Compressive Strength Analysis of Mortar Mixes Consisting of Recycled Plastics

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Abstract- In an effort to find new ways to minimize the amount of plastic waste the Virginia Military Institute sends to local landfills, a research project was performed to determine the viability of using recycled plastics as a fine aggregate in standard mortar mixes. The recycled plastics were collected, sorted by type, melted, shredded, batched into a standard mortar mix, and tested to determine the compressive strengths of the resulting mixes. Several testing procedures were developed in order to replace 25% of the fine aggregate by volume. On average, the mixes produced from the varying plastic types maintained roughly 55% of the compressive strength of a standard control mix. These compressive strengths are in line with previous research and show that it may be possible to use mixes produced from recycled plastics for systems that require lower strength concrete. This could ultimately minimize the amount of plastic waste in landfills.

Keywords: Recycled plastics, Mortar Mixes, Sustainability.

Introduction

Over the past several decades, household recycling has increased in the United States, but a large portion of recyclable materials still ends up in landfills. According to the Environmental Protection Agency (EPA), in 2010 Americans produced over 250 million tons of trash, and recycled or composted over 85 million tons of this material. While a 34% recycling rate looks good when compared to the 16% recycling rate of 1990, Americans still sent roughly 136 million tons of trash to landfills in 2010 [EPA, 6]. Roughly 1 million tons of plastic Polyethylene Terephthalate (PET) water bottles were produced in the U.S. in 2006 and 76.5% of these bottles ended up in landfills [GAO, 8].

Not all plastics can be recycled and must be sent to landfills. Additionally, recycling centers are often at capacity for various reasons, and are forced to send plastics to landfills. When plastics are put into landfills, they are compacted and covered with dirt. Because the plastics are shielded from sunlight, the already lengthy decomposition process is greatly extended.

According to South Carolina’s Office of Solid Waste Reduction and Recycling, when rainwater and other liquids leech through the layers of waste they collect contaminates. Landfills are required to collect and treat any liquids that leech through the layers of waste [Office of Solid Waste Reduction, 9]. Currently, EPA regulations require landfills to be monitored and the leachate be treated for 30 years after being closed [EPA, 7]. Plastics will continue to degrade and produce contaminates long after 30 years, creating an unaddressed environmental concern.

The Virginia Military Institute (VMI) Concrete Canoe team used recycled plastic (PET) bottles to produce a successful concrete mix in 2011. Based on this success the research team decided to investigate the possibility of using recycled plastics as a fine aggregate in a standard mortar mix. The compressive strengths of the mortar mixes containing plastics were compared to the compressive strengths of three different standard mixes. The overall goal

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was to determine the feasibility of further research involving recycled plastics in cement/mortar/concrete mixes in order to create a greater demand for recycled plastic.

Research was funded by the Summer Undergraduate Research Institute (SURI) at VMI with the purpose of fostering students through a ten-week research project. Students seek out a faculty mentor that will guide them through the application, research, and presentation processes. In addition to a faculty mentor, students were required to attend weekly forums consisting of all students, regardless of discipline, in SURI. These weekly meetings served as a peer support group that addressed research progress, current events, and other valuable topics. The resources provided by SURI allowed students to overcome any intimidation or fear that can be experienced when taking on large research projects and simultaneously opened their eyes to the endless possibilities that the world of research can provide.

Identification

Table 1: Resin Identification Code (RIC)

Plastic Identification Code	Name of plastic	Description	Some uses for virgin plastic	Some uses for plastic made from recycled waste plastic
1 PETE	Polyethylene Terephthalate *PET*	Clear, tough plastic, may be used as a fiber.	Soft drink and mineral water bottles, filling for sleeping bags and pillows, textile fibers.	Soft drink bottles, (multi- and mono-layer) detergent bottles, clear film for packaging, carpet fibers, fleecy jackets.
2 HDPE	High Density Polyethylene *HDPE*	Very common plastic, usually white or colored.	Crinkly shopping bags, freezer bags, milk and cream bottles, bottles for shampoo and cleaners, milk crates	Compost bins, detergent bottles, crates, mobile rubbish bins, agricultural pipes, pallets, curbside recycling crates.
3 V	Un-plasticized Polyvinyl Chloride *UPVC*	Hard, rigid plastic: may be clear.	Clear cordial and juice bottles, blister packs, plumbing pipes and fittings.	Detergent bottles, tiles, plumbing pipe fittings.
	Plasticized Polyvinyl Chloride *PPVC*	Flexible, clear, elastic plastic.	Garden hose, shoe soles, blood bags and tubing.	Hose inner core, industrial flooring.
4 LDPE	Low Density Polyethylene *LDPE*	Soft, flexible plastic.	Lids of ice-cream containers, garbage bags, garbage bins, black plastic sheet.	Film for builders, industry, packaging and plant nurseries, bags.
5 PP	Polypropylene *PP*	Hard, but flexible plastic - many uses.	Ice-cream containers, potato crisp bags, drinking straws, hinged lunch boxes.	Compost bins, curbside recycling crates, worm factories.
6 PS	Polystyrene *PS*	Rigid, brittle plastic. May be clear, glassy.	Yogurt containers, plastic cutlery, imitation crystal 'glassware'.	Clothes pegs, coat hangers, office accessories, spools, rulers, video/CD boxes.
	Expandable Polystyrene *EPS*	Foamed, lightweight, energy absorbing, thermal insulation	Hot drink cups, takeaway food containers, meat trays, packaging.	
7 OTHER	Other	Includes all other plastics, including acrylic and nylon.		

The varying plastic types are marked with an identifier as described in ASTM D7611 [ASTM, 4]. This publication details the size, shape and placing requirements of the Plastic Identification Code (PIC)/ Resin Identification Code (RIC) on plastic products. Each plastic is coded by its chemical composition. Descriptions and common uses for each plastic type can be found in Table 1 [Recycling and Resource Recovery Council, 10].

Collection

After making contact with the managers of Aramark, the company commissioned to provide campus-wide catering services for VMI, the research team established a recycling collection point in Crozet Hall, VMI's main dining facility. Aramark managers instructed their employees to place unclean plastic waste generated by food preparation at the designated collection point. The employees were helpful and willing to assist with the project. The most common plastics discarded at Crozet Hall were plastics labeled with the #2, #4, #5, and #7 Resin Identification Codes. As often as the collection point reached capacity, the plastics would be collected and pre-washed for future use. In order to find a source for plastics labeled with RICs #1, #3 and #6, researchers contacted VMI Physical Plant Engineer MAJ Jennifer deHart. With her approval, the recycling collection points in the concession rooms of Barracks (student housing) were mined for additional plastics. Only plastics labeled with RICs #1 and #6 were collected from Barracks.

After three weeks of collection, researchers decided not to include any plastics labeled with RIC #3, Polyvinyl Chloride, in the test materials. In addition to the hazard due to inhalation of Polyvinyl Chloride [Thompson, 12], waste of this type is not largely produced on campus. Because researchers want to determine alternate uses for plastic waste produced by a certain population (VMI), the decision was made to not seek alternate sources of plastics labeled with RIC #3. Figure 1 shows one type of plastic collected.

Figure 1: Collected plastics, RIC #2, HDPE.

Cleaning

Researchers wanted to maintain the theme of sustainability when exploring cleaning options. When researchers observed how much food waste was left in the plastics, researchers were presented with the challenge of properly disposing the food laden waste water. After discussing these concerns with MAJ deHart, researchers decided the cleaning process needed to take place in Crozet Hall. In addition to a grease entrapment system incorporated into the plumbing that allowed for proper disposal of food waste, Crozet Hall has a mop room with a hose that delivers 150°F water from a high pressure. While more energy intensive than originally hoped, this process ensured that all food waste was removed which eliminated the chance of mold growth on the plastics while being stored prior to the melting process. The necessity for clean plastics was essential to provide accurate and consistent data throughout the testing process. These facilities were used throughout the duration of the cleaning phase.

Sieve Analysis of Sand

The research team decided to use standard concrete mixing sand for the mortar mixes. Sand used in the production of standard mortar mixes should meet specifications as outlined by ASTM C33-02 [ASTM, 1]. This test defines what is considered "standard sand" by allowable passing percentages per sieve number. Refer to Table 2 for allowable passing percentage as outlined in C33-02.

Table 2: Fine Aggregate Grading Limits

Sieve (Specification E 11)	Percent Passing
9.5 mm (3/8 in.)	100
4.75 mm (No. 4)	95 to 100
2.36 mm (No. 8)	80 to 100
1.18 mm (No. 16)	50 to 85
600 µm (No. 30)	25 to 60
300 µm (No. 50)	5 to 30
150 µm (No. 100)	0 to 10

After performing a sieve analysis of the sand provided, researchers observed that it was finer than the specifications outlined by ASTM C33-02, even though the bag was marked as meeting these requirements. To ensure accuracy of the first test, researchers performed an additional sieve analysis test. Again, researchers observed that the sand was finer than that outlined in ASTM C33-02. Given that the discrepancies were minor, researchers determined the sand would be sufficient for the series of tests being performed as long as the same sand was used for the standard mixes and all subsequent experimental mixes. With that provided that, researchers would be able to accurately compare the overall compressive strengths.

Shredding

When discussing shredding options, researchers agreed upon the importance of producing a product that was consistent in size and shape, regardless of plastic type. Initially, researchers investigated the possibility of using large scale machinery that had the ability to produce the desired product. After attempting to coordinate the use of a large scale granulator at a Northwestern Virginia plastics manufacturing company, researchers had to rule out this option due to scheduling conflicts. Although further attempts to coordinate the use of a large scale granulator would have provided researchers with insight to how the process works, they decided against it with the goal of determining a smaller, more sustainable solution.

With hopes of being able to perform the shredding process on campus, researchers investigated the possibility of using an average, home use, cheese grater. The initial tests yielded a promising product but the process was not efficient. Due to the shape of plastic containers, high volume shredding was greatly limited, and resulted in too great of a time commitment. Researchers determined it was necessary to alter the shape of the plastics in order to maximize surface area of the plastics on the grater. After experimenting with several different ways of manipulating the shape, the attempts to produce satisfactory amounts of shredded plastic were still ineffective.

The need for a solid piece of plastic was evident, so researchers decided to experiment with the possibility of melting the plastics into a tin can, which was used as a mold. Using the sorted plastics, each type was cut into pieces small enough to fit into a tin can. The first attempt at melting was performed on an outdoor grill. This proved promising, as the heat provided by the grill melted the plastic down in a tin. When observing the solid plastic cylinder produced by the heat of the grill, researchers decided to use a heat source that did not produce a flame. On the grill, the plastic would occasionally catch fire prior to melting. This was caused by the difficulty of controlling the temperature and flame height of the grill. By using a heat gun, researchers were able to melt the plastics without the risk of fire. This produced a much cleaner and usable solid plastic cylinder. While creating solid cylinders of each different plastic type, researchers observed variations in melting temperatures. Further research proved this fact. According to Dynalon, a supplier of educational supplies, plastics labeled with RICs #2, #4, #5 and #6 could be melted using the ovens in the lab [Dynalon, 5]. These ovens made the process much more efficient as researchers were able to perform other tasks in the lab while simultaneously melting the plastics into the molds [Figure 2].

Once completing the melting process, researchers used a hand held grater to shred the plastics into a collection bowl. This method was slow but produced the desired shape and size of plastic necessary for the use in a mortar mix [Figures 2 and 3]. As researchers spent large amounts of time hand grating the plastics; the issue of sustainability became quite obvious. This process created a large demand for extremely time consuming, rigorous physical labor. Hand grating would work for the testing process, but this issue really interested researchers and motivated them to explore more efficient methods.

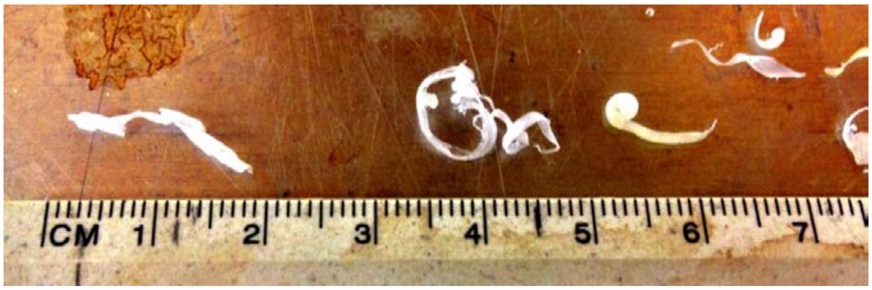

Figure 2: Size of shredded plastic, Type #7, other

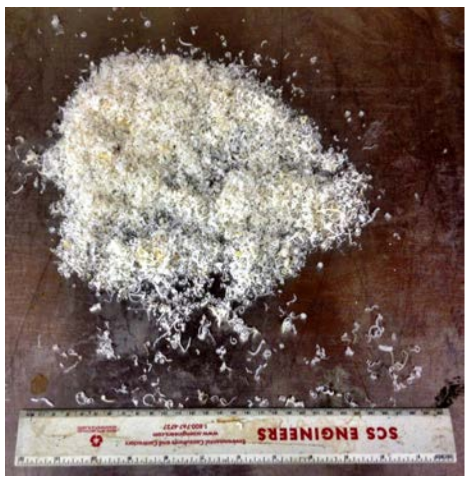

Figure 3: Shredded Plastic, Type #7, Other

Researchers investigated industrial size cheese graters to determine if one would be cost beneficial to the research process. Although this was not the case, researchers were able to emulate the function of an industrial grater. To do this, researchers drilled a 3/8 inch hole through the center of a plastic cylinder. A 1/2 inch bolt was fitted with a nut and washer before it was inserted into the cylinder. Once the bolt was threaded through the center of the cylinder, another washer and nut were threaded onto the bolt. The opposing nuts were securely tightened towards the center of the cylinder. This created a plastic cylinder that rotated symmetrically around an axis. Once the bolt was secured to the cylinder, the end of the bolt was secured into a power drill, just as a drill bit would be. The power drill provided the power needed to move the cylinder at a high RPM. After attaching a box grater to a table mounted vice, researchers were able to apply pressure to the spinning cylinder as it made contact with the grater. This action mimicked that of hand grating, but at a much faster pace. This procedure greatly increased the efficiency of the grating process.

Replacement

Once researchers had all the material that was to be added to the varying mortar mixes, the research team needed to determine the most consistent way to replace the fine aggregate (sand) of a standard mortar mix with the shredded plastic. After weighing out several samples of different plastics types, researchers determined that if they were to replace a portion of the sand with an equal weight of each plastic type, they would be adding largely different volumes of plastic to each mix. For example, plastic labeled with RIC #7 is far denser than RIC #6. To replace 20 grams of sand with 20 grams of each type of plastic would create one mix with a volume of RIC #6 far greater than the volume needed to add a similar weight of plastics labeled with RIC #7. With this knowledge, researchers decided to replace the sand with the recycled plastics by the “Absolute Volume Method.” With this method; when removing 250cm^3 of sand, researchers would replace the same volume (250cm^3), regardless of plastic type. In order to do this, the density of both the sand and varying plastic types needed to be determined. While some of this information is available in various sources, researchers were unsure what chemical changes were made by the melting process. It was necessary to know the density of the varying plastic types in the state at which they would be added to the cement mix.

Researchers used ASTM C128-01 [ASTM, 3], “Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate,” and were able to determine the relative density (specific gravity) of the sand. This test method was designed for, and works well with sand, which was found to have a relative density of 2.53 g/cm^3, but it proved to be far less effective with plastic. Because plastic is less dense than water, it caused the shredded plastics to float in water. This was problematic in finding the submerged sample weight as required by the test. Using ASTM C128-01 as a model, the researchers experimented with several different ways to take similar measurements as those required by the test.

In order to achieve a weighable submerged sample of the varying plastic types, researchers used a French-Press coffee maker. The screen in the French-Press kept the plastics submerged, but due to the diameter of the press, uncontrollable inconsistencies arose. In order to take a submerged weight of plastics, the press was filled strictly with water to a calibration mark and weighed. The water was then removed and the plastics were added and the press was then again filled to the calibration mark and weighed. The difference in weight would be the submerged weight of the plastics. The area of the press was so large that while the press would be filled to the calibration mark, differences of ± 5-10 grams in weight were noticed. The human eye is not keen enough to notice these minute changes in the volume. Though the French-Press was able to keep the plastics submerged, researchers needed to minimize uncertainty in the data. To do this, researchers used a 250mL Erlenmeyer flask and a number 6 stopper with a 1/8 inch hole drilled through its center. The plastics were added to a dry flask which was then filled within roughly 5mL of capacity. Next, the stopper was added to the flask and was pressed into place by a 20 lb. weight. This ensured that the stopper was fitted with the same pressure each time the test was performed. Any excess water would displace and the flask would then be weighed. The difference in this weight and the weight of a flask filled strictly with water determined the submerged weight. This method provided a much more consistent set of data. With this data, researchers were then able to determine the density of the different plastic types. See Table 3.

Table 3: Material Densities

Plastic Type (#)	#1	#2	#4	#5	#6	#7
Average Density (g/cm^3)	1.087	0.683	0.658	0.583	0.048	0.834

Using the equation for density: Density =mass/volume, researchers were able to determine what volume 25% of the required weight of sand occupied. Likewise, researchers were able to take the volume of sand being removed and determine the weight of each plastic that would be needed to occupy the same space. This method is known as the “Absolute Volume Method.” This data dictated the mix ratios for each batch, shown in Table 4.

Table 4: Material Amounts per Batch (Design and Actual)

Mix Ingredient	Cement (g)	Plastic (g)	Sand (g)	Water (g)
Plastic #1	500.00	147.67	1031.30	282.10
Plastic #2	500.00	92.78	1031.30	282.70
Plastic #4	500.00	89.36	1031.30	282.60
Plastic #5	500.10	79.49	1031.30	282.60
Plastic #6	499.90	6.57	1031.30	282.00
Plastic #7	500.00	113.34	1031.30	281.60
Standard Sand 1	500.00	0.00	1375.20	294.60
Standard Sand 2	500.00	0.00	1375.00	294.60
Standard Sand 3	500.00	0.00	1375.00	282.70

Mixing

Before mixing, each of the different mix ingredients were measured out and stored in separate containers until they were ready to be added to the mixer. It was important to ensure that the stainless steel mixing bowl was wiped down with a wet rag prior to adding any ingredients. This ensured no water content was taken from the mix. The sand and the cement were added first to the mixing bowl and mixed for one minute. This allowed the sand and the cement to be mixed evenly. Next, the plastic was added to the mixing bowl where it was mixed for another minute. Once the sand, cement, and plastics (if needed) were mixed, the water was added while the mixer was in the "on" position where it mixed for three minutes.

After the mixing process was complete the mortar mix was added into the molds in two different lifts. In the first lift, the cube mold was filled roughly halfway with the mortar mix before it was tamped (packed) down 32 times per cube as per ASTM C109-11b [ASTM, 2]. The second lift was added and the tamping process repeated. The tops of the molds were finished using a trowel prior to the mold being labeled and placed in a curing room, where it was covered with wet burlap. The wet burlap provided the cubes with moisture, allowing the cement to fully hydrate. This process is what allowed the cement to bond with the other ingredients. Six cubes were made for each mix. Three standard mixes (no plastic) and six plastic mixes were made.

Breaks

Each different mortar mix was aged in a curing room. After 24 hours in the molds, the cubes were weighed, marked with their identification code and four of the cubes were returned to the curing room to continue the aging process. The two cubes that were left out would be tested to determine their compressive strength using a compressive strength test machine. This test is referred to as "breaking." This process was repeated on days 3 and 28 of the aging process. Throughout the aging process, the cubes sat covered with wet burlap in the high moisture curing room. The cement would continue to hydrate and gain strength for the duration of the aging process. When the breaks were performed the following data was collected: Max Load, Compressive Strength, and Load Rate. This data was all compiled into spreadsheets along with initial and aged cube weight, for easy comparison to the varying mixes. Break strengths were similar to data collected by previous researchers [Soroushian, 11]. Figure 4 shows the compressive strengths for the different ages. Figure 5 shows the percent of the compressive strength of the standard mortar mix reached for each different plastic type.

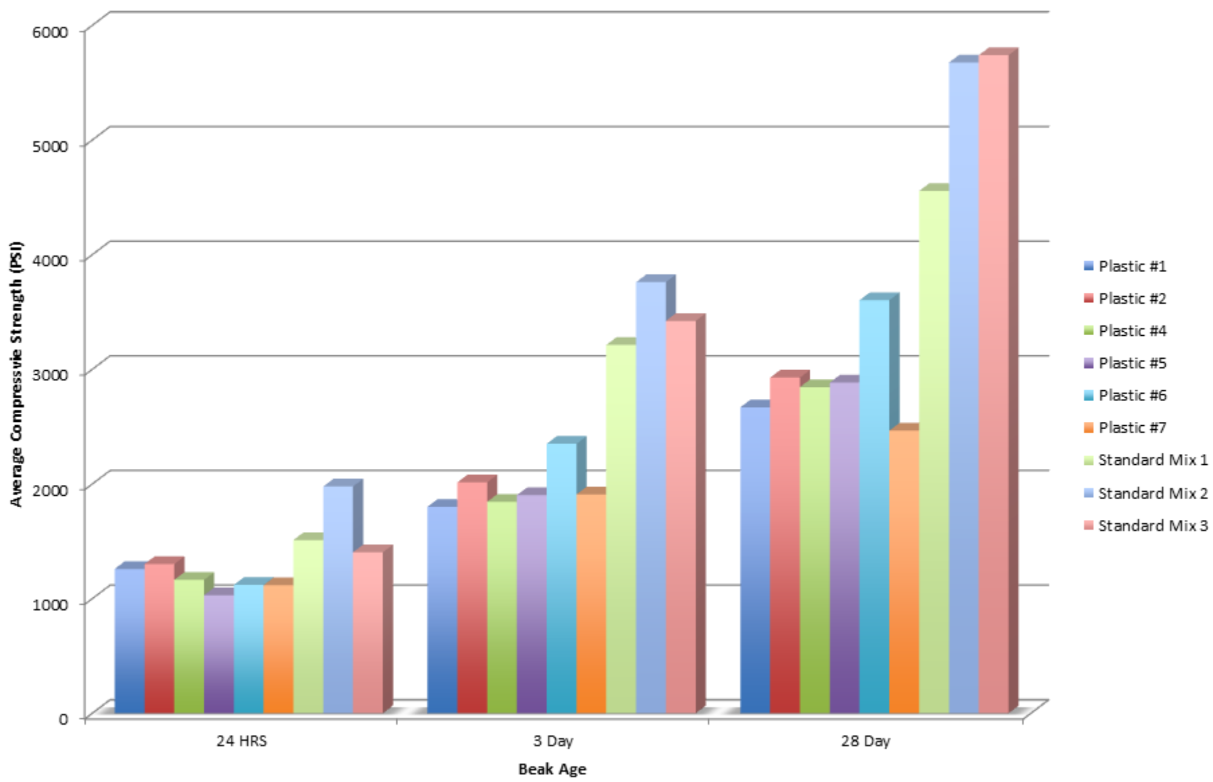

Figure 4: Comparison of Compressive Strengths

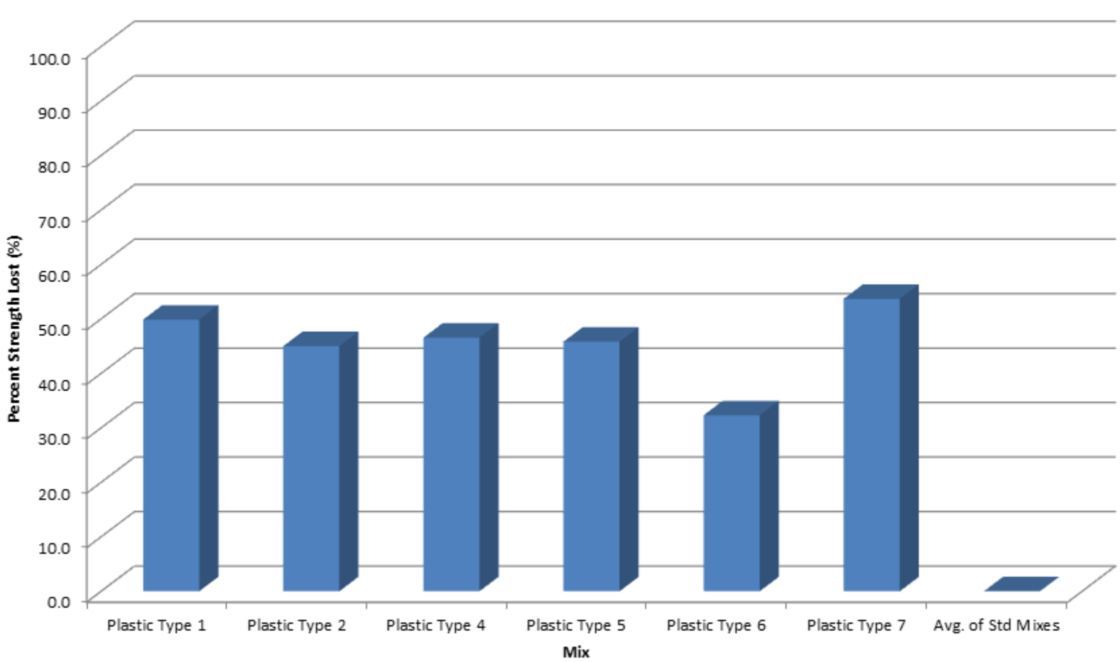

Figure 5: Percent Compressive Strength

Conclusions

In conclusion, the percent loss of standard compressive strengths was typical of previous research involving the use of recycled plastics in concrete. Although other research incorporated mixed plastics as the coarse aggregate, their compressive strength loss of roughly 52% of the control was similar to what was observed in this research [Soroushian, 11]. As an average, the varying plastic types used as a fine aggregate lost 45.55% the compressive strength of the control mixes, with the extremes being plastics labeled with RIC #3 losing only 32.2% compressive strength and plastics labeled with RIC #7 losing 53.7% compressive strength. Further research needs to be performed to determine a strength reduction curve with respect to the amount of recycled plastics used as a fine aggregate.

Only by means of visual observation, the cement bound better to the softer plastics than the harder, denser plastics. Further research should be performed in order to determine various methods increase bond strength between smooth, dense plastics and the cement interface.

One conflict researchers experienced over the duration of the mixing phase was discrepancies with proper water content. When comparing water content of the standard mixes to their respective compressive strengths, researchers discovered that variations in water content had a direct impact on compressive strength. The plastic mixes seem to demand larger water content than researchers anticipated. Further research is needed to determine the ideal amount of water in each mix to maximize its compressive strength potential.

While a compressive strength loss of 45% may seem too significant to qualify it for any practical use, this is not the case. Since the mortar cubes maintained 55%, on average, of their compressive strength, this qualifies them for use in a number of low strength applications in addition to several building construction applications. As highlighted by Parviz Soroushian, and Roz-Ud-Din Nassar, the plastics improve the thermal qualities of traditional concrete [Soroushian, 11], making concrete containing portions of recycled plastics ideal for concrete home construction.

While the results of this research justify further investigation into the use of recycled plastics in concrete, the research team aims to keep minimizing plastic's environmental implications in the forefront of their research efforts. It is important to design a product whose production does not create a larger impact than the current procedures. These baseline tests give researchers a place from which to move forward. Now that many of the initial testing procedures and road blocks have been addressed, researchers may focus their energy on finding solutions to specific issues that arose during this primary research phase.

At the end of the ten-week research period, SURI students were required to submit a research paper in addition to a presentation of their findings. Not only was this a valuable lesson in public speaking but also taught students how to take a technical paper and transform it into a comprehendible idea that others can understand. By attending other SURI presentations, students were able to see research from the perspective of both the presenter and the audience. As a whole, SURI gave students the opportunity to step outside of their normal undergraduate studies and experience the realm of research through a support, engaging, and fulfilling program.

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