PRECIOUS PLASTICS – PLASTIC BRICK MACHINE FABRICAITON

ARCE 453 SENIOR DESIGN PROJECT
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Abstract

The goal of this research is to determine the structural parameters of the recycled plastic polypropylene when molded into bricks resembling CMU blocks. To accomplish this, three mechanisms had to be assembled: the shredder, the injector, and the 1x1 mold. A tensile and compression test were to be performed on the plastic brick, and the values would be used to compare the tensile and compressive strength of PP plastic bricks, as well as their modulus of elasticity and stress vs. Strain performance. These values would be analyzed to determine whether it would be feasible to build an entire plastic wall. Unfortunately, the injector machine's rod, which is used to eject molten plastic into the mold in high pressure levels, bent, and the team was unable to construct a brick in time. The team, however, did complete each mechanism and performed troubleshooting to account for any unaccounted obstacles. A few design changes must be implemented on the injector machine to ensure the project's success, and the mold must be tested, however before the injector broke, it ejected a few samples of melted plastic, which demonstrate the amount of progress that has been accomplished throughout the quarter.

Background

This project started with the Precious Plastics Organization; a nonprofit organization based in the Netherlands. The company's goal is to not only recycle all types of commonly used plastics, but also teach and guide the public on doing the same. They sell several machines as well as provide the original blueprints for them, and they encourage viewers to build their own machines or purchase their own. They separate their machines in a basic category, which is for those just getting started, and the pro category, which includes machines for those looking to start a recycling business. Under their Basic Machines category, they have the Shredder, Extrusion, Injection and Compression machines. The machines used for this project are the shredder and injection machines, and their purpose and fabrication will be discussed further in the report. On top of these machines, they sell their own recycled plastic, both in shreds and in their repurposed forms. Their products consist of accessories (chess boards, coasters, art), furniture (chairs, benches, end tables), and other structural materials (bricks, beams, sheets, modular structure connectors). One can also purchase large amounts of shredded plastic, all separated by plastic type and color, for their own use. Several houses have already been built using recycled bricks by Precious Plastics in Colombia.

There are several types of plastics used by the daily consumer, ranging from numbers 1 through 7. In *fig 1* is a table provided by Precious Plastics showing each and their corresponding properties. For this project, #5 plastics, also known as polypropylene (PP), were used. The reason this project revolved around #5 plastics only is not only due to its high compressive and tensile strength (see fig. 1), but also because it only recently became a recyclable plastic in the county of San Luis Obispo. Finding a way to repurpose this plastic can be very beneficial for the environment.

This project's scope took inspiration from Marina Seeger's master thesis, which consists of a mix of education, surveying, and risk analysis involving the building of plastic walls out of recycled materials. She began her research with a series of surveys, asking the public on their take on plastic houses, whether they would live in one, the reasons they would live in one, etcetera. For the analysis of the structural walls, she purchased the shredder pro, extruder pro, and the V4 brick mold from Precious Plastics to construct plastic bricks. She then performed a series of tests on the bricks to determine their structural reliability and their health hazard risks. The tests are as follows:

- Odor test
- Emission test
- Element analysis
- Tensile test
- Pressure test
- Vertical flame test
- Brick weathering
- Water absorption

Seeger found that the bricks were quite structurally reliant, the main cause of concern being their lack of fireproofing. Some other health risks she determined were that they can contain heavy metals, outgas odor and other gasses, and secrete microplastics due to weathering. For this project, the team took inspiration from Seeger's thesis. The goal was to repeat the tensile and compression tests that she performed on the plastic bricks and determine their structural integrity compared to her own results.

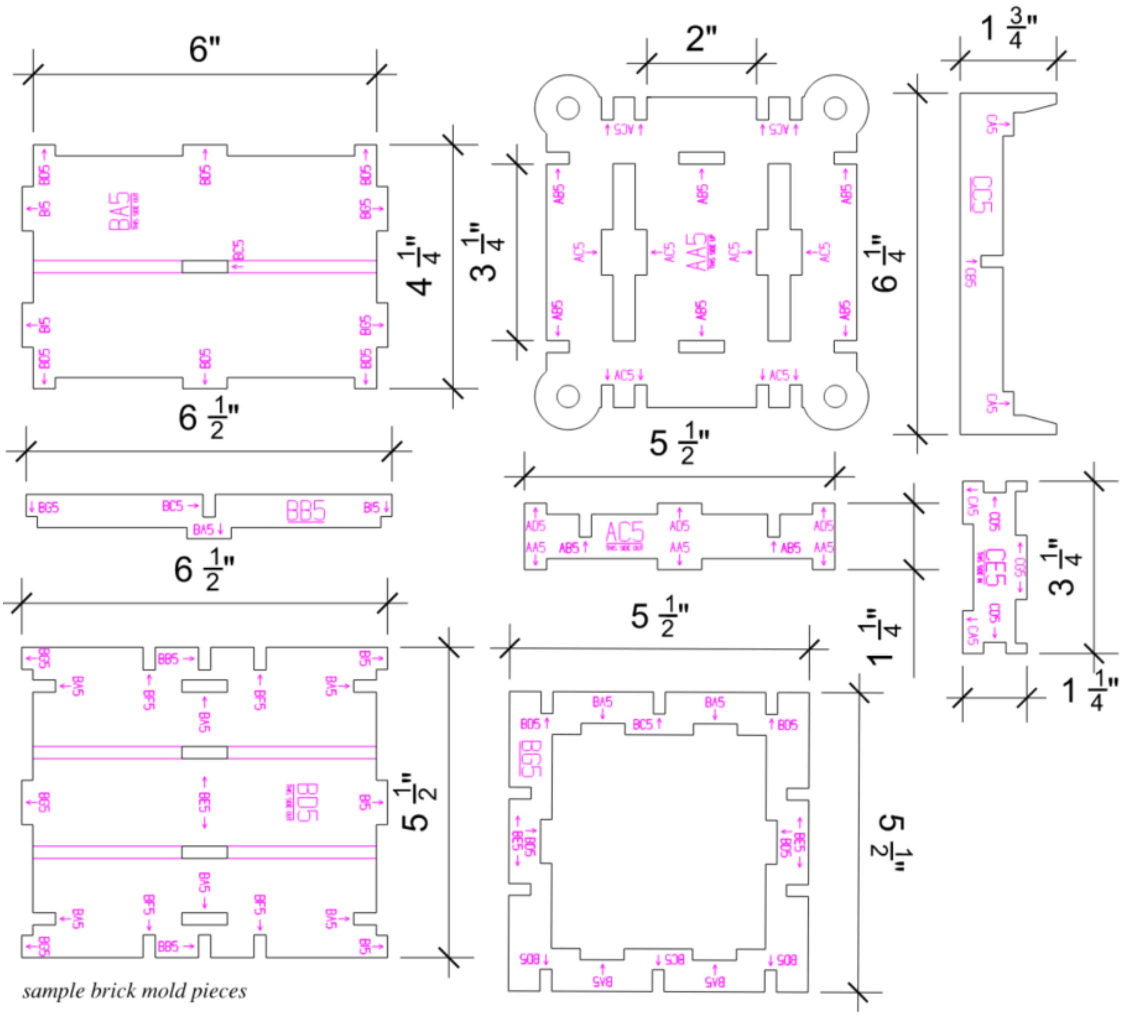
PLASTIC	THERMAL PROPERTIES				STRENGTH		DENSITY
ABBREVIATION - BRAND NAME	TM (°C)	TG (°C)	TD (°C)	CTE (PPM/°C)	TENSILE (PSI)	COMPRESSIVE (PSI)	G/CC
PET - Polyethyleneterephthalate	245 - 265	73 - 80	21 - 38	65	7000 - 10500	11000 - 15000	1.29 - 1.40
LDPE - Low density polyethylene	98 - 115	-25	40 - 44	100 - 220	1200 - 4550	-	0.917 - 0.932
HDPE - High density polyethylene	130 - 137	-	79 - 91	59 - 110	3200 - 4500	2700 - 3600	0.952 - 0.965
PP - polypropylene	168 - 175	-20	107 - 121	81 - 100	4500 - 6000	5500 - 8000	0.900 - 0.910
PVC - polyvinylchloride	-	75 - 105	57 - 82	50 - 100	5900 - 7500	8000 - 13000	1.30 - 1.58
PS - polystyrene	-	74 - 105	68 - 96	50 - 83	5200 - 7500	12000 - 13000	1.04 - 1.05

fig 1: Table showing plastics 1-6 in order along with their physical properties, provided by Precious Plastics

Methodology

Mold:

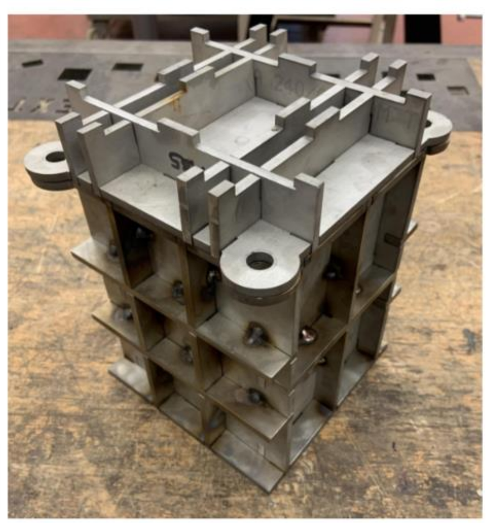
The mold is composed of 3/16" thick stainless-steel pieces cut using a water-jet machine. The drawings were sourced from Precious Plastics and were later dimensioned and edited (see fig. 2) for ease in fabrication processing. Since the mold is constructed from stainless steel, TIG - welding was used to connect the parts together, a combination of filler welds and fusion welds were used (see fig. 4) The mold consists of three main pieces that sit on top of each other (see fig. 3) to form the complete mold (see fig. 5) and TIG -welded together to form multiple parts that assemble into on whole piece.



sample brick mold pieces

fig. 2: Dimensioned Mold Part Drawings from Precious Plastics

male piece



female piece

cap piece

fig. 3: 3 main plastic brick mold components

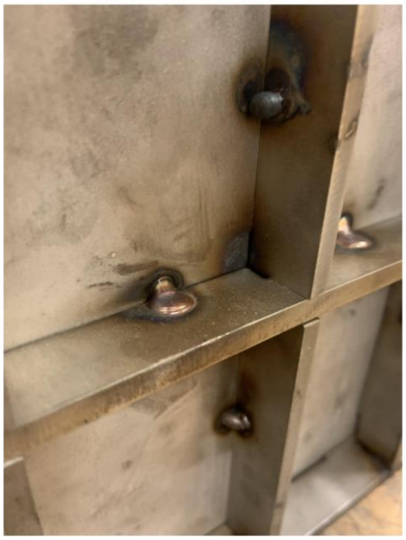


fig. 4A: Filler TIG Welds

fig. 4B: Fusion TIG Welds

fig. 5: Complete plastic brick mold assembled

Shredder:

The shredder is a crucial part of this process, as it is the mechanism that shreds the plastic to a size that is manageable to melt. Its three main components are the motor, the shaft, and the blades (see fig. 6). The 1 hp motor (30:1gear ratio) powers the entire system and is geared down to 70 rpm. The shaft connects the blades to the motor. The system was primarily constructed by the project advisor, Cameron Fredrickson.

fig 6: Complete motor assembly

Injector:

The injector is the machine that takes in all the plastic shreds output by the shredder. It melts and ejects the plastic in high pressure to fill up the attached mold. The blueprints for the injector were provided by the Precious Plastic Organization. The injector consists of 3 main elements: First is the funnel, where the shredded plastic is inserted into the machine. It falls into the barrel from there and is exposed to the heating temperature. Then there is the steel rod, which is used to push the melted plastic through the steel barrel and ejects it into the mold. Lastly, one of the most important parts of the injector are the heating elements that melt the plastic efficiently, which are attached across the barrel length. There are two identical parallel circuits attached to the voltage source due to two different temperatures being required to properly melt the plastic. The temperature at the tip of the barrel is meant to be higher. The heating system itself is composed of four main components:

- PID controllers:

The temperature controls act as the main control points of the entire system. They are used to set the target temperature of the heating elements while simultaneously presenting their current temperature. (see fig. 8)

- Temperature probes:
  The temperature probes are attached to the heating elements, which accurately measures the temperature and transfers the information to the PID controllers. (see fig. 9)

- Heating elements:
  There are four heating elements across the barrel, which are large resistors that resist current and export heat. Three of them were originally attached to one PID controller, and the last one was attached to the other PID controller. The three connect to each other in series to account for an equal distribution of current throughout them. See fig. 13 for their distribution along the barrel and (see fig. 10) for the elements themselves.

- Solid-state relays:
  To ensure there is not a constant current going through each resistor, a solid-state relay (SSR) is connected to each PID controller. This element acts as a switch activated when a direct current (DC) threshold is met. This current is provided from the temperature control, and once reached, it enables the alternating current (AC) coming from the source of the system to pass through and power the heating elements. (see fig. 7)

fig. 7 Solid State Relay

fig. 8 PID controller

fig. 9 Temperature Probe

fig. 10 Heating Elements

After some experimentation, it was found that the ideal temperature to melt the plastic shreds is 450 Fahrenheit for the sensors across the barrel, and 470 Fahrenheit for the one at the tip. The initial temperatures tested were 320 Fahrenheit and 350 Fahrenheit respectively, however those settings did not provide the necessary heat to melt the plastic. Calculations were performed to determine whether the provided voltage and amperage (120 volts and 10 Amps) would be sufficient. The whole system depends on the power provided, or wattage, which can be derived from *Equation 1*. It was estimated that each resistor would have a maximum of 150 watts available, and the goal was to reach the target temperature in 10 minutes. *Equation 2* was used to translate the change in temperature in the heating elements due to the provided power. About 120 Watts of power per heater were required to change the temperature by 300 Fahrenheit, or 422 Kelvin. This meant that the heaters should reach 350 Fahrenheit once adding the temperature of the room. To perform these calculations, a specific heat of c = 1.9 K/kg and mass of m = 180 grams were used. The mass was derived from estimating the plastic required to fill a one-inch depth layer of the 1x1 mold. To fill the entire mold, a mass of m = 6800 grams (15 pounds) would be required, which would require a power of over 10,000 Watts in the entire system to reach a change in temperature of 300 Fahrenheit in 10 minutes. Unfortunately, only 1,200 Watts are available for the entire system using the standard U.S. voltage system, so filling the mold would require multiple plunges from the injector.

$$P = V \times I \qquad \textit{Equation 1}$$

$$\Delta T = \frac{\Delta t \times P}{c \times m} \qquad \textit{Equation 2}$$

In order to provide enough wires for each element, 3-port Wagos were used to split the wires. The team determined that 14 gauge wires would be sufficient for chassis wiring, as they can withstand currents of up to 32 Amps. There was no need to reduce the wire gauge when splitting the wires with Wagos, as their corresponding resistance is minimal and hardly affects the system. When put together, the system layout (fig. 11) can be seen in fig. 12.

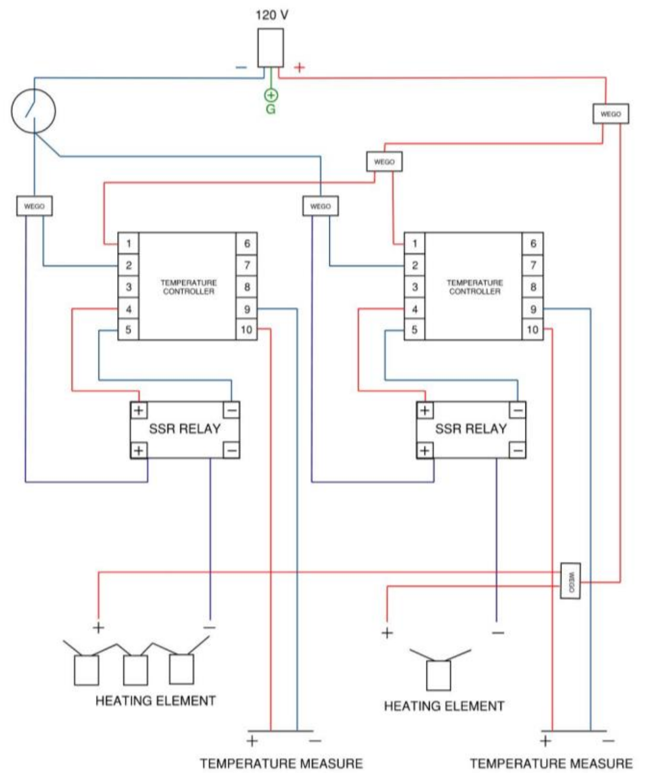


fig. 11 Initial Circuit Design

fig. 12 The built circuit layout

fig. 13 Heating element layout

Design Modifications

Some design modifications were made to the injector and the shredder listed below:

Injector Design Modifications:

Upon circuit assembly, it was observed that not enough amperage was being drawn from the source (only 1.8 Amps compared to the 10 Amps that were available). Furthermore, the injector was not reaching target temperatures in an efficient manner. Insulation was added around the barrel to contain the heat lost from the thermal couplers to the environment. This drastically reduced the wait time for the rod to reach its required temperature, and reduced the amperage required to power the system. See fig.18 below for images of the injector before and after its modifications.

- Injector Circuit Adjustment:
  For even and faster heat distribution throughout the injector, the number of heating elements connected to an SSR Relay and Temperature Controller were evenly split. Initially there were three heating elements attached to one half of the circuit, and the last one attached to the other half. Due to this, there was an uneven distribution of current across the thermal couplers and subsequently the barrel was not reaching the target temperature. This layout was thus adjusted to have two heating elements in with each SSR and PID Controller. This was done to ensure there was an equal distribution of heat across the barrel. The design modifications are explained in fig. 14 below.

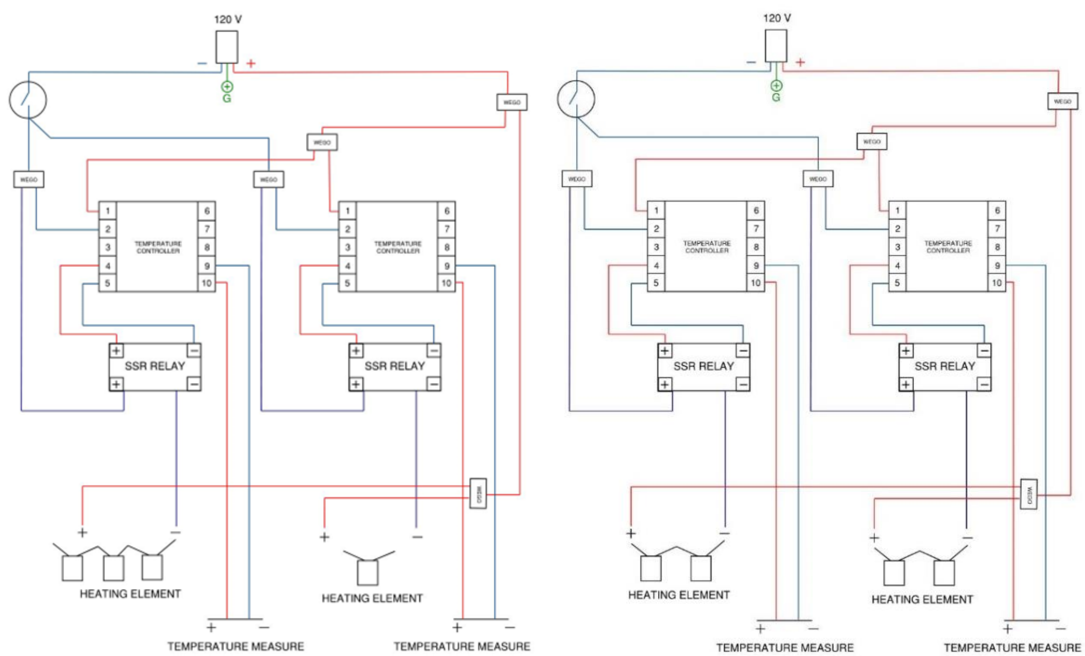


fig 14 :(L-R) initial circuit – 3-1 Heating Element split (old); 2-2 Heating Element split (new)

- Shredder Adjustment:
  The sieve (see fig. 16) underneath the shredder (see fig. 15) was causing the plastic pieces to accumulate on a corner of the blades. This was putting strain on the motor and

was causing the shredder to seize. Although the pieces attributed to machine seizure were not small enough to fit through the sieve, they were small enough to be used for melting via the injector. Thus, the sieve from the shredder was removed to eliminate machine seizure. To melt the pieces more efficiently, they were put through the shredder a second time to obtain smaller shreds of plastic. Fig. 19 shows the plastic shreds output from the shredder.

fig. 15: Shredder

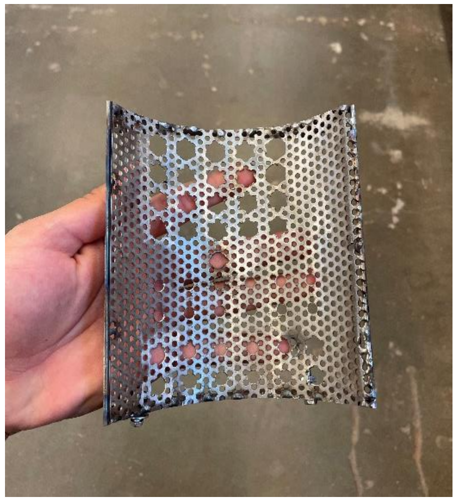


fig. 16: Shredder Sieve

- Brick mold to injector mechanism:
  To attach the brick mold to the injector, a screw-on attachment was welded on to the mold. See fig. 17 below.

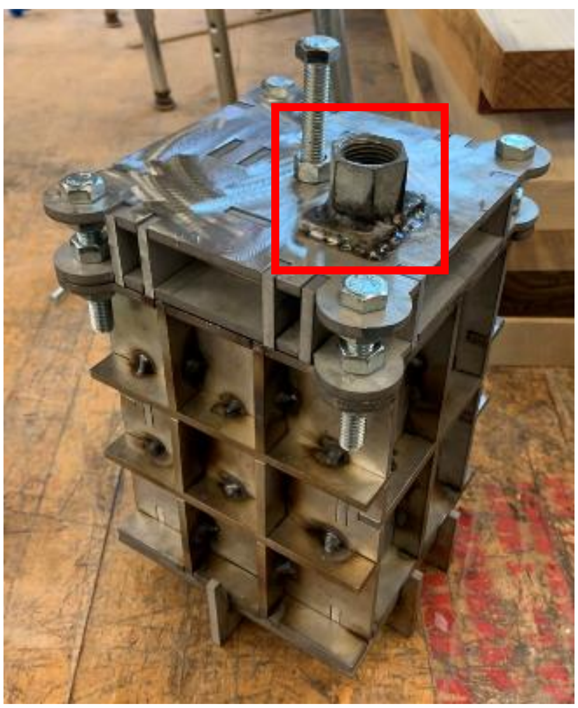


fig. 17: Screw – on attachment on brick mold

fig 18: (L-R) Injector's original layout; Injector after insulation was added.

fig 19: Plastic shreds output from the shredder

Causes of Failure

The main cause of failure can be traced to the existing design that was provided for the injector. These complications can also have originated from slight variations made in design implementation and lack of specification in the provided design in certain cases listen below.

- Injector Mechanical Seizure:
  During initial plastic melting tests, melted plastic spread across a tightly fitted barrel and rod build up during the injection process causing the machine to jam and this is not a robust process to fabricate bricks going forward. Despite being minor, thermal stresses can also be taken under consideration. The parts of the injector that were in the vicinity of the heating elements were exposed to inconsistent and drastic levels of heat ranging from 80˚F to 470˚F. Exposure to these levels of heat subjected the vertically oriented injector sleeve and moving tube to significant thermal contraction and expansion causing the mechanism to seize. The rod used to eject the plastic from the barrel was bent out of shape in an effort to remove it from inside the barrel. As a result, the team was unable to complete the brick fabrication and testing, as replacing the required materials and adjusting the injector's design was not accounted for in the provided timeline.

- Connection of the mold to the injector:
  There was no design provided to connect the plastic brick mold to the injector. A makeshift screw-on mechanism was implemented to attach the nozzle of the injector to the face of the mold. Upon implementation, the screw-on mechanism was inefficient and time consuming when the mold had to be attached to the injector due to the weight of the mold and the brace at the base of the injector.

- Rate of molten plastic:
  Before mechanical seizure, the rate of molten plastic that was being generated was significantly low. It would take an estimated time of one hour to fill the mold up with the molten plastic. The injector machine is originally designed to melt small portions of plastic, rather than 15 pounds at a time, which is the estimated amount required to fill an entire 1×1 mold. Due to this, regardless of the heating provided or the modifications applied to the design, constructing well-fabricated brick molds will remain challenging. Fig. 20 shows some samples of the molten plastic from the injector. Furthermore, there was no guarantee that the plastic in the mold would stay molten while the next amount of plastic was getting melted. This would lead to structural issues such as construction joints (construction joints are formed at the interface between solid plastic and molten plastic) as well as air-pockets, which would significantly weaken the strength of the brick. One way to prevent this is to heat the mold to match the temperature of the melted plastic, however maintaining that temperature throughout the hour does not work with the connection of the mold to the injector.

fig. 20: Molten plastic samples from the injector

Conclusion

The main obstacle that came with accomplishing this project's scope came with the design of the Injector. While the heating system worked and molten plastic was ejected (see fig. 20), the design of the injector was not made to build products of the desired scale. Initial complications were faced with reaching target temperatures for melting the plastic, and they were solved by the addition of insulation. Following this, a considerably low rate of molten plastic production hampered the formation of a complete brick. The injector is simply not constructed to take more than a few hundred grams of plastic shreds at a time. Furthermore, the rod going through the barrel and ejecting the molten plastic repeatedly seized up and prevented the efficient use of the machine. It led to the bending of the injector's frame and steel rod. Even if a plastic brick were to be formed without the injector mechanism's seizure, a brick with construction joints would be formed. Construction joints are formed at the interface between solid plastic and molten plastic. A plastic brick with construction joints would compromise its structural integrity.
For a brick to be formed without construction joints there are two possible solutions:

- Using a Professional Extruder: The extruder is another machine listed on Precious Plastics' website. It works similar to the injector; however it takes on larger amounts of plastic and automatically ejects them at a constant rate, rather than being manually controlled. Such an extruder would flood the brick mold with a high volume of molten plastic within the time it requires the molten plastic to solidify and cool down. It is more challenging to fabricate and uses a three-phase voltage source, increasing the risk of wiring the machine, especially for one who is unfamiliar with electrical circuits. Two ways of decreasing the added risks is to make the project more interdisciplinary and include students from other departments that have more experience with circuits and machine fabrication. The other alternative would be to purchase a professionally built extruder from Precious Plastics.

- Using a heated Brick Mold: Measures can be taken to keep the brick mold heated to ensure the liquid state of molten plastic is maintained until the mold is filled with the required volume of molten plastic. This measure is compatible with an injector that expels molten plastic at a much lower rate than a Professional Extruder.

Inferences upon the plastic brick testing and structural integrity of the brick cannot be made until a consistent and safe procedure for building plastic bricks can be implemented. To conclude, for the ease of processing and safety, purchasing a professional extruder should be considered to form plastic bricks. If obtaining a professional extruder is not a possibility, design revisions to the injector and having a heated brick mold should be taken under consideration.

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