Exploring Physico-Mechanical Properties of Recycled Plastic Amended Cement Concrete

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Abstract

Concrete is one of the most convenient construction materials to be utilized in primary and secondary constructions. One drawback of concrete is being heavy as it contains approximately 80% of aggregate. This pilot research focuses on utilizing recycled plastic waste as a percent replacement of aggregate to produce a lightweight concrete without adding further expense. At the same time, recycling waste is beneficial to our environment. Four concrete mixes were prepared in this research: one control mix without plastic, and three other mixes - one mix with 20%, one mix with 30%, and the last mix with 40% of coarse aggregate being replaced by plastic. Fresh concrete was examined through the slump and unit weight tests. Concrete specimens were cured at room temperature for up to 56 days and hardened properties were evaluated though compressive strength and dry density measurements. Concrete mix with 20% of recycled plastic exhibited comparable strength results after 7 days of curing. It could be hypothesized that recycled plastic added concrete is sustainable and inexpensive to construct many lightweight and secondary structures. Additionally, to enhance interests of freshmen and sophomores in engineering technology discipline, as well as to enhance their research experience at undergraduate level, faculties could involve them in such experimental research projects during summer or winter breaks.

1. Introduction

With the increasing demand for energy and materials, production of an environmentally friendly construction material has become a target for the construction industry in recent years. Not only the production of construction materials is alarming, but the amount of demolition, maintenance, and construction process generates substantial amounts of waste. This construction and demolition waste [Akanbi et al. 2018] disposal process is costly and challenging. Utilizing waste materials in concrete allows us to minimize the negative aspects of the production and disposal of construction materials. And utilizing waste products in construction is environmentally sustainable. The inclusion of waste materials often decreases the structural integrity of concrete and affects its durability. Despite these drawbacks, recycling waste in construction helps promote a circular economy and reduces the demand for new materials.

Aggregate plays a principal role in concrete which occupies 60-80% of the volume and 70-85% of the mass of concrete [Zhu et al. 2020]. Instead of collecting natural stones from quarries or sand from riverbeds, recycled waste could be utilized in manufacturing concrete for new constructions. Replacing natural aggregate with recycled plastic, which is one of the hardest materials in the ecosystem, helps to reduce plastic waste. Recycled plastic fibers or grains can be added to or replaced with normal aggregate to enhance concrete's durability [Ponmalar and Revathi 2022]. Substituting a portion of natural aggregate with plastic can lessen the need for quarrying and mining, and conserve natural resources. Incorporating plastic can lower the density of concrete [Dalhat and Wahhab 2016], leading to a lightweight structure [Almeshal et al. 2020]. Research revealed that the addition of plastic box waste particles [Adnan and Dawood 2021] improves the compressive strength of concrete and enhances ductility and stiffness. However, poor adhesion between plastic particles and the cement matrix [Mansour et al. 2024], resulting from the hydrophobic nature and smooth surfaces of plastics, decreases plastic's ability to bond effectively with cement paste. Dalhat and Wahhab [2016] found that a small quantity of recycled plastic added concrete exhibited enhanced compressive and flexural strength of concrete. Therefore, utilizing a small quantity of plastic waste in concrete not only strengthens concrete's performance but also reduces global warming, and it is a promising sustainable construction material.

Several research has been conducted on utilizing different types of recycled materials in concrete especially recycled fibers in concrete. Most of these waste materials were processed prior to applying to concrete

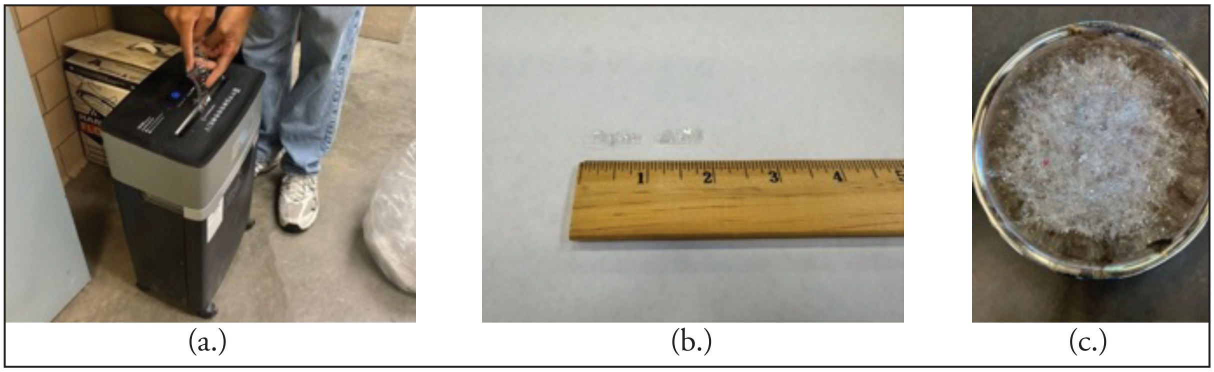

Figure 1. Plastic sample preparation: (a) shredding (b) measurement (c) shredded sample.

mix. In this research, the waste plastic particles were directly applied to the concrete mixes which is most convenient for real projects and is cost effective. Additionally, aggregate, which occupies the maximum volume of concrete, was partially being replaced with these lightweight waste materials which decreased the unit weight of concrete. Therefore, the resultant concrete was easier to handle and transport. In this way, the natural aggregate resources were preserved, and waste recycling is beneficial to the environment. In this research, 20%, 30%, and 40% of natural coarse aggregate were replaced by recycled plastic to make concrete. Cylindrical specimens were prepared and tested for compression after 7, 28, and 56 days of curing and concrete's strength was evaluated.

2. Methodology

2.1 Materials

2.1.1 Sources

Ordinary Portland Cement Type I-II, silica sand with specific gravity of 2.6, crushed stone with nominal maximum size of 19 mm and recycled plastic (polyethylene terephthalate, PET) were utilized in this research. Plastic water bottles were collected from recycled bins, lids and labels were removed, washed with water and air dried for about 24 hours. Then these bottles were split with scissors, and then using a paper shredder they were shredded into 50 mm x 6.25 mm x 0.003 mm portions. For this research, 1000 g of plastic fragments were prepared. Preparation of plastic samples are presented in Figure 1. Cement, sand and gravel were purchased from stores.

2.1.2 Properties

Sieve analysis was conducted on crushed stone according to ASTM C136 [2006] to obtain the grain size distribution, and the gradation curve is presented in Figure 2. Bulk density of plastic and crushed stone [ASTM C29. 2007], specific gravity and absorption capacity of crushed stone [ASTM C127. 2015], and moisture content of crushed stone and sand were obtained. The average tensile strength of three numbers of 13 cm x 5.2 cm x 0.003 mm PET plastic fragments was also obtained using a Universal Testing Machine (Figure 3) with a displacement rate of 0.5 inch/minute. The material properties are listed in Table 1.

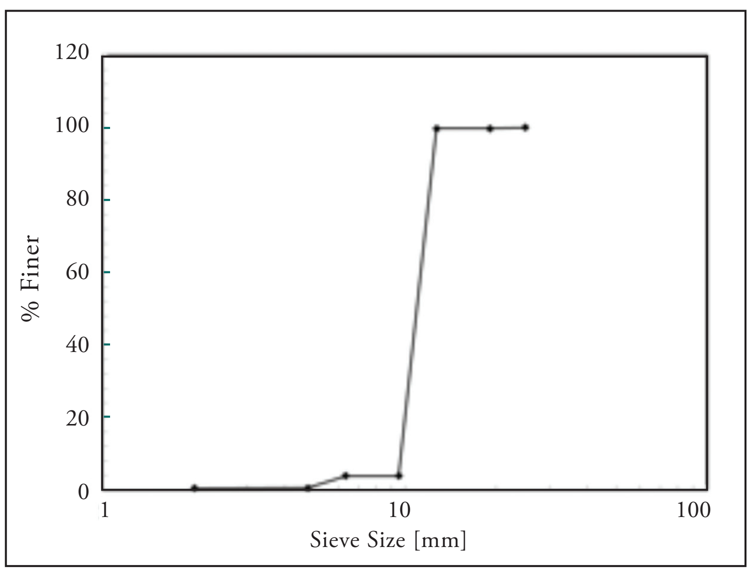

Figure 2. Grain size distribution of crushed stone utilized in concrete.

2.2 Experimental Program

Four concrete mixes were prepared. One of these mixes was a benchmark with natural crushed stone and sand and without any waste plastic. The second, third, and fourth mixes were prepared with 20%, 30%, and 40% of natural crushed stone being replaced by plastic fragments, respectively. These concrete mixes could be conveniently utilized in the real construction scenario as no supplementary cementitious materials, admixture or no additives were

Figure 3. Tensile strength test of plastic sample.

Table 1. Material properties.

Specific Gravity	Absorption [%]	Moisture Content [%]		Bulk density [kg/m3]		Tensile strength [MPa]
Crushed Stone	*Crushed Stone*	*Crushed Stone*	*Sand*	*Plastic*	*Crushed Stone*	*Plastic*
2.745	0.42	0	0.58	85.91	1497.88	2150.97

consumed here. The design slump was 75 mm, and 28-day required compressive strength was 5000 psi (34.5 MPa). The mix design information is reported in Table 2.

The workability of each concrete mix was examined through slump test according to ASTM C143 [2012]. The unit weight of fresh concrete was estimated according to ASTM C138 [2017] and displayed in Table 3. From each concrete mix, three numbers of 100 mm x 200 mm cylindrical specimens were prepared for each test date. The cylindrical specimens were cast in the plastic molds, secured with lids, and were stored in a cabinet at a controlled temperature (80.7° ± 2.9° F) and relative humidity (58.7% ± 7%) for up to 56 days.

3. Results and Discussions

After 7, 28, and 56 days of curing, compressive strength of control and plastic added cylindrical concrete specimens was estimated according to ASTM C39 [2021], and the test setup is shown in Figure 4a. The variation in compressive strength of control and 20% of plastic added cylindrical samples with duration of curing is displayed in Figure 4b. In addition, 28-day compressive strength and dry density of control and different percentages of plastic added samples are reported in Figure 5a and Figure 5b, respectively.

From the compression test results of concrete shown in Figure 4b, it was observed that recycled plastic added concrete produced comparable compressive strength as conventional concrete after 7 days of curing, which indicates early strength gaining was not impacted undesirably by adding plastic fragments in concrete. However, after 28 and 56 days of curing, compressive strength of plastic added concrete was significantly lower than the conventional

Table 2. Mix proportions of four concrete mixes.

Ingredients	Control Concrete	20% Plastic added Concrete	30% Plastic added Concrete	40% Plastic added Concrete
Water [kg]	4.15	4.15	4.15	4.45
Cement [kg]	8.56	8.56	8.56	8.56
Sand [kg]	14.60	14.60	14.60	14.60
Crushed stone [kg]	19.52	15.61	13.66	11.71
Plastic [g]	-	220.56	330.83	441.11

Table 3. Unit weight of fresh concrete.

Properties	Control Concrete	20% Plastic added Concrete	30% Plastic added Concrete	40% Plastic added Concrete
Unit weight [kg/m^3]	2384	2340	2319	2268

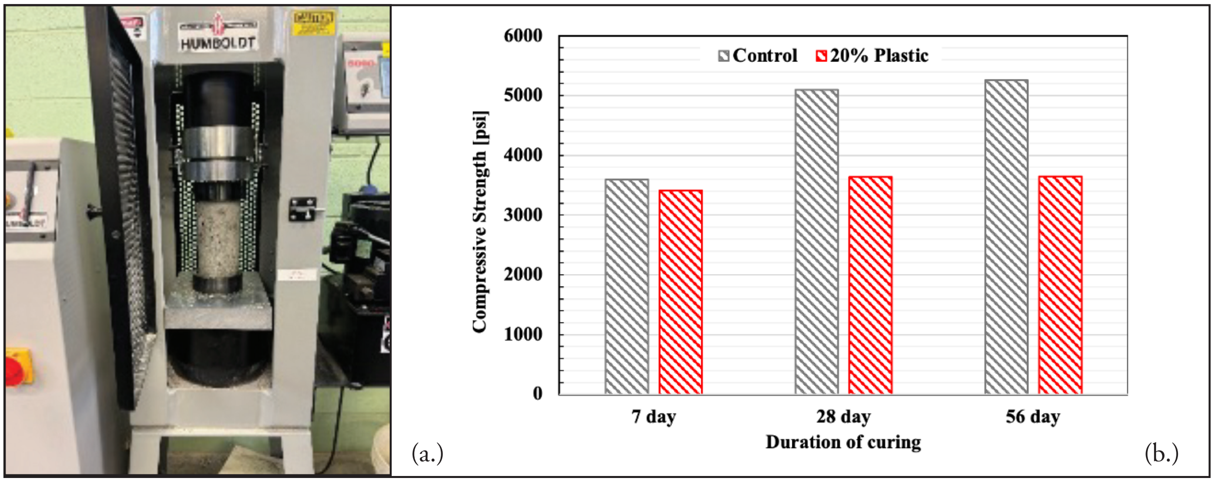

Figure 4. Compression test: (a) test setup (b) compressive strength after 7, 28 and 56 days of curing.

concrete, which signifies that plastic addition might impacted the production of cement hydrates, and adversely affected the interfacial transition zone in the cement concrete matrix, with duration of curing. The ruptured cylindrical samples of control and 20% of plastic added cylinders, displayed in Figure 6, suggest that plastic added samples resulted in less deteriorated failure as compared to the conventional concrete samples, though it yielded lower compressive strength. It was noticed from Table 1 that PET plastic has a tensile strength of 2150.97 MPa which is five times greater than that of mild steel. Due to this high tensile strength of added plastic fragments, a brittle failure of concrete was hypothetically prevented in compression.

It can be hypothesized that, due to lack of chemical compatibility between cement, aggregate and plastic [Naik et al. 1996, Mohammed et al. 2020], hydration was impacted by the presence of plastic particles inside the concrete. In addition, 20 to 40% of plastic added concrete were in range of 2.3 to 4.9% lighter than control concrete (Figure 5b) and these plastic fragments introduced lack of homogeneity in the concrete mix. In absence of 20 to 40% of coarse aggregate and in presence of plastic fragments, voids were generated inside concrete matrix after curing, which resulted in stress concentration zones while loading. As a result, 20 to 40% of plastic added concrete developed in range of 29 to 55% of lower compressive strength (Figure 5a) as compared to conventional concrete after 28 days of curing.

4. Educational Impact on Engineering Technology

Such experimental research has numerous impacts on engineering technology education and some of these potentials are listed below.

4.1 Innovations in Engineering Technology Education

Engineering students prefer reflective learning instead acting learning, while active learning e.g.,

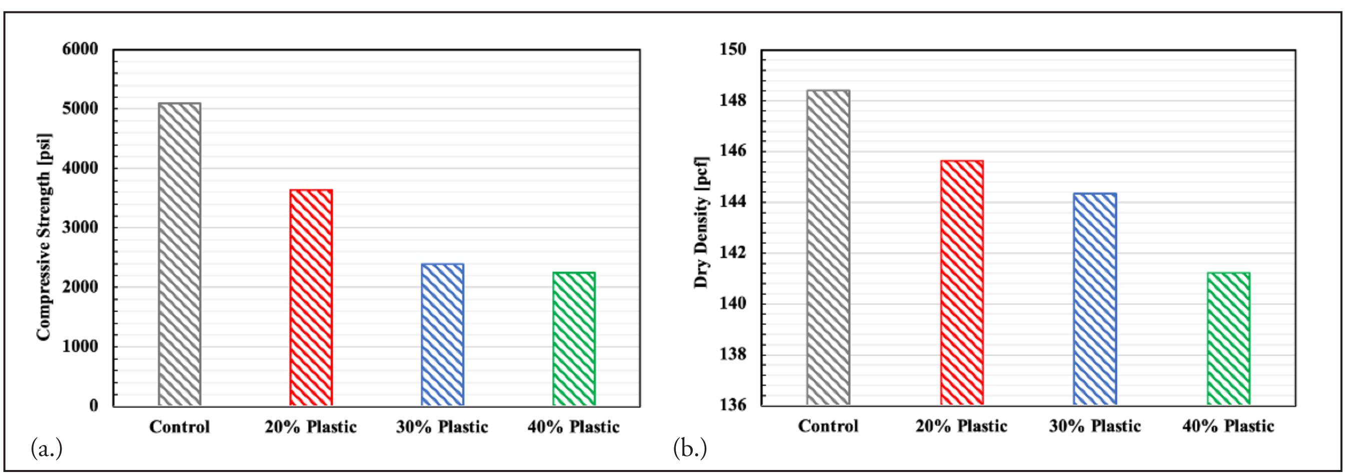

Figure 5. 28-day test results (a) compressive strength and (b) dry density.

Figure 6. Fractured specimens after 28-day compression test (a) control concrete (b) 20% plastic added concrete.

project-based learning offers enhanced understanding of basic engineering concepts [Prince 2004, Iffat 2023]. Involving students in such small projects could enhance their interests in engineering as well as could enhance their fundamental understanding of engineering concepts because hands on experiments in laboratories or fields always fascinate students more as compared to the classroom education. Additionally, students' teamwork skills could be enhanced which is essential for quality education [Uddin et al. 2024] and future leaderships.

4.2 Curricular Support to Engineering Technology Programs

Such small projects could be offered as technical elective courses where laboratory activities will be followed by the lecture. Students' performances could be evaluated through project reports and final presentations. Conducting experimental research works at undergraduate levels may enhance students interests in higher studies. As a result, relevant post graduate courses could be introduced to the program with advanced laboratory activities.

4.3 Enhancements to Student-Enrollment in Engineering Technology

This type of project-based courses will enhance students' enrollment in the engineering technology program while due to difficulties in understanding core engineering concepts in the first two academic years, many students transfer to many non-engineering disciplines. Additionally, student and faculty interaction, which is strategic for academic success of students [Yanik et al. 2021], could be enhanced through involving students in such experimental research projects conducted by faculty mentors.

5. Conclusions

From this experimental research, following decisions could be implemented:

- Early high strength after 7 days of curing was observed from 20% of plastic waste added concrete; however, no strength enhancement was experienced after 28 or 56 days of curing. After 28 and 56 days of curing, 20% plastic added concrete exhibited lower compressive strength compared to the control concrete.
- In this research, no supplementary cementitious materials i.e., fly ash, silica fume, or no admixtures were utilized to keep the construction expense minimal, and to ensure its quick application in real construction scenario.
- The recycled concrete was lightweight and less expensive as compared to conventional concrete. To reduce weight of large structures, these waste materials could be utilized in concrete in addition to some reinforcing agents and admixtures to offset the strength loss.
- As plastic fragments yielded high tensile strength, high flexural strength is hypothetically expected from recycled plastic added concrete.
- Recycled plastic added concrete could be utilized in low-rise residential buildings, partition walls of commercial spaces, curbs, sidewalks, driveways, road dividers and many other secondary structures. Uses of recycled plastic in construction will reduce the plastic waste and global warming.
- If undergraduate students are involved in such research projects, it enriches students' portfolios, boosts their teamwork-leadership skills, and finally, upgrades their interests in engineering studies. It is recommended to associate undergraduate students in research projects for all engineering technology disciplines, especially civil engineering

technology, architecture and construction management technology and mechanical engineering technology.

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