Substituting Plastic Fibers into Concrete

Civil Engineering MQP

March, 2021

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Substituting Plastic Fibers into Concrete

A Major Qualifying Project (MQP) Final Report
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements
for the Degree of Bachelor of Science

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March 2021

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Abstract

This project was completed with the goal of determining if plastic could be added to concrete as a means to recycle it in a safe manner. The idea was to incorporate the three most commonly used plastics in the United States as fibers. After months of research, a concrete mix design was created with the addition of the plastic fibers. The characteristics of the concrete were then determined through multiple tests and compared to a standard concrete control sample.

Acknowledgments

We would like to thank the following people for their support of this project:

Our advisor, **Associate Professor Aaron Sakulich**, for his guidance and support.

Also, to **Russell Lang** for allowing us to work with the Civil and Environmental Engineering department's machines and lab equipment as well as assisting us in the mixing and testing of concrete.

Authorship

Daniel Botelho contributed to the background, created all of the data sheets and graphs, as well as editing the entire report.

Zachary Burns contributed to the abstract, executive summary, introduction, methodology (section 3.2.5) results (section 4.1 & 4.5), as well as editing the entire report.

Rowena Sullivan contributed to the methodology (sections 3.1-3.2.4), the results (sections 4.1-4.4), the conclusion (sections 5.1-5.2), the design statement, and the licensure statement, leading the mixing and testing procedures, as well as editing the entire report.

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Executive Summary

One of the most prevalent problems societies face today is plastic pollution. Plastic is found in large quantities all over the world as it is very cheap to mass produce. The problem with this is that, depending on the type of plastic, is that it can take 400 to 1000 years to biodegrade. (Ritchie, 2018) Plastic pollution has drastically impacted wildlife and oceans to the point where it is nearly impossible to walk on the beach without coming across several water bottles. In 2015, the world produced 7.8 billion tons (6.96 x 10^9 imperial tons) of plastic waste which has affected wildlife in terrible ways such as indigestion and entanglement. It is estimated that at least 26 marine mammal species and 15 marine species have ingested plastic debris. (Silver Spring, 2014) While plastic pollution is a problem throughout the world, the United States contributes more than ten times to this phenomenon when in comparison to a country such as India. (Ritchie, 2018) This is relevant as India's population is over 700 million more than the United States.

The plastic types discussed in this report (polyethylene and polypropylene) are non-biodegradable and cannot easily be degraded by microorganisms. (Tokiwa et al., 2009) Since the waste that is produced does not degrade easily, it accumulates in the environment. There are multiple types of plastic waste, dependent on their size. The focus of this report is on mesoplastics (plastic pieces between 1-25 mm (0.039-0.98 inches) in size), and to some extent macroplastics (plastic pieces larger than 25 mm (0.98 inches)). (Kosior, 2020) The fibers used are in the mesoplastic range, while the sources of these fibers (straws, shopping bags and plastic wrap) are macroplastics. Regardless of their difference in size, these waste plastics enter the environment in similar ways, largely through littering and spills at waste management sites. (Kosior, 2020)

The goal of this project was to provide a solution that could potentially decrease the amount of plastic pollution that escapes into the environment harming ecosystems and wildlife. To do so, plastic waste was cut into fibers that can be used in concrete mixtures. The most common types of plastic waste are Low-Density Polyethylene (grocery bags), Polypropylene (straws), and Linear Low-Density Polyethylene (plastic wrap). These three specific types of plastic contribute roughly 90% of the world's plastic pollution. (LI, et al.) These three plastic types were mixed into concrete batches and put through experiments such as slump, hammer-pulse, tensile, and flexural tests to determine if this is a viable way to recycle plastic without deteriorating the strength and composition of concrete.

Before the different tests could start being performed, the samples had to be made. The materials that were used to make the concrete were: cement, coarse and fine aggregate, water, air entraining additive (A.E.A), and water reducer. To begin with, all the materials were weighed out into separate buckets. The amounts used are shown in table 1. The A.E.A and the water reducer were then added to the water and the coarse and fine aggregate were combined. The slump test was then performed on the mixture before it was scooped back into a bucket. Depending on the mix, an amount of plastic fibers were then added and the concrete was mixed for another minute. The amount of fibers added to each mix are listed below.

Table 1: Plastic fibers added to each sample.

Mixture	Fibers Added	Mixture	Fibers Added
Control Mix (C)	None	LLDPE Med Mix (LM)	94
HDPE Low Mix (HL)	16	LLDPE High Mix (LH)	218
HDPE Med Mix (HM)	67	PP Low Mix (PL)	19
HDPE High Mix (HH)	157	PP Med Mix (PM)	57
LLDPE Low Mix (LL)	31	PP High Mix (PH)	134

The slumps measured from a range of 8.5 inches to 10.5 inches. The average of all total samples was 9.85 ± 0.634 inches (25.02 ± 1.6 centimeters). This showed that all of the concrete mix designs were very similar in proportion when it came to water, concrete, fine aggregate, coarse aggregate, and plasticizer. The rebound hammer test provided a rapid indication of the compressive strength of the concrete and is used to help assess the uniformity and quality of the concrete. Concrete with low strength and low stiffness will absorb more energy to yield a lower rebound value. (Mishra, n.d.) The concrete cylinders had comparable results to the control sample. These similar hammer values imply that the different concrete cylinders had similar strength. All of the samples had an average rebound number of < 20, which means they all have relatively low compressive strength. The ultrasonic pulse velocity test is a non-destructive test used to assess the homogeneity and integrity of concrete. From this test, the Young's modulus for each sample was calculated. The results are shown in Figure 1 below.

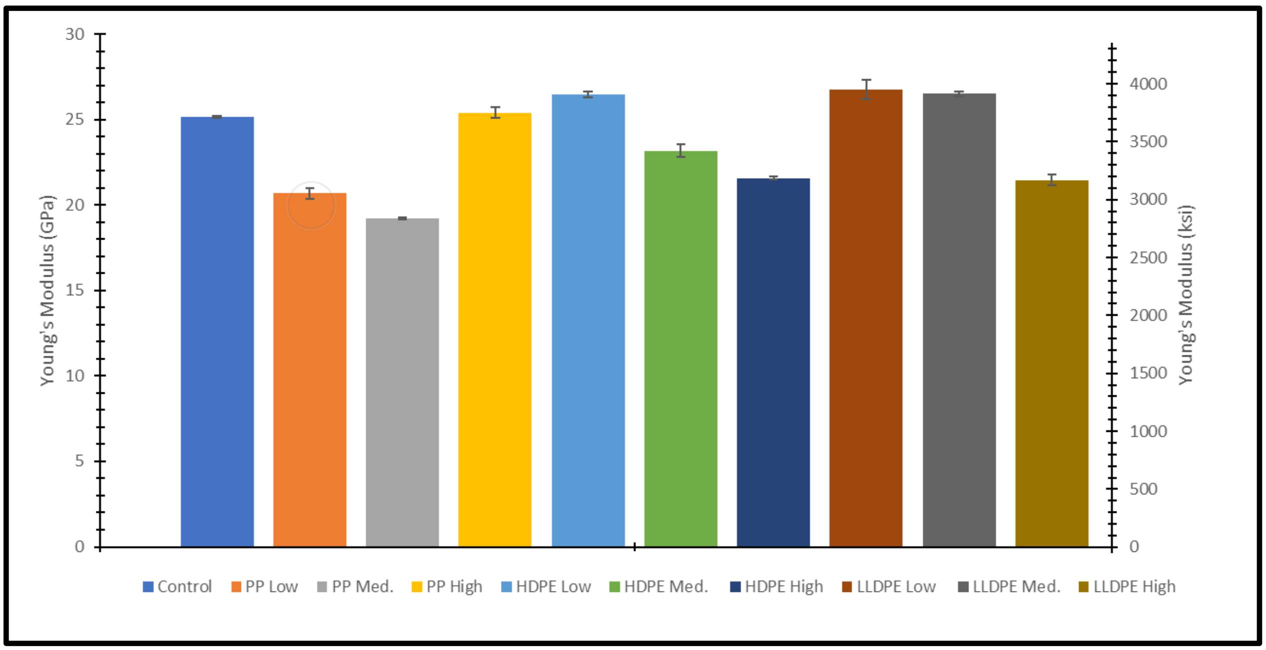

Figure 1: Average Young's modulus for all samples.

The splitting tensile strength test involves applying a diametral compressive force along the side of a cylindrical concrete sample to induce stress on the length of the specimen and is used to evaluate the shear resistance that the concrete provides. (ASTM C496, 2017) After looking at the results, it is clear that the straws held up better than the other types of plastics, almost matching the results of the control sample. PP low had the highest strength average out of all of the samples and PP overall performed the best compared to the plastic bags and wrap. The straws are more durable and rigid compared to the other plastic. This may have resulted in a better substance for the concrete to hold onto when curing. Since plastic bags and wrap can be easily crushed or deformed, they did not act how normal fibers would when in the concrete. This led the team to speculate as to why they were so easily crushed during the mixing or pouring process while the straws held their shape even after the concrete cylinders were crushed.

The results prove that plastic can be put into concrete to be both a viable material as well as a way to dispose of plastic. Looking at PP high and HDPE low, the averages are very similar to that of the control. This proves that with a few more trials, the most efficient amount of plastic can be found that allows the concrete to still be strong while still containing a large amount of plastic. Even though the amount of plastic used in this experiment was small, if these practices were implemented into the real world, it could still make a huge difference.

This experiment encountered multiple challenges during its duration. Some of these problems were due to the pandemic. Other problems were due to the team or other unforeseen issues faced during the experiment. Some examples include finding lab time around other project teams, a limited curing period due to a seven-week term, Covid restrictions, and lab equipment malfunctions. In any case, the following are important recommendations for those in the future who wish to continue this project. The first recommendation is to allow the concrete to cure for longer. There is a chance that the concrete in this experiment was not allowed to cure for long enough, causing it to be weaker. For future experiments, it is recommended that the concrete be set to cure for about a month before demolding it and performing any tests on it. For this experiment, the specimens were cured for 7 days, which partially cures it and makes the concrete strong enough to withstand traffic from vehicles and other equipment. However, 28 days allows the concrete to be more fully cured and probably would have resulted in stronger splitting tensile test results. (Palmer, 2020) In addition to different tests being conducted, more plastic should be added to the specimens in the future. A small percentage of plastic was added to these specimens, which allowed for knowing how proportionally sound the mixture was as well as giving preliminary results of what the quality of the concrete was with the plastic in it. But putting more plastic in the concrete would show how much can be put in before greatly decreasing the quality of concrete, making it useless. Once the maximum amount of plastic is found, then this practice can become widespread, allowing plastic to be added in more concrete, reducing the amount of plastic in the world.

Chapter 1: Introduction

One of the most prevalent problems societies face today is plastic pollution. Plastic is found in large quantities all over the world as it is very cheap to mass produce. The problem with this, depending on the type of plastic, is that it can take 400 to 1000 years to biodegrade. (Ritchie, 2018) Plastic pollution has drastically impacted wildlife and oceans to the point where it is nearly impossible to walk on the beach without coming across several water bottles. In 2015, the world produced 7.8 billion tons (6.96×10^9 imperial tons) of plastic waste which has affected wildlife in terrible ways such as indigestion and entanglement. It is estimated that at least 26 marine mammal species and 15 marine species have ingested plastic debris. (Silver Spring, 2014) While plastic pollution is a problem throughout the world, the United States contributes more than ten times to this phenomenon when in comparison to a country such as India. (Ritchie, 2018) This is relevant as India's population is over 700 million more than the United States.

High-income countries like the United States have tried to adopt effective waste management systems. While some plastic waste is recycled, reused or repurposed, the majority is usually kept in secured landfills away from bodies of water where possible runoff could become a problem. (Ritchie, 2018)

In 2019, roughly four billion tons (3.57×10^9 imperial tons) of cement were produced. Concrete is such a vital part of the United States infrastructure that even partial replacement of plastic waste fibers in these mixtures would have a great impact. Adding fibers to concrete has been a concept for thousands of years where builders used to use horse hair or straw to reinforce their building materials. (Illston, 1994) Mixing fibers in concrete can increase durability, control cracks and creep, and even reduce slump.

The goal of this project is to provide a solution that could potentially decrease the amount of plastic pollution that escapes into the environment harming ecosystems and wildlife. To do so, plastic waste was cut into fibers that can be used in concrete mixtures. The most common types of plastic waste are Low-Density Polyethylene (grocery bags), Polypropylene (straws), and Linear Low-Density Polyethylene (plastic wrap). These three specific types of plastic contribute roughly 90% of the world's plastic pollution. (LI, et al.) These three plastic types were mixed into concrete batches and put through experiments such as slump, hammer-pulse, tensile, and flexural tests to determine if this was a viable way to recycle plastic without deteriorating the strength and composition of concrete.

Chapter 2: Background

Despite the benefits of plastic, their widespread use has become a cause for concern over the past decades. Plastic has become ubiquitous since the beginnings of mass plastic production in the 1950s, and its production has increased consistently and massively, with 50 million metric tons being produced worldwide in 1976, and 368 million metric tons being produced in 2019 (49.2 and 362.2 imperial tons, respectively). (Kosior, 2020) (Garside, 2020) Most commonly used plastics, especially single-use plastic products, are intended to be disposable, and as such the world produces an extraordinary amount of plastic waste. Plastics intended for packaging and other disposable products account for one third of all plastic used in the United States and Europe. (Gewert et al., 2015) In 2018, the United States alone generated 3.5 million tons of plastic (3.55 metric tons), accounting for ~12% of all municipal solid waste. The majority (~75%) of this waste was sent to landfills, and this is the major issue regarding the use of plastic: the accumulation of plastic waste in the environment. (EPA, 2020) The 75% of plastic waste that was sent to landfills in the U.S. did not have a unique fate, as most plastic worldwide is sent to landfills-one study found that ~60% of all plastics ever produced have been sent to landfills. (Geyer et al., 2017) Most commonly used plastics are non-biodegradable, which refers to the breakdown of materials in the environment by microorganisms. (Poznyak et al., 2018)

The plastic types discussed in this report (polyethylene and polypropylene) are non-biodegradable and cannot easily be degraded by microorganisms. (Tokiwa et al., 2009) Since the waste that is produced does not degrade easily, it accumulates in the environment. There are multiple types of plastic waste, dependent on their size. The focus of this report is on mesoplastics (plastic pieces between 1-25 mm (0.04-0.2 in) in size), and to some extent macroplastics (plastic pieces larger than 25 mm (0.2 in)). (Kosior, 2020) The fibers used are in the mesoplastic range, while the sources of these fibers (straws, shopping bags and plastic wrap) are macroplastics. Regardless of their difference in size, these waste plastics enter the environment in similar ways, largely through littering and spills at waste management sites. (Kosior, 2020) An increasingly major topic of concern is plastic accumulating in the ocean, with rivers and other outlets serving as an entry point for litter and plastic spills. Terrestrial sources present the greatest risk of plastic entry into the ocean, 80% of plastic in the ocean was derived from land-based sources. (Kosior, 2020) Plastic waste flows into the ocean and is carried further by wind currents, where it degrades and forms vast patches of ocean with high concentrations of microplastics. These patches are often pictured as piles of floating meso- and macro- plastic pieces, but as Van Sebille notes in “The oceans’ accumulating plastic garbage”, “...an oceanic garbage patch is more like a plastic soup than a plastic island”. (Van Sebille, 2015) (Gewert et al., 2015) Microplastics are of special concern regarding ocean plastic. Microplastics come in two varieties, primary and secondary. Primary microplastics are microplastics that were manufactured to be microplastics, while secondary microplastics are fragments of larger plastic pieces that broke off. (Welden, 2020) Plastic does experience some degradation in the environment, including through thermal processes or by exposure to UV light. (Gewert et al., 2015) Microplastics also present another problem in that they are hard to quantify in the environment to their size and spread, however estimates have put the amount at around 5 to 51 trillion microplastic particles. (Welden et al., 2020)

The presence of microplastics in the ocean is a cause for alarm because they can harm aquatic biota. Ingestion of microplastics by animals is one such example. Ingestion can occur through many pathways, but one group of animals at particular risk are filter feeders, who are more susceptible to the high concentrations of microplastics suspended in the water. (Welden et al., 2020) Studies have shown that plastic ingestion is becoming increasingly common among animals, one study looking at the presence of plastic in fish stomachs found one hotspot where almost 30% of the fish samples had ingested plastic pieces. (Bråte et al., 2016) For larger animals like fish, and even birds, mesoplastics and macroplastics are an additional concern. Studies have also been done on the potential harm of plastic ingestion. One study that looked at other studies that discussed harmful effects of plastic ingestion found that “physical blockage and perforation of the GI, nutritional changes, tissue damage, increased trace element levels, and altered growth or condition” were among the potential effects, with blockages being the most common. (Puskic et al., 2020) Although invertebrates (including the filter feeders mentioned previously) are most often at risk, more research needs to be done to determine the risk posed to them. (Puskic et al., 2020) Ingestion is not the only way by which animals are put at risk by plastic. Entanglement has been an issue that has been a centerpiece of the public image of the plastic pollution problem, but entanglement is a significant risk to many marine animals, especially birds. One study found that 265 bird species have recorded cases of having been entangled by debris, with 147 of these being seabirds. Almost 40% of all seabird species have instances of being entangled. (Ryan, 2018) Entanglement is also thought to be a major source of sea turtle mortality, with one survey of researchers who have studied marine debris, finding that 84% reported that they had encountered instances of sea turtle entanglement. (Duncan et al., 2017) Entanglement can lead to reduced mobility and also contribute to starvation, exposure, and drowning. (Welden, 2020)

Since plastic pollution, especially in the oceans, is a major environmental problem that the world faces, there has been much work done to find solutions to this problem. Recycling has been a solution at the forefront of this issue, at least in terms of public perception. Despite recycling's promising aspects, there are several problems that make it a less viable solution. One is that only a small amount of plastic can actually be recycled, especially post-consumer plastic, or plastic that has already been manufactured and used. Another factor hindering recycling is that it is currently not profitable; costs to run a recycling facility outweigh what can be made from selling recycled plastic. (Rudolph et al., 2017) The world is already transitioning away from recycling as a viable solution to the problem of plastic pollution. China was a major center for recycling plastics but in 2018 banned the import of solid waste. (Semuels, 2019) Because recycling is currently an imperfect solution, further research should be done to find viable solutions to reducing plastic waste in the environment.

While recycling may not be the answer to the plastic pollution crisis, other potential solutions are being researched and developed. One developing innovation is incorporating plastic into concrete. The long service life of concrete (design service life can range from 10 - 100 years depending on the structure) makes it well suited for this application. (Dyer 2014) Storing the plastic in concrete can prevent the plastic from leaching into and accumulating in the environment, although as Sharma and Bansal note in their review paper, "this method is not a dominant method for disposing of waste plastic." (Sharma, 2016) Because the service life of concrete is finite and because of the massive scale of the plastic waste problem, incorporation of plastic into concrete should be a method for mitigation, rather than a full solution. Addition of plastic into concrete also affects concrete strength and other properties. In the case of strength, addition of plastic waste has been shown to weaken concrete, another potential barrier to the success of this method. (Sharma, 2016) The effect of plastic in concrete has been studied in numerous ways, and a variety of plastic types and shapes have been used as well. A number of studies have used plastic waste as an aggregate in concrete. Saikia and de Brito note that most studies involving plastic as an aggregate used mechanical grinding to create plastic pellets. The size of these pellets ranged from ~0.1 mm to ~1 cm (0.004 - .4 in). (Saikia, 2012) Most studies of this variety have replaced fine aggregate, although Fraj et al. replaced coarse aggregate with polyurethane foam and found that using the foam could create a much less dense concrete that "almost satisfied the mechanical and density criteria of structural lightweight concrete." (Ben Fraj et al., 2010) Almost all studies involving aggregate replacement tested the compressive strength of the resulting concrete, with most reporting decreases in compressive strength. (Saikia, 2012) Studies made use of plastic fibers as well, both replacing aggregate and being added on top of the other ingredients. Results for compressive strength are more varied. Bhogayata et al. used polyethylene fibers in different proportions (see Table 2 for proportions) and found a reduction of ~56 % in strength for the highest proportion of fibers. Ramadevi & Manju and Malagaveli found, contrastingly, that the use of fibers increased the strength of the concrete by ~20 % and 3.5 %, respectively. (Sharma, 2016). An interesting study by MIT students made use of irradiated plastic pulverized into a powder, and found that addition of this powder could produce concrete that was "up to 15 percent stronger than conventional concrete." (Chu, 2017) Concrete with plastic fibers has been used for real world applications as well. The Hishikari gold mine in Japan used PET-reinforced concrete to support a gateway. The PET concrete was used in place of steel-reinforced concrete for better workability. (Fukui, 2007) Vargas et al. investigated making precast slabs with added plastic waste, producing findings that may be more applicable to real world uses of concrete. (Vargas et al., 2014). Sharma et al. conclude in their review of plastic waste concrete studies that "Plastic fiber reinforced concrete can be used for structures that are not subjected to heavy loads, such as park benches and stone curb. This can lead to reduce [sic] the amount of waste plastic." (Sharma, 2016). While not a complete solution to the problem of plastic waste, recycling plastic waste in concrete may reduce the burden that the waste puts on the environment.

Plastic is one of the most versatile and widely used materials today. Plastic is a synthetic material made up of polymers, polymers being “a substance made up of a partial molecular structure or entirely of a large chain of bonded materials forming plastics or resins.” (Wesolowski, 2020) The first plastic is generally thought to be Bakelite, a polymer-based material discovered by chemist Leo Baekeland. Bakelite resulted from Baekeland’s experiments with phenol and formaldehyde. Baekeland’s initial testing took place in 1907 and he announced his findings in February, 1909. Almost a year later in December of 1909 he was granted patents in the US for various inventions and processes related to Bakelite. (Mercelis, 2020) This project will involve three kinds of plastic, high-density polyethylene, linear low-density polyethylene, and polypropylene. Polyethylenes are one of the more commonly used plastics in commercial and industrial applications. Polyethylene’s widespread use is due to its suitability for a variety of products, “PE [polyethylene] is extremely versatile and can be found in household durable goods, children’s toys, consumer packaging, beverage caps and closures, trash bags, and can liners. It is also widely used in industrial packaging systems, storage tanks, reusable pallets, composite decking materials, sealants for solar panels, and artificial turf.” (Spalding, 2017)

Polyethylene was discovered by different chemists in the late 1800s and early 1900s, but it wasn’t until the 1930s that industrial production and use of polyethylene took off. A major reason why industrial use of the polymer was so long after its initial discovery is that producing polyethylene in larger quantities required a high-pressure system and very specific requirements. The industrial process for producing polyethylene was discovered accidentally by chemists at the ICI Winnington facility in Northwich, England, and subsequently the first polyethylene facility opened in 1939. This polyethylene produced in the early facilities was low density polyethylene. (Spalding, 2017) A process for high density polyethylene was discovered in the 1950s independently in several countries as a result of a search for an easier process to make low density polyethylene. Linear low density polyethylenes are low density polyethylenes that have been produced in a different manner than the original high pressure process low density polyethylenes. Linear low density polyethylene is used in plastic films like plastic wrap, because "The new ethylene-octene copolymers [LLDPE] demonstrated outstanding toughness, tear resistance, and clarity." (Spalding, 2017) While there are many different kinds of polyethylenes, LLDPE, HDPE, and LDPE make up the bulk of polyethylene production. Each kind has properties that set them apart and make them suitable for different uses. HDPE is stiff but brittle, LLDPE tough but not stiff, and LDPE is easy to process. (Spalding, 2017) HDPE are polyethylenes with a density larger than 0.940 g/cm^3, and "HDPE is the highest volume type of PE used today." Linear low density polyethylenes are low density polyethylenes with a unique manufacturing process. (Spalding, 2017) Polypropylene is another commonly produced plastic type. Polypropylene is used similarly to polyethylenes for the most part, being used in packaging, films and medical equipment. Polypropylene does have some benefits that make it stand out, namely its high melting temperature and high rigidity. (Maier, 1998)

Concrete shares plastic's widespread use and ubiquity; according to Colin Gagg, "Today, second only to water, concrete is the most consumed material, with three tonnes per year used for every person in the world. Twice as much concrete is used in construction as all other building materials combined." (Gagg, 2014) Concrete use and consumption grew tremendously during the second half of the 20th century and continues to grow, with production increasing ~9.5 times in the past 50 years, and 4.1 billion tonnes (4.1 trillion kg) of cement being produced worldwide in

2019. (Sakai, 2012) While China is overwhelmingly the largest producer of cement (more than half of cement produced globally was produced by China), other top producers include India, Vietnam, the U.S. and Egypt. Because of the massive scale of cement production, greenhouse gasses produced during all stages of cement manufacturing are somewhat of a concern. In 2005, 5% of global CO_2 emissions were from cement production (USGS, 2019) Concrete is a composite material that generally consists of aggregates bound together by a cement-based binder. The use of concrete or concrete-like materials has a long history, aggregate based materials have likely been used since the beginning of human construction techniques. While aggregate materials originated in the early days of human civilizations, the Roman's use of concrete is most notable today. Many Roman structures built from concrete like the Pantheon still exist today and are largely intact. (Lechtman, 1986) Roman concrete was unique in that it contained volcanic ash. This ash was rich in alumina oxide and silica, which created a concrete that was particularly durable in sea water. (Oleson, 2014) With the collapse of the Roman empire, sophisticated concrete production and use largely declined, but concrete made a resurgence as a building material in the 1800s when scientists, manufacturers and engineers found ways to produce cement. Although not the first to rediscover Roman concrete, Joseph Aspdin made significant contributions to concrete productions after creating portland cement. Ordinary portland cement is still in wide use today. (Sakai, 2012) In concrete production, clinker is an intermediary product formed from limestone and clay in a furnace. Ground clinker is combined with gypsum to create cement powder. Cement powder combined with water creates cement paste, cement paste combined with sand (fine aggregate) creates mortar. Cement paste combined with fine aggregate and gravel (coarse aggregate) creates concrete. The primary mechanism in cement production is the formation of calcium silicates from the calcium carbonate (limestone) and silicon oxides (clay or other materials like fly ash). Tricalcium silicate (alite) and dicalcium silicate (belite) are the primary components in ordinary portland cement. Tricalcium aluminate is another important product of cement production that acts as a flux that allows the alite and belite to form at a lower temperature. Calcium silicate hydrate is one of the most important products associated with cement chemistry, as it is primarily what gives concrete its strength. Calcium silicate hydrate is formed from the hydration of concrete, when the calcium silicates in cement react with water. (Benvenuto, 2015) Concrete is generally used because it has good compressive strength. Its tensile strength is less impressive however (which is why concrete will often be reinforced with steel bars. Another desirable trait of concrete is that it can be worked and molded when it is freshly made. Concrete is also customizable, proportions of components like water and aggregates can be changed, and admixtures can be added to get certain results. This process of determining the amount, proportion, and type of materials to get certain results and characteristics from concrete is called mix proportioning. Mix design is the process of determining the final characteristics of the concrete, mix proportioning is used to achieve the desired characteristics layed out in the mix design. There are some important considerations to be made when creating a mix proportion; water to cement ratio mostly governs the workability of concrete, a larger proportion of water makes a more workable, but less strong concrete. Admixtures can be added to the concrete to achieve certain properties, entrained air can help prevent cracking from freeze-thaw cycles. Water reducing admixtures allow for less water to be used while still keeping the concrete workable. (Illston, 1994)

Chapter 3: Methodology

The goal of this project was to determine if putting plastic into concrete is a viable solution to reducing plastic waste in the environment, primarily looking at the effect of the plastic on concrete strength. To do this, different combinations of concrete mixtures were created with a variety of plastic fiber amounts. The resulting concrete blocks were subjected to different tests. In order to find a combination that will be strong enough to handle the different situations that concrete faces on a normal day-to-day basis.

To achieve this goal, the following objectives and work tasks were completed:

1. Identify the concrete mixtures
    - To do this, concrete proportioning was carried out and a mixing procedure was determined
2. Determine the characteristics of the concrete
    - Different tests were conducted in order to determine these characteristics

3.1 Objective 1: Identify the concrete mixtures

A variety of concrete blocks that include three different types of plastics and three different amounts of plastic fibers were used in this project. The different types of plastic that were used were: Low-Density Polyethylene (from plastic grocery bags), Polypropylene (from plastic straws), and Linear Low-Density Polyethylene (from plastic wrap). The amount of plastic put in each mixture, based on volume, were: high (.07%), medium (.03%), and low (.01%). The values chosen were lower than values typically seen in studies involving the addition of plastic to concrete. These values were chosen so as to get as close to literature values as possible, shown in

Table 2, while also keeping in mind that these fibers were to be cut by hand. The thousands of fibers required for larger volumes were impractical for the scope of the project. The three amount levels and types of plastic resulted in nine different concrete combinations, in addition to a control sample.

Table 2: Plastic volume percentages used in studies involving addition of plastic waste to concrete.

Authors of Study	Plastic Percent (Volume Basis)
Bhogayata et al. (2013)	0.5, 1, 1.5
Bhogayata et al. (2012)	0.3, 0.6, 0.9-0.12
Prahallada & Parkash (2013)	0.5
Cordoba et al. (2013)	1, 2.5, 5.0
Fraternali et al. (2011)	1
Ochi et al. (2007)	0.5, 1, 1.5

3.1.1 Initial Tests

Before the mix proportions of the concrete were determined, some tests were performed to find certain characteristics of the plastic and concrete ingredients. First, the density of each plastic type was determined. To do so, a piece of each plastic type was weighed to determine its mass, and a known amount of water was put into a graduated cylinder. The plastic samples were then fully submerged in the water, and the new volume, including the displacement was recorded. With a known mass and corresponding volume for each plastic, the density was calculated using $\rho = mv$. Using safety data sheets, the densities were found. These literature values matched with the ones found empirically. The mass of an individual plastic fiber was also determined (Table 3), the fibers were cut into .31 x 1.38 in (8 x 35 mm) strips (Figure 2).

Table 3: Mass of individual fibers for each plastic type.

Fiber Type	Mass/Fiber (g)	Mass/Fiber (lbm)
Polypropylene (Straws)	0.03	6.61e-5
High Density Polyethylene (Bags)	0.03	6.61e-5
Linear Low Density Polyethylene (Plastic Wrap)	0.01	2.2e-5

Figure 2: Plastic fibers, from left to right, high-density polyethylene, polypropylene, linear low-density polyethylene.

Next, the water absorption of the coarse aggregate was determined. This procedure roughly followed the methods described in ASTM C127-15. First, a sample of coarse aggregate was fully submerged in water and soaked for two weeks. The aggregate was then removed from the water and the surfaces were dried using a towel to achieve the saturated surface dry state (SSD). After being dried the aggregate's mass was determined. The aggregate was then fully dried in the oven and weighed once more. The absorption percentage was found using the following formula: $(\frac{SSD\ Mass - Dry\ Mass)}{Dry\ Mass}) * 100$. After the initial testing the mix proportions for the control sample were determined. The ingredients and ingredient proportions were arbitrary, but for this project they were obtained from a mix design previously used for the WPI course

“Construction of Materials” (Table 4). This mixture served as the control group and the base for each plastic sample. The amount of materials needed for each concrete batch was determined using this design. Each batch required enough concrete to fill five 4 x 8 in (10.16 x 20.32 cm) plastic cylinder concrete molds. The volume of each batch and the high, medium, and low volume percentages were used to determine the volume of plastic needed for each sample, and then using the density previously found, the needed masses were calculated. Finally, using the mass/fiber values, the number of fibers needed for each sample was determined. After all the ingredient amounts were calculated, some adjustments were made. The amount of water was increased to account for absorption by the aggregate, the absorption percent was used to find the corrected amount of water. Every ingredient amount was increased by 10 % to account for concrete that would be left behind in the mixing container This amount was arbitrary.

Table 4: Ingredients and amounts in concrete mix design.

Dry Materials	Wet Materials
Cement: 8.1 pounds (lbs) [3.67 kg]	Water: 3.3 lbs [1.50 kg]
Coarse Aggregate: 15.5 lbs [7.03 kg]	A.E.A: 21.75 milliliters (mL) [0.765 oz]
Fine Aggregate: 11.75 lbs [5.33 kg]	Water Reducer: 24.0 mL [0.845 oz]

3.1.2 Mix Design and Concrete Mixing

Three different types of plastics were used during this experiment: high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), and polypropylene. These were represented by plastic bags, plastic wrap and plastic straws respectively. Before the different tests could start being performed, the samples had to be made. The materials that were used to make the concrete were: cement, coarse and fine aggregate, water, air entraining additive

(A.E.A), and water reducer. To begin with, all the materials were weighed out into separate buckets. The amounts used are listed in table 5.

The A.E.A and the water reducer were then added to the water and the coarse and fine aggregate were combined. To allow for uniform mixing, the coarse and fine aggregate were transferred to different buckets three times, allowing the sand to be dispersed among the larger aggregate. The hand mixer was then used in the aggregate bucket as the rest of the materials were added. The wet materials and the cement were slowly added to the mix and the concrete was continually mixed with the mixer. Once the concrete was completely mixed with all the materials added, the concrete was again mixed with the mixer for two minutes. The slump test was then performed on the mixture, see below, before it was scooped back into a bucket. Depending on the mix, an amount of plastic fibers were then added and the concrete was mixed for another minute. The amount of fibers added to each mix are listed below.

Table 5: Plastic fibers added to each sample.

Mixture	Fibers Added	Mixture	Fibers Added
Control Mix (C)	None	LLDPE Med Mix (LM)	94
HDPE Low Mix (HL)	16	LLDPE High Mix (LH)	218
HDPE Med Mix (HM)	67	PP Low Mix (PL)	19
HDPE High Mix (HH)	157	PP Med Mix (PM)	57
LLDPE Low Mix (LL)	31	PP High Mix (PH)	134

Once all of the fibers were added, the concrete was scooped into 4 x 8 in (10.16 x 20.32 cm) cylinder molds. After each scoop, the sides of the molds were tapped in order to eliminate any trapped air pockets. Air pockets or air bubbles are tiny voids trapped in concrete after mixing. This can lead to water expanding into these voids and cracking can occur after several freeze-thaw cycles. Air pockets occur from air becoming trapped under coarse sediment within the mixture. To prevent this, the air from the bottom of the mix beneath the aggregate needs to be brought to the top, thus releasing any unwanted voids. To do this, all of the samples were mixed with an electric mixer drill bit. In addition, the molding was struck on its side several times throughout the mixing process in hopes to unsettle any voids lying beneath the coarse aggregate. A.E.A. was also added to minimize this phenomenon. Once all of the molds were filled, they were covered with plastic wrap and placed in the curing room to set. 24 hours later, the concrete cylinders were demolded and put back in the curing room to continue curing. They were set to cure for a full week, starting at the time that the molds were filled.

3.2 Objective 2: Determine the characteristics of the concrete

Multiple tests were then conducted on each of the concrete mixtures. This was done in order to test different characteristics of the concrete and determine the quality of the mixture. The tests performed were: slump test, rebound hammer test, ultrasonic pulse velocity test, and splitting tensile strength. The tests performed were modeled after ASTM and AASHTO standards for concrete.

3.2.1 Slump Test

The slump test is a measure of the workability of concrete, and mostly depends on the water content of the concrete. Since the samples used in this project all follow the same mix design (and thus same water content), the slump values of each sample should have been similar. Variations in the slump could be due to the plastic in each sample, or more likely due to small variations in the amount of water used in each batch. During the mixing procedure, a slump test was conducted following the methods described in ASTM C143. To begin with, the inside of a cone was moistened and put on a smooth, level surface. The cone was then filled with the concrete. While it was being filled, a rod was pushed down into the concrete, called tamping, to help the concrete fully settle and allow any air to escape. Concrete was added into the cone until the cone was slighted overfilled and then tamped again 25 times. The excess concrete was scraped off and the cone was slowly lifted away from the concrete. The cone was flipped upside down and then placed beside the concrete. A straightedge was rested across the cone and a ruler was placed just above where the average height of the concrete was to measure the distance down to the top of the sample. The distance from the concrete to the rod was the slump and was recorded. (ASTM C143, 2020)

3.2.2 Schmidt Rebound Hammer Test

To get a quick estimate of the uniformity and surface hardness of the concrete, as well as strength, a Schmidt rebound hammer test was performed on each sample. The Schmidt Hammer Test is a non-destructive test that measures the rebound of a spring after contact with a surface. Since the test is performed on one small part of the concrete, the test can be performed on multiple areas of the concrete sample, and those values can be compared to get an assessment of the uniformity of the sample, a more uniform concrete means less variation among the rebound values. (FPrimeC, 2019) (Preceq, n.d.) Following the ASTM C805/C805M methods, the hammer was calibrated against a test anvil included in the packaging. After being tested for accuracy, the hammer was held at right angles to the surface of the concrete for readings. The plunger of the rebound hammer was pressed against the surface of the concrete and a spring-controlled mass with constant energy was made to hit the concrete surface to rebound back. While still holding the plunger down, the lock button was pressed so that the rebound number could be recorded.

Each sample was tested eight times, and all of the tests were averaged together to determine the extent of the rebound. (Mishra, n.d.)

3.2.3 Ultrasonic Pulse Velocity Test

The ultrasonic pulse velocity test is a non-destructive test used to assess the homogeneity and integrity of concrete. It can be used to determine any discontinuities, like cracks, and their locations in the cross section. (Mishra, n.d.) From this test, the Young's modulus for each sample was calculated. Young's modulus is the ratio of stress over strain for a material, and can be a good measure of the stiffness of the material. Young's modulus is derived from the stress-strain curve of a material, and is the slope of the straight-line region of the curve. This curve is the elastic region, where the material exhibits elastic behavior. When in the elastic region, a material will return to its original position after a load causing deformation is removed. A material with a higher Young's modulus (higher slope for the elastic region line) deforms less when under stress than a material with a lower Young's modulus. (Lee, 2019) (Hibbeler, 2015) The ASTM C597-16 method was used to conduct the ultrasonic pulse velocity test. By using a reference bar provided, the instrument was checked and set to zero before beginning. A smear of couplant, a type of grease, was added to each transducer face before it was placed on the opposite ends of the bar. The set reference was adjusted until the reference bar transit was obtained. Couplant was applied to the surfaces of the transducer again and pressed hard onto the surface of the samples. They were lined up so that they were aligned with one another and the machine was set to go. Three pulses were conducted before the numbers were recorded. Young's modulus, velocity, and the transit time were recorded. Three rounds of pulses were conducted for each sample, each time the different numbers were recorded. (Mishra, n.d.) This test was conducted for each of the trials made for the samples. The data were recorded in an Excel document and the average

Young's modulus for each sample was calculated, as well as the standard deviation for each sample. (ASTM C143, 2020)

3.2.4 Split Tensile Strength Test

The strength of a material is, generally, a measure of its resistance to stresses, stress being the intensity of a force over an area. (Hibbeler, 2015) Strength is often expressed as a particular stress. An analysis of the strength of the concrete was chosen because strength is a good indicator of the concrete’s performance under load. For this project, an analysis of the tensile strength was performed. Direct tensile strength tests are, according to the International Code Council, difficult to perform, however, the split tensile test is an easier test to set up and perform. This test was chosen because of its simplicity. (Neville, 2015) Split tensile tests are an indirect test of the tensile strength of concrete. (ASTM C496, 2017) In this test, the concrete is placed on its side and load is applied so that it splits along its diameter vertically. The concrete cylinders were removed from the curing rooms once they were ready to be tested. The samples were placed on their side in an Instron Hydraulic Universal Testing System, and a rectangular metal bar measuring 4 x 8 in (0.1016 x 0.2032 m) was placed on top, parallel to the length of the cylinder. Two dumbbell-shaped plastic strips (plastic specimens used in ASTM D638) were placed on each side of the sample to hold it in place. The machine head was lowered so that it was right above the bar (Figure 3). The sample was then loaded at a rate of 10,000 pounds/min until it cracked. After cracking, a graph of load versus position (deformation) was obtained, as well as the values of the graph as data points. These data were put into an excel sheet and the peak load sustained by each sample was found. This process was repeated for each sample. Using these peak load values, the tensile strength of each sample was found using the formula to determine split tensile strength for a cylindrical sample, $T = \frac{2P}{\pi LD}$, where P is the peak load, L is the length of the sample, and D is the diameter of the sample. (Timoshenko, 1951) After finding the split tensile strength for each sample, an average value was calculated from the three trials for each sample, as well as a standard deviation. A graph of the average tensile strength for each sample was made.

Figure 3: Splitting tensile strength testing apparatus.

3.2.5 Statistical Methods

For each plastic type and level, three concrete samples were made, and three values for each test were obtained. Multiple trials were performed for each test to avoid basing the analysis on potential outliers. If only one trial had been performed, the result could have been an outlier due to any number of circumstances, and the analysis based on that result would not reflect the true behavior of the sample. For this reason, individual samples were not analyzed, but rather the average of the three trials was. A standard deviation was also calculated for each set of results. A standard deviation is a measure of how much variation there is among values in a set, a lower standard deviation means the values were closer to each other, and vice versa for high standard deviations. (Petrucelli, 1999) Calculating the standard deviation allows for more precise analysis, a smaller standard deviation means the average value is likely close to the "true" value, and a higher deviation likely means that an outlier could influencing the set, or perhaps that there is another variable influencing the test results that was not controlled for.

Chapter 4: Results

The different samples were created and then tested, with the results being analyzed and explained. In this chapter, the test findings are explained. Finally, the possibilities these results present are discussed for the future of plastic usage in concrete mixing.

4.1 Slump Test

The slump test is used to determine the concrete's workability by determining the consistency and stiffness of the mix. This indicates the water content within a batch of concrete. (Jamal, 2017) High slump indicates that the concrete contained too much water and will be weak as a result once it's fully cured. The slump test was the first experiment run after the mix design was created. The point of this test is to assess the consistency of the batch of concrete. When talking about concrete consistency, this boils down to making sure the correct amount of water was added into the mix. When the steel cone is removed from the mix, there are generally three results. The concrete stays in place, which means there is not enough water. This is referred to as a true slump. (Collins, 2019) The concrete could collapse completely and fill up the bin, which means there is too much water, known as a collapse slump. Finally, the concrete could slowly deform from its shape and begin to spread in a generally even fashion. This can lead one to assume there is a good amount of water and is referred to as a shear slump. (Collins, 2019)

The slump's measured from a range of 8.5 to 10.5 inches (21.59 to 26.67 cm). The average of all total samples was 9.85 ± 0.634 inches (25.02 ± 1.6 cm). This shows all of the concrete mix designs were very similar in proportion when it came to water, concrete, fine aggregate, coarse aggregate, and plasticizer. This was a good start to the experiments as it was useful knowing that the mix designs were all measured and executed well and would not cause any large error moving forward with the other tests.

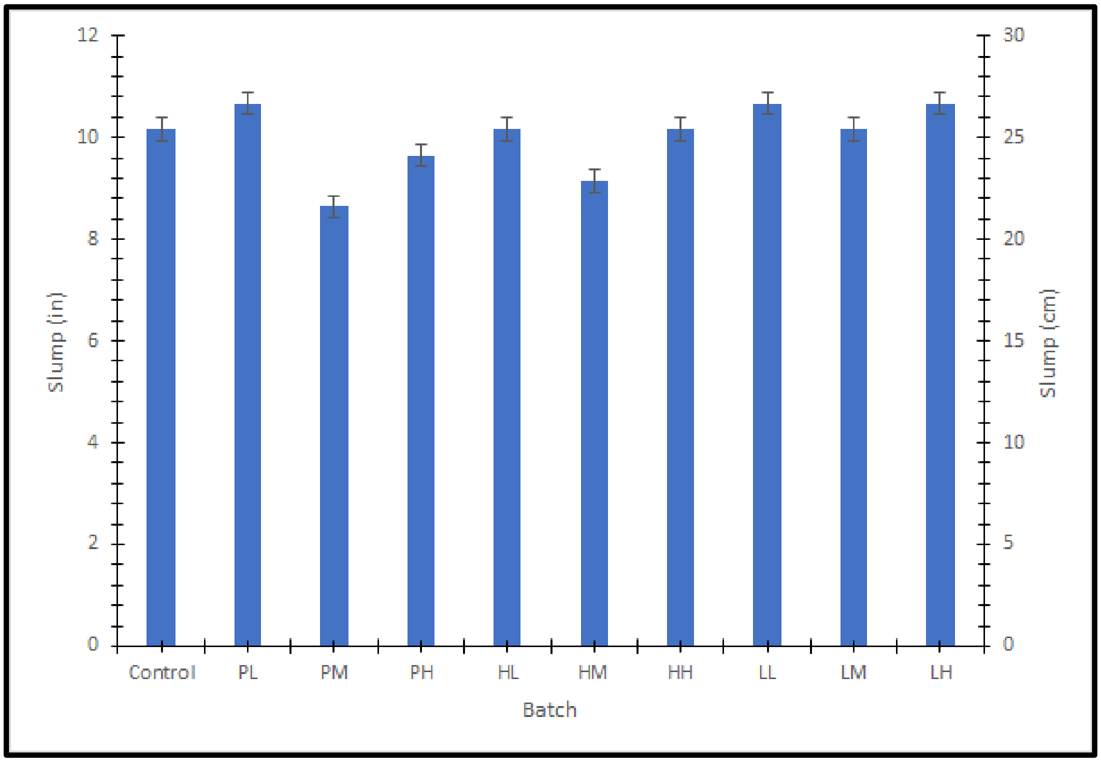

Figure 4: Slump values, in inches and centimeters, for each plastic type batch.

4.2 Rebound Hammer Test

The rebound hammer test provides a rapid indication of the compressive strength of the concrete and is used to help assess the uniformity and quality of the concrete. Concrete with low strength and low stiffness will absorb more energy to yield a lower rebound value. (Mishra, n.d.) Based on Figure 5, the concrete cylinders had comparable results to the control sample. These similar hammer values imply that the different concrete cylinders had similar strength. Many of them had similar or higher numbers than the control sample. However, according to a table used in a study evaluating the strength of structural concrete, rebound hammer tests resulting in an average rebound number of < 20 means that the quality of the concrete is poor. (Gupta, 2015)

This means that all of the samples have low compressive strength. It should be noted that the rebound hammer test is not a substitute for a standard compressive test and should instead be used to determine concrete uniformity. However, that doesn't change the fact that these specimens are determined to be of poor quality.

There are a variety of parameters that may affect the result of the rebound hammer test, including the type of aggregate or cement used and the size of the specimen or the surface's smoothness. (FPrimeC, 2019) There are many factors, including the type of aggregate or cement and/or the size of the specimen, that could have also affected the results. However, these factors can't be determined without more testing. It seems most likely that the surface of the specimen resulted in the low numbers, which indicate poor cement quality. The specimens only had one flat side, the side that was shaped by the mold. Although the tops of the molds were scraped and made as flat as possible, they weren't perfect. During testing, the rebound hammer was being used on slightly uneven surfaces.

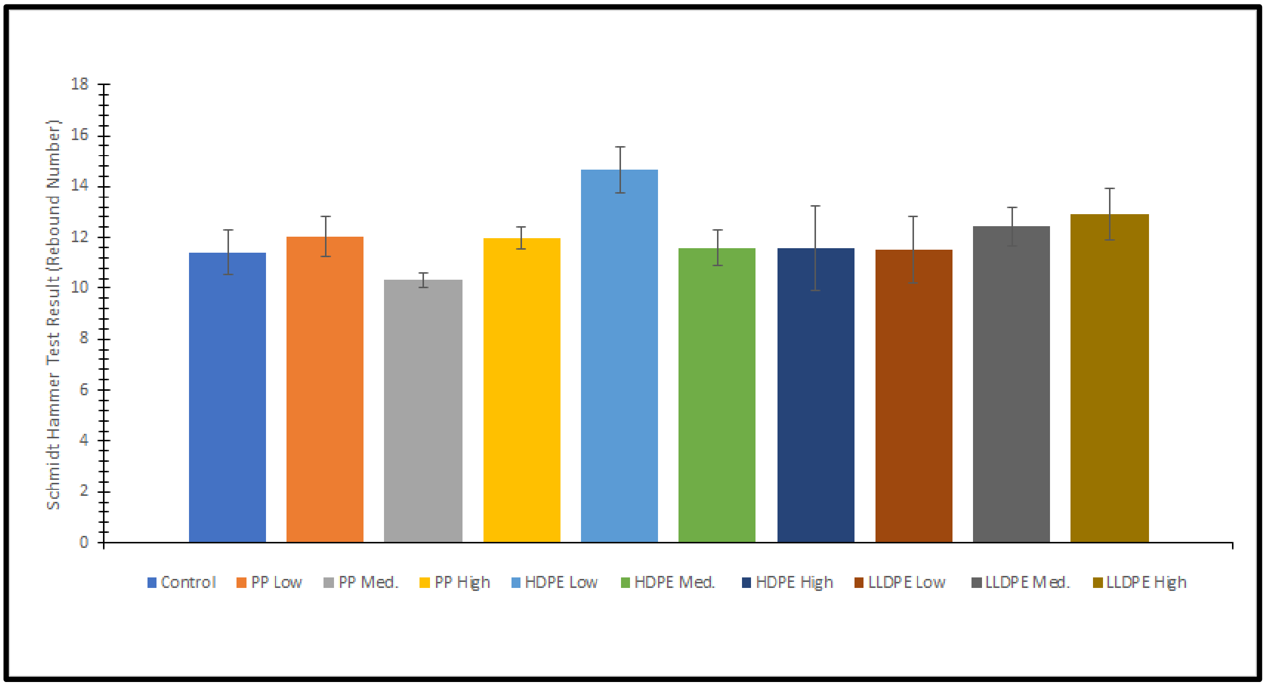

Figure 5: Average Schmidt Hammer Test results for each sample.

4.3 Ultrasonic Pulse Velocity Test

The ultrasonic pulse velocity test is a non-destructive test used to assess the homogeneity and integrity of concrete. It can be used to determine any discontinuities, like cracks, and their locations in the cross section. (Mishra, n.d.) From this test, the Young's modulus for each sample was calculated. Young's modulus is the ratio of stress over strain for a material, and can be a good measure of the stiffness of the material. (Lee, 2019) Figure 6 shows the average Young's modulus obtained for each sample, as well as the standard deviation. One observation is that Young's modulus appears to be inversely proportional to plastic amount, with Polypropylene High being a notable outlier. However, the Young's modulus does not seem to decrease consistently with each plastic amount increase, for example from Figure 6, the Young's modulus decreases by ~0.2 GPa (29 ksi) when going from low to medium LLDPE, but decreases by ~5 GPa (725.2 ksi) when going from medium to high LLDPE. For each plastic type, the samples are within 5 GPa (725.2 ksi) of each other, however the range (difference between highest and lowest value) of the samples is ~7 GPa (1,015.3 ksi). Because the variation within each sample type is almost as large as the whole range of the data it is reasonable to say that there is a large amount of variation within each sample type. Based on the inconsistent decreases of Young's modulus and large intra-type variation, the plastic type may not have been the driving factor behind this set of results.

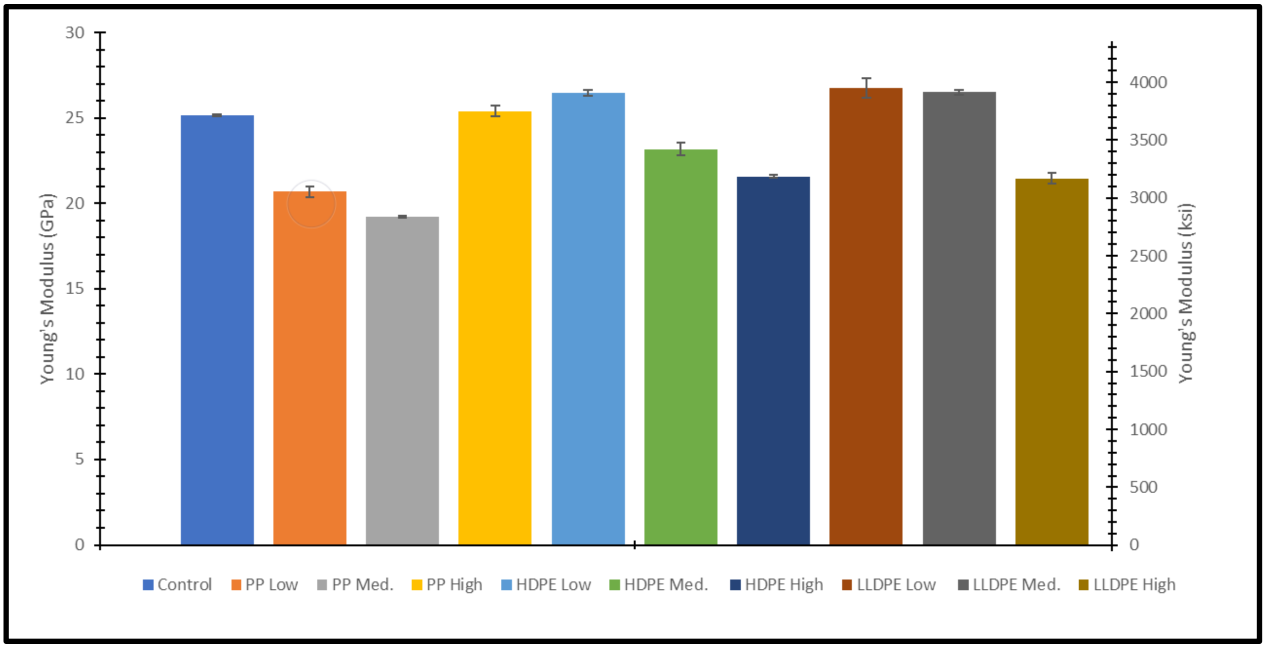

Figure 6: Average Young's modulus for all samples.

4.4 Splitting Tensile Strength

The splitting tensile strength test involves applying a diametral compressive force along the side of a cylindrical concrete sample to induce stress on the length of the specimen and is used to evaluate the shear resistance that the concrete provides. (ASTM C496, 2017) Figure 7 makes it clear that each sample has a lower strength than the control sample. There seems to be a few trends amongst the different types of plastics. To begin with, HDPE's strength decreased as the amount of plastic added was increased. The opposite can be said about LLDPE, where the strength increased as the amount of plastic was increased. The PP results are unique, with the low amount of plastic resulting in the highest strength, the medium amount of plastic resulting in the lowest strength and the high amount of plastic falling somewhere in the middle. By looking at the data presented, PP overall performed the best out of the different plastic types.

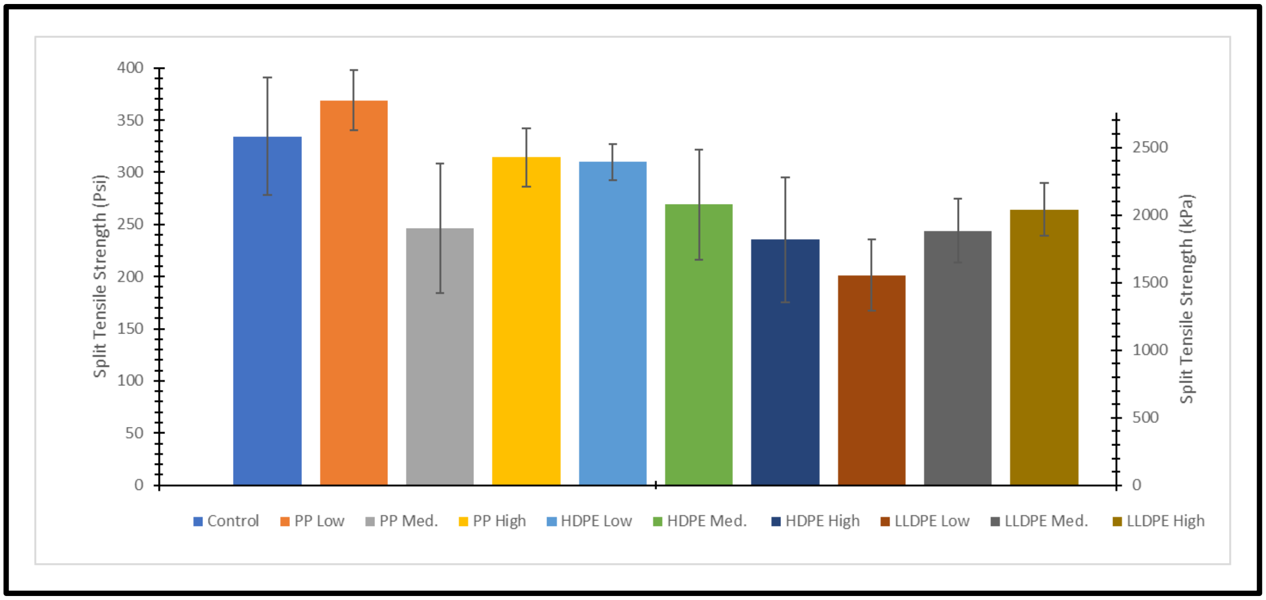

Figure 7: Average split tensile strength for each sample.

After looking at the results, it is clear that the straws held up better than the other types of plastics, almost matching the results of the control sample. PP low had the highest strength average out of all of the samples and PP overall performed the best compared to the plastic bags and wrap. The straws are more durable and rigid compared to the other plastic. This may have resulted in producing a better substance for the concrete to hold and latch onto when curing. Since plastic bags and wrap can be easily crushed or deformed, they did not act how normal fibers would when in the concrete. They were easily crushed during the mixing or pouring process while the straws held their shape even after the concrete cylinders were crushed.

4.5 Air Pockets

Although precautions were taken to avoid air pockets, several occurred in all of the samples as seen in the figure below. As all of the mixes were completed the exact same way, including tamping to eliminate air bubbles, this is believed to not be linked to the addition of any of the plastic fibers as all of the samples contained similar quantities.

Figure 8: Air pockets within the concrete cylinder.

When analyzing each sample, Image J software was tested. Image J allows one to upload pictures to analyze its characteristics and particles without having to manually count each miniscule air pocket. The problem was that each picture taken of the samples were on an iPhone and not zoomed in, so when the pictures were uploaded and zoomed in on the Image J software, they became extremely blurry. The software was unable to identify the difference between an air pocket, a dent, or just a crack. Overall, air pockets occur in all types of concrete and should therefore have had no relation to the addition of the plastic fibers. There were bubbles in each of all nine samples, and should therefore have had minimal effect on the characteristics of the concrete.

Chapter 5: Conclusion and Recommendations

5.1 Conclusion

The results prove that plastic can be put into concrete to be both a viable material as well as a way to dispose of plastic. Looking at PP high and HDPE low, the averages are very similar to that of the control. This proves that with a few more trials, the perfect amount of plastic can be found that allows the concrete to still be strong while still containing a large amount of plastic. Even though the amount of plastic used in this experiment was small, if these practices were implemented into the real world, it could still make a huge difference.

Ten samples with different combinations of plastic types and amounts went through a variety of testing in order to determine if plastic could be used concrete. This experiment was meant to test if plastic could substitute such things as fibers without sacrificing the integrity of the concrete. If plastic can be used instead of other materials, like conventional fibers, then not only would it be a new way for plastic to be recycled, but this could also lead to similar discoveries. New and improved ways of doing standard procedures could be found that also benefits the world.

The long-term goal of this project is to determine if putting plastic in concrete could be a viable way to dispose of plastic in a safe way. If plastic can be put into concrete and still function normally while also ensuring that the plastic isn’t ending up in landfills or the ocean, then the world can be made a little greener. If people made more of an effort to find new and better ways of doing things, like putting plastic in concrete as a way to recycle, then the world will be better for it. It is the hope that this experiment is continued and expanded on so that the perfect amount of plastic that can be added to concrete can be found, resulting in a better location for old, used plastic to end up.

5.2 Recommendations

This experiment encountered multiple challenges during its duration. Some of these problems were due to the pandemic. Other problems were due to the team or other unforeseen issues faced during the experiment. Some examples include finding lab time around other project teams, a limited curing period due to a seven-week term and Covid restrictions, and lab equipment malfunctions. In any case, the following are important recommendations for those in the future who wish to continue this project.

The first recommendation is to allow the concrete to cure for longer. There is a chance that the concrete in this experiment was not allowed to cure for long enough, causing it to be weaker. For future experiments, it is recommended that the concrete be set to cure for about a month before demolding it and performing any tests on it. For this experiment, the specimens were cured for 7 days, which partially cures it and makes the concrete strong enough to withstand traffic from vehicles and other equipment. However, 28 days allows the concrete to be more fully cured. Letting the concrete cure for the full 28 days probably would have resulted in better test results. (Palmer, 2020)

Due to time restrictions and limited lab access, every test that was originally planned to be run wasn't. Therefore, the next recommendation would be to conduct different types of tests, specifically compressive and flexural strength tests. The compressive strength test measures the ability to withstand loads (Cor-Tuf, 2019) and the flexural strength test measures the concrete's resistance to bending failures (Corrosion-pedia, 2018). Although knowing the results of the splitting tensile tests is a good baseline for showing the concrete's abilities, knowing both the compressive and flexural strength test results would show how the concrete performed under different circumstances and show the different circumstances that plastic can be safely and effectively be added to concrete. Maybe the plastic helps with compressive forces rather than tensile forces, etc. Other tests should be performed, like the freeze-thaw test, to help determine more of the specimen's qualities.

In addition to different tests being conducted, more plastic should be added to the specimens in the future. A small percentage of plastic was added to these specimens, which allowed for knowing how good the mixture was as well as giving preliminary results of what the quality of the concrete was with the plastic in it. But putting more plastic in the concrete would show how much can be put in before greatly decreasing the quality of concrete, making it useless. Once the maximum amount of plastic is found, then this practice can become widespread, allowing plastic to be added in more concrete, reducing the amount of plastic in the world.

Design Statement

This MQP was inspired by the WPI course CE3026 Materials of Construction, a course meant to provide an understanding of the engineering properties of construction materials through laboratory experiments. Specifically, this MQP was based on the mix design lab, which went over the processes involved with creating a quality concrete mixture, and the concrete lab, which involved putting the created concrete through different destructive testing to determine its properties. This MQP began with these labs sparking an idea in the team to combine what was learned during this course with their interest in helping the planet and reducing the amount of plastic in the world in a safe and helpful way. Through this MQP, the team learned more about the labs they had previously done and expanded their knowledge on concrete usage, production and testing in order to develop something new. As a result, a unique mixture and testing procedure were designed in order to accomplish the team's needs.

The processes used in CE3026 were used as a backbone in developing this MQP. With additional research, the team designed their own mix design, using percentages and already established mixtures in order to determine practical ingredient amounts. A lot of work was done to determine the amount of core ingredients that would need to be used and even more work and calculations were done in order to find the percentages of each type and amount of plastic that would need to be added.

The team also researched more into standard testing procedures, understanding how and why certain things are done and how to replicate it themselves. Previously, they had an instructor with them, telling them when and what was put into the concrete or there to use the machines that would destroy the cylinder while students watched. The team was required to understand the process of both mixing and testing in order to proceed with this experiment without the aid of an instructor with them. With this knowledge, the team then designed a set of experiments that could perform on their own that would also give the results that they desired.

The team knows that there is an issue with pollution in this world, that landfill and our oceans are filled with plastic. The team wanted to combine this issue with what they had learned in their course. Therefore, it was the team's goal to determine if there was a type and/or amount of plastic that could be put into concrete as fibers to make it stronger, or at the very least a mixture that would be just as strong. A successful result could possibly be implemented, allowing for a safe place for plastic to go as well as possibly finding a better or comparable way of making concrete.

Licensure Statement

"The purpose of engineering licensure is to uphold public safety by restricting practice of engineering to qualified engineers (professional engineers)." (Payne, 2018) Professionals in the civil and environmental fields design, build, and maintain infrastructure projects. These include roads, buildings, bridges, and systems for water supply and water treatment. With them working on such important projects, these professionals have a responsibility to keep people safe. Therefore, once they leave college or university, engineers go through the process of taking the Principles and Practice of Engineering (PE) exam in order to become licensed.

There are a few things that engineers must do in order to become licensed. Firstly, they must complete a four-year college degree. Secondly, they must work under a Professional Engineer for at least four years. Then, they must pass two intensive competency exams. After all of that, the engineer can earn a license from their state's licensure board. (NSPE, n.d.) In order to maintain their license, engineers are required to continually take education courses and see other opportunities for professional development in order to improve their skills. The specific requirements are on a state-to-state basis. Some states require annual renewal, while others require a biennial or sometimes a triennial renewal. (School of PE, 2018) Massachusetts, unlike many other states, does not require engineers to complete Professional Development Hours (PDH) and professional engineer licenses are not renewed every year but every even numbered year on June 30th. (PHD Academy, n.d.)

This license grants that engineer the authority to practice their profession within a designated scope of practice. Some projects can only be done and certain benefits only available to PEs. These include being able to stamp drawings and designs as well as having authority in certain situations. Benefits vary from state-to-state, however some benefits in Massachusetts include employment opportunities, promotability, quality assurance, and global competitiveness. (NSPE-MA, n.d.)

PEs are responsible for protecting the health, safety, and welfare of the public; therefore, they would be required to go over the team’s mix design before it was cleared to be used. They would have to make sure that there was no harm or possible future issues that could arise with putting plastic in concrete. It’s important to acknowledge that there may be potential problems with putting plastic in concrete that could not be determined during this MQP. Therefore, after ensuring that there was no issue with it, only a licensed engineer would be using this mix design.

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