and a small wooden stick was used to tap the concrete down to prevent any air pockets or uneven sections from forming. This was done three to four times until the cylinder was completely filled with the wet concrete mix. This procedure helped ensure that the entire sample was even, and that the measurements would not be affected by any inconsistencies. After being poured, the top of the sample was leveled off and flattened to ensure for easy testing and for the best possible results when running nondestructive tests. The concrete sample was then left at room temperature of 23 degrees Celsius. The sample was left for a total of 7 days which marks the first benchmark of the curing process where concrete gains most of its strength. On the seventh day the samples were removed from the wooden board and cut out of the plastic cylinders. To remove the plastic mold, a saw was used to cut multiple slits into the plastic cylinder to loosen the mold and take the concrete out, leaving the sample undamaged. The concrete was removed from the plastic to ensure that the plastic did not interfere with any results. To make concrete sample two which contained recycled concrete as the aggregate, a scale and sifter was needed to separate and measure the aggregate and cement. By using the sifter, the cement and aggregate inside the quickrete mix was separated. This was done by pouring the quickrete mix into the sifter and separating out aggregate from the cement. Upon doing this the weight of both the cement and aggregate inside of the mix was a 50-50 distribution of cement to aggregate. After separating the aggregate, it was weighed out that 4.5 pounds of cement from the quickrete mix was needed and 4.5 pounds of recycled aggregate was needed. To make the recycled aggregate, old samples of concrete that were approximately two years old were used. These samples were used as the recycled aggregate to help simulate using old concrete that could be recycled by concrete industries. With these two-year-old samples a hammer was used to shatter the concrete in a clean box down to the size of the aggregate that was separated from the quickrete mix (1-2.5cm). With the 2-year-old smashed concrete 4.5 pounds was weighed out making the material in this sample 50% recycled. This mix needed more water in order to make the sample have the same consistency of sample one (see figure 1) and the data was recorded and measured out by weight to account for the added water. Sample 3 contained fly ash and regular aggregate from the quickrete mix. Following the same procedure from sample two, the aggregate and cement was separated. Most concrete mixes that use fly ash can replace approximate 25% of cement inside of that concrete sample. To do this, 3.375 pounds of cement and 1.125 pounds of fly ash was used to make sample 3. Sample 3s material was 12.5% recycled. The same procedure for water was used for this sample (see Figure 1). For sample 4, which contained fly ash and recycled aggregate, the same procedure for sample 3 was used to mix in the fly ash with cement. The aggregate for the quickrete mix was replaced with the smashed up two-year-old sample of concrete that was also used for sample two. Sample four contained 3.375 pounds of cement 1.125 pounds of fly ash and 4.5 pounds of recycled aggregate. This made the sample four approximal 62.5% recycled. The water was then recorded as previously mentioned (see figure 1).

Rebound Hammer Test

The rebound hammer test was used on all samples. The concrete rebound hammer was a spring-loaded instrument. It is used on concrete samples by positioning the piston perpendicular to the sample and pushing down until the hammer releases. The hammer then strikes the concrete and the spring measurement will rebound and provide a measurement that can then be read and recorded. When taking measurements, the sample was put on top of steel blocks to ensure that the rebound hammer was recording the hardness of just the concrete and not of the floor as well. Each sample was placed on top of these blocks and by using the rebound hammer in the center of the concrete sample, measurements were taken by pushing the hammer down and letting the hammer hit and recording the R value that was displayed on the side. The R values correlate to the strength of the concrete. R values above 30 or generally considered a strong concrete sample along with the higher value the better. Below 30 is when the concrete sample would be considered weak or of poor quality. The test was performed fifteen times for each sample on day 7 of the curing process. Taking many data points is necessary for this test as the rebound hammer does not always record the same value for each test, therefore multiple data points need to be taken and averaged together to give the best estimated R-value for that sample. This test was performed on each of the four samples on day seven, nine, and eleven of the curing processes.

Direct Current Test

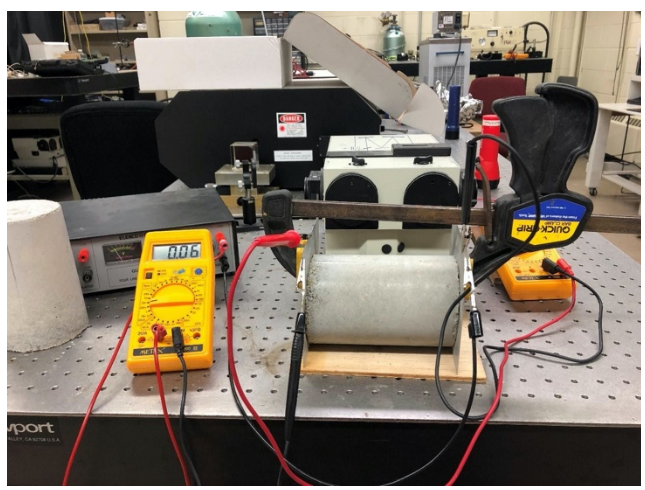

***Figure 2**: Example of a Direct Current Test.*

The direct current resistivity test is a nondestructive test that involves a direct current running through the concrete sample. This was done by measuring the current going into the sample and the voltage coming out of the sample. By using the samples, two metal plates were attached to each side of the samples (see figure 2) with electronic gel being put on the metal plates and acting as a transfer conductor from the metal plates to the concrete to get the best readings. An electric current generator was then used to vary the current going into the sample. Output on the current generator was linked to an ammeter to measure the current going in. A voltmeter was attached to each metal plate on either side of the concrete sample to measure the voltage drop across the concrete sample. By doing this it creates a circuit where the current was being measured before the resistor (the concrete sample) and the voltage drop across it. By varying the current, data was recorded for both the current and the voltage. By taking all of the data points it was then possible to plot and graph the data to get a linear graph. Using this graph, the slope of the graph which will give the R value can be taken. By using the equation $\rho = RA/l$ the resistivity of concrete can be found. In this equation the R value is the slope from the graph of the data points which also comes from the V=IR standard electronics equation of voltage is equal to current times resistance. A provides a value which is the area of the cross-sectional sample, this is the area of the face of the cylindrical sample. The L is the length of the cylindrical sample. The resistivity value that is given to us from this equation gives a p value that relates to corrosion. According to ATSM standards research, when the p value is under 60 ohmmeters then corrosion in the samples Is likely to occur.

Results

2.38	2.18	2.23	2.08

Figure 3: *Density of Samples - Sample one: control; Sample two: recycled aggregate; Sample 3: fly ash; Sample 4: recycled aggregate and fly ash. Data displayed in gram/cm^3*

Above is the density for each sample. Sample one recorded the highest density and Sample four had the lowest and also contained the most amount of recycled material. Sample two was 0.2 g/cm^3 less dense than sample one, showing the effects on the density of concrete when using recycled material. Sample three being the second most dense shows that using just fly ash as recycled material still lowers the density.

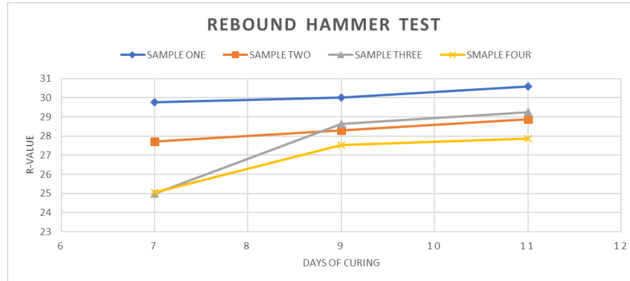

Figure 4: *Rebound Hammer Graph. Sample one: control; Sample two: recycled aggregate; Sample 3: fly ash; Sample 4: recycled aggregate and fly ash.*

day	7	9	11
Sample one	29.76	30	30.58
Sample two	27.7	28.29	28.88
Sample three	25	28.64	29.23
Sample four	25.05	27.52	27.88

Figure 5: *Rebound Hammer R values - Sample one: control; Sample two: recycled aggregate; Sample 3: fly ash; Sample 4: recycled aggregate and fly ash. Data is displayed in R- values for figure 5*

The rebound hammer test data as shown above in figure 4 and figure 5, shows data from the 7th, 9th, and 11th day of the curing process. Sample one being the controlled sample maintained a higher R-value throughout each test, reaching a value of 30.58. Sample two maintained a consistent increase, reaching an R value of 28.88. Sample one and sample two ended with close final R values and both had the most linear increase in strength out of all four samples. The increase in strength of the fly ash samples had the biggest increase from day 7 to day 11. Both sample 3

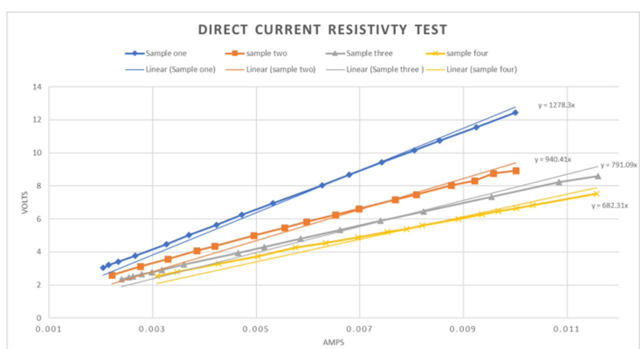

Figure 6*: Direct Current Resistivity Graph - The graph is displayed in volts (y- value) by amps (x-value). Each sample has a trendline whose values are the resistance of the sample of concrete from the equation V=IR*

and sample 4 started around an R-value of 25 and both made a significant jump between day seven and day nine, more so than the samples that contained no fly ash. Sample three reached the second highest R value out of the four samples with 29.23. Sample four did the poorest out of the four samples. This sample reached a total R value of 27.88. Sample four fell close to 2.7 R values below the controlled sample.

2.38	2.18	2.23	2.08

Figure 7: *Resistivity Values - Sample one: control; Sample two: recycled aggregate; Sample 3: fly ash; Sample 4: recycled aggregate and fly ash. Data displayed in ohmmeters.*

The resistivity measurements do show similar trends to the rebound hammer test values. Sample one showed a best fit value of 1278.3 ohms, a large margin greater than the next value from sample two of 940.4 ohms, and close to double the value of sample four of 682.31 ohms. The trendline numbers correlate directly to the resistivity values shown in figure 7 since all of our samples are the same size (the higher the trendline value the higher the resistivity). The higher the resistivity the less likely the concrete sample is to corrode or weaken over time. According to research from and standards from ATSM resistivity values below 60 ohmmeters is considered very likely to corrode. In figure 7, sample one was the only sample to reach above the 60 ohm-meter mark that shows the concrete is strong and not likely to corrode. Sample three and four, the fly ash samples, both recorded values in the thirties with high likeness of corrosion. Sample two recorded a 47.6 ohmmeter value. Although below the 60-ohmmeter mark, 47.6 is the next highest value behind sample one.

Conclusion

Reducing carbon emissions using a recycled concrete aggregate with a regular cement mix could be a possible solution to reduce carbon emissions compared to use of standard aggregate. The recycled aggregate sample showed similar strength and a lower likeliness to corrode compared to the fly ash sample, which is currently widely used. More research must be done on the corrosion possibility and perfecting the balance of the mix. There is also the possibility of using mixes that do not contain 100% recycled aggregate. Balancing percentages of recycled concrete as well as normal aggregate could be another possible solution to reduce the environmental impacts of the concrete industry. Using both fly ash and recycled concrete would not be a suitable solution based on this research. The sample with both fly ash and recycled aggregate produced data that is inferior to the controlled sample, the recycled aggregate and the fly ash sample and is not something currently worth looking further into as other samples showed more potential to be used in the concrete industry. From this research it can be concluded that recycled concrete can be used in the cement industry for certain concrete jobs. Using recycled concrete for concrete mixes for roads and driveways could benefit from the use of recycling concrete for aggregate. The lightweight and less dense mix from using recycled concrete as the aggregate, would likely be suitable for these kinds of jobs. This solution would not work for buildings or foundations of houses as the possibility of corrosion and a less dense and slightly weaker material could lead to structural issues.

Discussion

The concrete industry is one of the leading producers in the world of manmade carbon dioxide emissions. Using recycled material in concrete poses a possible solution to help reduce the environmental impacts of the industry. In this study multiple samples were looked at containing different levels and types of recycled material as possible solutions to reducing carbon emissions, as well as a controlled sample with no recycled material used. In this research it is was shown that using recycled concrete in place of aggregate does offer a possible solution to reducing carbon dioxide emissions. Sample two reached an R value of 28.88, while the controlled sample recorded 30.58. Concrete is considered to have a good hard layer at an R value of 30. Sample three is a type of recycled mix that is already used in the industry today. Sample three recorded an R value of 29.32 that is only .35 higher than sample two. A quickrete mix was used which is expected that the R values will not reach the same strength values that a concrete industry could produce with stronger industrial cement and more specified mixes for different jobs. There would need to be more research with different types of Portland cement mixes to ensure that the strength would hold up to standards. From looking at the recycled aggregate mix and fly ash mix the numbers being similar in strength is a strong indicator that this type of mix can be used if fly ash is already an accepted method. Comparing sample two with the controlled sample it is clear that the recycled aggregate may make the concrete slightly weaker, it also makes the concrete lightweight compared to the controlled sample. All samples were made the same size, so the data of density also correlates to the weight of each sample; showing recycled material lowers the overall weight of the sample. This aspect could be useful for the many different types of jobs that concrete is used for. For the resistivity test, using quickrete had a large impact on the samples having a high likeness of corrosion. With 60 ohmmeters being a benchmark from recent research, even the controlled sample hardly made that mark recording a resistivity value of 63.7 ohmmeters. Sample three is a type of sample that is already used in the concrete industry and recorded a very low value of resistivity of 39.75 ohmmeters. Sample two had a value of 47.6 ohmmeters. The significance of this is that although these values are still below 60, using recycled aggregate showed less possibility to corrosion compared to using of fly ash in the sample with regular aggregate. Sample two with recycled aggregate recorded a slightly lower strength value than sample three. The overall weight of the material also went by using recycled concrete as aggregate. This could also have benefits in different jobs adding to the benefits of using recycled concrete. From running these nondestructive test, it allowed us to properly asses each sample to see the recycled concrete as aggregate will help lower emissions, price, and maintain a suitable strength.

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