Testing of Recycled Polypropylene as a Viable Structural Material

By Cruz Bouquet, Gianna Rocca, Alycia Darby, Colin Waterhouse

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Senior Project Advisor: Cameron H Fredrickson, MS

Abstract

Over the course of 10 weeks, experiments were performed on extruded recycled Polypropylene (PP) to determine the feasibility of its use in construction. Motivated by environmental concerns, the project aimed to explore sustainable alternatives to conventional building materials. Polypropylene, classified as a type 5 plastic according to the Resin Identification Code (RIC), possesses favorable properties such as durability, chemical resistance, and recyclability, making it a promising candidate for construction applications. Type 5 plastics are commonly used in various industries, including packaging, automotive, textiles, and consumer goods. In construction, PP is primarily utilized in applications such as piping systems, insulation, roofing materials, and interior fittings.

Marina Seeger's master's thesis, Upcycling Holistic Study of a Sustainable Plastic Brick served as a foundational reference. The thesis aimed to assess recycled polypropylene's performance relative to traditional building materials, much like the objective in this study. Along with being easily accessible, PP shares structural similarities with Concrete Masonry Unit (CMU) bricks, making it an ideal candidate for comparison in terms of resiliency, load-bearing capacity, and construction versatility. To characterize Polypropylenes structural properties, Tensile, Flammability, and Water Absorption tests were conducted. The results indicate potential for PP in construction; however, further research is required to fully characterize its structural properties. This study lays the groundwork for future investigations into the use of PP in construction applications.

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Background

Escalating environmental challenges, particularly the pressing issue of plastic pollution, has led to the imminent need to seek new ways to utilize these resources. Plastics are non-biodegradable, synthetic polymers made of hydrocarbons with additives that can be molded into the finished products (Shiri). All plastic that has ever been produced is still present in the environment. When mass plastic production began around 1950, several positive changes in the global economy were seen due to its versatility, increased employment opportunities, and reduced costs of everyday commodities. Despite its positive attributes, the linear life cycle of plastic causes the environment to suffer detrimental repercussions. The substantial increase in plastic production, equating to around 9.2 billion tons between 1950 and 2017, results in a concerning annual deposition of 8-11 million tons of plastic waste in oceans (Williams). Despite the environmental threats posed, plastic production continues to increase due to societal dependency and modern-day consumerism. The harmful impacts plastic has on the environment, human health, and wildlife underlines the importance of finding effective strategies to repurpose plastics in ways that mitigate its negative effects.

The evolution towards more sustainable and bio-degradable materials involves innovation and commitment to sustainable practices. Plastic materials play a significant role in the field of structural engineering, contributing to various aspects of construction and design. To address the abundance of plastic in the environment, the potential of repurposing plastic waste into structural materials is further investigated. This approach offers the potential to reduce the environmental footprint of structural engineering practices, while maintaining crucial mechanical properties. By finding new ways to repurpose plastic waste, the environmental damage caused by the extraction of raw materials is minimized while simultaneously offering cost-efficient materials found in everyday waste.

Polypropylene (PP) exhibits many favorable characteristics along with being the predominant polymer produced, accounting for 17% of total production (Alsabri). The material contains promising characteristics ranging from strength and durability to its efficient recyclability. These attributes make polypropylene a compelling focus for studies aimed towards finding a sustainable approach that resonates with environmental objectives.

Limitations

Due to the challenges encountered and the brief time frame of the study, the scope was more limited than anticipated. The process of extruding the bricks presented significantly greater challenges than previously anticipated. To prevent the extrusion machine from jamming, the plastic shreds must be small. However, when recycled plastic is fed into the shredding machine, some pieces are larger than the extrusion machine can handle. This resulted in having to manually sort and shred the pieces multiple times, which led to inconsistencies. To combat this, sieves were used to sort the pieces. This process of getting the shreds to an extrudable size proved to be time-consuming, but the use of the sieves improved the process.

Similarly, extruding the brick proved to be challenging and time-consuming as well. It has been estimated that a full brick would take about 10 pounds of shreds to create. The extrusion machine takes about an hour to heat up and must be temperature controlled. Additionally, it took a little over half an hour on average to extrude a pound of plastic. Continuous supervision is necessary throughout the extrusion process. Difficulties were also encountered during extrusions. Originally, the mold was kept heated using an oven with the oven door ajar to give the extrusion machine room to connect with the mold. However, due to environmental factors and the amount of space needed to be heated, the temperature was not able to stay consistent. The use of the hot plate was preferred in comparison to the original method, as the extruded material when using the oven heating method caused bubbles to form in the finished product. This result was most likely due to uneven temperatures throughout the mold, causing the material to harden at uneven rates. When hot plates were used, there were substantially less bubbles formed in the material. Additionally, because the extruded PP material is more rigid compared to materials like concrete, it proved challenging to guide into shape once it is extruded. It also proved difficult to remove the material from within the mold.

After implementing these changes, an attempt to complete a full brick was made in order to conduct a compression test. Due to the unknown volume of plastic required to complete a full brick, the mold was opened prematurely. The rigidity of the extruded material and lack of heat at the top of the mold prevented the top of the mold from going back into place, leading to an incomplete brick.

Figure 1 Porous Extrusion (left), Partially Extruded Brick (right)

Manufacturing Process

To produce the specimens for the various tests performed during the project, an extensive manufacturing process was executed. Initially, plastic containers labeled with the Resin Identification Code (RIC) or recycling number 5 designation for Polypropylene were fed into the Precious Plastic's shredding machine, constructed by the previous project group. Through experimentation, it was determined that the extrusion machine yielded optimal results when smaller plastic pieces were used. This preference for smaller pieces is due to its ability to undergo extrusion at a faster rate, mitigating issues with the machine jamming. Through maintaining consistent shred sizes and faster production, the likelihood of encountering air bubbles or disparities in the polypropylene slab significantly reduced. When it was found that size drastically impacted the manufacturing process, the shredded material underwent sieving with openings of ½" and ¼" to segregate smaller pieces. Remaining plastic shreds were repeatedly fed through the shredder until all material passed through the ¼" sieve, ensuring consistency in size, a critical requirement for subsequent manufacturing stages.

Figure 22 Extrusion Process

Before production began, lubricant was applied onto both the machine and mold to reduce friction and allow PP to seamlessly flow through the extrusion barrel and to easily remove the finished product from the mold. To ensure proper heating of the polypropylene, the extrusion machine is set to 230ºC and extruded at 40 rpms. Along with this, the mold is placed on a set of hot plates, set to the same temperature, to maintain a uniform temperature across the mold during operation. When the necessary materials are heated to proper temperatures, the extrusion process is ready to begin. The plastic shreds are fed slowly into the hopper located at the top of the machine. As the plastic enters the machine, it is pushed down the length of barrel by a rotating extrusion screw. The heat in the barrel causes the plastic to melt as it progresses. When the molten plastic reaches the end, it is then extruded into the mold.

Figure 33 Mold Filled During Extrusion Process

The mold used during the extrusion process was designed by Precious Plastics with the intention of creating plastic bricks with similar geometry to CMU bricks. For tests employing recycled plastic specimens, a sheet was fabricated. To make the sheets, the inserts for the mold, which typically act as the formwork for the voids in the brick, were removed. This allowed the extruded material to pool in the base of the mold unimpeded, forming a sheet. The sheet was then removed from the mold, and specimens subsequently cut as needed.

Flammability Test (UL94)

A Flammability Test was conducted in accordance with UL94, a standard for evaluating the flammability of plastic materials used in devices and appliances. Understanding the fire resistance of materials is crucial, especially when intended for building applications, where ensuring the safety and durability of materials is critical. The test simulates real-world scenarios where the material may encounter a flame, such as in the case of a fire. By evaluating the fire performance of recycled plastics, this test plays a crucial role in determining the viability of using such materials in construction applications. Additionally, it offers valuable insights into potential fire risks associated with the use of recycled plastics, allowing for informed decision-making regarding their use in various construction projects.

Procedure

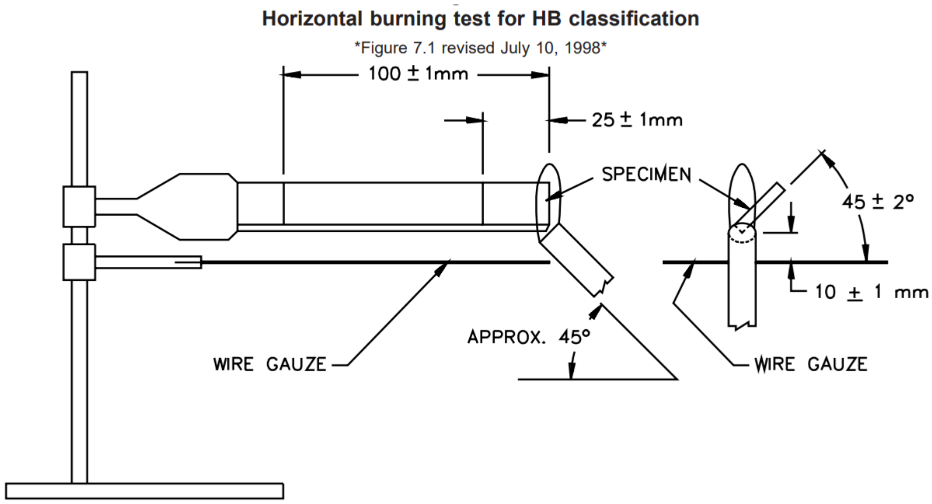

Figure 44 UL94 Test Set Up (UL)

The testing procedure involved preparing 3 specimen of the material with dimensions of 125.0±5mm in length and 13.0±0.5mm width. Prior to testing, each strip was marked with perpendicular lines at 25mm and 100mm intervals along its in accordance with the standard. These markings allowed the human eye to see when important measurements were reached. With the help of the chemistry department the strips were suspended horizontally in a ventilated hood allowing for a controlled environment, with ventilation, ensuring consistent test conditions. A Bunsen Burner was used to generate a controlled flame, which was initially held at the end of each strip until either 30 seconds had elapsed, or the flame front reached the 25mm mark. Following this, the timer was then used to record the time for the flame front to progress from the 25mm to the 100mm mark on the specimens.

Figure 55 UL94 Test Specimens

Throughout the testing process, observations were made regarding the behavior of the material when exposed to the flame. The linear burn rate, defined as the distance traveled by the flame along the length of the specimen per unit time, was measured using the marked lines on the strip. Additionally, the extent of flame propagation along the surface of the material and any instances of flaming droplets or particles generated during the test was documented. These observations were essential for evaluating the material's flammability characteristics and determining its performance relative to established standards and classification criteria.

Figure 66 Experimental UL94 Test Set Up

Results

During the Flammability Test, qualitative observations revealed common traits among the three specimens. When exposed to the flame, each specimen emitted dense black smoke indicating the presence of incomplete combustion and the release of carbonaceous particles. Additionally, all specimens exhibited the generation of burning droplets, indicative of polymer melting and dripping. These droplets can pose a significant fire hazard by spreading flames to surrounding materials or surfaces. The presence of black smoke and burning droplets underscores the importance of assessing not only the ignition resistance but also the materials fire distribution behaviors, especially in scenarios where fire safety is critical, such as in construction applications. These qualitative observations provide valuable insights into the behavior of the materials under fire conditions and emphasize the importance of comprehensive flammability testing in ensuring the safety and suitability of materials for use in various applications.

Figure 77 Typical UL94 Test Specimen During Test (Left) and After Test (Right)

Table 1 - Quantitative results for UL94 Test

Specimen	Did Flame reach 25mm (Y/N)	Did Flame reach 100mm (Y/N)	Elapsed Time (sec)	Liner Burn Rate (mm/sec)	Linear Burn Rate (in/sec)
1	Yes	Yes	141.5	0.530	0.0209
2	Yes	Yes	143.9	0.521	0.0205
3	Yes	Yes	178.8	0.419	0.0165
AVG	N/A	N/A	154.7	0.490	0.0193

It is important to note that the specimen used in the third round of testing appears as an outlier in the data set. Inspection demonstrated that this specimen had a more consistent structure and minimal air bubbles in comparison to the other two specimens. The lack of bubbles throughout the effective area of the specimen results in a longer burning time because there is more material to go through. While the data collected may show a lower burn time for the material, it can be assumed that specimens without imperfections would result in elapsed times aligned closer to the results of specimen three. Despite the limitations noted above, all three specimens still passed the 100mm mark and had similar qualitative results. It is crucial to acknowledge that the outcomes of this test pertain to small specimens of the recycled PP, so variability in results is not uncommon. Additional testing may be necessary to assess the burning characteristics of larger specimens, such as a full polypropylene brick as it is vital to see the behavior of practical applications.

Conclusion

The test concludes that the specimens do not meet the Horizontal Burning "HB" classification criteria outlined in the UL94 standard. Specimens exhibited sustained burning and emitted flaming particles, characteristics inconsistent with HB classification requirements. The findings closely align with those reported in Seegers master's thesis. Specifically, the polypropylene test yielded comparable results to those in the referenced thesis, with both studies observing sustained burning and flaming particle generation. These findings highlight significant concerns regarding the fire safety of polypropylene materials, indicating a heightened risk of ignition and flame propagation. To mitigate this risk, it is strongly recommended to apply a flame-retardant coating when using polypropylene in structural applications. Such measures are essential for ensuring the safety and reliability of structures constructed with PP materials. An example of a flame retardant commonly used in the construction industry is hexabromocyclododecane (HBCD), a retardant which can be applied to a materials surface and has proved to be effective in reducing the flammability of various building materials while meeting regulatory standards for fire safety.

Tensile Test (ASTM D638-22)

Understanding a material's behavior under tension is critical for ensuring the safety and reliability of structures as well as understanding how the material will behave when subject to pulling forces. To determine the characterization of tensile properties for unreinforced plastic specimens, a tensile test was done in accordance with ASTM D638-22. This standard provides values for the materials modulus of elasticity, forces, stresses, and strains at the different states imposed on the material. The primary significance of this test is determining the maximum tensile force the material can withstand before failure. Through conducting a tensile test, recycled polypropylene can be evaluated for meeting the required tensile strength and elongation properties for its intended use.

Procedure

Upon manufacturing the polypropylene slab, it was pushed through a planar in order to achieve a thickness of ¼”. Choosing the method to cut the dog bones was difficult because of the slab’s strength and material. Using a basic machine would leave rough edges, while attempting to cut with heat could cause melting and harm to the geometric properties. The specimens were cut into Type I dog bones using a Ward kit water jet machine courtesy of the Industrial Technology and Packaging Department. The overall dimensions are 6-½” by ¾” with a width of the narrow section being ½”.

To run the test, a universal testing machine was used as seen in Figure 8. The samples were clamped at the ends and an extensometer was used to record the data. When the test began, 6 specimen were pulled apart at 0.1 in./in.-min. Force and strain data was collected at each time step during the test. Per ASTM D638-22, the yield point indicates the onset of permanent deformation to the material, while the ultimate point refers to the maximum load that the material can withstand. When the break point is reached, it signifies the point at which the material fractures and fails. Stresses are calculated at each of these three points using the formula:

$$\sigma = {}^{f}/_{a}.$$

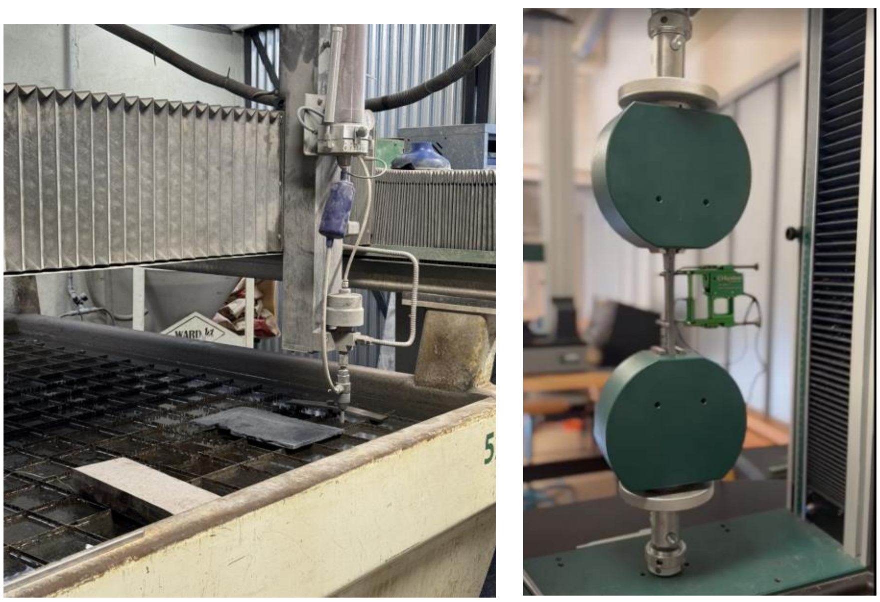

Figure 8 Ward kit water jet cutter (left) and Universal Testing Machine (right)

Results

Table 2 – General Results of the ASTM D638-22

Test	Modulus (ksi)	Yield force (lbs)	Ultimate Force (lbs)	Break force (lbs)	Yield Strain	Break Strain
1	219	97.8	139	139	0.00353	0.00533
2	259	149	185	181	0.00496	0.00697
3	229	151	184	180	0.00570	0.00808

4	222	101	127	126	0.00358	0.00457
AVG	232.3	124.7	158.8	156.5	0.00444	0.00624

Table 3 – Stress Results of the ASTM D638-22

Test	Yield Stress (psi)	Ultimate Stress (psi)	Break stress (psi)
1	763	1080	1080
2	1160	1450	1410
3	1180	1440	1400
4	791	991	987
AVG	973.5	1240.3	1219.3

Conclusion

While typical bricks primarily resist compression, understanding the material's tensile behaviors as well is crucial in safety and design. Seeger reported an average tensile value of 3326psi (22.93 N/mm^2) for polypropylene from household waste (Seeger). The tensile test found an average stress of 1,240 psi, demonstrating a 37.3% decrease from Seeger. One reason for this drastic difference can be attributed to the presence of air bubbles in the specimen. The presence of air bubbles resulted in a reduced effective cross-sectional area leading to a higher stress on a smaller area, ultimately leading to a lower tensile strength.

The average modulus of elasticity found in this experiment was 232.3 ksi. This value is in line with Seeger's reported range of 181 to 319 ksi. This value concludes that the air bubbles had a negligible effect on the modulus of elasticity. The range in values found can be attributed to the differences in composition of the PP extrusions. A study reported concrete masonry's modulus to be 827 ksi (Mosalam et al.). The extruded material made has 0.28% of the modulus found in the study. A materials modulus of elasticity is significant because it demonstrates the force required for material deformation and highlights the range where the material remains ductile. When designing a structure, a ductile material is preferred because it can undergo substantial deformation before failure, providing warning signs and allowing for predictable failure modes. However, reinforcing extruded bricks with steel allows for a low elastic modulus due to steel's high elastic modulus. When utilizing PP, this shortcoming needs to be taken into consideration and different strategies need to be taken to enhance its current tensile behavior.

Figure 9 Test samples before (left) and after (middle) test. Air bubble occurring at failure (right)

Water Absorption (ASTM D570-22)

Understanding how moisture affects material properties is a crucial consideration when selecting materials for specific applications and ensuring the resiliency of plastic components. The moisture content of materials impacts properties such as electrical insulation resistance, mechanical strength, appearance, and dimensions. The rate of water absorption can vary significantly depending on factors such as the shape of the specimen and the material's homogeneity.

When analyzing the water absorption of PP, the plastic will be immersed in a liquid, distilled water in this case. When immersed, the water interacts with polymers, and spreads into the polymer over time, a process known as diffusion. The rate of diffusion is not linear but is related to the square root of the time the polymer spends immersed in the liquid, giving it a more curved shape. This leads to a conclusion that increasing the amount of time the material is submerged does not double the rate of absorption but rather increases it by the square root (ASTM D570-22). Additionally, the time it takes for the polymer to become fully saturated depends on the thickness of polymer material, meaning that thicker pieces take longer to become saturated. This concludes that the rate at which a liquid spread into a polymer is not constant over time but slows down as time goes on meaning that the thickness of the specimen affects how quickly it becomes fully saturated with the liquid.

Examining water absorption properties in polypropylene compared to masonry adds another layer of importance to the testing of its strength properties. This is due to the drastic impact water absorption can have on a material's durability, dimensional stability, performance across diverse environments, and many other factors. Water absorption is a crucial factor in determining the longevity of materials, as it can erode the materials properties leading to failure. ASTM D570-22 was the procedure used to evaluate the rate of water absorption by plastics when immersed. This test method is applicable to all plastics and is used as a guide to the effects of water exposure.

Procedure

To begin the test, three disk-shaped specimens were created, each measuring 2 inches in diameter and 0.125 inches in thickness. It is imperative that the specimens undergo conditioning according to standard protocols. The conditioning process ensures the standardization moisture content, elimination of surface moisture, and maintenance of consistency and accuracy in the obtained results. This practice is vital for acquiring reliable and meaningful data to accurately assess the water absorption characteristics of materials. Due to the different laminations of the plastics shredded, our material is likely to be classified under 'nonhomogeneous' meaning that the specimen may absorb water at different rates across different edges and surfaces.

The melting point for polypropylene is 320º F (Selke). Based on the conditioning procedure in the standard, the specimen's water-absorption values remain largely unaffected by temperatures up to 230º F. In accordance with the ASTM-D570 conditioning procedure, the three specimens were dried in a Quincy Bench Oven for one hour at 225º F. Following the conditioning process, the three specimens were immediately weighed, for the recorded initial weight, and then immersed in accordance with procedure 8.1 (ASTM-D570). The specimens were then removed from the water and immediately weighed. The results of these procedures are detailed below.

Results

Conditioning:

Figure 1010 ASTM-D570 Conditioned Specimen

Increase in weight, % = $\frac{wet\ weight - conditioned\ weight}{condition\ weight} * 100$

Specimen 1:

Conditioned weight: 6.23 g

Wet weight: 6.33 g

Increase in weight, % $= \frac{6.33g - 6.23g}{6.23\ g} * 100 = 1.61\%$

Specimen 2:

Conditioned weight: 6.11 g

Wet weight: 6.27 g

Increase in weight, % $= \frac{6.27g - 6.11g}{6.11\ g} * 100 = 2.62\%$

Specimen 3:

Conditioned weight: 6.63 g

Wet weight: 6.79 g

Increase in weight, % $= \frac{6.79g - 6.63g}{6.63g} * 100 = 2.41\%$

Specimen, average**: 2.21 %**

Table 4 - Water Absorption Test Results

Specimen	***Conditioned Weight***	***Wet Weight***	***Increase in Weight***
1	6.23 g	6.33 g	1.61%
2	6.11 g	6.27 g	2.62%
3	6.63 g	6.70 g	2.41%

Conclusion

The ASTM-D570 test results confirm the anticipated outcomes: Polypropylene exhibits low water absorption characteristics, making it suitable for usage in environments where moisture poses a concern. Per code the water absorption rate of masonry cannot exceed anywhere from 13-18% depending on its weight classification (Brandow, 7). If masonry surpasses these rates, issues related to the structural integrity, durability, and aesthetic appearance of the masonry can arise. Polypropylene's remarkable resistance to water absorption mitigates these concerns causing it to be less susceptible to swelling, deterioration, or structural damage caused by moisture ingress. This characteristic enhances its durability and long-term performance in applications where moisture management is essential.

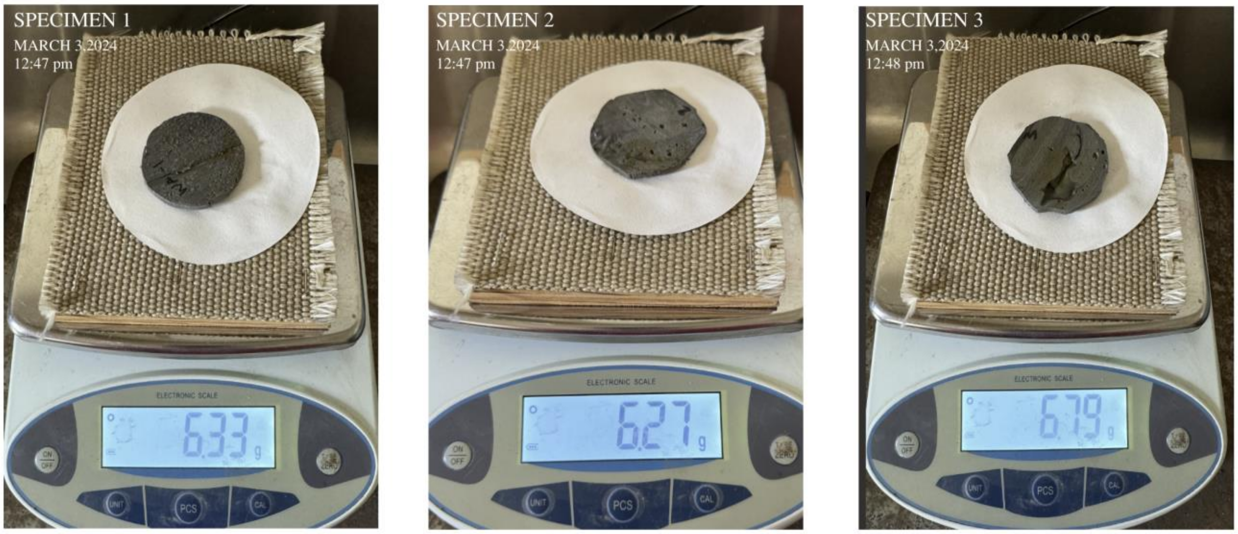

Figure 1111: Post Immersion Specimens

The specimen also demonstrated dimensional stability throughout the test as there were no changes in shape between the conditioned specimen compared to the saturated specimens. This is another key component that differs from masonry as saturated masonry beyond its designed capacity, can undergo physical changes such as expansion and contraction. This underscores polypropylene's suitability for applications requiring resistance to moisture, while highlighting its ability to maintain dimensional stability, mechanical properties, and aesthetic appearance in different environmental conditions.

Recommendations for Further Research

In future studies, it is recommended to conduct Compression and Ultraviolet Weathering (UV) testing along with other tests simulating polypropylene under different scenarios. Originally, these tests were a part of the project scope but due to the limitations and challenges faced, these tests were not able to be executed. A tension test should also be performed again, using test specimens with a more uniform composition to compare with the results found in this study. Other additions to the scope should be testing the feasibility of fabricating PP as structural connections, the addition of steel reinforcement in the bricks, and adding sand admixtures to create the bricks.

Compression Test

The compression test is recommended to follow ASTM D695 (Standard Test Method for Compressive Properties of Rigid Plastics). To conduct this test several specimens, will be tested using a compressometer. This test provides the material's compressive strength and modulus giving insight to how a polypropylene brick would perform when subject to compressive loads.

Understanding a material's compressive behavior is essential in design engineering. This is due to ensuring the structure can withstand compressive forces as well as ensuring a structure's stability. Polypropylene demonstrates characteristics leading to a high compressive strength. It is important to find the compressive strength of PP to fully analyze its feasibility as a building material.

Masonry is a material known to have high compressive strength. Since the extruded bricks are similar in both mechanical and geometric structure to CMU, PP is often compared to it. Masonry bricks with type S mortar (most common in California) have a compressive strength ranging from 1900-3000psi, while Polypropylene has been found to have a compressive strength ranging from 5511-7977psi, a much higher range compared to CMU bricks. While the creation of Polypropylene bricks is relatively new, they demonstrate promise to serve as a sustainable alternative to CMU blocks. Envisioning the future of brick construction, PP could be utilized with the addition of steel rebar for increased tensile strength. While not officially in the standard, it will be insightful to see the results of a PP brick in comparison to CMU, similar to ASTM C140/C140M-22 (Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units), where whole CMU bricks are compressed.

Ultraviolet Weathering (UV) Testing

For the UV Test, it would be recommended to follow the ASTM D4329 (Fluorescent Ultraviolet (UV) Lamp Apparatus Exposure of Plastics) standard using the Material's Engineering (MATE) departments QUV Accelerated Weathering Tester (QUV) to test the effects of outdoor weathering. The QUV machine stimulates damage caused by weathering (sun, rain, etc.). Sunlight is replicated through UV light, and rain is replicated through humidity. This test was arranged with the MATE department for this quarter, but due to scheduling issues as well as time needed to run the test, it did not take place. However, since everything has already been arranged and the specimens are ready it is strongly encouraged to begin this test as soon as possible.

The chemical properties of Polypropylene demonstrate that over time the material is susceptible to degradation when outdoors, regardless of the season. This exposure leads to brittleness as well as a significant loss in tensile strength (RajaKumar). Currently additives are needed for outdoor applications to minimize damage. It is recommended to compare the degradation of the extrusion with and without additives or investigate solutions that detriment the degradation. Because the extruded bricks are created from recycled materials, the composition is unknown leading to disparities in the results.

Conclusion

Over the course of 10 weeks, experiments on Polypropylene, a proposed sustainable building alternative, were conducted to determine its structural properties and behaviors as a building material. Tests conducted include a flammability test, tension test, and water absorption test.

The UL94 Horizontal Burning test results indicated that the recycled polypropylene specimens did not meet the standard for HB qualification. All three tested specimens exhibited sustained burning, emitted burning droplets, and produced black smoke. These findings suggest that this material would need a flame-retardant coating to meet satisfactory standards for most structural applications. The data collected throughout the project highlights a significant concern regarding the fire risk associated with recycled PP. To capitalize on the material's advantages, such as its lighter weight compared to CMU bricks, it holds promise for use in applications like retaining walls or other structures with minimal fire risks.

The ASTM D638-22 Tension test showed an ultimate yield stress of 973.5 psi and a modulus of elasticity of 232.3 ksi. The material was not ductile and broke apart suddenly. Like masonry, the PP bricks are weak in tension. However, tension strength should be retested because the specimens used were porous, making it fracture sooner than anticipated. The tests concluded higher tensile stresses compared to masonry but a lower modulus of elasticity. Based on these findings, it is not recommended that this material be in applications susceptible to tension forces.

ASTM-D570-22 demonstrated polypropylene’s positive water absorption characteristics. The specimen had an average absorption rate of 2.21% while showing no physical change in its geometric properties. The standard highlighted polypropylene’s ability to resist moisture while maintaining dimensional stability and its mechanical properties.

Challenges faced during this study include the time-consuming nature of PP extrusion, coupled with the limited time frame and failed extrusions. Nevertheless, additional research is necessary to thoroughly understand the structural properties of PP. It is recommended to conduct a compression test and Ultraviolet weathering test in the future. This study serves as a hopeful foundation for future explorations into the utilization of polypropylene in construction.

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