RECYCLED AGGREGATE AND RECYCLED PLASTIC IN CONCRETE

by

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ABSTRACT

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Disposal of waste plastic and waste concrete aggregates is a widespread issue across the globe. If not responsibly disposed of, the waste winds up in sensitive ecosystems where it leeches toxins into its surroundings. In an effort to utilize the waste plastic and waste concrete, studies have been done to test if recycled waste plastic can be mixed with fresh concrete and studies have been done to mix recycled waste concrete in fresh concrete. However, none have been found mixing both recycled wastes in the same mix design. This study determines the effects of recycled plastic and recycled concrete on specific concrete properties. Tests performed in this study include slump, compressive strength, modulus of elasticity, and water permeability. This study had an issue with inconsistent results with the compression test, but conclusions were able to be drawn from the three other tests. The

slump test showed the recycled concrete reduced the workability while the recycled plastic had little effect on the workability. The batches tested with recycled plastic content performed better for elasticity and the recycled concrete was deduced to have no advantages in terms of improved strength based on the modulus of elasticity test results.

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CHAPTER 1

INTRODUCTION

Plastic pollution is one of most the pressing issues facing environmental concerns today. All types of plastic are winding up in streams, oceans, and landfills. Additionally, since plastic is a petroleum-based product, most plastic will never biodegrade and will instead poison the surrounding areas. Ideally, people could simply recycle their used plastic through in-place municipal solid waste programs. However, even if everyone recycled all their waste plastic, not all types of plastics can be processed and recycled through the current municipal waste system [8]. To address this, alternate ways of utilizing the used and recycled plastic should be investigated. A potentially groundbreaking way for plastic to be effectively recycled is to integrate it into widely used commercial products, such as concrete. Concrete is a staple of the construction industry and can be found at most, if not all, construction sites. While concrete's uses and advantages are well known, what happens after its service life is not often discussed. Concrete accounts for an estimated 23.1 million tons of active construction waste and 358.7 million tons of demolition waste per year [4]. The construction industry relies heavily on concrete which makes removing concrete from the construction industry impractical; nevertheless, there is the possibility of mixing both plastic and concrete waste into concrete and creating a new mix design. However, changing the ingredients in one of the strongest and most relied upon building materials brings concern about the structural integrity of the new mix in terms of durability and strength.

CHAPTER 2

BACKGROUND INFORMATION

There has been a considerable amount of research testing the mixtures of different plastics in concrete, yet there have been substantially fewer studies looking at mixing recycled concrete aggregates in concrete. There has been no research to date including both recycled concrete and recycled plastic aggregates in the concrete mix design. In one study, Ankur Bhogayata and Narendra Arora [2] collaborated on a paper titled “Workability, strength, and durability of concrete containing recycled plastic fibers [RFP] and styrene-butadiene rubber latex [SBR latex]". In this paper, they used a mixture of the two mentioned types of recycled plastic and added it to the concrete mixture. Once cured, the resulting concrete was subjected to tests for workability, axial compression, splitting tensile, chloride penetration, water sorptivity, and impact strength. The conclusion was that a mixture of both the RPF and SBR latex improved cracking resistance, flexure resistance, and reduced the rate of chemical and water ingress into the specimens [2].

A different study by Hossein Mohammadhosseini and Mahood Tahir focused on "durability performance of concrete incorporating waste metalized plastic fibers and palm oil fuel ash" [6]. The report used these plastic types since there have been no previous tests done utilizing these materials. The tests they performed almost mirrored the previous study; air content of fresh concrete, water sorptivity, water absorption, chloride penetration, and drying shrinkage of hardened concrete. In their conclusions, it was found that waste metal plastic fibers have the potential to enhance the structural durability of standard concrete [6].

In one of the fewer studies concerning recycled concrete aggregates, Ahmend Bendimerad, Emmanual Roziere, and Ahmed Loukili worked together to publish a paper titled “Drying of Recycled Aggregate Concrete: Plastic Shrinkage, Cracking Sensitivity, and Durability”. For this study, a few different percentages of recycled aggregate and natural aggregate were mixed into concrete specimens and all tests conducted focused on the “early age behavior” [1]. Their methodology was based on water content and how it correlates to durability, cracking, and plastic/drying shrinkage. According to the paper, "oversaturation of recycled concrete gravels can be recommended," because it was found to provide "higher strength, lower cracking sensitivity" as standard concrete [1].

CHAPTER 3

SIGNIFICANCE OF RESEARCH

This research will attempt to alleviate separate issues in two industries: plastic pollution and construction concrete waste. With this project, there is the possibility of creating a solution that utilizes both wastes and helps curb detrimental effects on the environment.

To put it differently, this research is significant because waste plastic is non-biodegradable and causes major damage to the environment. The negative effects of plastic pollution depends on where it ends up. For example, if the waste goes into bodies of water, it will leach toxins into the human food supply and if left in a landfill it will leak the same chemicals into the soil. While recycling seems to be a good way to keep waste plastic out of oceans and landfills, only three of the seven types of plastic can be recycled by most municipalities, and often the waste plastic is too contaminated to be processed [7]. The most ideal solution to the plastic problem would be to eradicate the use of plastic, but the world is so dependent on plastic that eliminating plastic use is not a plausible solution. Additionally, while curbing the use of plastic will help reduce the amount of new waste, there are still mountains of old plastic waste. Therefore, finding marketable uses for waste plastic is an important concept that needs to be explored.

This research is significant also because of the recycled concrete aspect. Like plastic, waste concrete is not biodegradable. Concrete is praised for its resistance to nature's forces and the resistance does not stop when it becomes construction waste. There are existing methods to recycle concrete as a base for roads, driveways, and backfill materials [14] in addition to being mixed in fresh concrete. Therefore, while there are methods to recycle the concrete, the significance of using it in this study stems from the colossal amount of concrete continuing to be used and thrown away. This project will provide another outlet for the concrete waste to prevent it from being discarded irresponsibly.

CHAPTER 4

METHODOLOGY

This lab-based research study used both experimental and quantitative methodology pratices. The tested specimens contained a set percentage of two different types of recycled plastics: high-density polyethylene and polypropylene. The plastics were purchased from a plastic recycling and reselling company, Packaging One Inc. Specimens had two varying percentages of recycled concrete aggregate content and there were multiple control sets with no plastic and/or no recycled concrete included in their mix design to compare the impact of each recycled product independently. The recycled concrete was collected from a local construction site and the cement mix was purchased from a hardware store. The cement mix used was Sakrete Pro-Mix All-Purpose Cement Mix. The tests performed were slump (ASTM C143) [11], compressive strength (ASTM C39) [9], modulus of elasticity (ASTM 469) [12], and water permeability (ASTM C1585) [10]. The information collected from the tests allowed the comparison of the recycled plastic and recycled aggregate to the control specimen set.

4.1 Slump Test

The slump test is used to determine the workability of the concrete per ASTM C143 "Standard Test Method for Slump of Hydraulic-Cement Concrete" [11]. Workability in concrete is important to know because when placed into forms or molds, the concrete needs to be able to consolidate and fill as well as surround the reinforcement. The slump test was performed immediately after mixing the concrete and did not require further calculations.

4.2 Compressive Strength Test

The compressive strength test determines the compressive strength of cylindrical concrete samples per ASTM C39 “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimen” [9]. For this study, all samples were capped using Hytech #9 Capping Compound to make the samples as level as possible. This test was performed simultaneously with the modulus of elasticity test using a 400 Kip Tinius Olsen machine. All batches excluding A1 and A2 were tested at the age of 18 days; while A1 and A2 were tested at the age of 28 days.

Outputted data was then collected and used in further calculations. The machine outputted load values in meganewtons which was then divided by the cross-sectional area to calculate the compressive strength.

4.3 Modulus of Elasticity Test

The modulus of elasticity test will determine the stress-strain ratio and ratio of lateral to longitudinal strain on the sample per ASTM C469 "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression" [12]. A greater modulus of elasticity [MoE] is desirable when working with concrete [12].

As stated previously, this test was performed simultaneously with the compression test. The outputted data included not only the load values in meganewtons but also two deflection values. Before calculating the modulus of elasticity, the load values were converted to kips and the deflection was averaged between the two outputted values. The microstrain was then calculated by multiplying the change in length (average deflection) by 10,000 to yield strain in a usable number format. Stress was then calculated in Ksi by dividing the load value in Kips by the cross-sectional area, 12.6 in^2.

After load (kips), deflection, strain (micro), and stress (KSI) were determined, two equations were used to determine two moduli of elasticities. The first modulus of elasticity equation is based on the American Concrete Institute standards [ACI] and results in a predicted modulus of elasticity for the data set. The second equation is based on the values from the experiment [EXP] and outputs the actual modulus of elasticity for the data set. Ideally, the numbers should be as similar as possible. The two equations are given below.

$$ACI\ MoE = \frac{57000 * \sqrt{(ultimate\ stress * 1000)}}{1000} \quad (1)$$

$$EXP\ MoE = \frac{S_1 - S_2}{\Sigma_1 - \Sigma_2} \quad (2)$$

Where:

$S_1 = ultimate\ load * 1/3$

$S_2 = stress\ @\ 50\ micro\ strain$

$\Sigma_1 = (micro\ strain\ @\ S_1) * 10^{-6}$

$\Sigma_2 = (50\ micro\ strain)\ * 10^{-6}$

4.4 Water Permeability Test

The water permeability test establishes the rate of absorption of water by the concrete per ASTM C1585 “Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic Cement Concretes” [10]. In this study, one sample from each batch was cut into two pieces that were approximately 2 inches tall. Additionally, the test was performed for an hour instead of up to seven days.

Once all the data was collected, an equation was used to determine the absorption, I.

$$I = \frac{m_t}{a * d} \quad (3)$$

Where:

$m_t = the\ change\ in\ specimen\ mass\ in\ grams\ at\ the\ time\ t$

$a = the\ exposed\ are\ of\ the\ specimen\ in\ mm^2$

$d = \left(0.001 \frac{g}{mm^3}\right) the\ density\ of\ the\ water\ in\ g/mm^3$

The absorption was plotted against the square root of time, and the slope of the best fit line is the rate of water absorption.

CHAPTER 5

MIX DESIGNS

Tables 1-6 below break down each of the mix designs used in the study.

Table 5.1: Control Batch Mix Design

Ingredient	Quantity
Cement	20% by volume
Sand	30% by volume
Water	W/C ratio: 0.35
Coarse Aggregate	30% by volume
Plastisol 6400	8 oz/100 lbs of cement

The control batch contains no recycled concrete or recycled plastic aggregate. It does contain plastisol and has water to cement ratio of 0.35.

Table 5.2: A Batch Mix Design

Ingredient	Quantity
Cement	20% by volume
Sand	30% by volume
Water	W/C ratio: 0.35
Coarse Aggregate	30% by volume
Recycled Plastic	0.2% by volume
Plastisol 6400	8 oz/100 lbs of cement

"A" Batch contains recycled plastic aggregate but no recycled concrete. "A1" and "A2" are referring to the two different plastics.

Table 5.3: B Batch Mix Design

Ingredient	Quantity
Cement	20% by volume
Sand	30% by volume
Water	W/C ratio: 0.35
Coarse Aggregate	20% by volume
Recycled Concrete	10% by volume
Recycled Plastic	0.2% by volume
Plastisol 6400	8 oz/100 lbs of cement

"B" Batch consists of a reduced amount of coarse aggregates from previous mixes and contains both recycled concrete and recycled plastic aggregates. "B1" and "B2" are referring to the two different plastics.

Table 5.4: C Batch Mix Design

Ingredient	Quantity
Cement	20% by volume
Sand	30% by volume
Water	W/C ratio: 0.35
Coarse Aggregate	10% by volume
Recycled Concrete	20% by volume
Recycled Plastic	0.2% by volume
Plastisol 6400	8 oz/100 lbs of cement

"C" Batch has an increased amount of recycled concrete aggregates from previous mixes and contains both recycled concrete and recycled plastic aggregates. "C1" and "C2" are referring to the two different plastics.

Table 5.5: D1 Batch Mix Design

Ingredient	Quantity
Cement	20% by volume
Sand	30% by volume
Water	W/C ratio: 0.35
Coarse Aggregate	20% by volume
Recycled Concrete	10% by volume
Plastisol 6400	8 oz/100 lbs of cement

"D1" contains the same amount of recycled plastic as batch B but contains no recycled plastic.

Table 5.6: D2 Batch Mix Design

Ingredient	Quantity
Cement	20% by volume
Sand	30% by volume
Water	W/C ratio: 0.35
Coarse Aggregate	10% by volume
Recycled Concrete	20% by volume
Plastisol 6400	8 oz/100 lbs of cement

"D2" contains the same amount of recycled plastic as batch C but contains no recycled plastic.

CHAPTER 6

SAMPLES/ RESULTS/ DISCUSSION

6.1 Samples

Below is a table of the sample height, diameter, and weight for all the samples used in the study. All samples were measured in centimeters and weighed in kilograms. There were four samples per batch and with a total of 36 samples tested in this study.

Table 6.1: Sample Data

Sample Name	Height (cm)	Diameter (cm)	Weight (Kg)	Sample Name	Height (cm)	Diameter (cm)	Weight (Kg)
Control A	20.32	10.16	3.87	B2RP2C	20.32	10.16	3.83
Control B	20.32	10.16	3.87	B2RP2D	20.32	10.16	3.85
Control C	20.32	10.16	3.67	C1RP1A	20.32	10.16	3.81
Control D	20.32	10.16	3.78	C1RP1B	20.32	10.16	3.81
A1RP1A	20.32	10.16	3.80	C1RP1C	20.32	10.16	3.79
A1RP1B	20.32	10.16	3.77	C1RP1D	20.32	10.16	3.79
A1RP1C	20.32	10.16	3.87	C2RP2A	20.32	10.16	3.77
A1RP1D	20.32	10.16	3.82	C2RP2B	20.32	10.16	3.79
A2RP2A	20.32	10.16	3.76	C2RP2C	20.32	10.16	3.77
A2RP2B	20.32	10.16	3.84	C2RP2D	20.32	10.16	3.75
A2RP2C	20.32	10.16	3.84	D1A	20.32	10.16	3.83
A2RP2D	20.32	10.16	3.85	D1B	20.32	10.16	3.80
B1RP1A	20.32	10.16	3.91	D1C	20.32	10.16	3.82
B1RP1B	20.32	10.16	3.88	D1D	20.32	10.16	3.83
B1RP1C	20.32	10.16	3.91	D2A	20.32	10.16	3.76
B1RP1D	20.32	10.16	3.85	D2B	20.32	10.16	3.73
B2RP2A	20.32	10.16	3.86	D2C	20.32	10.16	3.76
B2RP2B	20.32	10.16	3.84	D2D	20.32	10.16	3.71

6.2 Results

Table 6.2: Slump Test Results for All Batches

Batch	Slump (cm)	Batch	Slump (cm)	Batch	Slump (cm)
Control	22.86	B1RP1	19.05	C2RP2	17.15
A1RP1	21.59	B2RP2	18.42	D1	19.05
A2RP2	22.86	C1RP1	16.51	D2	17.15

Table 6.3: Compressive Strength Test Results for All Batches

Sample	Max Load (KN)	Compressive Strength (MPa)	Sample	Max Load (KN)	Compressive Strength (MPa)
Control A	210.58	25.99	B2RP2 C	149.77	18.48
Control B	170.81	21.08	Average	165.61	20.44
Control C	47.60	5.87	C1RP1 A	180.20	22.24
Average	143.01	17.65	C1RP1 B	116.23	14.34
A1RP1 A	109.20	13.48	C1RP1 C	165.34	20.40
A1RP1 B	248.03	30.61	Average	153.91	18.99
A1RP1 C	115.43	14.25	C2RP2 A	93.59	11.55
Average	157.56	19.44	C2RP2 B	209.02	25.79
A2RP2 A	108.40	13.38	C2RP2 C	109.96	13.57
A2RP2 B	128.69	15.88	Average	137.54	16.97
A2RP2 C	187.18	23.10	D1 A	101.42	12.52
Average	141.45	17.46	D1 B	113.87	14.05
B1RP1 A	112.32	13.86	D1 C	131.80	16.27
B1RP1 B	165.34	20.40	Average	115.70	14.28
B1RP1 C	97.51	12.03	D2 A	116.99	14.44
Average	125.04	15.43	D2 B	123.26	15.21
B2RP2 A	202.04	24.93	D2 C	99.06	12.23
B2RP2 B	145.10	17.91	Average	113.12	13.96

Table 6.4: Modulus of Elasticity Test Results for All Batches

SAMPLE	ACI (MPa)	EXP (MPa)	DELTA	SAMPLE	ACI (MPa)	EXP (MPa)	DELTA
Control A	24090	26363	2272	B2RP2 C	20315	40209	19894
Control B	21696	29618	7922	Average	21301	39972	18670
Control C	11451	1058	10393	C1RP1 A	22283	30122	7839
Average	19079	19013	66	C1RP1 B	17896	54619	36723
A1RP1 A	17347	35905	18558	C1RP1 C	21347	42810	21463
A1RP1 B	26144	24693	1452	Average	20509	42517	22009
A1RP1 C	17836	18305	469	C2RP2 A	16060	26571	10511
Average	20442	26301	5858	C2RP2 B	24001	23089	912
A2RP2 A	17285	11312	5973	C2RP2 C	17409	23882	6473
A2RP2 B	18832	43333	24500	Average	19157	24514	5357
A2RP2 C	22713	1784	20929	D1 A	16716	9596	7120
Average	19610	18810	800	D1 B	17715	54719	37004
B1RP1 A	17593	82667	65074	D1 C	19059	17446	1613
B1RP1 B	21347	34048	12701	Average	17830	27254	9424
B1RP1 C	16392	23619	7228	D2 A	17956	26099	8143
Average	18444	46778	28334	D2 B	18429	17363	1066
B2RP2 A	23595	58942	35348	D2 C	16522	27416	10893
B2RP2 B	19995	20763	768	Average	17636	23626	5990

Table 6.5: Water Permeability Test Results for All Batches

Sample	Height (cm)	Kg @ 0 sec	Kg @ 60 sec	Kg @ 5 min	Kg @ 10 min	Kg @ 20 min	Kg @ 30 min	Kg @ 60 min
Control D1	5.08	0.93	0.94	0.95	0.95	0.98	0.96	0.97
Control D2	5.08	0.90	0.91	0.92	0.93	0.93	0.93	0.94
Average	5.08	0.91	0.92	0.93	0.94	0.95	0.95	0.96
A1RP1 D1	5.08	0.87	0.87	0.88	0.88	0.88	0.88	0.88
A1RP1 D2	4.76	0.85	0.85	0.86	0.86	0.86	0.86	0.86
Average	4.92	0.86	0.86	0.87	0.87	0.87	0.87	0.87
A2RP2 D1	5.08	0.85	0.86	0.87	0.88	0.88	0.88	0.88
A2RP2 D2	5.08	0.93	0.93	0.94	0.95	0.96	0.96	0.96
Average	5.08	0.89	0.90	0.91	0.91	0.92	0.92	0.92
B1RP1 D1	4.45	0.78	0.80	0.80	0.81	0.81	0.81	0.81
B1RP1 D2	5.40	0.97	0.98	0.98	0.99	0.99	0.99	0.99
Average	4.92	0.88	0.89	0.89	0.90	0.90	0.90	0.90
B2RP2 D1	5.08	0.90	0.90	0.92	0.93	0.93	0.93	0.93
B2RP2 D2	5.08	0.89	0.90	0.91	0.91	0.91	0.91	0.92
Average	5.08	0.89	0.90	0.91	0.92	0.92	0.92	0.93
C1RP1 D1	4.76	0.83	0.84	0.85	0.84	0.88	0.88	0.89
C1RP1 D2	4.76	0.86	0.87	0.88	0.89	0.90	0.90	0.91
Average	4.76	0.84	0.86	0.87	0.87	0.89	0.89	0.90
C2RP2 D1	4.76	0.90	0.91	0.92	0.93	0.93	0.94	0.93
C2RP2 D2	5.08	0.87	0.89	0.90	0.90	0.90	0.90	0.90
Average	4.92	0.89	0.90	0.91	0.91	0.92	0.92	0.92
D1 D1	4.76	0.89	0.90	0.91	0.91	0.91	0.91	0.92
D1 D2	5.08	0.88	0.89	0.89	0.89	0.89	0.89	0.90
Average	4.92	0.89	0.89	0.90	0.90	0.90	0.90	0.91
D2 D1	5.08	0.87	0.88	0.90	0.90	0.90	0.90	0.90
D2 D2	5.08	0.87	0.88	0.89	0.90	0.90	0.90	0.90
Average	5.08	0.87	0.88	0.89	0.90	0.90	0.90	0.90

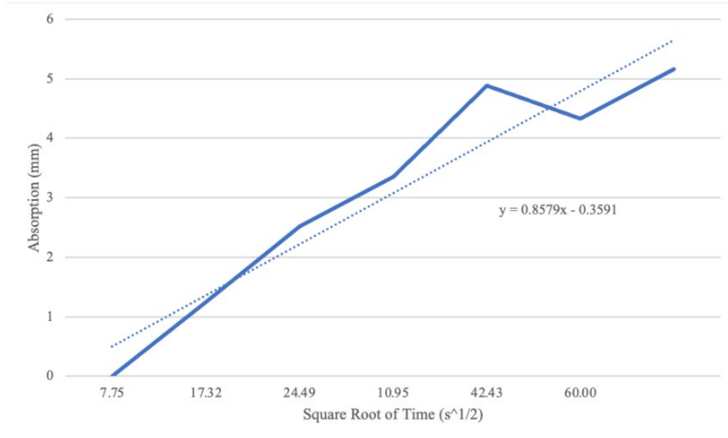

Figure 6.1: Control Batch Water Absorption Vs Square Root of Time

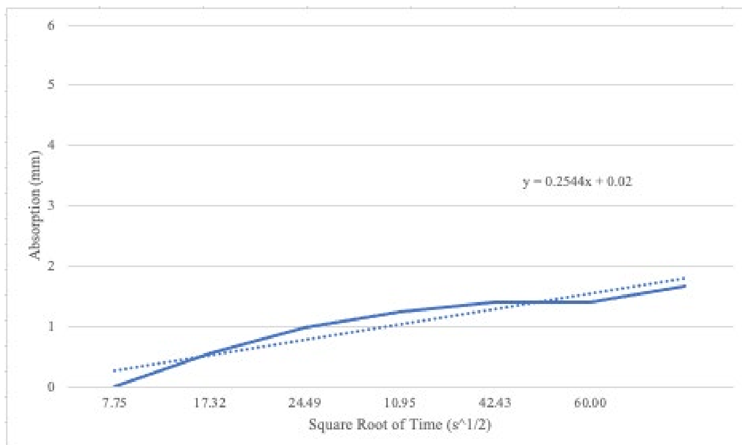

Figure 6.2: A1 Batch Water Absorption Vs Square Root of Time

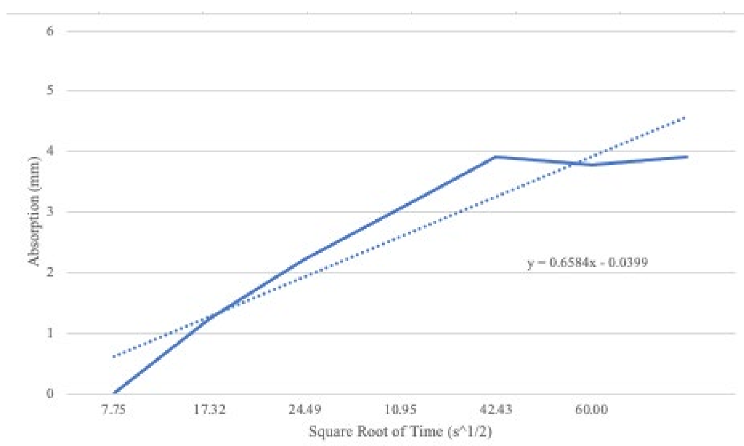

Figure 6.3: A2 Batch Water Absorption Vs Square Root of Time

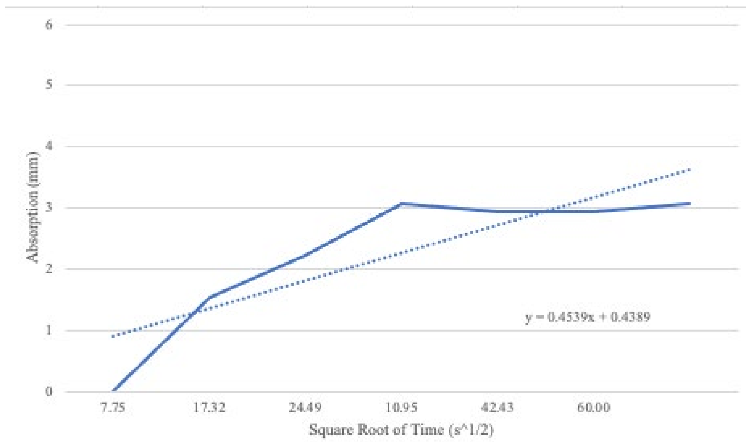

Figure 6.4: B1 Batch Water Absorption Vs Square Root of Time

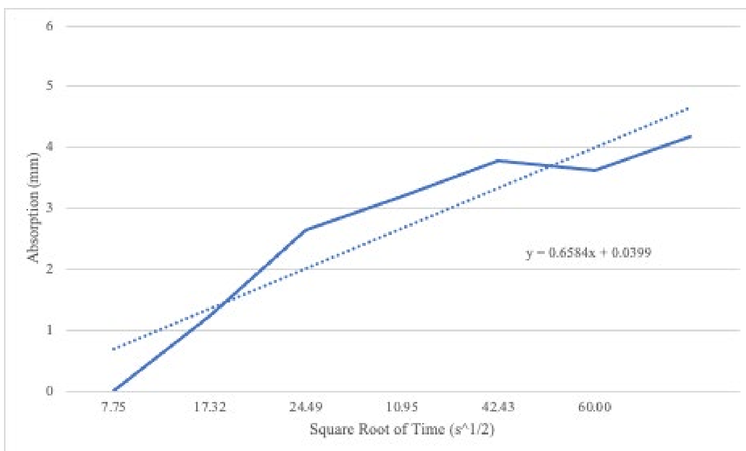

Figure 6.5: B2 Batch Water Absorption Vs Square Root of Time

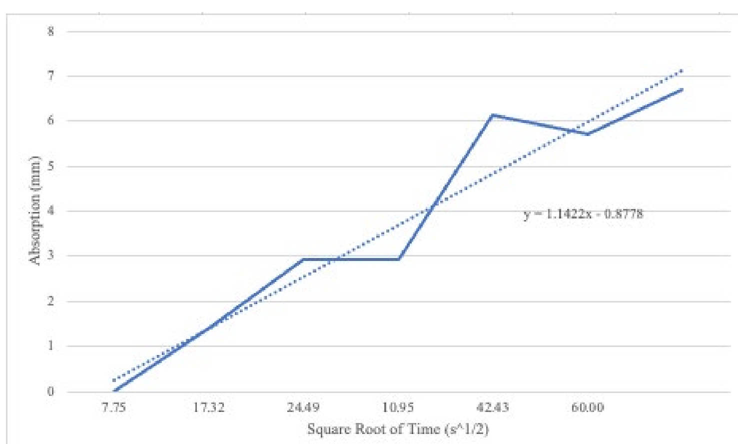

Figure 6.6: C1 Batch Water Absorption Vs Square Root of Time

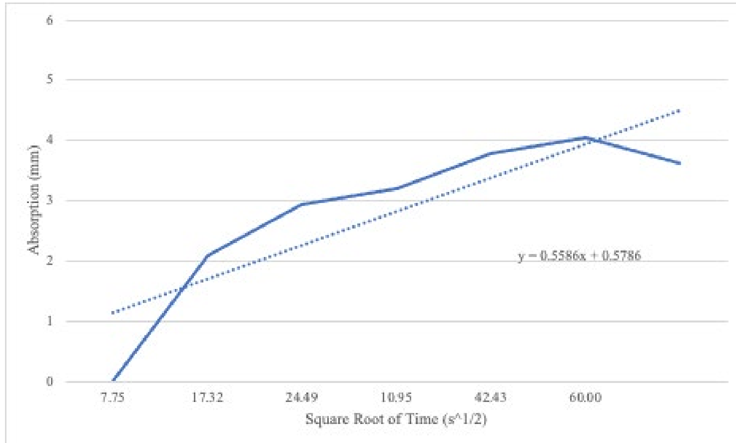

Figure 6.7: C2 Batch Water Absorption Vs Square Root of Time

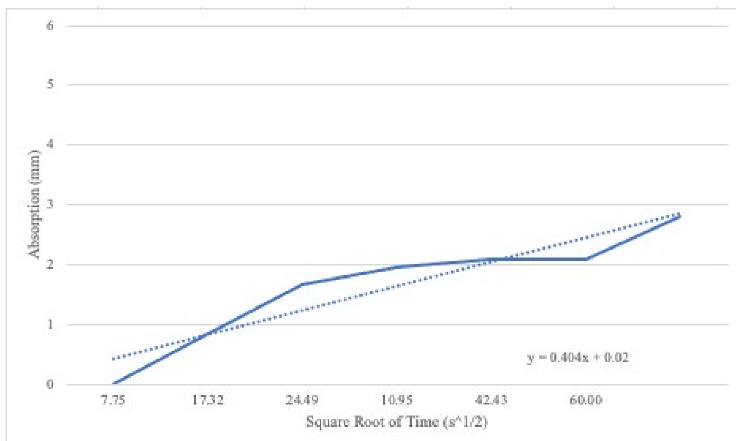

Figure 6.8: D1 Batch Water Absorption Vs Square Root of Time

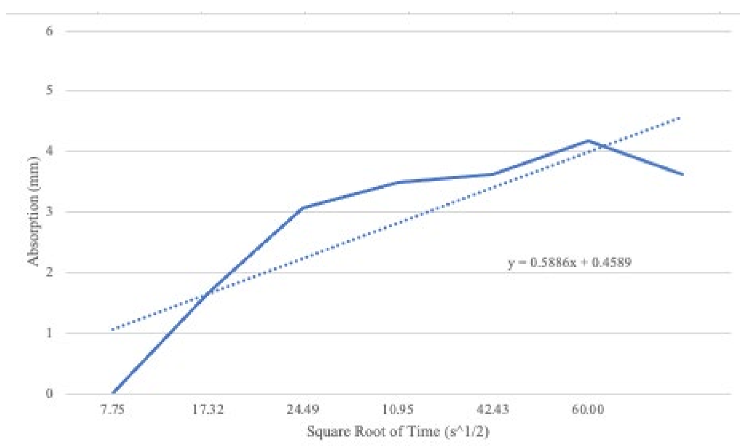

Figure 6.9: D2 Batch Water Absorption Vs Square Root of Time

6.3 Discussion

6.3.1 Slump Test

As more recycled concrete was included in the mix design, the mixture yielded a lower slump value than the control batch (Table 6.2). When comparing the control batch to A1 and A2 batches it can be deduced the cause of the reduced slump values shouldn't be attributed to the recycled plastic content. It is plausible that the reason for the reduced workability was the inconstancy in aggregate size and shape in the recycled concrete.

6.3.2 Compressive Strength Test

The samples with visual deformities did not perform well in the compression test due to the compromised structural integrity. Additionally, most samples were not level, which caused the sample to crack early in the testing which further reduced the compressive strength of the samples. The sample with the largest maximum load was A1RP1 B (Table 6.3). The batch that had the highest average maximum load was B2RP2 C (Table 6.3). While most results were not consistent between the three samples, both D1 and D2 had the most consistent results among the samples tested (Table 6.3). The control batch's average maximum load outperformed a majority of the average maximum loads, with exception to A1, B2, and C1 batches (Table 6.3). Due the inconsistency of the results across the study from the compression test, and the differing ages tested, a credible comparison cannot be drawn between the batches.

6.3.3 Modulus of Elasticity Test

The ACI calculated modulus of elasticity consistently yielded between 16,000 – 25,000 Mega Pascal, while the EXP calculations resulted in sporadic but mostly greater moduli than the ACI calculated (Table 6.4). Again, this was due to the poor quality of samples used in the testing. Samples with non-leveled and uneven surfaces caused uneven amounts of strain on either side of the sample and skewed the results of the EXP calculations. ACI and EXP calculations that were similar were due to a sample that was properly cast or leveled. Batches including recycled plastic averaged greater moduli than the control batch while D1 and D2 did not yield better moduli (Table 6.4).

6.3.4 Water Permeability Test

The rates of water absorption were higher for batches including recycled polypropylene as opposed to batches containing recycled high-density polyethylene (Table 6.5). It is reasonable to deduce from the data that mixing either recycled concrete or recycled plastic in the concrete reduces the rate of water absorption. Batches with recycled concrete performed similarly to batches without recycled concrete (Figures 6.1-6.9). Conversely, batches with recycled plastic performed similarly to batches without recycled plastic. If the mix design included recycled concrete or plastic, the test yielded a lower rate of water absorption (Figures 6.1-6.9).

CHAPTER 7

CONCLUSION

To reduce the amount of waste plastic and waste concrete being disposed of in non-environmentally friendly ways, this study explored the feasibility of mixing these two wastes into a new concrete mix design. The following conclusions may be made based on the results from this study:

1. The slump test found that the recycled concrete content made the mix less workable while the recycled plastic had little to no effect on the workability of the concrete. However, the negligible effect of recycled plastic can be attributed to the low percentage of recycled plastic content by volume.
2. The compression test had numerous inconsistencies due to low sample quality and the inconsistency in ages tested.
3. The modulus of elasticity test was able to give some insight to changes in the concrete durability properties. The calculations showed that batches including recycled plastic had greater moduli of elasticity. This means that mixes including recycled plastic content will likely have improved strength when cast and tested correctly. However, it also shows that batches including only recycled concrete likely do not have improved durability when compared to standard concrete.

4. Batches that included either recycled plastic and/or recycled concrete performed better than the control batch when tested for water permeability.

APPENDIX A

SAMPLE CALCULATIONS

Part A: Compressive Strength

The machine used outputted time in seconds and load in meganewtons.

Step 1: Find the maximum value of load using the MAX equation in excel.

For control sample c, at 25.9 seconds the load was 0.04758 meganewtons.

Step 2: Convert meganewtons into newtons.

To convert meganewtons into newtons, values were multiplied by 1,000,000. This converts 0.04758 meganewtons into 47580 newtons.

Step 3: Find area of sample using standard equation for finding the area of a circle.

Samples were 10.16 cm in diameter and therefore had a radius of 5.08 cm. Plugging 5.08 cm into the equation $area = pi * r^2$ the area of the samples were 81.03 cm^2.

Step 4: Convert area value from cm^2 to m^2

To convert cm^2 to m^2, values were multiplied by 1 x 10^-4. This converts the area of 81.02 cm^2 into 0.0081032 m^2.

Step 5: Divide the maximum value of load by area to get compressive strength in pascal.

Maximum load value of 47580 newtons divided by 0.0081032 m^2 gave a compressive strength of 5871747.41 pascals.

Step 6: Convert pascals to megapascals.

To convert pascals to megapascals, values were divided by 1,000,000. This converts the compressive strength from 5871747.41 pascals to 5.87 megapascals.

<u>Part B: Modulus of Elasticity</u>

The machine used outputted time in seconds, load in meganewtons, and deflection in mm.

Step 1: Convert load values in meganewtons to kips.

This was done by multiplying the meganewton values by 224.81.

Step 2: Average the two deflection values.

This was done using the standard average equation, (x+y)/2.

Step 3: Find strain values using the average deflection value.

To find strain from deflection, the average deflection value was multiplied by 10,000.

Step 4: Divide load value in kips by area in inches to find stress in kips.

The area used was 12.6 inches square and all load values were divided by 12.6.

Step 5: Use the ACI equation to find the ACI modulus of elasticity.

The below equation was used to find ACI MoE.

$$ACI\ MoE = \frac{57000 * \sqrt{(ultimate\ stress * 1000)}}{1000} \quad (1)$$

For control sample c, the ultimate stress was found to be 0.8489 kips. Using the equation, the ACI MoE was calculated at 1660.77 ksi.

Step 6: Use the EXP equation to find the EXP modulus of elasticity.

The below equation was used to find EXP MoE.

$$EXP\ MoE = \frac{S_1 - S_2}{\Sigma_1 - \Sigma_2} \quad (2)$$

Where:

$S_1 = ultimate\ load * 1/3$

$S_2 = stress\ @\ 50\ micro\ strain$

$\Sigma_1 = (micro\ strain\ @\ S_1) * 10^{-6}$

$\Sigma_2 = (50\ micro\ strain)\ * 10^{-6}$

For control sample c, the ultimate load was 10.70 kips. 1/3 of the value is 3.57 kips. The stress value at 3.57 kips was 0.2922 ksi. The stress value at 50 micro strain was 0.05567 ksi. The micro strain at 1/3 of ultimate load value was 1592.5. Using the equation, the EXP MoE was calculated at 153.38 ksi.

Step 7: Convert units from kilo pounds per square inch to megapascals.

To convert the values, both ksi values were multiplied by 0.68947529. This gave ACI MoE to be 11450.61 megapascals and EXP MoE to be 1057.52 megapascals.

Part C: Water Permeability

The test conducted gave the weight of the sample in pounds at time in seconds and minutes.

Step 1: Convert all pound values to grams.

To convert the values, all pound values were multiplied by 453.592.

Step 2: Convert all time into seconds.

To convert all of the time values in minutes to seconds, the time was multiplied by 60.

Step 3: Convert exposed are from cm^2 to mm^2.

From previous work it is known the area of the sample is 81.032 cm^2. To convert to mm^2, the value was multiplied by 100. This gave an area of 8103.21 mm^2.

Step 4: Average the values of grams between the two samples.

This was done using the standard average equation, (x+y)/2.

Step 5: Use the absorption equation to calculate absorption.

The below equation was used to calculate absorption.

$$I = \frac{m_t}{a*d} \tag{3}$$

Where:

$m_t = the\ change\ in\ specimen\ mass\ in\ grams\ at\ the\ time\ t$

$a = the\ exposed\ are\ of\ the\ specimen\ in\ mm^2$

$d = \left(0.001\frac{g}{mm^3}\right) the\ density\ of\ the\ water\ in\ g/mm^3$

Absorption was calculated at each time interval using the average mass in grams of the two samples.

Step 6: Plot against square root of time to find rate of water absorption.

The slope of the best fit line is the rate of water absorption.

APPENDIX B

DETAILED PROCEDURE

Part A: Procedure for Mixing Concrete Ingredients

Equipment: measured out ingredients, concrete mixer, masonry trowel, scoop, two dirty 5-gallon buckets, and a timer.

1. Add sand and coarse aggregate into the drum and turn on the mixer.
2. Let the ingredients mix for 1 minute.
3. Add approximately 1/3 of the total amount of water into the mixer while mixer is still running.
4. Let the ingredients mix for 1 minute, then turn off the mixer.
5. Add approximately ½ of the total amount of cement into the mixer and turn on the mixer.
6. Let the ingredients mix for 1 minute.
7. Add approximately ½ of the remaining water into the mixer while mixer is still running.
8. Let the ingredients mix for 1 minute, then turn off the mixer.
9. Add the remaining cement into the mixer and turn on the mixer.
10. Let the ingredients mix for 1 minute.
11. Add the remaining water into the mixer while mixer is still running.
12. Let the ingredients mix for 3 minutes.
13. Turn off mixer and use the handle of the mixer to pour the mix into the dirty 5-gallon bucket. Use a masonry trowel to scrape the inside of the drum to get as much of the mix as possible into the bucket then move to the side.

14. Use the hose to add about a gallon of water into the drum immediately after emptying out as much concrete mix as possible. Turn on the mixer to start the cleaning process.

<u>Part B: Procedure for Slump Test</u>

Equipment: slump cone, a plastic sheet/ garbage bag, a tamping rod, a scoop, release agent, and measuring tape.

1. Layout the plastic sheet or cut garbage bag on flat surface for testing.
2. Rinse off cone, tamping rod, and scoop.
3. Spray release agent on inside of cone and place in center of plastic sheet.
4. Place the bucket of cement mix from the mixer near the slump cone and grab the scoop.
5. Stand on the flanges at the bottom of the cone, straddling the cone.
6. Use the scoop to begin fill the cone approximately a third of the way full.
7. Use the tamping rod to tamp the layer 25 times uniformly over the cross section.
8. Continue filling up the cone another third of the way full.
9. Use the tamping rod again to tamp the layer 25 times. The rod should reach slightly into the previous layer but not the entire previous layer.
10. Fill the rest of the cone, making sure to add concrete above the mold before tamping to allow for consolidation.
11. Tamp the remaining layer using the same method as step 9.
12. Use tamping rod and roll over the top of the cone, leveling off the surface.
13. Make sure the bucket is clear of the slump cone.

14. Slowly step off the cone and lift the slump cone vertically.
15. Let the concrete settle, then place the cone next to the concrete, making sure the cone is flat on the ground.
16. Place the tamping rod over the top of the cone, hanging over the settled concrete. The tamping rod will then represent the top of the slump cone.
17. Use the measuring tape to measure the distance from the top of the settled concrete to the bottom of the tamping rod. This distance is the result of the slump test.

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BIOGRAPHICAL INFORMATION

Allison Fenske came to UT Arlington in Fall of 2018 and will be earning an Honors Bachelor of Science in Construction Management and an Honors Bachelor of Arts in Interdisciplinary Studies in Spring of 2022. At UT Arlington she was involved in a variety of programs, the most notable being the Peer Academic Leader program, Leadership Honors Program, Honors College, and McNair Scholar's program. Allison was able to create two interlocking but separate senior projects for the Honors College and completed both a semester early. In Fall of 2022 she will be attending a graduate school with the intent of earning a doctorate in philosophy in a field related to environmental engineering. Her research interests lie within the field of sustainable construction with a specialization in life cycle assessment and sustainable alternatives to construction materials. During graduate school she hopes to continue to teach undergraduate students and continue to be involved in a variety of research projects. After completing her graduate schooling, she intends to stay in academia to take her research further and teach about sustainable construction practices.