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Final Project Report for Bricks from Recyclables

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Final Project Report for Bricks from Recyclables

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ENGR 4382

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Executive Summary

The Bricks from Recyclables team is dedicated to designing and constructing an eco-friendly concrete brick that incorporates plastic to tackle the issue of plastic waste in the environment. The sponsor, Samadhi Yoga Retreat, plans to use this innovative product as a building material on-site to recycle and repurpose plastic, thereby eliminating the impracticality of transporting plastic waste to a recycling center in the remote location.

The team conducted tests on four essential subsystems: shredder, mixer, mold, and brick. The shredder tests involved evaluating the shredder's capability and speed. The capability test demonstrated that the shredder could process both PET and HDPE plastic effectively into appropriate sizes, with HDPE producing slightly more of the targeted size. The speed test demonstrated that the shredder could process five bottles of both plastic types in under five minutes. These tests showed that the shredder adhered to the shredder functionality working criteria.

The mixer test evaluated whether the mixture could produce a visually uniform blend in less than five minutes. All mixtures created in the mixer successfully met the criteria. However, the team recommends using a larger mixer for producing full-size bricks.

The mold functionality test evaluated the effectiveness of the molds utilized to fabricate the coupons. The 3-D printed molds demonstrated excellent performance, with easy ejection of coupons and convenient cleaning and reusability. However, the melamine coupon mold proved less efficient due to being hand-manufactured and requiring the application of messy silicone for sealing. To accommodate the size limitations of the 3-D printers available to the team, the full-size mold comprises a combination of melamine and 3-D printed components. This test showed that the 3D printed mold adhered to the mold functionality working criteria.

The brick tests included a compression test to determine the optimum plastic-concrete formulation and a weather resistance test to assess the brick's water resistance. The compression test showed that pure Quikrete achieved a compressive strength of over 1900 psi for water ratios ranging from 7-7.5%. The team selected 7.5% water as it retained plastic particles more effectively. PET outperformed HDPE in compression tests. However, none of the coupons with plastic ratios ranging from 1 to 15 percent plastic on a mass basis, or 1.54 to 23.11 percent on a volume basis, met the 1900 psi requirement mandated by ASTM C90 [1]. The team recommends longer curing times as a way to increase compressive strength.

The final phase of compression testing was anisotropic tests, which tested the bricks' performance in a more consistent orientation with how full-size bricks will be loaded. The results indicated that an increase in plastic particle size resulted in an increase in compressive strength. The rough surfaces of the coupons, caused by molds designed for testing in the other orientation, led to some of the lower fatigue stresses. This test demonstrated that modifying the mold's orientation could increase the compressive strength and potentially lead to a formulation that meets the 1900 psi requirement. The team recommends further research and testing on the anisotropic orientation.

The weather resistance test evaluated the water absorption capacity and the formation of salt deposits as the bricks/coupons dried. All specimens underwent both tests and successfully passed. To meet the requirements of the absorption test, the bricks/coupons needed to absorb less than 20% of their original weight. The full-size ASTM C90 bricks performed better, with a range of 6-7%, compared to the coupons, which had a range of 8.8-14.9%.

1. Introduction

Excessive plastic waste is a critical issue that society faces today. The environmental build-up of single-use plastic products is known to negatively impact wildlife and human populations. The objective of this project is to explore a solution to the plastic crisis by innovatively recycling waste plastic at a local organization. Samadhi Yoga Retreat, located in a rural area outside of Wimberley, Texas, is unable to recycle plastic water bottles, packaging, and containers generated by their business. The goal of this work is to create a machine that recycles plastic and repurposes it into bricks for structural purposes, such as housing or fencing. This year's focus was to research and develop the process by which plastic is shredded and incorporated into concrete bricks to create specifications for the bricks and tooling methods that will be components of the machine. Senior designers in future years will continue this research to develop a machine designed to achieve these specifications.

At the start of this project, the team came up with a list of four requirements the final bricks must adhere to. Firstly, the bricks must have a compressibility strength comparable to commercial Standard Concrete Masonry Units (CMUs). This value is rated at 1900 psi as dictated in ASTM C90, a code describing the standards for loadbearing CMUs. Second, in accordance with the sponsor's request, the bricks must be stackable up to a height of 8 feet to facilitate the brick's purpose as housing. Third, the bricks must be weather resistant and follow the weather resistance specifications in ASTM C90. Lastly, the bricks must contain the maximum weight percent ratio of plastic that permits adherence to the above requirements.

To assess the viability of the team's plan to shred plastic and mix it directly into concrete, tooling methods were used to construct prototype test bricks. This year's design included molds for small brick testing, modifications to the shredder, fabrication of grates to order the plastic particles by size, and extensive research analyzing the abilities of the test bricks. The research and experimentation looked at variables such as the water to concrete ratio, plastic particle size, plastic to concrete ratio, and anisotropic behavior resulting from the brick pouring process. Working criteria such as process time and tooling method functionality were evaluated, while other criteria like portability and solar power will be addressed in future comprehensive machine designs.

Overall, this year's design consisted of molds used to create small bricks used for testing, modifications to the shredder, fabrication of grates for ordering plastic particles by size, and a research process analyzing the material properties of concrete-plastic bricks. The research and experimentation of the bricks looked at the water to concrete ratio, the plastic particle size, and the plastic to concrete ratio as variables. Lastly, this year's research investigated the anisotropic behavior—how the bricks' compressibility behavior changed depending on the orientation—which resulted from the brick pouring process.

2. Overview of the Final Design

For this project, the team attempted to perfect the method of mixing shredded plastic with concrete to assess its success as a solution to the design problem. This process was achieved using three primary tooling methods: a shredder, a mixer, and a mold. To properly evaluate design, each subsystem was tested against the working criteria separately. Testing also entailed performing compression tests on numerous smaller blocks of concrete, called coupons, with varying plastic ratios and particle sizes to ascertain the best combination of variables to produce an acceptable brick. The compressibility and weather resistance test on the coupons and capability testing of the tooling methods were the focus this year.

2.1 Shredder

The shredder was used to shred cleaned plastic bottles into smaller, more usable pieces. The shredder used this year was a pre-existing machine available in the Makerspace which utilizes a 0.55 kW induction motor (recycled from a bandsaw), a cycloidal drive, and a custom cut steel assembly as seen in Fig. 1. To improve the safety and efficiency of this machine, one of the first accomplishments of this project was the installation of an on/off switch and an emergency stop button on the shredder. A major issue when first using the shredder was the tendency for the plastic to continually rotate in the hopper of the shredder instead of actually getting shredded. To fix this, a plunger was built in the woodshop as detailed in Appendix A. This tool was built with relatively low tolerances because doing so prevents the plunger from being inserted at an angle, which consequently prevents the shredder blades from gaining enough leverage to damage the plunger or the shredder itself. After the plastic was processed by the shredder, the particles were sifted through a series of grates, as seen in Fig. 2, to sort the particles according to their size. To prevent these grates from clogging the shredder, they were manually operated rather than installed as a stationary grate underneath the shredder. Some of these grates were purchased (specifically the 3-, 6-, 9-, and 12-mm aperture mesh sifters), and two of these grates (4.5 and 7.5-mm aperture mesh sifters) were manually constructed as detailed in Appendix B.

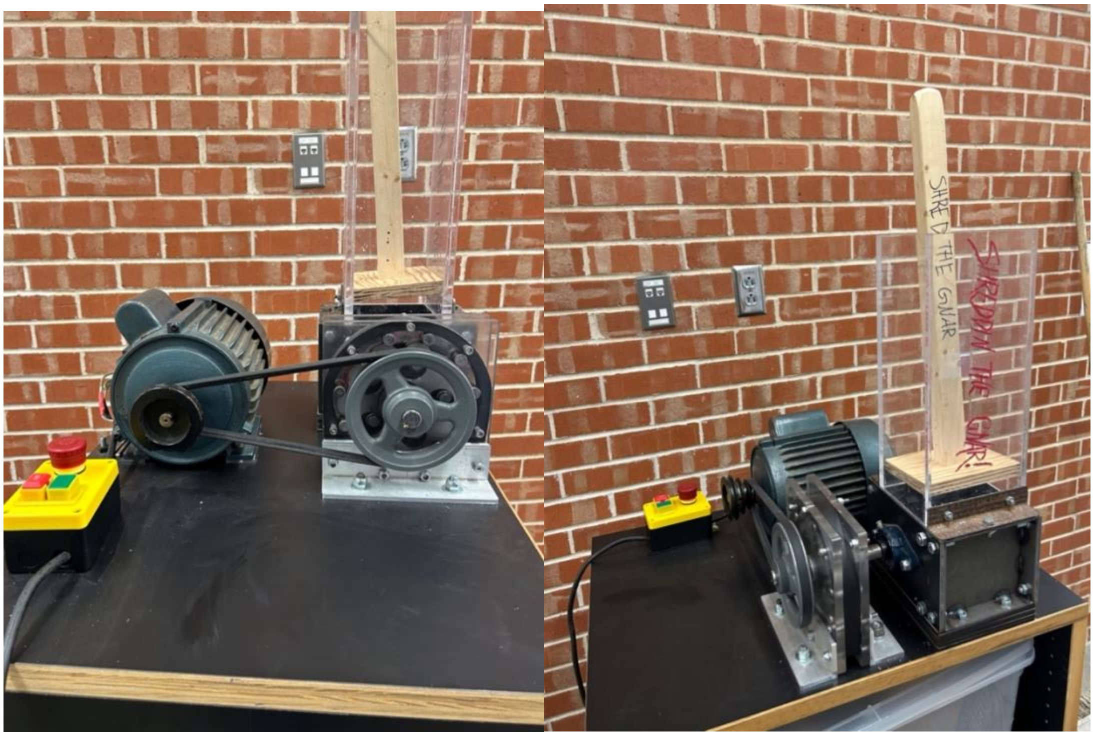


Figure 1: Side and front view of the shredder with the plunger inserted.

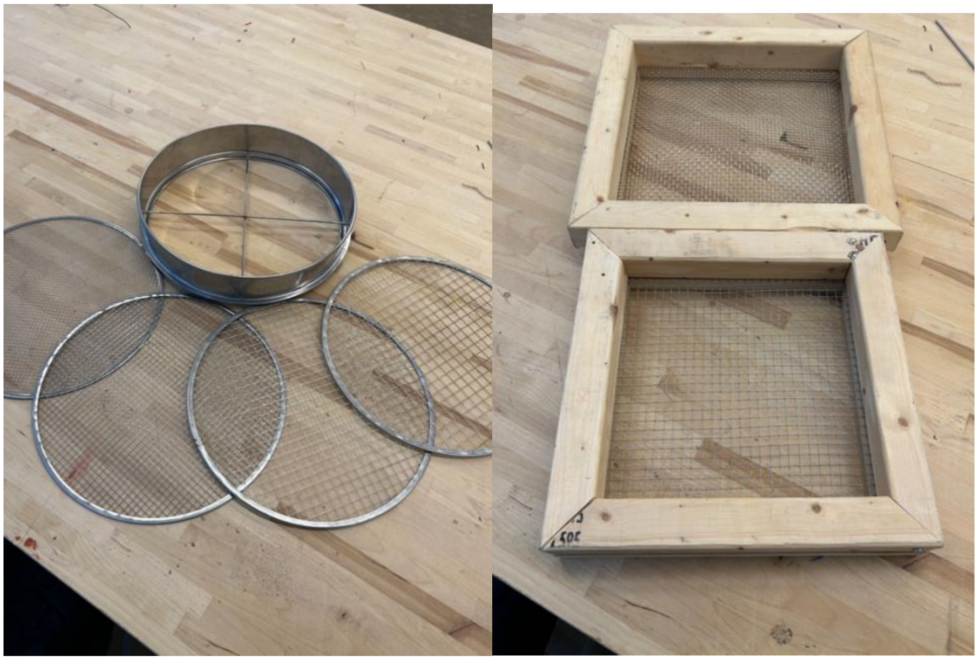


Figure 2: Purchased sifters (left) and constructed sifters (right)

The primary working criteria concerning the shredder were its ability to produce plastic particles of the desired size and whether the process time needed to produce these particles was reasonable. Although process time was not a critical requirement for this year, it will be a working criterion for the future machine that will implement this process; therefore, the lower the working time of each subsystem the better. To assess the shredder working time, the rate at which the shredder processes input plastic into usable material was determined on a mass basis. By assessing the process time on a mass basis this data can be extrapolated to approximate the shredding time needed for a full-size brick.

2.2 Mixer

The mixer tooling method consisted of a KitchenAid stand mixer with an attachable bowl that was acquired by one of the team members. The mixer has an adjustable mixer head that can sit in and lift out of the bowl. There are a multitude of mixing speeds that the KitchenAid mixer can be set to, but for the purpose of this project, only the first setting is necessary. In addition, an eggbeater and bucket were purchased with the intention of producing full-sized bricks considering the quantity the bucket can hold compared to the KitchenAid mixer, as seen in Fig. 3 and 4. However, since no full-size bricks were made this year, the eggbeater and bucket were not used or tested. Therefore, all necessary mixing was done with only the stand mixer.

The mixer must be able to effectively mix the plastic into the concrete solution, mitigating any heterogenous features. Clumping or settling of the plastic is indicative of poor mixing, which would produce volatile and invalid data for compressive testing. The effectiveness was evaluated through observation at three stages of the mixture. The team noted the homogeneity of the mixture after the initial mixing, after curing of the coupons, and finally after the coupon breaks in compression testing exposing its interior. The observations never raised any concerns of mixing capability, so the team maintained the KitchenAid mixer for the entirety of the project without modification.

Figure 3. KitchenAid stand mixer used for producing concrete coupons

Figure 4. Eggbeater and bucket mixer intended for full-brick production

2.3 Mold

The last major tooling method is the mold used to shape the concrete coupons. This mold is responsible for allowing the coupon to dry and must maintain its shape without any sagging or deforming from the weight of the concrete. Another very important aspect of the mold is the ejection. Ideally, the concrete coupons release from the mold with minimal effort and without damage to either the coupon or the mold. For this reason, the mold was designed to be disassembled, allowing for the concrete to break surface contact with the mold walls. This condition introduced the concern of reusability. The mold would need the capability to reassemble for use in additional concrete pours. To address this challenge, the mold was designed as three parts: two parts 3D printed, and one part laser cut. Bolts and wingnuts were used to connect each component together firmly while allowing the user to unscrew and disassemble easily. The 3D printed components made up the vertical walls that held the coupons in place. When placed together, these two components create a 2 x 2 inch square with a depth of 1.25 inches. The line of separation for these two components was designed to run through the corners of the coupons. This is important because if the components separated perpendicular to the coupon walls, concrete that leaks into the separation crack could create peaks along the coupon walls. The coupon walls are required to be flat for compression testing so these peaks would render the coupon unusable. Finally, the third laser cut component acts as a bed that sits under the 3D components. It firmly screws into the upper components, keeping any mixture from leaking and allowing the users to have a firm foundation for concrete pours. The fully assembled mold can be seen in Figure 5.

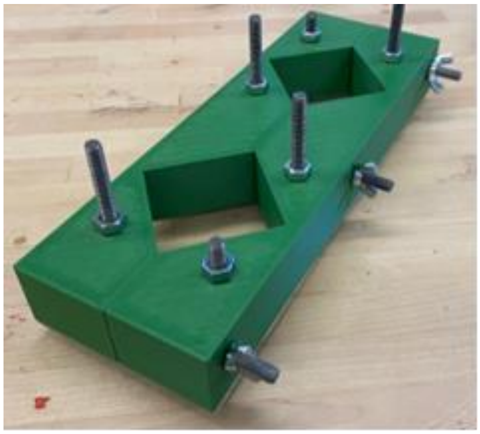


Figure 5. 3D printed mold for concrete coupons featuring a laser-cut bed component

The major concern that was introduced during testing was the effect the mold had on the coupon's anisotropic effect. It was noted that the tamping of plastic mixed concrete was forcing the plastic to sit parallel to the 2 x 2 in walls. Since the coupons are rotated to sit on the 1.25 x 2 in walls for compression testing, the plastic particles essentially act as columns under pressure. To address this issue the mold needed modification so that the mold is not rotated for compressive testing. A mold was designed in CAD but not fabricated for usage. The design can be seen in Figure A of Appendix E. Full discussion of the future uses of this design can be found in Section 4.

An additional mold was made of melamine coated wood as seen in Figure 6, with its construction detailed in Appendix C. There were initial concerns about permeability of water through the melamine, as well as a non-precisely dimensioned coupon as a result of being made by hand rather than 3D printed. After initial use, it was clear that the melamine mold was inferior and prone to decrease in quality with each pour. As a result, this design was scrapped for small scale coupons, however, it is still incorporated into our full-brick mold as seen in Figure 7. This mold has not been used yet; however, next year's team can hopefully continue by fabricating a full-sized brick. The issues with melamine are expected to be less severe for this mold since it only composes the perimeter of the mold and will be much larger, rendering the defects negligible relative to a small coupon. The construction of this mold is found in Appendix D.

Figure 6. Melamine coated wood mold for concrete coupons.

Figure 7: Melamine mold intended for full-size concrete bricks

2.4 Bricks

The final brick design was chosen based off of standard dimensions for a CMU, with nominal dimensions of 16 x 8 x 8 inches. This brick was not constructed this year, due to the team's focus on coupon testing to determine the optimal concrete-plastic formula; however, this design is the end goal for the product of this design project. This brick has a face shell thickness of 1.25 inches, and a web thickness of 0.75 inches (seen in Appendix F, Fig. C). These dimensions informed on the sizes of the small bricks, which the team referred to as coupons.

The coupons that were designed and fabricated this year using the aforementioned tooling methods were dimensioned according to ASTM C90. Since these coupons were designed solely for testing purposes, it was crucial that the specimen fit on the machine used for compression. The machine, an Instron 5969 Dual Column Testing System, has compression plates with 5.75-inch diameters—as such, the coupons were designed to be smaller, and have a thickness in contact with the plate the same as the face shell thickness. The full dimensions of the coupons can also be seen in Fig. D of Appendix F, and both a pure concrete and plastic-hybrid coupon can be seen in Fig. 8.

Figure 8: Pure concrete coupon and plastic-concrete coupon.

The exact water to concrete ratio, plastic weight ratio, plastic particle size, and plastic orientation were not fully determined during this project. However, throughout all tests, the bricks contained between 1.54 and 23.11 percent by volume of plastic. Table 1 shows a conversion between mass percent and volume percent to show how much plastic was used in all coupons based on the density of PET plastic. This conversion uses the volume of the coupons, 5 in^3, the density of PET plastic, 22.62 g/in^3, and an estimated density of Quikrete of 34.85 g/in^3. This conversion is for purely illustrative purposes and is based on approximations; all future discussion of plastic ratios will be in terms of mass percent, as it is a more accurate measure of plastic content.

Table 1: Plastic ratio conversion from mass percent to volume percent for coupons.

Plastic Ratio Mass Percent [%]	Plastic Ratio Volume Percent [%]	Volume of Plastic in a Coupon [in^3]	Estimated number of water bottles in a coupon
1	1.54	0.077	0.2
6	9.24	0.462	1.0
8	12.32	0.616	1.4
10	15.41	0.770	1.7
12	18.49	0.924	2.1
15	23.11	1.155	2.6

3. Design Evaluation

The evaluation of the team's design is split up into two primary sections: discussion of the brick's adherence to the project requirements and discussion of the tooling method's adherence to the working criteria. Section 3.1 discusses the compressibility strength test, which addresses the compressibility strength requirement, and assumes that this test also encapsulates what is required of the stack-ability project requirement. Given that this project is still in progress, the maximum plastic ratio that can viably be used in a brick has not been determined yet, and therefore this project requirement is not directly addressed;

discussion is instead incorporated into the evaluation of the bricks. Section 3.2 addressed the weather resistance project requirement and Sections 3.3, 3.4 and 3.5 discuss the functionality of all tooling methods.

3.1 Compressive Strength

To address the project's requirement for compressibility strength, a multi-phase research process was conducted. This process involved modifying several variables and observing changes in the compressibility behavior. These variables included the water to concrete ratio (phase 1), plastic type (phase 2), that is, polyethylene terephthalate (PET) or high-density polyethylene (HDPE), plastic size and ratio (phase 3), and anisotropic properties (phase 4). The analysis was conducted thoroughly to determine whether the chosen method would result in bricks that meet the compressive strength requirements. Unfortunately, none of the coupons met the project requirements beyond phase 1. However, the results from phase 4 showed promise and could be explored further in the future.

Associated Test: Brick Compressive Strength

Test Overview

In order to identify the optimal combination of plastic particle size, plastic ratio, plastic type, and water ratio that would result in a brick meeting the 1900 psi requirement, tests were carried out. These tests utilized the Instron machine to measure the maximum compressive strength of the coupons. Furthermore, to investigate the anisotropic behavior of certain coupons, they were subjected to testing in two different orientations.

Objectives

1. Determine the best water ratio to use for the team choice of binding agent (Quikrete).
2. Determine the plastic ratio and plastic particle size that maximizes the plastic in the brick while also satisfying the 1900 psi compressive strength standard given in ASTM C90.
3. Determine the ideal plastic to use for the final formula (PET vs HDPE)
4. Assess the anisotropic behavior of the coupons

Feature(s) Evaluated

This test measured the maximum load each coupon could handle before failure.

Test Scope

The test was conducted following ASTM C140 (the testing procedure for ASTM C90) guidelines, which assumed that using a sample of 3 coupons would accurately represent all bricks constructed using the same procedure and plastic ratio [2]. The maximum load in pounds for each coupon was directly obtained from the Instron machine and compared numerically to derive the test results. During phase 4, a modification was made to the orientation of the coupons, with the 2”x2” faces being placed in contact with the Instron machine instead of the 1.25”x2” faces.

Test Plan

The test was divided into four phases after creating a design of experiments matrix (seen in Appendix G), which details all plastic-concrete coupons that were tested across the last three phases. The team started testing at higher percentages as dictated in a study on the compressibility and water retentivity of concrete bricks containing melted LDPE. According to Bhushaiah et al.'s research, bricks containing 20% plastic had the highest compressive strength. However, since the team's process had the potential to produce weaker bricks than those made with melted plastic, the design of experiments started at 15% plastic [3].

This approach allowed the team to effectively measure the samples that would yield the most significant data.

Phase 1 involved measuring the strength of concrete coupons to determine the optimal water ratio for all subsequent concrete pours. In phase 2, coupons with different plastic ratios and particle sizes were tested using both PET and HDPE plastics to establish a foundation for formula optimization. In phase 3, additional variations of plastic ratios and particle sizes were evaluated, but with a single plastic type based on the performance observed in phase 2. Finally, phase 4 involved creating new coupons using plastic ratio and particle size combinations that had already been tested, with their anisotropic behavior being assessed by orienting them such that the square faces were in contact with the Instron plates, as depicted in Figure 9.

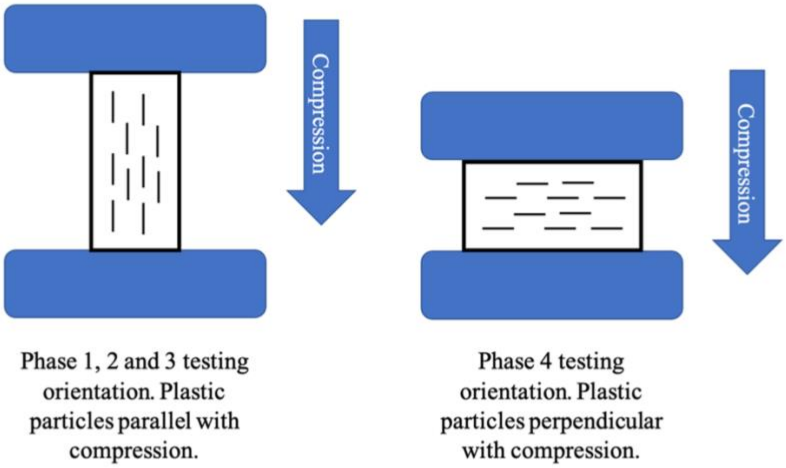


Figure 9: Diagram showing the different orientations of coupons during phase 4 of compression testing with the plastic alignment shown.

Acceptance Criteria

Coupons that could withstand a force greater than 1900 psi before breaking were deemed successful, while any coupon that failed to meet this standard was considered unsuccessful. The optimal formula would have the highest plastic content and the success or failure of the experiment would be determined based on the 1900 psi threshold. All other goals would be evaluated based on maximum compressive strength.

Test Results

Table 2 displays the results of the compression test for phase one, which was conducted without plastic. It was observed that Quikrete met the 1900 psi requirement with a water ratio ranging between 7-7.5%.

Table 2: Phase 1 results

Phase Number	Experiment Number	Water Ratio [%]	Average Max Load [lbf]	Average PSI [psi]
1	1	7.1%	5813.92	2325.56
	2	14%	4044.8	1617.92
	3	7.1%	8883.06	3553.22
	4	5.4%	1018.59	407.436
	5	6.5%	1307.85	523.14
	6	8%	3879.26	1551.70
	7	7.5%	5056.96	2022.78

The results of phase two, as seen in Table 3, indicated that although HDPE achieved the highest average psi of 292.412, it was inferior to PET in general. Regrettably, none of the coupons met the 1900 psi criterion.

Table 3: Phase 2 results

Phase Number	Experiment Number	Water Ratio [%]	Plastic Size [mm]	Plastic ratio [%]	Plastic Type	Average Max Load [lbf]	Average PSI [psi]
2	8	7.5%	< 3	15%	HDPE	241.75	96.7
	9	7.5%	3 - 4.5	12%	HDPE	313.28	125.312
	10	7.5%	4.5 - 6	10%	HDPE	731.03	292.412
	11	7.5%	< 3	15%	PET	458.81	183.524
	12	7.5%	3 - 4.5	12%	PET	441.84	176.736
	13	7.5%	4.5 - 6	10%	PET	517.52	207.008

The outcomes of phase three are seen in Table 4. They demonstrated a rise in compressive strength as the plastic particle size and ratio were decreased. Despite this improvement, the plastic coupons only achieved a maximum of 50% of the required strength at best.

Table 4: Phase 3 results

Phase Number	Experiment Number	Water Ratio [%]	Plastic Size [mm]	Plastic ratio [%]	Plastic Type	Average Max Load [lbf]	Average PSI [psi]
3	14	7.5%	< 3	6%	PET	1406.37	562.55
	15	7.5%	3 - 4.5	8%	PET	953.80	381.52
	16	7.5%	< 3	6%	PET	1520.63	608.25
	17	7.5%	< 3	8%	PET	1286.95	514.78
	18	7.5%	< 3	1%	PET	1842.99	737.20

In phase four, the outcomes revealed that pure Quikrete was weaker in the alternative orientation, with a result of 827.554 psi compared to the normal orientation's 2022.78 psi. Experiment 20 exhibited a lower strength of 445.982 psi compared to experiment 18's 737.197 psi, even though both utilized the same formula. However, experiment 21 demonstrated encouraging findings, with its average of 897.202 psi being the highest of all test groups in phases two through four. These results are shown in Table 5.

Table 5: Phase 4 results

Phase Number	Experiment Number	Water Ratio [%]	Plastic Size [mm]	Plastic ratio [%]	Plastic Type	Average Max Load [lbf]	Average PSI [psi]
4	19	7.5%	-	0	-	3310.22	827.55
	20	7.5%	< 3	1%	PET	1783.93	445.98
	21	7.5%	4.5 - 6	6%	PET	3588.81	897.20

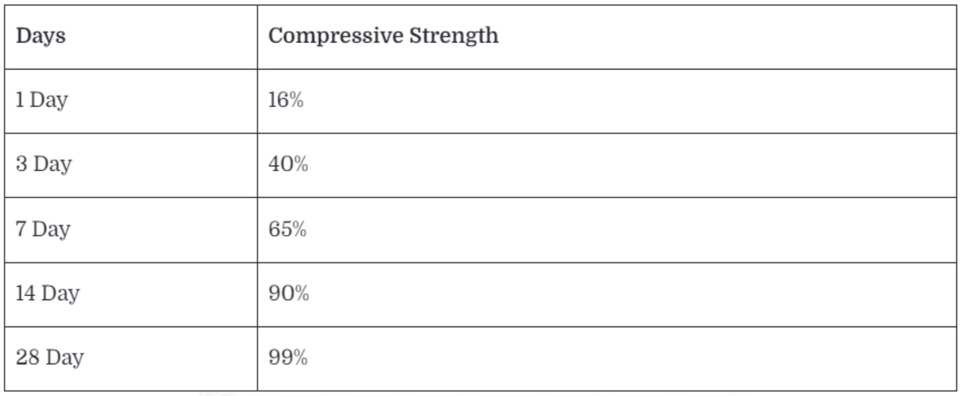
Evaluation

The results from phase one show that a water to concrete ratio of 7.1% resulted in the highest possible compressive strength. However, the 7.1% water ratio was only ideal for maximizing compressive strength in a solely concrete brick; during preliminary phase 2 testing, it was discovered that the texture of the concrete at the ratio could not feasibly hold the plastic particles in the coupon without abundant fallout and crumbling of the coupon. Therefore, the team made the decision to switch to a slightly higher water ratio for all future tests to ensure that the mixed in plastic would remain in the coupons. A ratio of 7.5% water was used for all remaining tests.

During phase two, PET outperformed HDPE on average. Based on the results from this phase, the team ultimately decided to go with the PET plastic as the chosen plastic for the remaining experiments. Although the HDPE had one experiment which yielded a higher average compressive strength, the PET shows a much more consistent trend—and also higher values—at specifically lower particle sizes. Given that variability between coupons is undesirable, the team theorizes that a smaller size particle will yield greater strength when the ratio is lowered; as such, the team opted for PET as the chosen plastic type for all future experiments. This decision aligns well with the sponsors request, as the most common plastic they hope to recycle is plastic bottles and plastic packaging, which are commonly PET.

Phase three's 14th and 16th experiments tested the same formula, with the former being cured for only four days and the latter for seven days like all other phase three tests. A slight increase in compressive strength was observed. However, the plastic coupons were still unable to meet the 1900 psi criterion. The team recommends longer curing times as they increase compressive strength [4], as indicated in Table 6.

Table 6: Compressive strength vs curing time



Days	Compressive Strength
1 Day	16%
3 Day	40%
7 Day	65%
14 Day	90%
28 Day	99%

In phase four, anisotropic tests were performed, demonstrating that changing the orientation of the coupons and increasing the plastic size and ratio may lead to achieving the required compressive strength. Additionally, the anisotropic testing showed that coupons with plastic particles had significantly larger strains, indicating that this material may be more ductile than traditional concrete in this orientation. Table 5 shows that the compressive strength of the plastic hybrid coupons was higher than that of the pure concrete coupons, indicating the feasibility of producing eco-bricks that surpass the compressibility of solely concrete. The tamping process's uneven surface may have lowered the phase four test results, a variable that could potentially be resolved by utilizing the vertical mold depicted in Figure A.

3.2 Weather Resistance

The project's weather resistance requirement is a result of the sponsor's intended use for the final product. This criterion evaluates the ability of the bricks to withstand outdoor conditions by examining their resistance to water. The absorption rates of all bricks and coupons were found to be in accordance with ASTM C90 standard, with the store-bought bricks demonstrating better performance than the coupons.

Associated Test: Brick Weather Resistivity

Test Overview

The team assessed the weather resistance of the bricks by conducting an ASTM C140-based absorption and efflorescence test. To evaluate the effect of plastic on weather resistance, the team tested full-size bricks from a local vendor as a reference and compared them to coupons. All bricks and coupons met the ASTM C90 standards for absorption.

Objectives

1. The weight of the brick should increase no more than one fifth of its original weight.
2. After absorbing water, the brick should not display any white or gray salt deposits.

Feature(s) Evaluated

This test evaluated the brick’s/coupon’s resistance to water absorption as well as its salt content under conditions that simulate different weather environments.

Test Scope

The test assumed that a sample of 3 bricks/coupons was representative of all concrete bricks. This test also assumed that an absorption and efflorescence test is representative of a weather resistance test.

Test Plan

After curing for 7 days, the store-bought bricks were already cured, the bricks/coupons were submerged in a water bath for 24 hours. The weight of each brick/coupon was recorded before and after the immersion, and a spacer covering less than 10% of the bottom surface of the brick was used to create at least a 0.125 in (3 mm) separation from the bottom of the water bath. The absorption percent and moisture content were calculated according to ASTM C140, section 9, and compared to the standards for weather resistance [2]. The bricks were then dried in a shaded area and monitored for five days to observe the presence of salt deposits on the surface, a sign of efflorescence.

Acceptance Criteria

In the initial testing phase, the success criteria for bricks/coupons were based on their absorption of water not exceeding 20% of their initial weight. The presence of salt deposits on the surface of the bricks was also observed, as they can cause a white discoloration. The test was deemed successful if no visible salt deposits were observed on the bricks.

Test Results

Table 7 presents the data and results of the weather resistance test. The store-bought bricks exhibited absorption percentages between 6-7%, which is below the 20% acceptance criterion, and showed no visible salt deposits during the 5-day drying period. Hence, they successfully adhered to the ASTM C90 standards. Conversely, the pure Quikrete coupons had absorption percentages between 8.8-9.7%, which is still below the threshold. The plastic-containing coupons, which had plastic particle sizes between 4.5mm and 6mm and plastic percentages of 3% and 6%, had absorption percentages between 9.5-14.9% and 12-13.6%, respectively. Nonetheless, all coupon results were below the 20% absorption threshold, and no evidence of salt deposits was found.

Table 7: Weather Resistance Results

Brick Type	Brick #	Absorption [%]	Salt Deposits? [Y/N]
Store-Bought Full-Size	1	6.061	N
	2	6.870	N
	3	6.977	N
0% Plastic Coupons	1	9.648	N
	2	9.341	N
	3	8.879	N
3% Plastic Coupons	1	14.876	N
	2	10.255	N
	3	9.510	N
6% Plastic Coupons	1	12.094	N
	2	13.523	N
	3	12.836	N

Evaluation

The results from the coupon tests indicated that the Quikrete formulas had slightly higher absorption properties compared to the store-bought bricks. Nonetheless, all bricks and coupons that underwent the absorption and efflorescence tests passed, which gives the team confidence that the final formula will also pass the weather tests.

3.3 Shredder Functionality

The shredder functionality consisted of two aspects: its ability to produce appropriate size particles and the process time needed to produce enough particles for a full-size brick. After the initial compression tests were performed, the appropriate size particles were determined to be less than the 3mm grate, between the 3mm and 4.5mm grates, and between the 4.5 mm and 6mm grates. The final compression tests were for 1% plastic, but the anisotropic test showed the potential for coupons up to 6% plastic; therefore, the shredding time for a full-size brick at 1% and 6% were both assessed.

Associated Test 1: Shredder Capability

Test Overview

The team first determined if the shredder could operate with both PET and HDPE plastic. After testing the shredder's ability to shred different plastic types, the team measured the plastic particle sizes of PET and HDPE, respectively, to determine if one plastic type shreds into smaller pieces than the other. Finally, based on the plastic type chosen for the compressive strength tests, the team measured the distribution of particle sizes after various cycles through the shredder.

Objectives

1. Confirm that the shredder can operate with PET and HDPE plastic.
2. Approximate the PET and HDPE particle size distribution after 3 cycles through the shredder.
3. Determine if the shredder can produce particles of the sizes needed for the brick compressive strength test after 3, 6, or 9 cycles through the shredder.

Feature(s) Evaluated

This test evaluated the shredder, its ability to shred PET and HDPE, and the distribution of particle sizes after being shredded.

Test Scope

This test assumed that the shredded plastic size can be approximated with grates of a different sizes. This test also assumed that the sample size of this test will produce a distribution of plastic particle sizes that will be the same as the distribution for the sample size needed for a full-size brick.

Test Plan

Initially, the shredder's ability to work with both PET and HDPE was assessed by shredding 5 PET bottles, followed by an equivalent mass of HDPE plastic. All bottles had the top and bottom plastic cut off prior to insertion into the shredder because this plastic is thicker and can easily damage the shredder. If the shredder was able to accomplish this without clogging or requiring maintenance, the shredder was considered capable of handling both plastic types. While performing this test, the PET and HDPE plastic was separated to ensure there was no confusion between the plastic types once eco-brick production began. After this, each sample of shredded plastic was cycled through the shredder 2 more times, and then the particles were sifted through using hand operated grates. Then the particles between each grate were weighed. Using this data, the distribution of particle sizes after 3 cycles through the shredder was established for each plastic type. This test was performed for the PET and HDPE respectively to determine if one plastic type resulted in different particles size distributions. Based on the distribution of particle sizes after 3 cycles, the shredder's capability to produce small enough particles to meet the demand of the Brick Compressibility Test was assessed. If not enough of the desired particles was produced, a further test was performed on the plastic type chosen for the Brick Compressibility Test. For this test, the plastic size distribution was determined after 3, 6, and 9 cycles through the shredder.

Acceptance Criteria

For the initial test, the shredder was considered successful if it could shred 5 PET bottles and approximately the same mass of HDPE without clogging or needing maintenance. If less than 50% of the desired particle sizes were created after 3 cycles, this test was repeated for plastic particles that have been cycled through the shredder 6 and 9 times. If this shredder couldn't produce more than 50% of particles of the desired size after 9 times, a new shredder with smaller blades will be recommended for a future team.

Test Results

The shredder capability results can be seen in Fig. 10 and 11. As seen in Fig. 10, the HDPE tended to have smaller particles after 3 cycles through the shredder, but the distribution of particle sizes was centered on the 4.5-6 mm range for both PET and HDPE. As seen in Fig. 11, as the plastic particles were cycled through the shredder, they gradually became smaller, and the distribution becomes more and more centered on the 4.5-6 mm range.

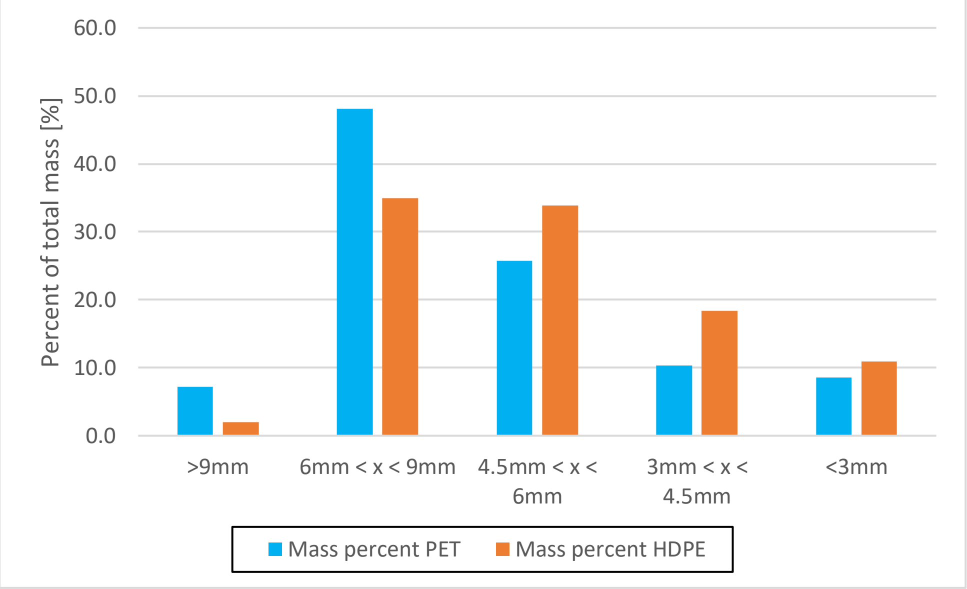


Figure 10: Mass percent of PET and HDPE by size of plastic particle after 3 cycles through the shredder.

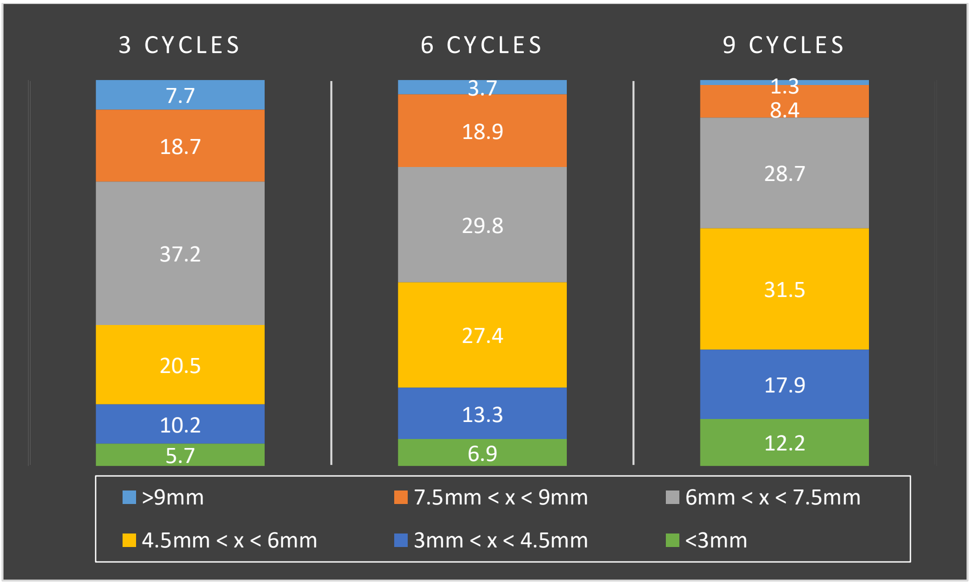


Figure 11: Mass percent of PET by size of plastic particle after 3, 6, and 9 cycles through the shredder.

Evaluation

The raw data for approximately 150 grams of PET and HDPE, respectively, can be seen in Table D of Appendix J, and a graph summarizing this data can be seen in Fig. 10. The team used grates that were 3 mm, 4.5 mm, 6 mm, and 9 mm during the initial shredder capability test as seen in Fig. 2; however, an additional 7.5 mm grate was constructed before performing the test for particle sizes after 3, 6, and 9 cycles through the shredder. After the initial Compressive Strength Tests, the particle sizes of interest were determined to be less than 6 mm. As seen in Fig. 10, approximately half of the plastic particles for PET were larger than 6 mm, and slightly less than half of the HDPE particles were larger than 6 mm after 3 cycles through the shredder. The results of Fig. 10 revealed an interesting trend of HDPE having smaller plastic particles after 3 cycles through the shredder. This was likely due to HDPE being more brittle than PET, and this conclusion was further supported when observing the shredder during operation because only the PET would bend to the shape of the blade-holes. Even with HDPE having smaller particle sizes after 3 cycles, little more than 50% of it was of an appropriate size for the compression tests (less than 6 mm).

Because the initial compressive strength tests indicated that PET had less variability, it was considered a better plastic for this project. Additionally, the choice of PET more appropriately addressed the sponsors proposal to process plastic bottle. That being said, less than 50% of the PET plastic was of the desired size after 3 cycles through the shredder, so the shredder capability test for 6 and 9 cycles was tested for PET. During this iteration of this test, the team used the 3 mm, 4.5 mm, 6 mm, 7.5 mm, and 9 mm grates. The results of this iteration of the shredder capability test can be seen in Table E of Appendix J and they are summarized in Fig. 11. After 9 cycles, approximately 60% of PET particles were of the desired sizes as seen in Fig. 11. The fact that the distribution appears to gradually get more centered on the 4.5 to 6 mm range makes sense because the shredder blades are 5 mm thick. For the purposes of this year's project this was considered a successful design, but this process exponentially increases the process time. If future tests will focus on particles of less than 5 mm, the creation of a new shredder with thinner blades should be considered, but it is not essential.

Associated Test 2: Shredder Speed

Test Overview

The process time was measured for several plastic bottles to be run through the shredder.

Objectives

1. Measure the average process time required to shred 5 plastic bottles.
2. Establish a dataset that can be used to approximate the process time needed for the shredder to process one eco-brick.
3. Determine if PET and HDPE have different shredding process times.

Feature(s) Evaluated

This test will evaluate the shredding process time.

Test Scope

When performing this test, all bottle caps, tops, and bottoms will be removed to prevent clogging and to prevent PET (bottle) from mixing with HDPE (bottle cap). This test assumes the process time for 5 bottles (about 50 grams) will be scalable to the amount of plastic needed for a full-size brick. This test only measured the time that the shredder was actively operating, not the time needed to clean or unclog the shredder.

Test Plan

The process time was measured for 5 PET bottles to be cycled through the shredder one at a time. These bottles had their tops and bottoms removed and they were sliced into eighths to prevent the shredder from clogging. Before shredding these bottles, their mass was measured (without caps and bottoms) to approximate the shredder process time on a mass basis. Time began to be measured once the shredder was activated, and it was paused when the shredder was turned off. Pieces were added three at a time, and subsequent pieces were only added to the shredder after there were 5 or less plastic particles remaining from the previous pieces. This test was repeated 3 times to establish an average process time for 5 bottles to be shredded. This was repeated for an equivalent mass of HDPE plastic to determine if there is a difference between the PET and HDPE shredding process time. After all iterations of this test have been completed, the average process time for a given weight of plastic will be calculated. By extrapolating this data, the needed process time for a given mass of plastic after a certain number of cycles through the shredder can be approximated.

Acceptance Criteria

A 5-bottle process time of less than 5 minutes (300 seconds) was considered a success. An acceptance criterion of 5 minutes was chosen because this should ensure that over half a kilogram of plastic could be cycled through the shredder in an hour.

Test Results

The raw data for approximately 50 grams of PET and HDPE, respectively, can be seen in Table F of Appendix J, and a graph summarizing this data can be seen in Fig. 12.

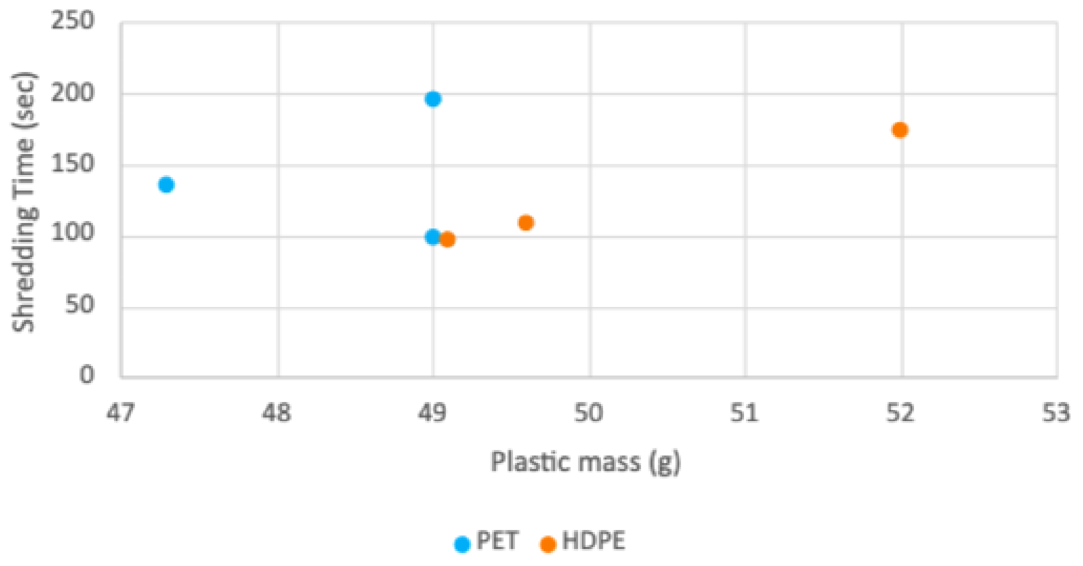


Figure 12: Results for the required shred time for approximately 50 grams of PET and HDPE.

Evaluation

The required shred time is not significantly larger for PET or HDPE, but neither plastic took more than 5 minutes to shred 50 grams of plastic. Therefore, the shredder process time was satisfactory for both plastic types. Based on Table F, 50 grams of PET had an average process time of 143 seconds, or 2:23, and 50 grams of HDPE had an average process time of 126 seconds, or 2:06, for one cycle through the shredder. This data can now be used in tandem with the results of the shredder capability tests to approximate the required process time to produce enough plastic particles of a given size to create a full-size eco-brick. Because the final, and best, compression tests were performed on 1% plastic and 6% plastic, the full-size process time was approximated for these plastic ratios. For a 1% plastic ratio brick, the full-size brick would require approximately 148 grams of shredded plastic. Based on the PET shred speed results, this much plastic could be cycled through the shredder a single time in approximately 7 minutes and 3 seconds, but if it needed to be cycled through the shredder 9 times, this would require approximately 1 hour and 3 minutes. For a 6% plastic ratio brick, the full-size brick would require approximately 885 grams of shredded plastic. Based on the PET shred speed results, this much plastic could be cycled through the shredder a single time in approximately 42 minutes and 11 seconds, but if it needed to be cycled through the shredder 9 times, this would require approximately 6 hours and 20 minutes. Although this process time passed the shredder speed test, 6 hours is considerably more time shredding than anticipated. In the future, if the plastic particles need to be smaller than 5mm a new shredder with smaller blades should be fabricated, to avoid the need to cycle the plastic through 9 times.

3.4 Mixer Functionality

The mixer functionality is defined by how capable the mixer is at combing all necessary substances into a homogenous mixture within a given work time. This includes mixing only concrete and water as well as concrete, water and plastic particles. A homogenous mixture is defined as no visual clumping, settling, or uneven distribution of the substances as determined through observation. The team's chosen mixer had no issues adhering to this requirement.

Associated Test: Mixing Capability

Test Overview

The team determines the success of the mixer by examining its ability to effectively combine concrete and plastic within a 5 minute work time. This test is conducted during the concrete pouring process for producing the concrete coupons.

Objectives

1. Ascertain if the mixer can successfully mix brick components within a period of time that does not compromise the concrete.
2. Ensure the mixture has a consistent plastic distribution to avoid faults and voids within the mixture.

Feature(s) Evaluated

The test evaluates how consistently the mixing method can mix plastic particles with concrete. Additionally, the time taken to reach homogeneity will be measured as an evaluation of mixing speed.

Test Scope

Firstly, the test assumes that future mixing following the same procedure results in equivalent mixing of plastic as well as an equivalent setting time for the concrete. After the components are mixed, the homogeneity is judged from visual examination and is determined successful or not by the team as there is no code to use as protocol. The 5 minute mixing time is based on the recommended 3 to 5 minute mixing period advertised by Quikrete. After the mixture is set and cured in the molds the homogeneity can be observed along the exterior sides of the coupon. This test assumes that the interior of the coupon is consistent with the exterior and has a negligible difference in homogeneity.

Test Plan

The team prepared a ratio of Quikrete, water, and plastic particles to be mixed. The concrete and plastic are first poured into the mixing bowl followed by the water being poured. The timer starts when the water is added to the mixture and ends after 5 minutes. Once the time limit is reached, the mixture is observed by the team and then set into the molds. After curing is finished, the brick coupons can then be observed to see if there is any clumping visible on the brick exterior.

Acceptance Criteria

A successful pour has a visually even distribution of plastic within the mixture as well as approximately the same number of plastic particles on each surface of the brick. The time it takes to mix the components into a homogenous mixture will be within the 5-minute mixing period.

Test Results

For every given ratio of Quikrete, water, and plastic particles, the mixer test was successful. More specifically, the mixing time limit never exceeded 5 minutes as the mixture was clearly even upon investigation during all states of the fabrication process.

Evaluation

The 5 minute limit for mixing time was more than sufficient in order to achieve an effective mixture regardless of the mixer setting or plastic and water ratios. This can be deduced by the fact that for every mixing process, the mixer was operating at its minimum mixing speed setting and always reached its maximum level of homogeneity with at least a minute to spare in the 5 minute limit. Furthermore, every coupon that was produced had an even distribution of plastic along their surfaces and within their surfaces once broken after compressive testing, as seen in Figure 13. After being unable to denote any clumping of plastic during each stage of our process, the team could confidently determine that the mixer performed its job effectively and should not be considered an area to improve.

Figure 13. Plastic distribution of concrete coupon post-compressive testing

3.5 Mold Functionality

The mold functionality requirement is defined by how usable the mold design is for brick production. For the first year of this project, only the coupon mold was assessed against this requirement. A functioning mold must be usable and reusable for coupon creation, resulting in bricks with no visual deformation or cracking, and without deforming or cracking themselves. The melamine mold was less successful at this requirement and started showing signs of wear after multiple uses. The 3D-printed mold had limited issues as well, only showing any signs of cracking when excessive force was applied during the pouring process.

Associated Test: Mold Usability

Test Overview

The team verified the efficacy of the mold design by ensuring that it does not break during usage and can properly eject bricks.

Objectives

1. Determine if the mold designs are feasible for continuous coupon production.

Feature(s) Evaluated

The test evaluates the integrity of the mold and the brick under the stresses caused from ejecting the brick. This test also evaluates the ability of a mold to be reassembled after usage to set another brick.

Test Scope

The team judged the features of the mold irrespective of the mold design. The mold must release a brick without breaking the brick or itself. The mold designs consist of 3D printed molds and a melamine mold.

The 3D printed molds are composed of two plastic printed parts which are screwed horizontally together and screwed vertically onto a bed that is laser-cut. The melamine coated wooden mold operates by using a hinge mechanism for ejection.

Test Plan

One day after placing the concrete mixture into the mold, the brick were released using the appropriate method depending on the mold design (hinged vs. screwed). The mold was inspected for cracks, breaks or any deformations caused by the molding process itself or during the brick's removal. This process was repeated 3 times using the same mold.

Acceptance Criteria

If no visual indication of compromise, such as cracking or chipping, is present on the mold after 3 uses, then the mold design is deemed acceptable. There is no quantified depth limit of cracking or chipping, the existence of a flaw regardless of size could compromise the surface area and shape of the coupons, especially during regular use.

Test Results

All 3D printed molds achieved all acceptance criteria without any signs of concerns. The melamine coupon mold did not achieve all acceptance criteria as there were visual indications of compromise such as cracks where the concrete mixture would seep into. Additionally, it was only able to be used twice before the team determined it was unusable.

Evaluation

The 3D printed molds proved successful whereas the melamine mold was less successful. The 3D printed molds consistently produced quality coupons without difficulty or damage. They are also fully reusable after being cleaned. The number of times a 3D printed mold can be used is currently indefinite as there have been no noticed flaws. The melamine mold experienced issues due to the inaccuracy of man-made fabrication. Since the melamine mold was handmade, there were larger gaps and uneven surfaces. These flaws were remedied by using silicone to fill the gaps; however, the silicone was difficult to clean which made reusing the molds improbable. Therefore, the objective of this test, which was to determine the feasibility of the mold designs, was successful, and the 3D printed design will continue to be used for the remaining coupons. A hybrid mold, with both melamine and 3D printed parts will be used for the full-size mold as certain components are too large to be 3D printed.

4. Conclusions

This year's prototype was unable to meet the compressibility and associated requirements for the designed brick, but the weather resistivity, shredder functionality, mixer functionality, and mold functionality requirements were all accomplished. Although this year did not create a fully functional prototype brick, there is a clear direction for future research, specifically regarding the anisotropic brick behavior and the concrete-plastic-water ratios needed to meet the 1900 psi compressibility requirement.

Throughout this year's work, the shredder modifications, mold design, and mold fabrication were successfully implemented. Additionally, over 70 test coupons were tested using the Instron machine, and another 9 coupons were weather tested. Although none of the compression tested plastic-concrete coupons met the compressive strength requirement, significantly more research is needed to assess the anisotropic behavior of this material. During the anisotropic compression tests, not only did the coupons with 6% plastic have a higher average compressive strength than the pure concrete coupons, but one 6% plastic coupon had a strength that was over 1.35 times the average compressive strength of the pure concrete coupons. Although 6% plastic may seem small, it is less dense than concrete, so it takes up a significantly larger volume percentage of the mixture. Furthermore, if a full-size cinder block (~14500 g) were to be created at 6% plastic ratio by mass, this would amount to approximately 871 g of plastic. After the tops and bottoms of bottles were removed, there was approximately 10 grams of useable plastic per bottle, so approximately 87 plastic bottles could be used in a full-size 6% plastic brick.

The first phase of compression testing showed the water to concrete ratio played a massive role in the compressive strength of the pure-concrete coupons. This finding will need to be expanded upon in future research to better encapsulate the effects the water to solids ratio has on plastic-coupon bricks. In addition, phase 1 testing of pure-concrete coupons met the compressive strength requirement; however, the pure concrete coupons did not meet this requirement in the anisotropic orientation. Future research needs to be conducted to investigate how to make the pure concrete coupons meet the compressibility requirement in the anisotropic orientation. Furthermore, additional research is needed to investigate the effect of different size and ratios of plastic on the compressibility of coupons in the anisotropic orientation.

When testing the anisotropic behavior of this material, the coupons with larger plastic particles had higher compressive strength, and it is believed that this is a result of the plastic being perpendicular to the cracks, thereby preventing crack propagation. This observation could greatly benefit the shredding process time because it means the plastic would have to be cycled through the shredder fewer times. That being said, if future tests find that particles smaller than the 4.5-mm grate are desired, a new shredder should be fabricated with smaller blades. The existing shredder had 5-mm wide blades, therefore, the plastic particle distributions were centered on the 4.5-6 mm grate size.

The mixer was successful in all its tests; however, if a full-size brick is created, a larger mixing apparatus will be needed than the KitchenAid mixer. A large eggbeater and 5-gallon bucket were purchased for this purpose; however, they were never tested because the construction of a full-size brick was not needed for this year’s project.

Lastly, all 3D printed molds easily passed the mold functionality test. The melamine coupon mold successful passed this test, but soon afterwards it fell apart because the hinge was too small. Another issue with this mold was that the measurement tolerances couldn’t be controlled as well as the 3D printer, so there was a seam along the bottom that had to be sealed with silicon. The major modification to the molds that should be implemented is a top compression plate. This plate is needed to produce even sides on every surface of the coupon because uneven surfaces greatly reduce the strength of the material when in contact with the compression plate. By evening every side of the coupon, the anisotropic behavior can more appropriate be compared to this year’s data because the stress will be more uniformly distributed throughout the surface. In contrast, when testing the coupons in the anisotropic orientation this year, the uneven surface in contact with the Instron plate resulted in an uneven stress distribution which initiated cracks in the specimen before the compression plate was fully in contact with the surface.

5. Appendices

A. Plunger Materials and Construction Process

Materials

- 20”x2”x2” wood
- 1 x 3” screws
- 5.75”x4.625”x0.75” wood

Necessary Tools

- Power drill
- Band Saw
- Industrial Sander

Construction

1. Using the Band Saw, cut a 5.75”x4.625”x0.75” rectangle of wood
2. Drill a hole through the center of the wood, and connect it to the 2”x2” piece of wood with the 3” screw
3. Use the industrial sander to smooth all sides of the wood that will be in contact with hands.

B. Sifter Materials and Construction Process

Materials

- 1’x1’ mesh of desired size
- 4’ of 2”x2” wood
- 4’ of ¾"x1.25” wood
- 8 x 1.5” screws
- 4 x 1” screws

Necessary Tools

- Power drill
- Miter Saw
- Circular Sander
- Impact drill

Construction

1. Cut 2”x2” wood at 45˚ angles using the Miter saw, so that the outside length is 13.5” and the inside length is 10.5”.
2. Cut ¾"x1.25” wood at 45˚ angles using the Miter saw so that the outside length is 12.5” and the inside length is 10.5”.
3. Use the circular sander and its attachment to perfect the 45˚ ends of all wood pieces.
4. Assemble the square using 2”x2” wood using the 1.5” long screws. Predrill all holes.
5. Assemble the square using ¾"x1.25” wood using the 1” long screws.
6. Align the two squares with the 2”x2” wood on the bottom and predrill holes in the center of each side for the last 1.5” long screws.
7. Put the mesh between the wooden squares, and connect the two squares while ensuring that every screw goes in its predrilled hole (this ensures the squares will be aligned)
8. Using an impact drill, screw the last 4 screws so that they do not exceed the wood dimensions because these screws can damage the table when using the sifter if they aren’t screwed all the way in.

C. Melamine Coupon Mold Materials and Construction Process

Materials

- ¾" melamine
- Hinge
- 6 x 1.5” screws

Necessary Tools

- Power drill

- Miter Saw
- Circular Sander

Construction

1. Cut 2 triangles with the melamine with side lengths of 3.5” and a hypotenuse of 4.875”.
2. Cut 4 melamine segments with sides at 45˚ so the exterior length was 3.5” and the inside length was 2”. Both inside and outside surfaces should have melamine textures.
3. Use the circular sander and its attachment to perfect the 45˚ sides of all wood pieces.
4. Connect 2 sides together with a 1.5” screw. Repeat for the remaining 2 sides. Pre-drill all holes
5. Connect the triangles to the bottom of each of the pieces just made with 2 screws, one in the center of each side.
6. Align these pieces to form the square mold shape and connect them with the hinge.

D. Melamine Full-Brick Mold Materials and Construction Process

Materials

- ¾" melamine
- 18 x 1.5” screws
- 3D printed cell pieces (CAD model seen in Fig. B)

Necessary Tools

- Power drill
- Band Saw

Construction

1. Using the Band Saw, cut 3 9.5”x17.5” rectangles from the melamine.
2. Cut 2 8”x9.5” rectangles from the melamine
3. Screw a 9.5”x17.5” rectangle to an 8”x9.5” rectangle with 2 screws with the smaller rectangle on the inside of the larger rectangle. Pre-drill all holes
4. Repeat the above step.
5. Connect the 2 pieces just assembled so the smaller rectangles are between the larger rectangles. After this is completed, there should be a rectangular box with 4 screws on both of the longer sides of this box.
6. Align the last rectangle on top of the box created in the previous step and connect these components using the remaining 10 screws.
7. Insert the 2 3D printed cell pieces inside the melamine box and align them so the gaps are the appropriate dimensions for the brick.
8. Drill holes in the melamine box that align with the pre-existing holes in the cell pieces to be able to bolt the cells in place during molding and curing.

E. CAD Models

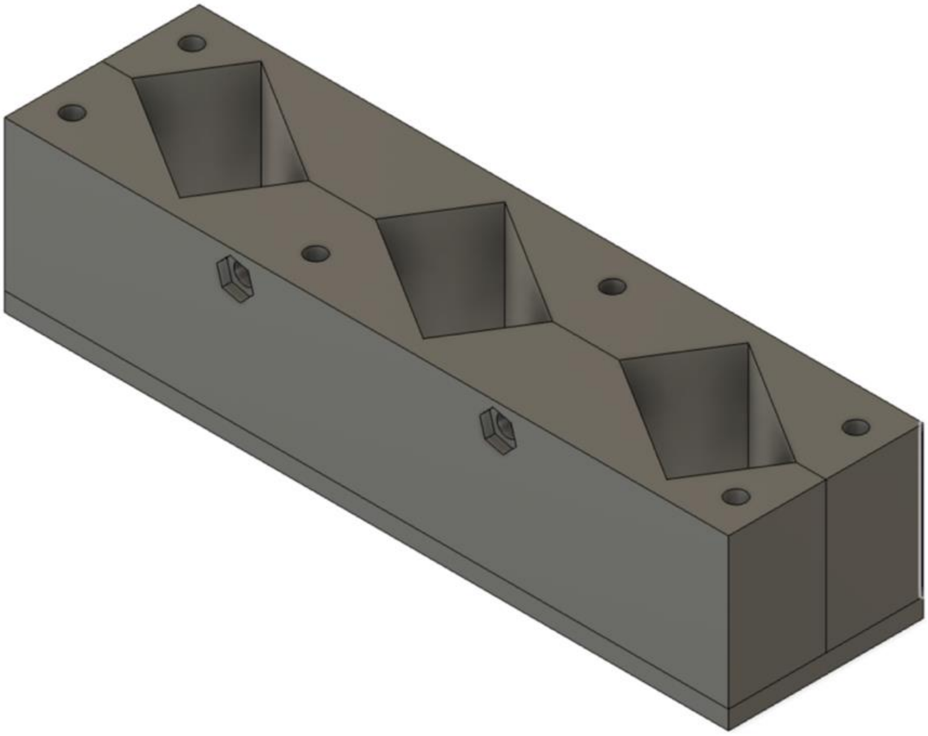


Figure A: Vertical mold CAD model for use in future compression tests.

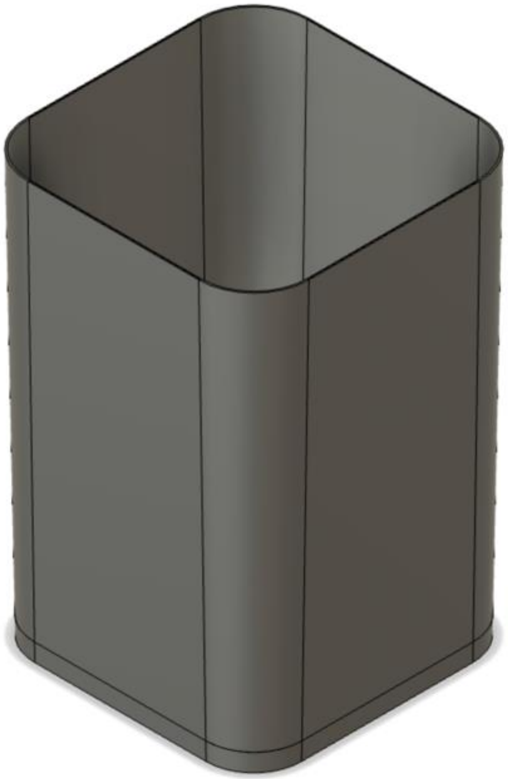


Figure B: Full-size brick mold cell.

F. Drawings of Brick Designs

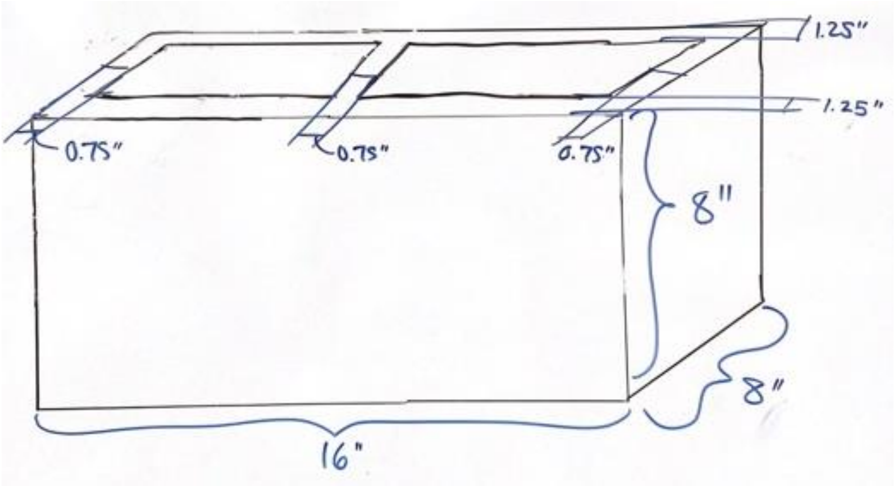


Figure C: Nominal dimensions of a standard CMU.

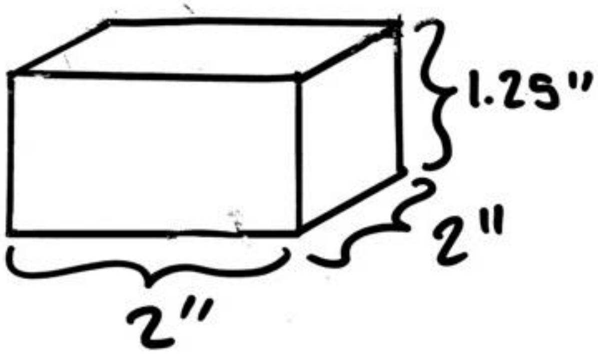


Figure D: Dimensions of test coupons.

G: Design of Experiments Matrix for Compression Testing

Key: 🟧 Phase 2 🟩 Phase 3 🟦 Phase 4

		Plastic Particle Size [mm]			
		< 3	3 – 4.5	4.5 – 6	N/A
Plastic Ratio	0%				🟦 ✓
	1%	🟦 ✓ 🟩 ✓			
	6%	🟩 ✓	🟩 ✓	🟦 ✓	
	8%	🟩 ✓	🟩 ✓		
	10%			🟧 ✓	
	12%		🟧 ✓		
	15 %	🟧 ✓			

H: Compressive Strength Test Raw Data

Table A: Raw data from each phase of compression testing. Phase 4 was tested in a different orientation for anisotropic purposes.

Phase Number	Experiment Number	Water Ratio [%]	Plastic Size [mm]	Plastic ratio [%]	Plastic Type	Max Load #1 [lbf]	Max Load #2 [lbf]	Max Load #3 [lbf]	Average Max Load [lbf]	Average PSI [psi]
1	1	7.1%	-	-	-	6251.45	4879.58	6310.73	5813.92	2325.56
	2	14%	-	-	-	3911.56	4509.08	3713.74	4044.8	1617.9
	3	7.1%	-	-	-	8800.32	7920.61	9928.26	8883.06	3553.22
	4	5.4%	-	-	-	1198.46	812.02	1045.29	1018.59	407.43
	5	6.5%	-	-	-	2558.53	749.47	615.56	1307.85	523.14
	6	8%	-	-	-	3900.87	3712.47	4024.45	3879.26	1551.70
	7	7.5%	-	-	-	4287.56	6417.92	4465.40	5056.96	2022.78
2	8	7.5%	< 3	15%	HDPE	150.11	382.83	192.31	241.75	96.7
	9	7.5%	3 - 4.5	12%	HDPE	242.12	457.72	240.01	313.28	125.31
	10	7.5%	4.5 - 6	10%	HDPE	467.90	1037.18	688.01	731.03	292.41
	11	7.5%	< 3	15%	PET	518.35	491.3	366.69	458.81	183.52
	12	7.5%	3 - 4.5	12%	PET	464.22	302.38	558.92	441.84	176.73
	13	7.5%	4.5 - 6	10%	PET	260.73	262.01	1029.81	517.52	207.00
3	14	7.5%	< 3	6%	PET	1786.604	1253.718	1178.78	1406.36	562.55
	15	7.5%	3 - 4.5	8%	PET	860.1157	1251.086	750.189	953.796	381.52
	16	7.5%	3 - 4.5	6%	PET	1879.687	1017.406	1664.80	1520.63	608.25
	17	7.5%	< 3	8%	PET	1022.353	762.4528	2076.05	1286.95	514.78
	18	7.5%	< 3	1%	PET	1666.034	1368.142	2494.81	1842.99	737.20
4	19	7.5%	-	0%	-	3576.647	3303.517	3050.49	3310.21	827.56
	20	7.5%	< 3	1%	PET	2293.577	1229.18	1829.03	1783.92	445.99
	21	7.5%	4.5 - 6	6%	PET	3872.677	2411.236	4482.51	3588.80	897.20

I: Weather Test Raw Data

Table B: Control bricks weather resistance results

	Brick 1	Brick 2	Brick 3
Initial weight (w_r) [lb]	33	32.5	32
Saturated weight (w_s) [lb]	35	35	34.5
Dried weight at time0 (w_{d0}) [lb]	33	33	32.5
Time0 percent difference [%]	5.714	5.714	5.797
Dried weight at time1 (w_{d1}) [lb]	33	32.75	32.25
Time1 percent difference [%]	0.000	0.758	0.769
Dried weight at time2 (w_{d2}) [lb]	33	32.75	32.25
Time2 percent difference [%]	0	0	0
Final Dried Weight (w_d) [lb]	33	32.75	32.25
Absorption % [%]	6.061	6.870	6.977
Moisture Content [%]	0.000	-11.111	-11.111
Visible Salt Deposits? [Y/N]	N	N	N

Table C: Coupon weather resistance results with 7.5% water and 4.5mm<x<6mm plastic

	0% plastic			3% plastic			6% plastic		
Coupon #	1	2	3	1	2	3	1	2	3
Initial weight (w_r) [g]	152.8	155.1	153	132.2	135.7	139.3	143	135.3	133
Saturated weight (w_s) [g]	168.2	170.9	168	152.9	151.6	154.3	162.2	155.3	151.2
Dried weight at time0 (w_{d0}) [g]	153.6	156.5	154.3	133.2	137.5	140.9	144.8	136.8	134
Time0 percent difference [%]	8.680	8.426	8.155	12.884	9.301	8.684	10.727	11.912	11.376
Dried weight at time1 (w_{d1}) [g]	153.4	156.3	154.3	133.1	137.5	140.9	144.7	136.8	134
Time1 percent difference [%]	0.13	0.13	0.00	0.08	0.00	0.00	0.07	0.00	0.00
Final Dried Weight (w_d) [g]	153.4	156.3	154.3	133.1	137.5	140.9	144.7	136.8	134
Absorption [%]	9.648	9.341	8.879	14.876	10.255	9.51	12.094	13.523	12.836
Moisture Content [%]	-4.054	-8.219	-9.489	-4.545	-12.766	-11.94	-9.714	-8.108	-5.814
Visible Salt Deposits? [Y/N]	N	N	N	N	N	N	N	N	N

J: Shredder Test Raw Data

Table D: PET and HDPE particle size results after 3 cycles through the shredder

	Mass (g)		Mass percent	
	PET	HDPE	PET	HDPE
>9mm	10.4	2.9	7.2	2.0
6mm < x < 9mm	69.8	51.6	48.1	34.9
4.5mm < x < 6mm	37.4	50.0	25.8	33.8
3mm < x < 4.5mm	15.0	27.2	10.3	18.4
<3mm	12.5	16.1	8.6	10.9
Total	145.1	147.8	100	100

Table E: PET size results after 3, 6, and 9 cycles through the shredder

	Mass (g)			Mass percent		
	3 Cycles	6 Cycles	9 Cycles	3 Cycles	6 Cycles	9 Cycles
>9mm	10.8	5.2	1.8	7.7	3.7	1.3
7.5mm < x < 9mm	26.4	26.5	11.7	18.7	18.9	8.4
6mm < x < 7.5mm	52.4	41.8	40	37.2	29.8	28.7
4.5mm < x < 6mm	28.9	38.5	44	20.5	27.4	31.5
3mm < x < 4.5mm	14.4	18.7	25	10.2	13.3	17.9
<3mm	8.1	9.7	17	5.7	6.9	12.2
Total	141	140.4	139.5	100	100	100

Table F: Shredder Speed Test Results

	Test #	Mass (g)	Shred Time (s)
PET	1	49	99
	2	47.3	135
	3	49	195
HDPE	1	52	174
	2	49.6	108
	3	49.1	96

K. Process Flowchart

L: Complete Instruction Manual for Process Reproduction

I. PRE-POUR

i. Plastic Preparation

1. Collect plastic bottles (PET bottles not HDPE). Can be sourced from local recycling bins.

2. Remove all labels and caps from bottles so all that remains is the PET portion of the bottle.

3. Wash the bottles with water.

4. Make horizontal insertions approximately 1.5 in below the cap and above the bottom of the bottle. Remove the top and bottom portions as they are too curved for the shredder to operate effectively.

5. Cut the remaining center region of the bottle into 3-to-5-inch rectangles (approximately 4 pieces of plastic for an average soda/water bottle).

6. Dry the pieces for shredding using paper towels.

ii. Shredding Procedure

7. Make sure the shredder is off. Ensure all users are wearing safety goggles.

8. Place a bucket or plastic tub under the shredder to catch any plastic that exits.

9. Place cut plastic pieces into the shredder—no more than 3 pieces at a time to avoid jamming.

10. Place the wooden plunger within the shredder hopper to keep plastic from flying out and ensure that the shredder teeth catch the plastic. Keep a hand on the control panel at all times.

11. Turn the shredder on and let the batch shred entirely, then turn the shredder off.

<u>If the shredder does jam, turn the shredder OFF immediately. Rotate the pulley by hand to move the shredder teeth backwards, releasing any plastic that is jammed. If the jammed pieces must be removed by hand or with pliers, unplug the shredder before anyone inserts their hand into the hopper.</u>

12. Repeat steps 9-11 until enough plastic is shredded.

13. Unplug and clean shredder using pressurized air gun or pliers if any plastic is stuck in shredder teeth.

iii. Plastic Sorting

14. Gather shredded plastic and desired sifting grate for the range of plastic particle diameter that is intended for testing (Available are 12-, 9-, 7.5-, 6-, 4.5-, and 3-mm grates).

15. For the sake of sifting efficiency, sift groupings of plastic particles in piles with diameters of approximately 4 inches.

16. To achieve more plastic of a smaller diameter, previously shredded plastic can be re-shredded to reduce overall size.

17. Sort piles of plastic into appropriate ranges for intended brick fabrication and store in labeled zip-loc bags.

II. POUR PROCEDURE

1. Assemble the molds.

2. Spray molds with concrete release spray and allow it to dry for 20-30 minutes or until it turns clear. If the spray begins to pool, spread it with a paper towel.

3. While waiting, put a trash bag in a 5 gallon bucket to be used for concrete disposal. Lay the tarp over the working area to protect from wet concrete. Have all participants wear gloves, as concrete can cause acidic burns.

4. Measure out the desired mixture of shredded plastic, concrete and water using plastic cups and a digital scale.

5. Combine the dry concrete and plastic (if needed) first. Add the water and immediately start mixing on the lowest speed setting.

6. Mix the concrete for 5 minutes to ensure adequate combination.

7. Once the 5 minutes is up, begin pouring/spooning the mixture into the assembled molds.

8. While pouring, tamp the concrete with a wooden block by pushing it into the mixture to fill any air voids. Do this until the entire area has been pushed down. After this, pour more concrete in the mold to completely fill it. Repeat the tamping process.

9. Scrape the top of the mold with the caulking spatula to make sure all coupons are even and a uniform height.

10. Clean all utensils (mixing bowl, mixing paddle, silicone spatula and caulking spatula) with dry or wet paper towels to get the concrete off while it is wet. Throw all paper towels in the concrete disposal bucket. DO NOT let any sediments fall into the sink as they can harden and destroy the plumbing system.

11. Set the molds aside to cure for 1 days. After a minimum of 24 hours, the molds can be released, and the coupons can be left out to dry for the desired curing time.

12. Set the disposal bucket aside for several days to allow the wet concrete to harden. After several days, break the hardened concrete and throw it in the trash.

III. POST-POUR

i. Compression Testing (ASTM C90)

1. Turn on the Instron machine

2. Open the Bluehill 3 application on the computer and log in

Username: SD

Password: 54321

3. Select "Test" from the Bluehill 3 home screen.

4. Select the "King's ASTM C109 Cement Cube Method.im_comp

5. Name the sample with relevant parameters (batch #, plastic percent, water percent, plastic size)

6. Enter the dimensions of the coupon.

7. Load the coupon and use the "Jog" and "Fine Position" buttons on the Instron to bring the two plates to the coupon.

8. Select "balance all"

9. Start the test.

10. Do not let the load exceed 10,500 lbf. The load cell begins to break at 11,000 lbf.

11. After the coupon has failed, stop the test and select "Return" to be able to clear the Instron plates.

12. Clean all debris from plates using a brush and load the next coupon.

13. Repeat steps 7-12 until all coupons have been tested.

M: Bill of Materials

The bill of materials describes all purchases made by the team. All other materials mentioned in this report were either pre-owned by one of the group members or owned by the CSI Makerspace.

Item Name	Item Description	Manufacturer	Source	Relevant Subsystem	Quantity	Cost
5 Gallon Bucket	Large bucket for multiple purposes	Home Depot	Home Depot	Bricks	3	14.94
Quikrete 80lb Concrete Mix	Bag of pre-mixed concrete	Home Depot	Home Depot	Bricks	4	20.52
Melamine White Panel	49 x 97 x 0.75 inch panel of melamine coated wood	Home Depot	Home Depot	Mold	1	43.44
Anvil Eggbeater Mixer	Large mixing head to mix big batches of concrete	Home Depot	Home Depot	Bricks	1	11.76
Concrete Release Spray	Spray used on materials to prevent concrete sticking	Home Depot	Home Depot	Bricks	1	15.48
Blue Medium Futy Tarp	8 x 10 ft tarp to cover workspace while pouring	Home Depot	Home Depot	Bricks	1	14.98
A31 V-Belt	31 inch long, 0.5 inch wide, 5/16 inch thick belt	Grainger	Grainger	Shredder	1	11.22
Concrete Cinderblocks	16 x 8 x 8 inch standard concrete bricks	Home Depot	Home Depot	Bricks	7	13.79
A33 V-Belt	33 inch long, 0.5 inch wide, 5/16 inch thick belt	Grainger	Grainger	Shredder	1	10.58
Hex Bolt	Bolt to hold mold together	Home Depot	Home Depot	Mold	2	1.04
Wing Nut	Wing nut to pair with bolt	Home Depot	Home Depot	Mold	2	2.76
V-belt Pulley	Pulley to fit with the v-belt	Grainger	Grainger	Shredder	1	50.06
5 gallon bucket lids	Lids to cover 5 gallon buckets	Home Depot	Home Depot	Bricks	3	5.04
Galvanized Steel Hex Bolts	Pack of 30 .20 x 4 inch hex bolts to hold mold together	Home Depot	Home Depot	Mold	1	29.10
Zinc Plated Wing Nuts	Pack of 50 .20 inch wing nuts to hold mold together	Home Depot	Home Depot	Mold	1	13.93
Stainless Steel Caulking Spatula	Steel spatula to smooth the tops of coupons	Home Depot	Home Depot	Bricks	1	17.22
Silicone Baking Spatula	Spatula for scooping concrete from mixer	Home Depot	Home Depot	mixer	1	7.99
Mesh Sieve	Multiple sizes of wire mesh for sifting plastic	YaeCCC	Amazon	Shredder	1	31.99
Plastic Measuring Cups	Measuring cups for concrete and water	IMUSA	Amazon	Bricks	2	7.98
Tile and Grout Brush	Brush for cleaning molds	Home Depot	Home Depot	Mold	1	2.97
Latex Gloves	Gloves to be worn while pouring concrete	Safegaurd	Amazon	Bricks	1	13.63
Ziploc Bags	Used to hold plastic pieces	Ziploc	Amazon	Shredder	1	9.10
Sticky Notes	600 pack of notes to label coupons after poured	Teskyer	Amazon	Bricks	1	3.98
					Shipping	$70.5
					Total	$424.00

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[3] R. Bhushaiah, S. Mohammad, D. Srinivasa Rao. "Study of Plastic Bricks Made from Waste Plastic." *International research Journal of Engineering and Technology*. vol. 6, no. 4, pp.1122-1127, Apr. 2019, Available: https://www.irjet.net/archives/V6/i4/IRJET-V6I4238.pdf?_ga=2.159312254.554640849.1666638576-785829463.1666638576 [Accessed 3/30/2023]

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