Biochar Bricks for Building Material

Closed Project File

Team Jackalope

Maxwell Barton, Joshua Kim, Brina Patel, & Aime Laurent Twizerimana

University of Rochester
Chemical Engineering Department

Contents

1 Executive Summary

The project outlined in this paper consists of the assessment of biochar bricks as building materials for implementation in third world countries for residential and academic buildings. This topic is important to explore due to the limited knowledge on biochar building materials and the potential to reduce global CO_2 emissions, recycle organic and plastic waste materials, and create more jobs for the residents in these countries. Biochar is a charcoal-like substance made from organic matter decomposition at high temperatures in the absence of oxygen [1]. The current usages consist of soil additives to improve water absorption, plaster to capture humidity, and energy alternatives to replace fossil fuels [10]. The approach to this project was that of a design cycle for efficient and effective biochar brick production and characterization. Characterization of each brick consisted of five tests: (1) Insulation Value; (2) Water Absorption; (3) Flammability; (4) Hardness; (5) Compressive Strength. Prototypes that were one-third the dimensions (one-twenty-seventh the volume) of a standard modular brick were created to reduce the waste of material and resources before the full scale brick was made. Two wood molds were made for each brick size to ensure consistency. The four different types of prototypes were of the following: (1) Concrete (as a standard); (2) Biochar (75%) and Cement (25%); (3) Biochar, Plastic, and Sand; (4) Biochar and Plastic. The procedure for the different bricks consisted of varied ratios of biochar combined with a binding material such as plastic or cement and additives in some prototypes. The concrete bricks were utilized as standard values for comparison and characterization. The insulation value test showed that the biochar based bricks have higher insulation values compared to concrete bricks and the reference common brick. The insulation test also shows that there is a small change in insulation value of biochar and plastic bricks associated with addition of sand. Results from the water absorption test showed the biochar bricks had a higher water absorption than concrete in 24 hours due to the highly porous nature of biochar. Flammability tests conducted on the biochar and cement brick showed a longer ignition than extinguish time and a separation time of over 85 minutes. Hardness tests were conducted with a Shore D durometer that revealed varied average values for concrete and biochar and cement bricks. However, concrete exhibited values close to literature and higher than biochar and cement as expected due to the lower amount of cement present. The compressive strength tests revealed the biochar and cement bricks to have a lower compressive strength (between 1500 to 2000 psi) than the concrete bricks (2500 psi). The biochar and cement prototypes did not meet the minimum ASTM standard for concrete bricks, however the 50% plastic, 50% biochar brick did fall within the range of ASTM standards for concrete bricks. Results from this project reveal more tests should be conducted to assess viable applications of biochar bricks.

2 Introduction

2.1 Customer Requirement

The customer requirement was to characterize (four specific tests) a standard modular biochar (75%) and cement (25%) brick and compare it to other building materials to determine the utilization of such bricks. This team made the decision to take it a step forward and explore biochar, plastic, and additive bricks to determine if they were comparable to concrete and biochar and cement bricks as well.

2.2 Background

Biochar is a charcoal-like substance made from organic matter decomposition at high temperatures in the absence of oxygen. This process is known as pyrolysis and prevents the organic matter from reacting with oxygen as it decomposes, thus, hindering the formation of carbon dioxide and carbon monoxide [1]. The result is a solid carbon structure that locks the carbon from the organic matter in solid form, which reduces the decomposition of the matter and ultimate formation of methane, carbon monoxide, or carbon dioxide. This further prevents carbon dioxide from entering the atmosphere.

Two of biochar's defining properties are its low thermal conductivity and high water absorption properties of up to 5 times its weight [2]. This is caused by the very porous nature of biochar. The porosity of biochar is dependent upon the type of organic material used to make the biochar, and the temperature at which the material is decomposed [3]. Biochar can be used in multiple ways from filtration to a soil additive to making building materials. The structure of the biochar, being porous yet sturdy, gives biochar its most useful characteristics [3].

2.3 Statistics

When organic matter is put into landfills and left to decompose, the natural byproduct of this process is a large amount of gas, named "landfill gas." The microorganisms that break down the organic material release carbon dioxide and methane in the process. The composition of landfill gas consists of 99.9% methane and carbon dioxide, with a small percentage of non-methane organic compounds. Roughly half of the 99.9% is methane gas, and the other half is carbon dioxide [4]. This makes landfill gas a huge source of methane pollution; landfill gas is ranked as the third largest global source of human-based methane emissions. Methane is known to be 28 to 36 times more effective at trapping heat than carbon dioxide, therefore posing as a very harmful threat to the environment. As it can be observed, utilizing organic matter to make biochar can provide a solution to global emissions and prevent large quantities of methane and carbon dioxide from entering the atmosphere.

The most common building material is concrete which has a 332 billion dollar global market value that translates to 4.1 billions tons of concrete being produced every year [5]. The main component of concrete is cement, and cement manufacturing relies heavily on thermal decomposition of calcium carbonate to lime, which releases carbon dioxide as a byproduct. This process is responsible for 4-8 % of global man-made carbon dioxide emissions [6]. Increases in global carbon dioxide emissions heighten the global warming effects that affect the global climate, population, and other species.

In addition to carbon dioxide pollution, increased incorporation of plastics in society has resulted in the rise of plastic pollution. Plastics can be found in the oceans, and approximately 270,000 tons of plastic waste is in the multiple oceans. This comprises 60%-90% of all marine debris, and plastic waste continues to increase as an additional 13 million metric tons of plastics are found in the ocean each year [7]. Plastic waste kills up to 1 million seabirds a year, and affects at least 800 species worldwide, as animals ingest plastics or get entangled in them. Plastic presents a big challenge since it takes hundreds of years to decompose [7]. This project has the potential to eliminate the negative effects of plastic pollution by providing an alternative use to accumulation in a landfill.

2.4 Benefits of Biochar

Using biochar in building materials will reduce much of the greenhouse emissions and pollution caused by waste plastics, concrete, and organic waste. By sequestering the carbon from organic waste materials, biochar reduces the methane and carbon dioxide emissions released from landfill gas. If all of organic waste from landfills were to be converted to biochar, the reduction in landfill gas would amount to a potential 11% global reduction in human-sourced methane emissions [8]. Furthermore, the addition of biochar in concrete bricks would reduce the amount of used cement, thus reducing the carbon dioxide released in the process. The current brick available for testing is composed of three parts biochar and one part portland cement. If these composite bricks are scaled globally, there is potential for a 6% decrease in the original 8% global carbon dioxide emissions produced from cement [9]. Biochar can be used with waste plastic to create bricks to reduce global plastic waste as well. This will be explored in further sections.

Other benefits of biochar have been explored by previous research teams in the field of soil fertility, dairy farm methane emissions, building plaster, and much more. The use of biochar as a soil additive increases the fertility of soils as it has the ability to absorb heavy metals and other dissolved organic compounds. When biochar is added in the soil, there is a change in the pH of the soil, increase in soil porosity, and adsorption of gases, metals and other organic compounds on the biochar surface, enhancing soil fertility [10]. When biochar is added to manure composts, it can reduce methane emissions by 27-32%. Research conducted at the University of Merced on biochar use in dairy farms stated that methane emissions from manure could potentially drop by 2.74 million metric tons of carbon dioxide annually through the success of the mobile biochar unit [11]. Biochar has also been used as an ingredient in wall plaster which effectively absorbs odor and other pollutants. This research conducted by the Ithaka Institute showed the water-absorption properties of biochar also aids in regulating humidity to decrease the development of mold and other harmful microbes [2]. This will be discussed more in depth in the previous work section.

2.5 Previous Work on Biochar and Plastic

The previous work conducted with biochar consists of a plaster, an energy source, and a soil additive among other uses. The plaster composition is 50% biochar, 30% clay, and 20% sand, and it serves as an alternative to styrofoam insulation. This type of plaster allows houses to become carbon sinks as it absorbs smells and toxins. It has the potential to be implemented in hospitals, factories, and residential places among other buildings. As previously mentioned, the water absorption ability and low thermal conductivity allows for the biochar plaster to be an ideal replacement for insulation [2]. Next, biochar has been implemented as a carbon neutral energy source, but was proven to be an expensive process due to the pyrolysis process of certain biomass [12]. Therefore, this use of biochar is not observed in many places, but with more research and testing, it has the potential to serve as a cost-effective energy source. The steps toward a bioenergy world with biochar would start at the potential genetic engineering of plants to produce more biomass to convert to biochar. The last and most common use of biochar consists of it as a soil additive to improve soil quality through the retention of nutrients and water. It also has the ability to sequester carbon in the soil. However, this does allow for perturbation of the soil and subsequent release of carbon into the atmosphere. Alternative uses of biochar consists of waste management and air quality control [12]. As it can be observed, there are positives and negatives to utilization of biochar. However, there are novel approaches to determining how to use biochar in a cost-effective and efficient way.

Moreover, the use of plastic materials for buildings has become increasingly popular in third world and developing countries as concrete bricks have become more difficult to obtain. On the Ivory Coast, UNICEF and a Columbian company have partnered together to create nine classrooms from 100% recycled plastic bricks [13]. It takes 20 plastic water bottles to make the bricks which exemplifies how it fights plastic pollution as well. These bricks are lighter and cost approximately one-third less than their concrete counterparts [14].

This idea has also been translated to the use of waste plastic and sand to make paving stones and roofing tiles in countries like Uganda and Cameroon [15]. Constructing plastic bricks in a specific country or area allows for less waste build-up and more job opportunities for native people. The following provide relevance for this project by combining the ideas of biochar and plastic to make bricks for residential and academic buildings.

In addition, previous work with biochar has been conducted by a University of Rochester team, Team Cheddar. The scope of the project was to eliminate the use of acetone as a solvent to create and characterize biochar and polymer composites. The work consisted of different mass ratios of biochar and polymers: Polypropylene (PP), High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), and Polystyrene Crystal 500 (PSC 500). However, the polymers utilized for further testing consisted of LDPE and PSC 500 because of machine constraints. Material properties were tested through characterization to help determine deformation and failure of material. One relevant test to this project is the hardness testing with the Shore D Durometer. The procedure was outlined in the report that will be used for this project as well. It was important to note the reading time and multiple trials on the same material [16].

3 Key Assumptions

The following assumptions were made in order to construct bricks and conduct the specific tests. All bricks were assumed to be able to achieve even surfaces and equal sizes for future use. It was assumed that there was uniform mixing of all components in all mixtures for bricks, and that particle size had no effect on the brick composition or mixing. The concrete bricks made for prototypes and full scale were assumed to be the standard for all other brick testing. It was assumed that the biochar available for manufacturing purposes was softwood biochar as each type has its own properties.

3.1 Biochar and Cement Bricks

It was assumed that biochar and cement would be readily available at the construction site. The correct size molds, sieve (or grinder), mixer, water, and tarp should be provided as well.

3.2 Biochar, Plastic, Additives Bricks

It was assumed that the recyclable plastic (Type 2 only) and specific additives was readily available as well as biochar, and all components were able to be the same particle size as biochar. For the plastic (HDPE), it was assumed that the additives within this plastic had no effect on the brick or its properties. The hot compression of the mixture was assumed to be accessible for these bricks as well.

3.3 Characterization Methods

For compressive testing, the force on the bricks was assumed to be only from the top and one direction. For water absorption testing, it was assumed that the temperature of the water wouldn't fluctuate from room temperature and the longest duration of continuous water exposure was twenty-four hours. For insulation testing, it was assumed that heat transfer was in one direction. For flammability testing, the determination of burn and extinguish time was assumed with visual cues. These assumptions needed to be made in order to conduct the tests on each brick: concrete, biochar and cement, and biochar, plastic, and additives.

4 Engineering Calculations

4.1 Insulation Value

A comparative test was used to measure the insulation value (R-value). In this test a reference material, red oak, in our experiment, with a known insulation value was used to determine the insulation value of the sample using the equation below. The red oak used in this experiment had an insulation value of 0.79 per inch [17]. The bricks were covered with insulation on a heated mat, and their respective temperatures were measured using TMP36 sensors. The following equation was utilized once the system achieved steady-state to determine the brick's insulation (R) value [18]:

$$R_{test} = \frac{R_{ref} A_{test} (T_{Htest} - T_{Ctest})}{A_{ref} (T_{Href} - T_{Cref})} \tag{1}$$

The definitions for each variable in the equation above can be found in Appendix A.

4.2 Water Absorption

This test consisted of recording masses before (Mass 1) and after (Mass 2) a brick was placed in water for twenty-four hours. This allowed for the observation of how much water was absorbed from the different bricks that were tested. The following equation was utilized:

$$WA(\%) = \frac{Mass_2 - Mass_1}{Mass_1} * 100 \tag{2}$$

4.3 Compressive Strength

This test consisted of the MTS Compression machine in the mechanical engineering department. A flat plate was utilized and force was applied until the "point of failure." The procedure used in this test was matched to ASTM standards, however the bricks did not due to the uneven surfaces of the prototypes. It is also noted that cylindrical bricks are most commonly used for ASTM compressive strength testing. The following equation was utilized to determine the compressive strength of the bricks:

$$Compressive\, Strength = \frac{Load\, at\, Point\, of\, Failure}{Cross\, sectional\, Area} \tag{3}$$

5 P&ID for Insulation Value Test

5.1 Wiring Diagram

Figure 1 describes the wiring diagram of insulation test conducted on the prototype bricks.

5.2 System Design

The insulation test required a heating source that would allow for only one dimensional, constant heat transfer to one face of the brick. The solution was a resistive heater with both faces insulated with the exception of a hole for the brick. The resistive heater came unwired with wire to connect to a power supply. In order to not burn out the heater, a solid state relay (SSR) control box was needed. The system also required a temperature sensing component that was run off of LabView using 8 TMP36 sensors (see Appendix A).

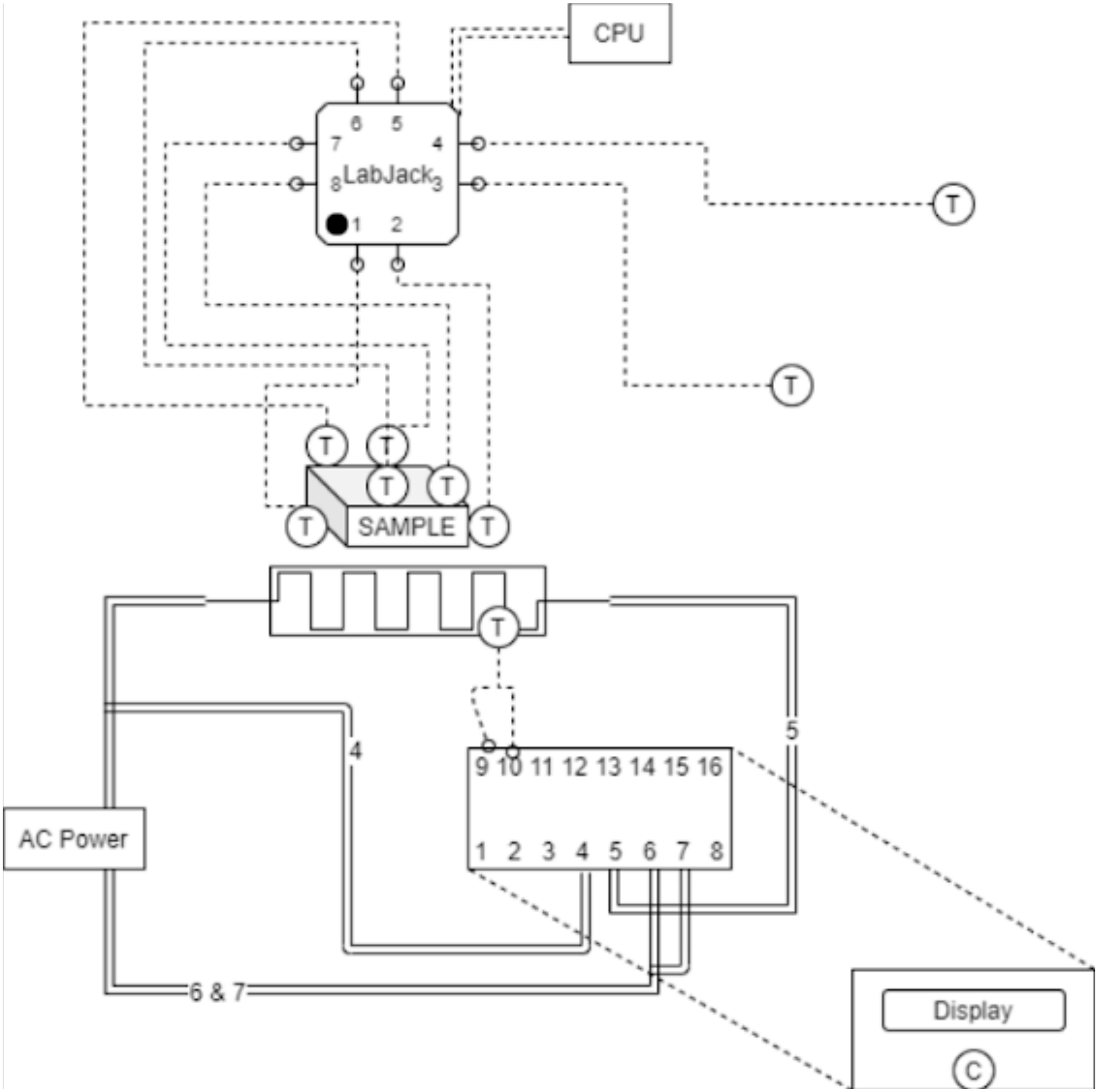


Figure 1: Wiring Diagram for Insulation Value Test

5.3 Wiring of System

Note: If a different control box is used, do not use these wiring instructions. The box will need a power supply (common and hot), a power supply with the heater contained in the circuit (common and hot), and a thermocouple. The exact wiring may be different than the described box.

1. Wire a power supply cord for the control box into ports 6 7 on the rear of the control box. Wire the common and positive lines into the ports. The control box will identify which port should be selected.
2. Wire a power supply cord for the heater. The hot line will wire into port 4. The common will be connected using wire nuts to one of the heater's terminals. The other terminal on the heater is wired into port 5.
3. Wire the thermocouple into ports 9 and 10. The thermocouple will have a positive and negative terminal. The positive terminal should be more corroded. The control box will have direction for the corresponding port and wire.

5.4 Wiring of Temperature Sensor System

The TMP sensors will have three wires connected to the LabJack (see Appendix A). The three terminals will be connected into a ground, a +5V and an analog input. The wiring for this system had a white ground, a blue +5V and a striped wire for the signal. Each sensor will need a unique signal input but can share ground and +5V ports.

6 Materials List

6.1 Table of Materials

The following table exemplifies the main materials of this project with their corresponding price. The table of all materials and equipment with their respective locations can be found in Appendix B.

Material	**Price**
Softwood Biochar	Provided by Ithaka Institute
Waste Plastic (HDPE#2 Plastic)	Free
Additive Materials (Sand, Paper shavings, metal shavings)	$6 (Lowe's)
Mold: Oak and Pine	$45 (Lowe's)
Portland Cement	$15 (Lowe's)
Propane Tank	Provided by Jeff Lefler and Clair
Parchment Paper	$4 (Amazon)
#8x2" Outdoor screws	$10 (Lowe's)
Canvas	Provided by Rachel
Insulation	Provided by Jeff Lefler
Gravel	Provided by Jim Alkins
Cryogenic Gloves	Provided by Prof. Porosoff/Clair
Estimated Total Cost	$125-130

Table 1: Estimated Cost of Materials; Purchased by the Department

The important material specification would be the the type of wood for each mold. The oakwood mold has a higher heat tolerance than the pinewood, and this was needed for the specific bricks made. The small mold for the prototype bricks was expected to undergo heat and compression for the biochar and plastic bricks, so the wood needed to be more durable under higher heat conditions. It was not expected that full scale bricks were to be made for the biochar and plastic bricks. Moreover, the type of biochar is important because different types can have different properties. This could contribute to varying values and behavior under similar conditions.

6.2 Hardware

The components to make the two molds, prototype and full scale, were oak and pine wood, respectively. The outdoor screws were utilized to hold the mold together. The platform for the flammability tests was made out of stainless steel parts. The four legs on the platform were screw-in, so it was detachable for ease of storage.

7 Methodology

7.1 Mold Preparation

7.1.1 Oak Prototype Mold

The first mold constructed was a red oak mold that made bricks to one-third scale of a standard modular brick volume. The dimensions are 2 $\frac{1}{2}$" x 1 $\frac{1}{4}$" x $\frac{3}{4}$" (see Appendix A). This scale was chosen to reduce material needed in early stages of brick construction. Making the oak mold was completed with the help of Jim Alkins in the Rettner machine shop. Oak was used in favor of its high flammability temperature. The mold was constructed with twelve separate spots for prototype bricks. The top of the mold was made in order to smooth out the top of the prototype bricks.

Lessons Learned: While molding the cement and biochar prototype bricks, the mold deformed on the ends and resulted in needing clamps horizontally to hold the mold together. The reason for this was that the ends were attached using wood glue which allowed for the water in the bricks to soften the wood glue and the wood itself until it curved outwards. While molding the prototype concrete and biochar and cement bricks, the tops were rough and the top of the mold was needed to create a smooth surface. If the mold had been the exact height of the bricks then the tops could have been smoothed out without the need of a top for the mold. However, without the deeper mold, the plastic bricks would have needed a different form of compression or another mold altogether. Initially, waxed paper was used to be the mold release. This was problematic because it left creases in the bricks that would have impaired testing. Graphite spray and vegetable oil were tested early on for which could be used as a mold release and the vegetable oil worked much better.

7.1.2 Softwood (Pine) Full Scale Mold

The large scale mold for concrete and biochar and cement bricks was made out of 2x4 pine boards because they are low cost and very accessible. The dimensions of the mold are that of a standard modular brick, 7 $\frac{1}{2}$" x 3 $\frac{5}{8}$" x 2 $\frac{1}{4}$" (see Appendix A). The mold was made to fit 10 bricks at a time. The height of the mold was exactly that of the bricks and smoothing the top of the bricks was much easier. The mold was sprayed with a water sealant in an effort to preserve the wood.

7.2 Prototype Bricks

7.2.1 Concrete

In this project, the concrete brick prototype was made using Portland cement, gravel, sand, and water. The prototype brick's dimensions were $\frac{3}{4}$" x 1 $\frac{1}{5}$" x 2 $\frac{1}{2}$". To create the concrete prototype gravel, sand, and cement were mixed in 3:2:1 ratio by volume.

Procedure

In this process, 450 mL (9 scoops in 50 mL beaker) of gravel, 300 mL (6 scoops in 50 mL beaker) of sand, 150 mL (3 scoops in 50mL beaker) of cement, and 150 mL (3 scoops in 50 mL beaker) of water were used. First, cement and water were mixed, and gravel and sand were slowly added to the mixture while mixing. The mix was thoroughly mixed to ensure equal distribution of materials in the brick, and the amount of water was determined by observation of how much water makes the mixture viscous enough. The mold was prepared by coating it with canola oil to prevent bricks from sticking on the mold walls. After mixing the concrete ingredients, the mix was poured in the mold and equally distributed in each chamber. The top surface was smoothed, and the mold lid was placed on the mold. The bricks were left in the mold to dry overnight at room temperature. After 24 hours, the bricks were removed from the mold and numbered based on their location in the mold. After numbering the bricks, a damp cloth was placed on the top of the brick for two days. After this period, the bricks were left to dry and were weighed everyday to record the weight loss (see Appendix C).

Lessons Learned: Initially, the parchment paper and graphite spray were used in the concrete mold to prevent the concrete from sticking to the mold, but the parchment paper resulted in formation of creases on the brick, and the graphite spray made the mold black. The team chose to proceed with canola oil as it successfully prevented the brick from sticking to the mold surface without affecting the brick and the mold structure.

7.2.2 Biochar and Cement

The Biochar and Cement bricks were made using Ithaka Institute's procedure for making biochar bricks [19]. These bricks were made using a 3:1 ratio of biochar and Portland cement by volume. Water was added, maintaining a 1:1 ratio with the cement.

Biochar Preparation

The biochar for the plastic bricks needed to be small in an effort to increase bonding area per volume of biochar. This helped form a more homogenous mixture and does not allow for large particles of biochar to be structural weak points within the brick. The maximum diameter of the biochar used for these bricks was $\frac{1}{8}$". The biochar was first passed through a 0.1" sieve. Biochar that passed through was used for the bricks and the remainder was shredded using a blender and passed through the sieve again.

Lessons Learned: The grinder was initially used to crush the biochar into a powder, but this proved to not work because the biochar would pack onto the sides of the grinder blades and stop the machine.

Procedure

175 mL of Portland cement (3.5 scoops in a 50mL beaker) was mixed with 175 mL of water to form a 1:1 ratio mix. Then 525 mL of sieved biochar (10.5 scoops in a 50mL beaker) was added for the recommended 3:1 biochar to cement ratio and stirred until a homogeneous mixture. 35 mL of additional water was added to increase moisture of the biochar, minimizing dust formation. The biochar and cement mix was then poured into the prototype brick mold (initially sprayed with canola oil to prevent sticking) and the mold lid was fitted on top. A sandbag was placed on the lid to compress the bricks and create a smooth surface. After 24 hours, the bricks were removed and a damp canvas was placed over them for an additional 24 hours. The bricks were then submerged in distilled water for 24 hours and removed to dry and cure. After this period, the bricks were left to dry and were weighed everyday to record the weight loss (see Appendix C).

Note: Use of DI water to remove white substance (speculated to be mineral deposits from tap water).

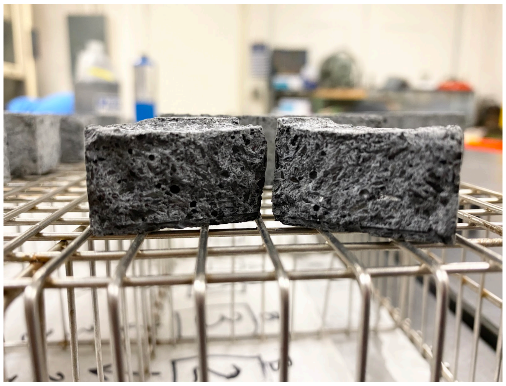


Figure 2: Biochar and Cement Brick: Porous Structure Inside

Figure 3: Biochar and Cement Brick: All Prototypes

7.2.3 Biochar, Plastic, and Additives

Preparing High Density Polyethylene (HDPE)

The HDPE for the bricks came from recycled (Type 2) containers. The plastic needed to be ground down in a grinder to improve the mixing with the biochar. The plastic was cut into small pieces, fed to a blender, and cut small enough to fit into the feed tube of the grinder. The pieces were then submerged in a vat of liquid nitrogen for five minutes. The pieces were removed using a metal spoon and fed into the grinder slowly, approximately half a cup at a time. If the pieces were fed too fast, the grinder would become clogged and if they were fed too slow, the grinder would not have enough material inside to push out the plastic particles. The plastic was collected in a plastic bag clamped around the output nozzle of the grinder.

Lessons Learned: The first plan to break up the plastic was to submerge the plastic into a vat of liquid nitrogen until it was brittle and then using a mallet, break the pieces into small pellets. This failed because the plastic never became brittle enough. Before using the blender, the plastic was cut into pieces small enough to feed to the grinder, however, this was time consuming and the blender was used instead.

Procedure

Method 1: **(1)** 75% Biochar - 20% HDPE - 5% Sand, **(2)** 50% Biochar - 40% HDPE - 10% Sand, **(3)** 25% Biochar - 60% HDPE - 15% Sand

To make the plastic prototype bricks via method 1, the plastic, biochar and sand were mixed together in an oven safe pan. A total of approximately 500 mL of mixture was created to adequately fill half the mold. For prototype **(1)**, a total of 1000 mL of mixture was created, 750 mL biochar, 200 mL HDPE, and 50 mL sand. For mixture **(2)**, a total of 750 mL of mixture was made. This was made from 500 mL of the mixture **(1)** with 200 mL HDPE and 50 mL of sand added. Prototype **(3)** was made up of 134 mL from mixture **(1)** with 213 mL of HDPE and 53.3 mL of sand added for a total volume of 400 mL. Each mixture was heated in the oven at 220°C for approximately 45 minutes, or until the plastic had melted. The mixture was then removed from the oven and scooped into six of the twelve spots in the mold. The top was placed on the mold and four c-clamps were used to compress the bricks, one at each corner. The prototypes in the mold cooled overnight in a fume hood and were removed the following day.

Lessons Learned: The mixtures were initially made up in high quantities. Using this method, only about 400-500 mL of mixture was needed to fill the six spots in the mold. This method of molding left large air bubbles in the prototypes because the plastic hardened before being fully molded. Additionally, the compression of the mold in this manner was not adequate to purge the air bubbles and make a fully homogeneous prototype.

Method 2: 50% Biochar - 50% HDPE

To make the plastic prototype bricks via method 2, the plastic (200 mL) and biochar (200 mL) were mixed together in a beaker. The dry mixture was then scooped into six of the twelve spots in the mold, filling 1.5x the volume that the final brick was supposed to be, allowing for shrinkage. The top was set on the mold and four c-clamps were attached to compress the mold, one clamp at each corner. The mixture was heated in the mold in the oven for 2.5-2.75 hours at 220°C until the plastic was melted. Once the mixture was melted, the mold was removed from the oven and placed in the fume hood to cool overnight. The prototype bricks were removed from the mold the following day.

Lessons Learned: The bricks came out of the mold smaller than they were supposed to be. The mixture shrunk more than it was expected to and led to the bricks not being compressed while cooling.

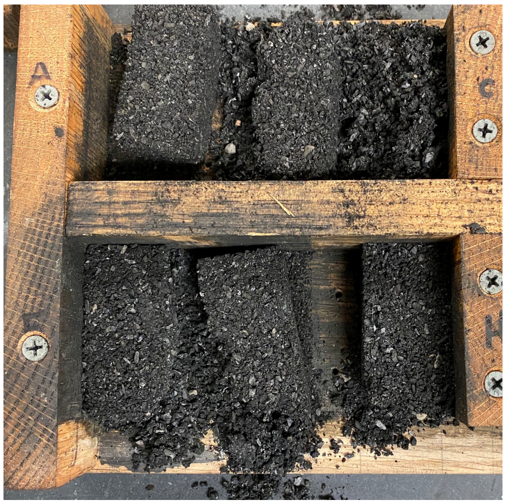


Figure 4: Biochar (75%), Plastic (20%), and Sand (5%) Prototype Bricks

Figure 5: Biochar (50%), Plastic (40%), and Sand (10%) Prototype Bricks

Figure 6: Biochar (25%), Plastic (60%), and Sand (15%) Prototype Bricks

Figure 7: Biochar (50%) and Plastic (50%) Prototype Bricks

7.3 Full Scale Bricks

7.3.1 Concrete

The concrete modular brick was made using 6000 mL of gravel, 4000 mL of sand, 2000 mL of Portland cement, and 2000 mL of water in the full scale mold. The modular brick had dimensions of 7 $\frac{1}{2}$" x 3 $\frac{5}{8}$" x 2 $\frac{1}{4}$". Cement and water were added first, followed by gravel and sand while mixing the water and cement. Because of the large volume of materials used to make modular bricks, a Home Depot bucket was used as a vessel for this mixture. The mixture was mixed thoroughly first using a scoop, followed by an electric mixer. The mold was prepared by spraying canola oil in the mold to prevent the brick from sticking to the walls as they cure. A well mixed concrete was poured in the mold, and the top was smoothed out using a putty knife. The bricks were left in the mold to dry overnight. After 24 hours the bricks were removed from the mold and numbered according to their location in the mold. A damp canvas cloth was placed at the top of the bricks for two days, and afterward, the bricks were left to dry and cure until needed for tests.

7.3.2 Biochar and Cement

2.67 L of cement, 2.67 L of distilled water, and 8 L of sieved biochar were mixed in a large bucket until homogeneous consistency. The mixture was poured out into the full scale brick mold (initially sprayed with canola oil to prevent sticking) and the top was flattened out using a putty knife. A wet canvas cloth was placed on top of the mold and the bricks were left to solidify for 24 hours. After 24 hours, the bricks were removed from the mold and placed in DI water for another 24 hours. Once removed from distilled water, the bricks were left out to dry and cure.

8 Design of Experiments

The approach to this project was that of a design cycle with three main components: design, test, and refine. The design aspect consisted of the requirement and the exploration which includes creating a biochar brick with cement or recycled plastic. The specific customer requirement was to characterize a standard modular brick composed of 75% biochar and 25% cement. The exploration of the team consisted of the creation of a waste plastic composite brick composed of Type 2 high density polyethylene (HDPE) recycled plastics, biochar, and sand. These composite bricks were to be comparable to other building materials and, if viable, used for residential and academic buildings in developing countries.

The design consisted of a prototype brick with one-third dimensions of a standard modular brick to ensure multiple trials can be conducted without the waste of materials. The next part of the design cycle consisted of two tests to determine if the biochar bricks were held together, and if so, to characterize them. With the characterization test, it was desired to be comparable to its concrete counterparts. From this point, there were two paths that could be taken in the refinement period. This includes making more prototype bricks for characterization (thus, leading back to the design/prompt) or beginning to scale up to full size bricks for characterization. From this design cycle, there was a focus on the development of a brick while allowing the ability to refine the design. This is an important part of the approach to add meaning and insight into the project. Comparison to concrete values was conducted by the creation of a concrete prototype as well. This ensured a standardization among the tests to eliminate external variables.

This design cycle was utilized for each brick that was made, and the only full scale bricks were concrete and biochar and cement as expected. For example, it was noticeable that the 75% biochar, 20% plastic, and 5% sand bricks did not hold together, and thus, the design cycle was utilized to change the amount of biochar, but not the ratio of plastic to additives in the subsequent bricks. This was one example of many that were utilized throughout this project to determine the prototype bricks that would be made. Moreover, due to time constraints, the ability to observe if the biochar, plastic, and additive bricks were viable for full scale production could not be fully determined.

8.1 Insulation Value

The insulation tests were used to calculate the insulation value (R-value) of a material, which shows the capacity of an insulating material to resist heat flow. This test is very important as it shows how biochar bricks compare to other building materials in terms of separating the external and internal environments of a building. In order to measure the insulation values, a comparative test was used in this project, and this test used a red oak brick as reference material to calculate the insulation value of the sample bricks. In this experiment, the insulation value was determined by measuring the temperature difference between the cold and hot surface of the brick. The comparative test was chosen because its accuracy depends on the test accuracy of the reference material. By using the standard insulation value of red oak, the results should show high measurement accuracy that is comparable to that of a standard test measurement.

The experimental setup consisted of a heating mat connected to a temperature controller. The heating mat used in this experiment was bigger than the surface area of the brick, hence an insulating foam was used to cover the exposed heating mat surface. The temperature on the cold and hot sides of the brick were recorded using TMP36 sensors attached on the cold and hot sides of the brick. The TMP36 sensors were connected to a LabJack, and a LabView program was used to collect data from each sensor. The LabView program converted the TMP36 signals to temperature and recorded the temperature on both sides of the brick.

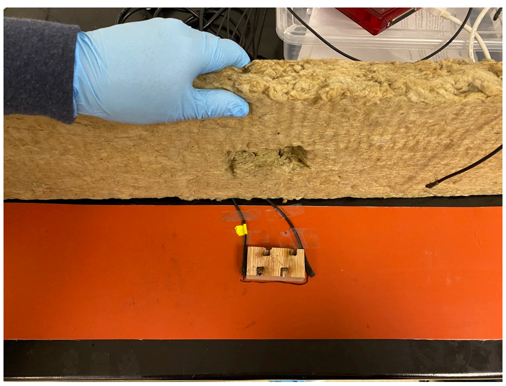


Figure 8: Insulation Value Test Set-up (Bottom)

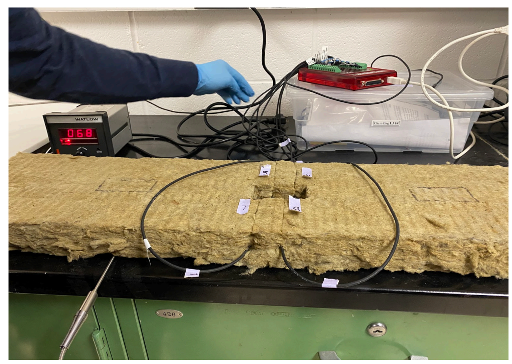


Figure 9: Insulation Value Test Set-up (Top)

To run the insulation test, the red oak brick was placed on the heating mat with two sensors at the bottom for measuring the hot side temperature as shown in Figure 8. There were also four sensors at the top of the brick in the four slits of the insulation as shown in Figure 9. The insulation foam was placed on the top of the heating mat, and the temperature was set to 63°C to make sure that there was a sufficient temperature gradient between the hot side and the cold side (open to the room temperature). Once the temperature was set, the LabView program was started and displayed the various temperatures as a function of time. The program was run until the temperatures reached steady state, the program was stopped after, and the preparations for the next round of testing was conducted. A complete set of insulation testing experiments consisted of two runs: (1) reference red oak brick, (2) sample brick. After recording the temperature data using the LabView program, the data was exported and analyzed using an excel spreadsheet. The other important parameter for this analysis were the dimensions of the brick, since the R-value is reported as a per inch value. After completing the experiment, the clean up procedure involved turning off the power supply to the heating mat and letting it cool down. After the heating mat cooled down, the TMP36 sensors were carefully removed from the brick, and the brick was taken from the heating mat to storage.

8.2 Water Absorption

Water absorption is important to study in order to assess the durability of the brick in humid or high rainfall conditions, but it also provides insight into the permeability of the material. The procedure for water absorption tests was to submerge the brick in a large beaker of deionized water for 24 hours at room temperature with little to no disturbance.

Figure 10: Water Absorption Set-up with Biochar Brick

The mass was recorded before and after in order to obtain a mass fraction of water absorbed. Since some of the samples were buoyant enough to float, a small beaker and two metal rods were used to hold the brick in place under the water while maximizing the surface area of the brick exposed to the water as shown in Figure 10. The brick was set on top of the small beaker with the two metal rods placed sticking up vertically on the brick to hold it in place. Thermometers were used to record the temperature of the water at the start and end of the experiment to assess any possibility of temperature fluctuation.

8.3 Flammability

Flammability characteristics, or more specifically, the ability to withstand heat and prevent the spread of fire is crucial for all building materials. It is especially important for the building materials containing plastic if they are to be utilized in underdeveloped locations with no organized fire-fighting service.

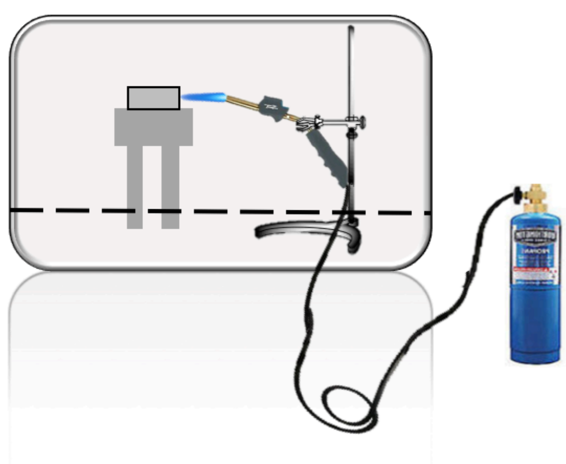


Figure 11: Flammability Set-up with Biochar Brick

Testing the flammability characteristics of prototype bricks began with a standard operating procedure found in Appendix D. After this was approved and hot work training was received, the burn stage was placed in a flame-rated fume hood. This consisted of a four post metal stand to set the brick on, made out of stainless steel to withstand the temperature. The brick sample for the test was placed on the stage as shown in Figure 11. Next, the torch was clamped into place with the nozzle one inch from and orthogonal to the brick face. This was done using a ring stand with a three pronged clamp. A torch with a three foot hose was attached and used in order to set the propane tank a safe distance away from the flame. The propane tank was connected to the torch hose and set outside the hood, as far away from the flame as the hose would allow (see Figure 11).

Once setup was complete, the experiment began with the ignite and extinguish time tests. For these tests, the torch was turned on until the brick face was determined to be ignited by compressing the trigger and using the lock mechanism to prevent direct contact of the torch during the experiment. The burn process was timed in order to obtain an ignition time. For this test, since one cannot look at a brick with a flame to it and see if it is sustaining its own flame, the distinguishing characteristic of an ignited face was material decomposing from the flame. Once the brick was ignited, the torch was turned off and the time required for the brick to extinguish was recorded. The extinguish time was determined to be when the brick stopped glowing red with embers.

The second part of flammability testing was the separation time tests. This test was used to determine how long it takes the flame to pass through the brick. For this test, the torch was turned on and the brick was observed while the flame continuously burned on the brick. Time was recorded for this test to determine the speed at which the flame was passing through the brick. The brick was observed to see the progression of the flame front. The test was completed when the flame front reached the far side of the brick or the brick collapsed and fell from the stage. After tests were completed, the bricks were monitored for half an hour to allow for cooling. There should be no attempt to handle the bricks during this time as they were very hot.

8.4 Hardness

The hardness of a material is important to determine its ability to resist erosion and surface deformations. To test the hardness of the bricks, a Shore D durometer was used as shown in Figure 12. Shore D was chosen due to the relative hardness of each brick determined by receiving a value over 80 on the Shore A scale.

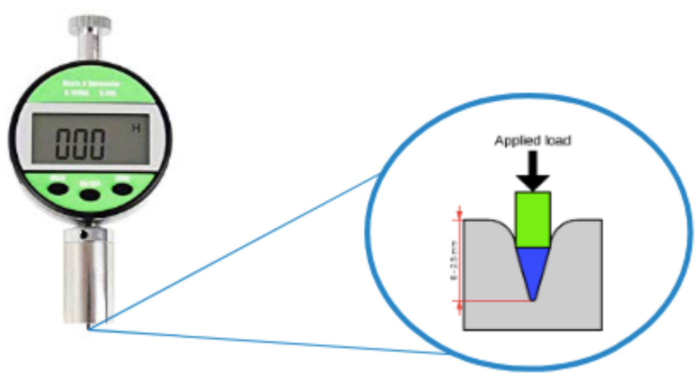


Figure 12: Shore D Durometer for Hardness Testing

The durometer's tip was pressed into the sample, five times on the top and five times on the bottom, scattered around the brick to obtain an average hardness. A measurement was collected with the durometer by pressing the durometer tip into the sample while keeping a uniform and even pressure on the durometer using one's hand. The durometer tip was orthogonal to the sample and measurements were taken from flat sections of the sample brick.

8.5 Compressive Strength

Compressive strength testing is the most common performance measure used to identify and characterize building materials. The results of this test determine the load that the material can carry before cracking or deforming under the stress. It is important for building material to have a relatively high compressive strength so that it can withstand the load of the building without structural degradation.

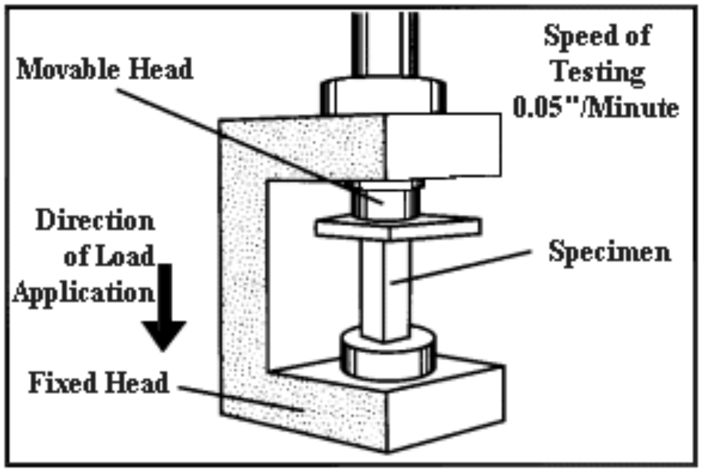


Figure 13: Simplified and Annotated Compressive Strength Machine

All testing for compressive strength was done with the assistance of the lab PI, Chris Pratt, who operated the MTS Alliance RT/50 mechanical compression machine for each brick sample. A simplified depiction of this machine can be shown by Figure 13. The bricks were brought into the lab and an appropriate plate was fitted to ensure the full surface area of the brick was in contact with the metal plates. Once the sample brick was placed on the center of the plate, a program was run to apply constant load via the top plate head and stopped when a crack or visible deformation of the brick was observed. The data from the program was recorded to analyze the load force at the point of brick failure. The output graph of various prototype bricks can be found in Appendix C. The compressed bricks were then removed from the metal plates and the plates wiped down after every test run.

9 Results

9.1 Overall

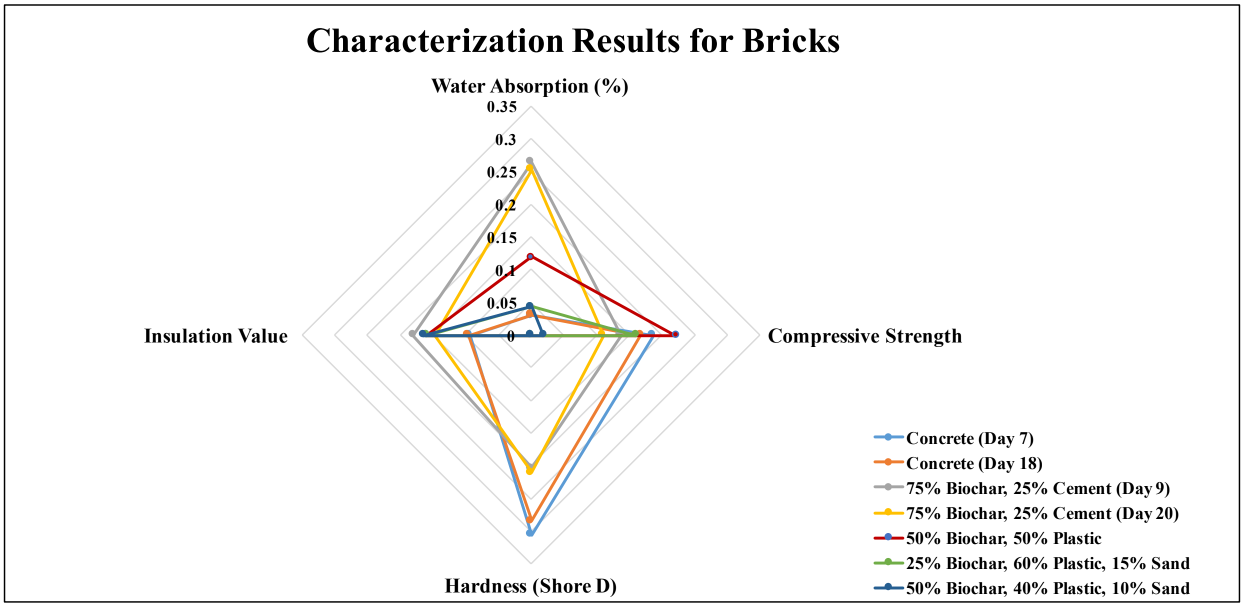


Figure 14: Radar Chart of Prototype Brick Characterization

Figure 14 above shows a comparison of each brick type based on the four parameters (tests) with a normalized scale. As each parameter is scaled radially from the center, the performance of each brick can be easily identified. The vertices at each parameter show the best brick prototypes for that test, and conversely a point closer to the origin shows a prototype that performed poorly for that parameter. The data shows the biochar and cement bricks rank highest in water absorption but relatively lower in hardness value and compressive strength of concrete. The concrete ranked highest in hardness, but there were visible trade offs with the lower water absorption and insulation values. The 50% biochar and 50% plastic brick ranked highest in compressive strength, but fell below the biochar and cement brick in water absorption, insulation value, and hardness. Overall, this chart shows that each type of brick exhibits strong characteristics in certain parameters, but may be compromised in others. This allows for a simple representation of results obtained and allows for a quick selection of the best brick in the parameter of interest.

9.2 Insulation Value

The insulation values are very important in assessing how the bricks will transfer heat. This is useful to determine the geographical suitability of the building in which these bricks will be used. For instance, in cold, polar climates, building materials with higher insulation values are desired to keep the heat inside the building and minimize the heating utilities. For developing countries that are mostly located in tropical, equatorial, and arid climates, building materials with high insulation values need to be efficiently integrated in a passive design of housing in order to minimize the need of heating and cooling utilities. From the experiments in this project, the obtained results are summarized in the figure below.

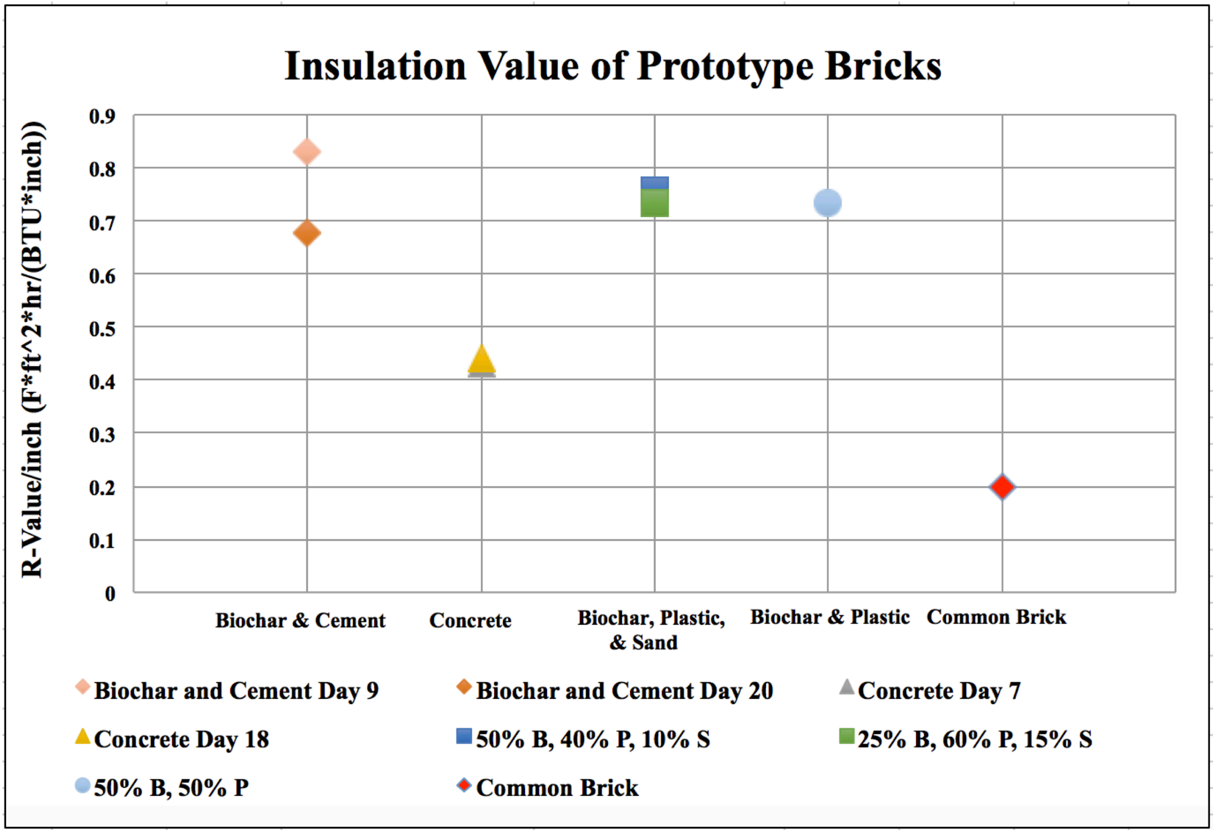


Figure 15: Insulation Values for Prototype Bricks and Literature Common Brick

In order to add context to the results, a common brick, which is typically a brick made from natural clay with no special surface treatment, is used as a reference building material in developing countries to see how the samples made in this project compare to it. All the bricks made in this project have higher insulation values than the common brick. Material wise, the common brick is expected to have low insulation value since it is composed of quartz and metal oxides that are more conductive to heat than a biochar based material that contains mostly carbon [20]. As biochar is made of carbon shells, the bricks that contain biochar have higher insulation values than the concrete bricks.

For the biochar and plastic bricks, sand was added as an additive to investigate its effect on the insulation values. The addition of sand shows a small change in the insulation value in comparison to the 50-50 biochar and plastic brick. There is no evidence of the effect of sand on the biochar and plastic brick for insulation values, since this experiment needed more data for a possible conclusion.

In this experiment, there were errors associated with the experimental set up, sensors accuracy, and temperature controller accuracy. In the experimental setup, the whole experiment was designed with a premise that the heat conduction in the brick was unidirectional. In this experiment, a rectangular hole was cut in the insulation foam to hold the brick during the testing. The more this hole was used for holding the brick, the wider the air space between the brick side and the insulation foam became. The formation of air pockets between the brick and the insulation introduced some errors, since the calculations were based on complete insulation of the four sides of the brick. The TMP36 sensors and the heating mat controller had errors associated with them, and this could have potentially introduced errors in the calculations.

9.3 Water Absorption

As previously mentioned, water absorption is important to assess if the brick is viable under humid or high rainfall conditions in third world and developing countries.

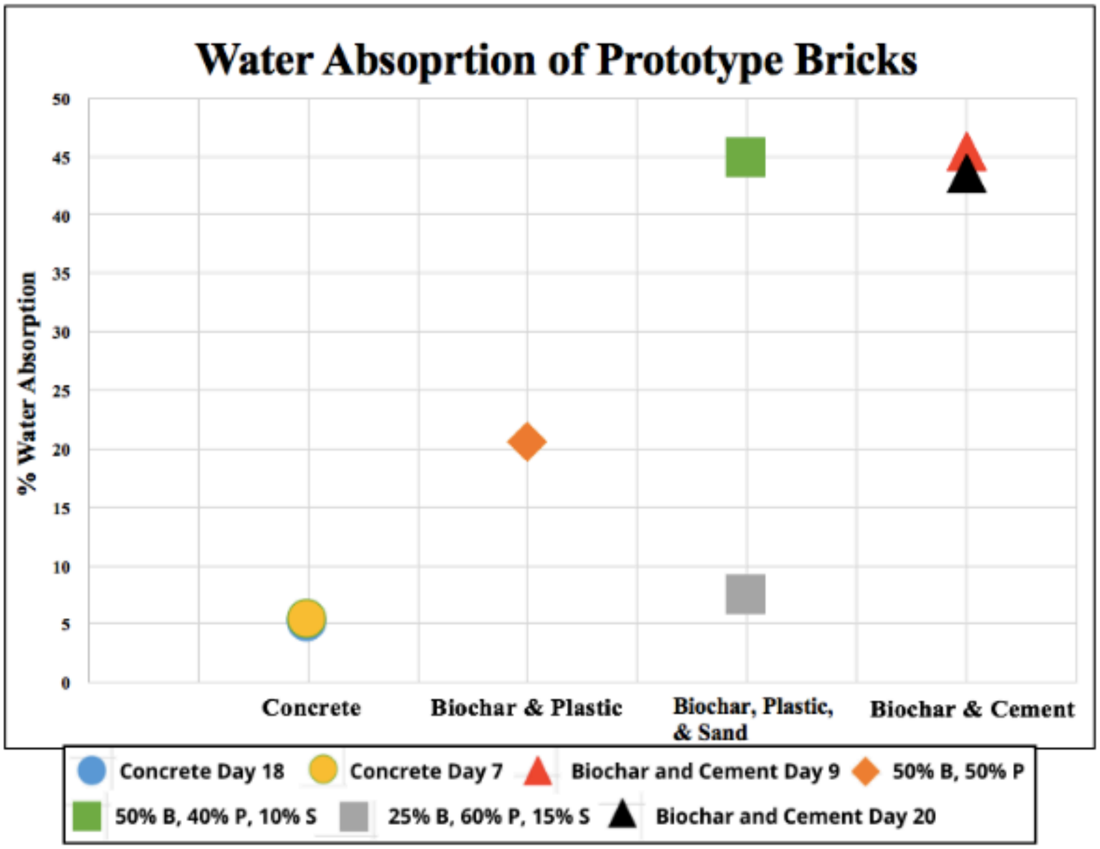


Figure 16: Water Absorption Values for Prototype Bricks

The figure above exemplifies the results from the water absorption tests described in the previous section. Concrete and biochar and cement have a 2 day difference for measurements due to the extra procedure involved with the biochar and cement bricks (put damp canvas on for one day and soak in water for another day). This was an attempt to standardize the values and make the curing times as close as possible.

From this figure, it can be observed that there is a difference between the concrete and biochar bricks. This trend was expected because of the porous nature of biochar and its increased surface area for water absorption. Specifically, analysis of concrete and biochar and cement within their curing days show little differences. This was particularly interesting for biochar and cement because it was not completely dry at day 9 in comparison to day 20. Therefore, it would be expected that there would be less water absorption due to water already present.

Among each biochar brick, there were varying values from each composition. The 25% biochar, 60% plastic, and 15% sand brick had the lowest water absorption, and this was potentially due to the hydrophobicity of the HDPE plastic. An experiment was conducted to determine that HDPE was hydrophobic to confirm results. Thus, this brick has the most plastic, and the least amount of water absorbed. Moreover, it can be observed that a 20% difference in the amount of plastic has a great effect on water absorption. This can be attributed to the amount of HDPE in each brick and the hydrophobic nature of this plastic. Direct implications of this experiment could have led into expansion and contraction issues within the bricks, if a volume was taken before and after. This would be important for building materials to uphold their structural integrity. It could also provide more insight into the amount of humidity it could capture in a building to keep air less humid.

The experimental results exhibit uncertainties due to the nature of the experiment. The water was assumed to be a room temperature in the developing countries, which cannot always be stated due the temperature fluctuations. A temperature fluctuation could lead to varying results, and thus, different properties observed. Furthermore, the expectation of continuous rainfall/humidity for twenty-four hours could lead to uncertainty. The bricks might exhibit different behavior for two days and it was not accounted for in this experiment. These limitations could cause varying results, and thus, more experiments should be conducted.

9.4 Flammability

Flammability characteristics of materials are important to determine their safety for structures. The experiments in this project were used to determine the ignition, extinguish, and separation times of the 75% biochar and 25% cement brick. Tests were conducted twice on different samples, once on day 9 and once on day 20. The results on day 9 were inconclusive as the equipment was not fully developed and a c-clamp was used to stage the brick which resulted in the brick falling before the separation test was complete.

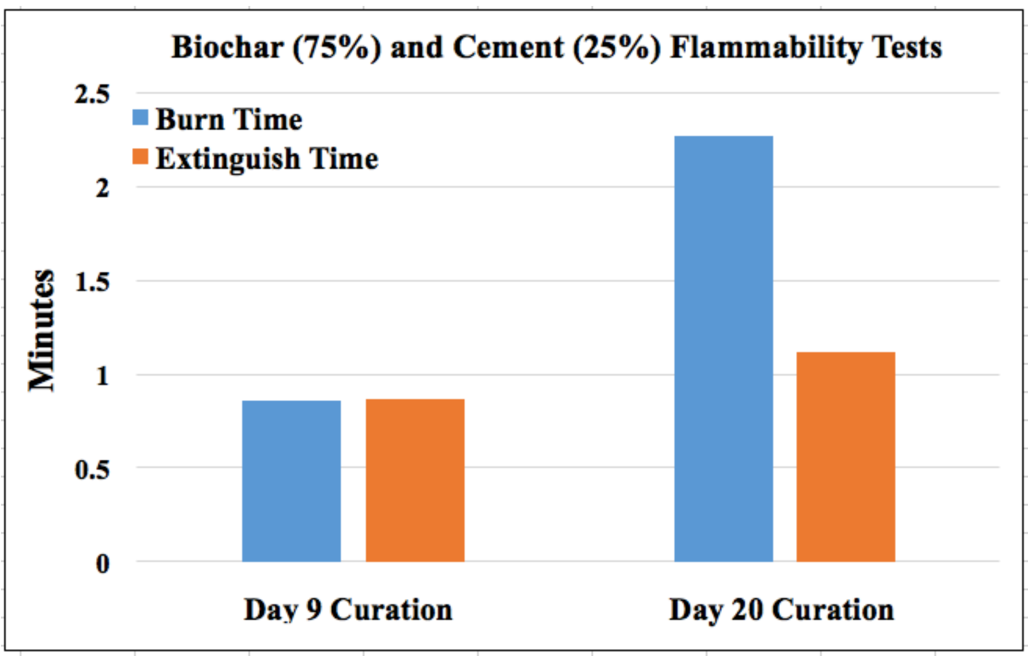


Figure 17: Flammability Values for Prototype Bricks

The ignition and extinguish times were still collected for day 9. The results are shown in the figure above where on day 9, the ignition and extinguish times were both 50 seconds. On day 20 the ignition and extinguish times were recorded to be 135 and 70 seconds respectively. No smoke was observed at any point during the test.

The large variation between the two days may have been caused by a variety of factors, including the curing of the cement, the drying of the brick, and human error. The longer ignition time than extinguish time on day 20, compared with day 9 could be explained by the brick having 11 days to cure, and the structure would have been more sturdy and resistive to decomposition while burning. However, this would mean curing has a greater effect than drying because a brick that is more dry, such as the brick at day 20 compared to day 9, should ignite much faster and burn longer. More likely, the difference is caused by experimental uncertainties and error within human observation since the time it took for the brick to burn was determined subjectively.

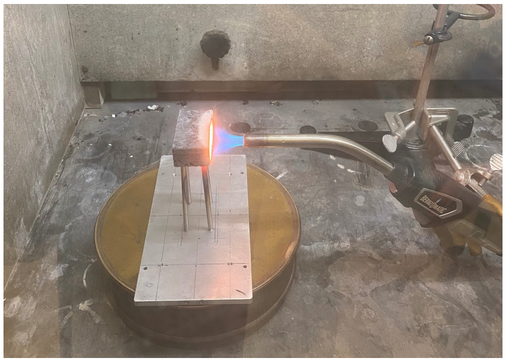


Figure 18: Flame front after 55 minutes

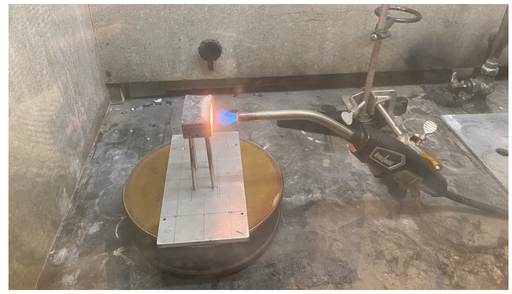


Figure 19: Flame front after 85 minutes

Separation time was not measured on day 9 because of experimental setup difficulties. The separation time measured on day 20 was not fully completed, but showed a minimum separation time of 85 minutes with little to no progression of the flame through the brick as shown in the figures above. On day 20 when the brick was burned, a flame was exposed to one face for 85 minutes. Observations suggested that the torch was not pushing the flame front any further as the depth that the flame penetrated into the brick was constant or near constant at approximately $\frac{1}{3}$ of the way through the brick from 55 to 85 minutes, as seen above. The reason that the flame front stopped could be due to the insulation characteristics of the brick. The brick was seen to prevent heat transfer to a higher degree than many other materials. This may have resulted in the flame front not carrying enough heat with it to burn further. It is possible that the explanation for this result lies in experimental uncertainty. For this test, burning the propane tank for 85 minutes consumes a substantial amount of fuel and it is possible that the flame was becoming less powerful and could not burn with the same intensity. When comparing this value to literature, it was seen that a commercial brick wall had a separation time of approximately four hours [22]. The four hour separation time was due to the full size brick with insulation and other materials layered on it. However, this experiment did not consist of extra materials as it only had the brick.

9.5 Hardness

Hardness testing is important to determine a building material's resistance to weathering, corrosion, and other surface deformations. The hardness testing conducted on the prototype bricks was that of indentation hardness with a Shore D durometer.

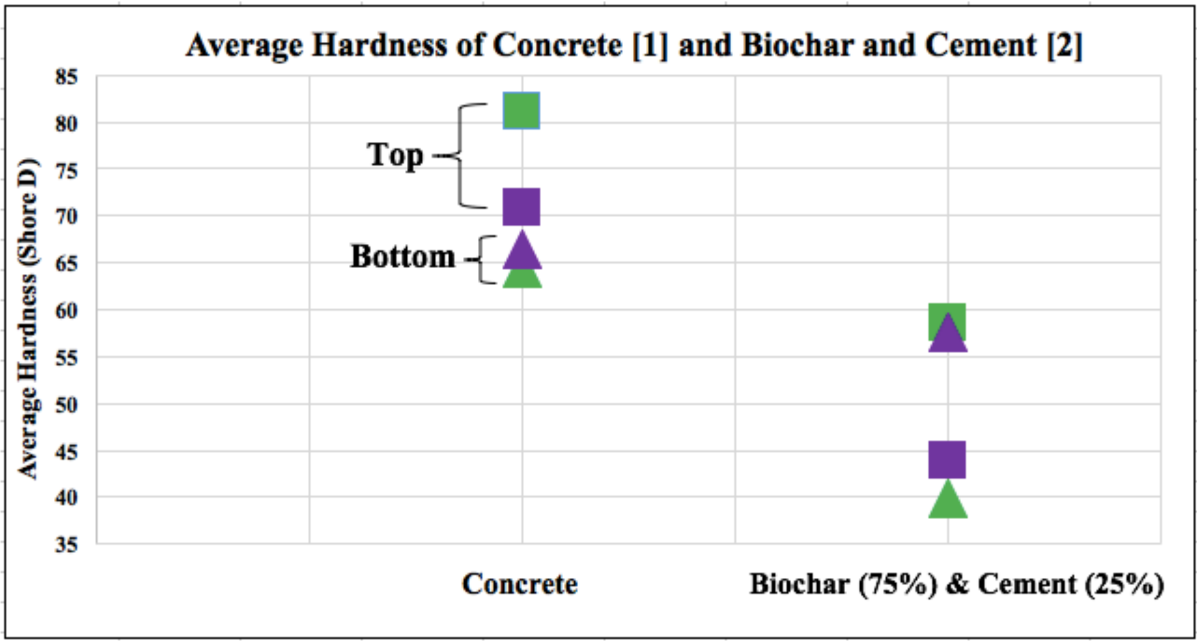


Figure 20: Hardness Values for Prototype Bricks

The figure above shows the averaged results obtained from the hardness testing of concrete and biochar and cement prototype bricks. Five values were recorded for each side and averaged to obtain the experimental values in the figure. The green data points are from the first day of testing, day 7 for concrete and day 9 for biochar and cement, and the purple data points are from the second day of testing, day 18 for concrete and day 20 for biochar and cement. The square shapes represent the top surfaces with respect to the mold whereas the triangles represent the bottom surfaces. Hardness testing was able to be conducted on concrete and biochar and cement because all other prototypes were too porous. One of the requirements for this test was for the brick to sustain the force created by the durometer- a requirement that the biochar and plastic bricks did not meet.

From literature, the values of concrete on a Shore D hardness scale are in the range of 50-70 [21]. The experimental data for concrete shows values within this range except for the top of the first day. The discrepancy in the data could be due to the uneven surfaces of the brick and the potential of the durometer to hit a piece of gravel.

Comparison of the two bricks shows biochar and cement at lower values than concrete, as expected. The porous nature of the biochar and cement brick can contribute to lower values. Also, the biochar brick's composition consists of a majority of softer material than its concrete counterparts and that contributes to the observed differences in hardness. Therefore, it was expected to exhibit lower values than the concrete bricks.

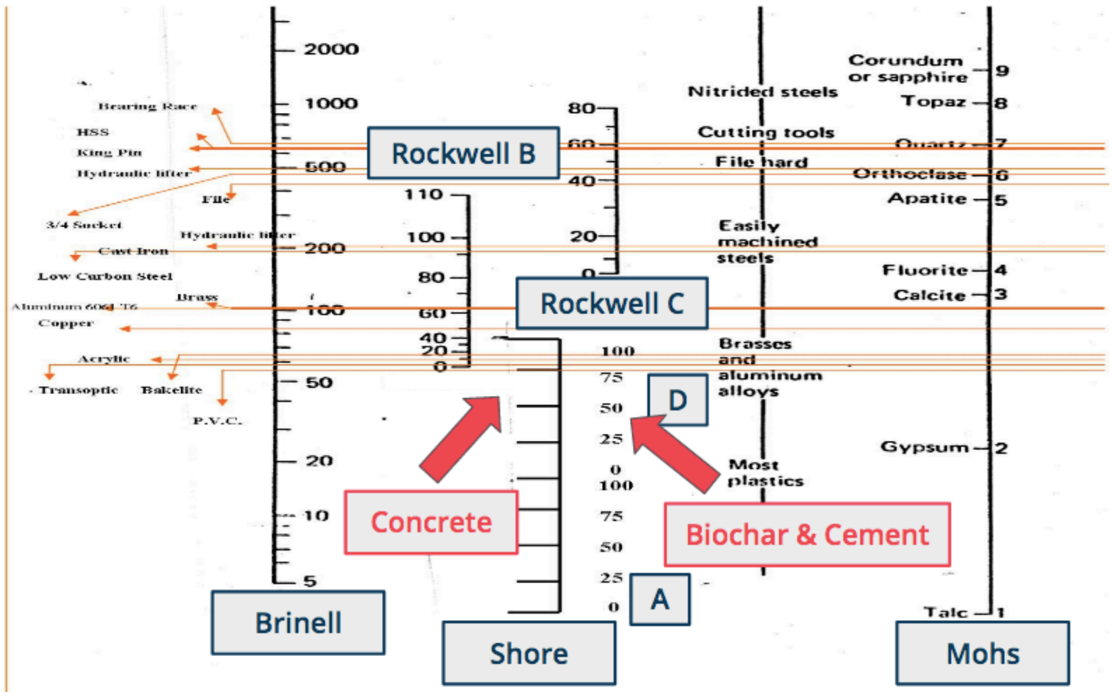


Figure 21: Comparison of Prototypes across Multiple Scales

The figure above shows the comparison of the hardness data across multiple scales [25]. It shows where the experimental values are in comparison to other materials as well. For example, a 75 on the Shore D scale, is approximately a 60 on the Brinell scale, and this is indicative of PVC material. This provides context to the experimental values received for each prototype brick and how they are in comparison to other materials. Although the values were much lower than the materials across the different scales, it did confirm that Shore D was a viable scale for this material.

There are noticeable experimental uncertainties among this data when observation is conducted within each brick type. There are a variety of values for the top and bottom of each brick which can lead to conclusions based on inconsistent data, and this should be recognized as a potential for uncertainty. Also, the force placed on the durometer to make an indentation caused a fluctuation of values when data was taken. The Shore D durometer was sensitive to force fluctuations provided by a team member that which could have caused a disparity in the results received as well.

9.6 Compressive Strength

The compressive strength test for building materials is an integral design characteristic to determine the load that the material can safely carry without cracking or deflection. ASTM standards for concrete range from 2500 psi for residential concrete to 4000 psi and higher for commercial buildings [23]. The goal for this part of testing was to compare the compressive strengths of the prototype bricks to the minimum ASTM standards for concrete.

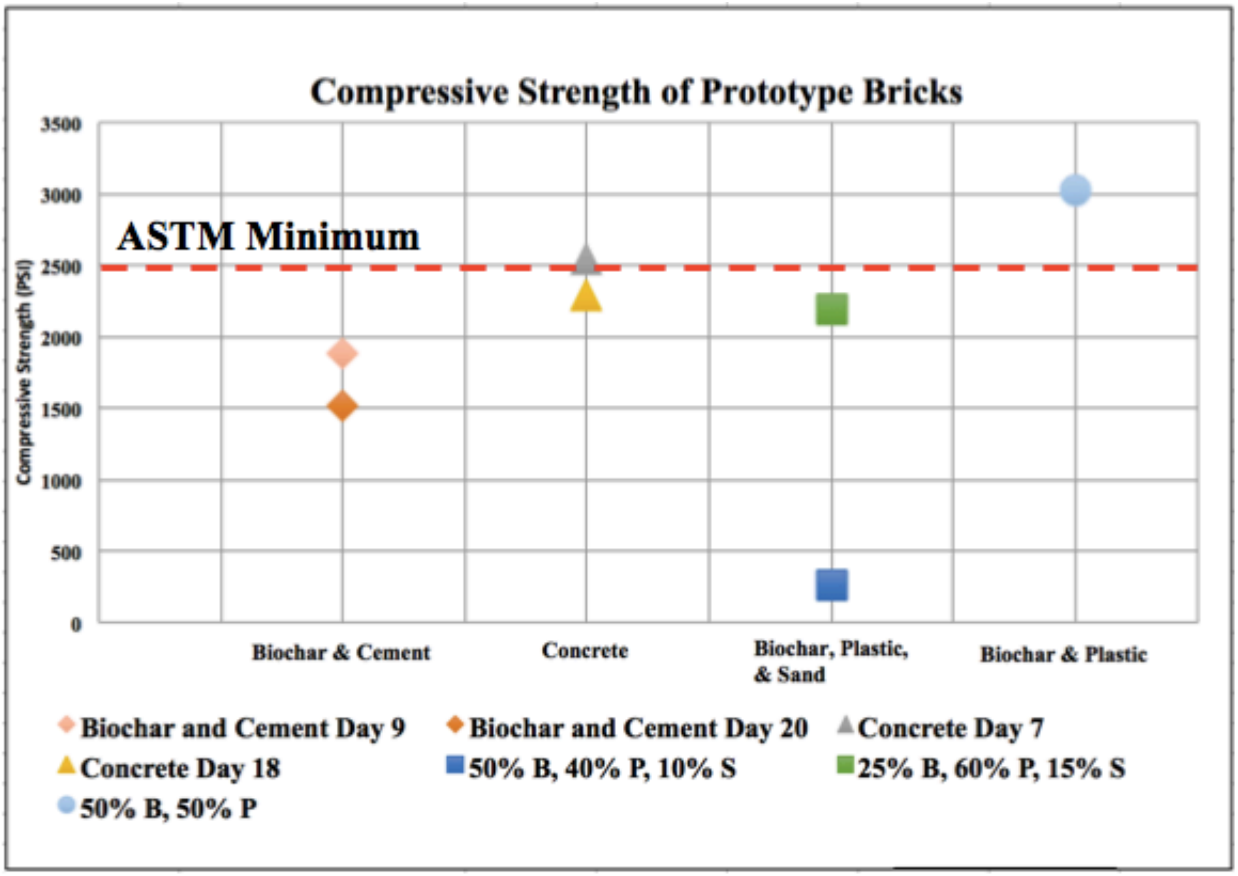


Figure 22: Compressive Strength Values for Prototype Bricks

The figure above shows the compressive strength of the prototype bricks as well as the ASTM minimum compressive strength for concrete. Prior to obtaining these results, the expectation was for there to exist a positive trend between compressive strength and curing time as cement continues to harden over time. However, the data shows the opposite trend for both the biochar and cement and the concrete prototype bricks. Both the compressive strength data for biochar and cement day 20 and concrete day 18 were lower than their counterparts for day 9 and day 7, respectively. This decrease in apparent compressive strength is most likely due to the uneven surface of the brick samples, prematurely cracking and deflecting due to localized force on one area of the brick. This experimental uncertainty must be taken into account as the compression testing is most effective if the samples being tested have smooth surfaces.

The dotted red line in the figure represents the lower bound of the ASTM compressive strength standard for concrete bricks at 2500 psi. The prototype concrete bricks show a compressive strength around 2500 psi which matches the lower bound of the ASTM concrete standard. However, the biochar and cement prototypes fall between 1500 to 2000 psi which is lower than concrete, but this was to be expected since biochar is a softer material than the gravel and sand used in the concrete mix. Since compressive strength is directly related to structural strength, the amount of "hard" material is important for brick composition.

Figure 23: 50% Biochar, 40% Plastic, & 10% Sand Prototype Brick after Maximum Load

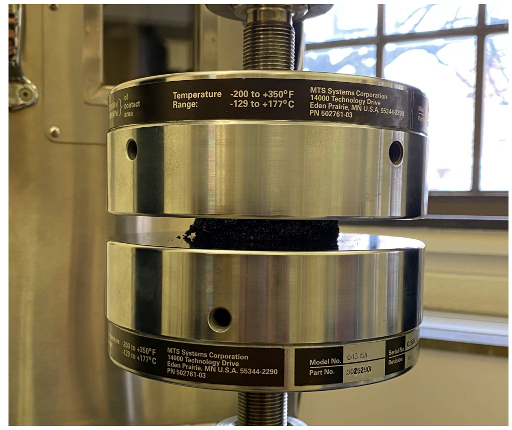


Figure 24: 50% Biochar & 50% Plastic Prototype Brick Elasticity

For the plastic and biochar composite bricks, a lower plastic ratio is attributed to a lower compressive strength. This is because for these plastic brick prototypes, the plastic (HDPE) serves as the binding material. In the case of the 40% plastic, 50% Biochar, and 10% sand brick, the brick was very brittle and did not hold together well. Figure 23 shows the lack of structural integrity due to a low ratio of binding material (HDPE).

However, the other two plastic composite bricks performed much better in the compressive tests. The 50% plastic, 50% biochar brick, and the 60% plastic, 25% Biochar, and 15% sand brick were more durable and held structure better than the 40% plastic brick prototype. This could be due to the larger amount of plastic (or binder) present in the bricks. It is to be mentioned that in the future a 50% plastic brick with additives (sand) should be tested to isolate the effects of additives on compressive strength.

The only prototype that was within the ASTM concrete standard range was the 50% Biochar, 50% plastic brick. This brick had the greatest value for compressive strength, however it was the most elastic of the brick prototypes where some of the compressive strength may have been a result of the brick's increased ability to compress without cracking or visibly deforming as shown in Figure 24.

10 Conclusion

This project has the potential to affect the lives of people in third world countries by providing them with a home, an academic building, or even a job among other opportunities. Biochar bricks provide a safe alternative to concrete because they are relatively inexpensive, good for the environment, and simple to produce. Various applications of biochar have been explored, but the potential to use it as a building material still needs more research and testing. This project added to previous knowledge about biochar bricks to assess if they were viable for implementation in third world countries.

This project allowed for the characterization of prototype biochar and cement, biochar and plastic, and biochar, plastic, and additives bricks. Characterization of each type of brick consisted of five tests: Compressive Strength, Water Absorption, Hardness, Insulation Value, and Flammability. The customer requirement was the characterization of biochar and cement bricks with respect to all tests except for flammability. Flammability was included due to the importance of this characteristic for building material. Through the utilization of the design cycle, bricks were able to be made in an efficient and effective manner to provide more information on biochar bricks as a building material. Standard modular bricks were produced for concrete and biochar and cement bricks. These were unable to be characterized due to time constraints. However, the method of action would have been to characterize each and compare to literature building materials.

The prototype concrete and biochar and cement bricks were able to undergo all testing, except for flammability due to the time constraint. However, the 75% biochar, 20% plastic, and 5% sand bricks were unable to go through any testing due to their immediate deformation. This was observed due to the low amount of plastic which acted as a binder for the bricks. The 50% biochar, 40% plastic, and 10% sand, 50% biochar and 50% plastic, and 25% biochar, 60% plastic, and 15% sand bricks were able to undergo all testing except hardness and flammability. The idea behind these bricks was to determine the lowest amount of binder (plastic) possible and the effect of additives (e.g. sand).

The insulation value test results show that the biochar based brick has a higher insulation value compared to the concrete brick and the reference common brick. The higher insulation value in biochar bricks was expected since biochar is mainly composed of carbon. The addition of sand in the biochar and plastic bricks show a small change in insulation value when compared to 50-50 biochar and plastic brick. However, there is not enough data to conclude the effects of sand on insulation values of the bricks.

Results from the water absorption testing reveal that there was a difference between concrete and biochar bricks, as expected due to the porous nature of the biochar. Another trend that was observed is the differences in the amount of plastic led to different water absorption properties. The water absorption tests could be helpful in high humidity conditions to absorb the water and maintain a cooler building. Implications from this study can lead to further work with expansion and contraction of the brick itself.

From hardness testing, concrete bricks showed values close to the literature value range and higher than biochar and cement bricks. This was expected due to the composition of the biochar brick and lower amount of cement in comparison to concrete. However, these results do have experimental uncertainties due to the nature of the Shore D durometer and brick composition. There were limitations of this testing due to the brittleness of the biochar and plastic brick prototypes as well.

Flammability characteristics of the biochar and cement bricks were seen to vary greatly as the curing and drying process progressed. After 20 days of curing, the results of the flammability test showed an ignition time of about 2 minutes and 15 seconds and an extinguish time of 1 minute and 15 seconds. The result of the separation time test showed no progression of the flame past one-third of the brick. It took less than an hour to reach one-third of the way through the brick, but it did not proceed any further for half an hour. This seems very promising for a building material since a long separation time like this means people would have more time to respond to a fire and protect themselves and their belongings.

It was seen from the results of the compressive strength tests that the biochar and cement bricks did not meet the minimum ASTM standards for concrete brick. The compressive strength of the biochar and cement samples fell below the minimum concrete ASTM value of 2500 psi by around 600-1000 psi. However, the 50% biochar and 50% plastic brick did outperform all of the other prototype counterparts as it was the only brick to surpass the minimum concrete ASTM value with a compressive strength of around 3000 psi. There was also a trend of increasing compressive strength with a higher ratio of plastics as both the 50% and 60% plastic prototypes scored much higher than the 40% plastic composite brick. However, this does suggest a "minimum threshold" of plastic ratio that is required to adhere the biochar and additives and thus, stabilize the brick.

10.1 Applications

The results from this project are indicative of a promising future for biochar bricks as a building material. However, due to time constraints, the project would need to be continued to confirm results and conduct a wider range of tests. A practical application of this work leads to usage of biochar bricks as brick veneer. Potential applications of biochar bricks can be as an insulator to other building materials, pavement bricks, and roof tiles as well.

While the applications of biochar bricks appear to be numerous, many tests should be completed to confirm the feasibility of the applications. Brick veneer is an application that Team Jackalope can confidently say would be an appropriate application of the current biochar bricks. Biochar bricks would make good veneer because they have an easily manipulated shape and surface during molding, are very good insulators, and quite light compared to classic bricks. The high R-Value and light weight of the bricks would help cut down on necessary insulation and structural support components of the wall using the veneer. However, brick veneer is not commonly used anymore and certainly not used in developing countries. Additionally, the bricks were not tested in long term erosion tests such as sun exposure or weathering, which limits the current applications to indoor veneer.

Team Jackalope believes the biochar bricks could be used for pavers and roof tiles with confirmation from a few additional tests. To use the bricks as pavers, tests for bend strength and impact erosion would need to be conducted. Pavers are often large and expected to support large amounts of weight that inflicts pressure points and stress the material. The biochar brick's bend strength would need to be tested to determine the pressure they can withstand and then, how big of a paver could be made out of biochar brick material before the paver is not durable. Roofing tiles could be an application of biochar bricks as they would provide better insulation than typical stone or concrete roofing tiles and would significantly cut down on weight. The issue with roofing tiles, as with outdoor brick veneer, is that the bricks were not able to be tested for erosion. Additionally, a key component of a roof is to keep the house dry and the biochar bricks have high water absorption which may mean the bricks are permeable to moisture and would be insufficient roofing material on their own. However, the bricks may be able to be coated with a sealant to prevent the water absorption or weathering and would more likely be suitable for roofing.

The ultimate goal of Team Jackalope was to create suitable building materials for employment in third world countries and developing nations that would help the environment. The goal was achieved but not in the way initially imagined, or so it seems. The results of the compressive tests suggest the biochar bricks could not be used to replace standard concrete on a one to one basis, however, the biochar bricks could still support a significant load. If the biochar bricks were used to build smaller structures, such as is common in third world countries, the biochar bricks may be able to support the load sufficiently. Additionally, placing multiple bricks side by side or making wider bricks would increase the structural integrity of the bricks. If the increased material (biochar bricks) was not excessive, the initial goal to create suitable replacements for building materials and to help the environment may have been achieved already. More compressive tests would be necessary before this conclusion would is supported.

Team Jackalope believes that the brick could be used outdoors and withstand the erosion, but without testing, no supported conclusion can be drawn. Testing weather erosion, sunlight exposure, and bend strength would be enough to support a conclusion for whether the bricks can be applied in these ways. Using the bricks as concrete replacements in third world countries also appears to be very close to a reality with just a few more tests. However, another speed bump on the road to biochar brick application is finding a more efficient method of production, ensuring thorough mixing and uniformity to prevent weak spots. If Team Jackalope had been able to finish conducting tests and solve the problems encountered, this project could have potentially led to the next great innovation in engineering green buildings.

11 Recommendations

11.1 Plastic Prototype Bricks

Continuing to experiment with new mixtures and methods for making plastic, biochar, and additive bricks is a crucial next step in the overall project. While some plastic prototypes, including 50% plastic, 50% biochar and 60%-25%-15% plastic biochar and sand bricks, were seen to hold together well, there are many unexplored paths that should be considered. Initial goals for the project included testing the effect of additives on the characteristics of the brick. To continue on this path, Team Jackalope suggests making more samples with varying additives. Adding metal shavings or paper shreddings and recycled wood, which is done in Trex, would be a suitable next step in testing additives [24]. Additionally, new mixing methods could be considered if the current molding method was pursued. Melting the plastic thoroughly before hot biochar and additives are mixed in may allow for a more uniform coating of the material and a more uniform mixture that, if kept above the plastic melting temperature, would allow for uniform pouring into the mold.

Team Jackalope also suggests new procedures in molding the plastic bricks. These include using a Morgan Press and using two hot plates. A Morgan Press would ensure the plastic is kept at a high temperature and compressed well while being molded. Possible setbacks with this process include limitations on what is in the bricks and separation. A large Morgan Press would be needed to inject any clumps that might come with additives or larger particles of biochar. Separation may also occur while molding which would lead to undesired weak points in the bricks. Hot plates would be an effective way to ensure the plastic is heated thoroughly while under pressure. Mounting the hot plates on hinges, much like a sandwich maker, would ensure a constant pressure could be applied. Problems with this method may be that the bricks are not able to be molded to the desired size and would need to be cut down to size once cooled. A more expensive and complex mold method to experiment with would be an extruder.

11.2 Insulation Value Test

The insulation value test had a big assumption that the conduction of heat inside the brick is in one direction, and not perfectly insulating the four sides of the brick can result in multidirectional heat conduction. In order to avoid errors associated with heat transfer in multiple directions, an additional insulation should be used on the brick to minimize the air pocket between the brick and the insulation form. This can be achieved by wrapping an insulation tape around the four sides of the brick before putting the brick on the heating mat.

11.3 Flammability Test

Flammability tests are important to conduct to determine if the building material can withstand a residential fire, especially because that is where the bricks will be implemented. For these tests, there were various tests that were not conducted due to time constraints. The longest test was separation time. This required observation of the brick as the flame continuously burned through the brick. The first test that should be conducted is on the separation time of the biochar and cement brick. Team Jackalope did not fully finish this test due to unexpected time constraints. Flammability tests on concrete would have to be completed to obtain a standard comparison value as well. Additionally, conducting tests on compressed bricks could provide more insight to the burn characteristics of the bricks. Moreover, it could be helpful to conduct tests on biochar and plastic bricks and the bricks with additives to see the effect of sand or lack thereof. If the flammability results reveal something interesting between the the prototype bricks, it could allow for the exploration of alternative additives to see the effects on flammability. However, the implications of this work could be satisfied by adding a cement coating to eliminate concerns.

11.4 Compressive Strength

To isolate and clearly see the effects of additives on the compressive strength, Team Jackalope recommends a test should be completed with a 50% plastic, 40% Biochar, and 10% sand prototype brick. Adjustments of the additive ratios can be tested for more conclusive data on its effect on compressive strength. Also, since the uneven surfaces of the concrete and the biochar and cement bricks introduced experimental uncertainty, it is recommended to grind down the surfaces of the brick prototypes with a sanding machine prior to compressive testing in order to produce more accurate results.

11.5 Future Steps

Due to the time limitations, Team Jackalope was not able to perform all of the testing on each brick. The impact of water absorption on compressive strength, insulation, flammability, and hardness could be helpful for implementation as building materials. In addition to the previously mentioned tests, erosion, bend strength, and sunlight exposure tests can be helpful to understand how bricks respond to natural environment actions like wind, rain, and solar radiation. An erosion test will investigate the mechanical impact of a fluid (water, wind, particulate matter) on a brick. The bend strength test evaluates the maximum stress a brick can withstand until failure. Lastly, sunlight exposure tests would explore the effects of sunlight on the properties of the brick.

Determination of Minimum Binder Amount

A potential next step for developing prototypes would be to determine the minimum amount of binder needed for a brick to hold together. It can be seen from the plastic prototype bricks ranging from 20% to 60% plastic that there was a threshold concentration of plastic required to hold the bricks together. The threshold seemed to be around 40% plastic as our 50%-40%-10% biochar, plastic and sand bricks held together but just barely. Experiments that change the amount of plastic in each brick would allow for identification of the minimum concentration which could then be used to broaden the materials in the bricks. It would be reasonable to think that the procedure for brick molding has an effect on the minimum amount of binder required and so one single procedure should be used during this experiment. Additionally, better compression would likely decrease the minimum amount of binder required as the plastic is pressed more tightly into the biochar pores during molding. A similar phenomena would be expected in biochar and cement bricks. There is likely to be a minimum concentration of cement at which the brick holds together. This would be useful to identify in order to reduce the highly energy intensive material necessary for brick production.

References

[1] *Yip, Kongvui, et al. "Effect of Alkali and Alkaline Earth Metallic Species on Biochar Reactivity and Syngas Compositions during Steam Gasification." Energy and Fuels, ACS Publications. 24 Jul. 2009.*

[2] *"Biochar as Building Material." Ithaka Institute - Building Material, Ithaka Institute, www.ithaka-institut.org/en/ct/97.*

[3] *Chen, Yingquan, et al. "The Structure Evolution of Biochar from Biomass Pyrolysis and Its Correlation with Gas Pollutant Adsorption Performance." Bioresource Technology, Elsevier, 24 Aug. 2017*

[4] *"Basic Information about Landfill Gas." EPA, Environmental Protection Agency, 18 Dec. 2019, www.epa.gov/lmop/basic-information-about-landfill-gas.*

[5] *Wang, T. "U.S. and World Cement Production 2018." Statista, 9 Aug. 2019, www.statista.com/statistics/219343/cement-production-worldwide/.*

[6] *Watts, Jonathan. "Concrete: the Most Destructive Material on Earth." The Guardian, Guardian News and Media, 25 Feb. 2019, www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth*

[7] *"Plastic Pollution Affects Sea Life Throughout the Ocean." The Pew Charitable Trusts, www.pewtrusts.org/en/research-and-analysis/articles/2018/09/24/plastic-pollution-affects-sea-life-throughout-the-ocean.*

[8] *Global Methane Initiative. "Landfill Methane:Reducing Emissions, Advancing Recovery and Use Opportunities." Globalmethane.org, Sept. 2011*

[9] *Rodgers, Lucy. "Climate Change: The Massive CO2 Emitter You May Not Know About." BBC News, BBC, 17 Dec. 2018, www.bbc.com/news/science-environment-46455844.*

[10] *Joseph, S D, et al. "Biochar for Carbon Sequestration, Reduction of Greenhouse Gas Emissions and Enhancement of Soil Fertility; A Review of the Material Science." Researchgate.net, 9 Dec. 2007.*

[11] *Mashinchi, Kenneth. "Researchers Hope to Tackle Methane Emissions in Manure Through Use of Biochar." Researchers Hope to Tackle Methane Emissions in Manure Through Use of Biochar — Newsroom, UC Merced, 19 Feb. 2019.*

[12] *"Potential Uses of Biochar." Access Science, McGraw-Hill Education, 1 Jan. 1970, www.accessscience.com/content/potential-uses-of-biochar/BR111816*

[13] *"Ivory Coast Is Using Plastic Waste to Build Schools." BBC News, BBC, 23 Jan. 2020, www.bbc.com/news/av/world-africa-51213133/ivory-coast-is-using-plastic-waste-to-build-schools.*

[14] *"Plastic Bricks Made from Used Water Bottles." Expert Skip Hire, Expert Services Group Ltd., 2 July 2018, www.expertskiphire.co.uk/plastic-bricks.*

[15] *6 roof and pavement tiles", Earth Titan, www.youtube.com/watch?v=ckWqR1JD158.*

[16] *Jung, Seung Hun et. al. "Biochar Journal Final Report" The University of Rochester, 16 December 2017.*

[17] *Gillespie, Evan. "How to Use Oak for Log Homes." Home Guides — SF Gate, 7 Oct. 2016, homeguides.sfgate.com/use-oak-log-homes-64632.html*

[18] *Hubert , George, and Timothy Moss. R-Value Testing of Compressed Earth Blocks. Sandia National Laboratories*

[19] *"Biochar Bright Spots: Biochar Bricks ." Finger Lakes Biochar, Finger Lakes Biochar, 10 Jan. 2019, fingerlakesbiochar.com/biochar-bright-spots-biochar-bricks/.*

[20] *Alam, Tahsina. "Tahsina Alam." Civil Engineering, civiltoday.com/civil-engineering-materials/brick/132-brick-composition-ingredients-with-functions*

[21] *"Epoxy Systems: Stronger Than Concrete." Simon Surfaces, 30 May 2019, www.simonsurfaces.com/blog/epoxy-systems-provide-strong-relief-from-concretes-weaknesses/.*

[22] *"Fire Resistance of Brick Masonry." Technical Notes on Brick Construction, The Brick Industry Association, 16 Mar. 2008, www.gobrick.com/docs/default-source/read-research-documents/technicalnotes/16-fire-resistance-of-brick-masonry.pdf.*

[23] *NRMCA. "CIP 35 - Testing Compressive Strength of Concrete." National Ready Mixed Concrete Association, 2003, www.nrmca.org/aboutconcrete/cips/35p.pdf.*

[24] *"Frequently Asked Questions." Trex, Trex Company Inc., www.trex.com/why-trex/faq/.*

[25] *Paglierani, Gary. Hardness Testing of Materials. CSU - Fresno, lennon.csufresno.edu/ mhk03/hardness*$_1$*.htm.*

.

12 Appendix A

12.1 Abbreviations for Insulation Equation

R_{test}: R-value of the sample

R_{ref}: R-value of the reference material

A_{test}: cross-sectional area of the sample

A_{ref}: cross-sectional area of the reference material

T_{Htest}: Temperature on the hot side of the sample

T_{Href}: Temperature on the hot side of the reference material

T_{Ctest}: Temperature on the cold side of the sample

T_{Cref}: Temperature on the cold side of the reference material

Q: heat transfer rate

ANALOG DEVICES

Low Voltage Temperature Sensors

Data Sheet **TMP35/TMP36/TMP37**

FEATURES

Low voltage operation (2.7 V to 5.5 V)
Calibrated directly in °C
10 mV/°C scale factor (20 mV/°C on TMP37)
±2°C accuracy over temperature (typ)
±0.5°C linearity (typ)
Stable with large capacitive loads
Specified −40°C to +125°C, operation to +150°C
Less than 50 µA quiescent current
Shutdown current 0.5 µA max
Low self-heating
Qualified for automotive applications

APPLICATIONS

Environmental control systems
Thermal protection
Industrial process control
Fire alarms
Power system monitors
CPU thermal management

GENERAL DESCRIPTION

The TMP35/TMP36/TMP37 are low voltage, precision centigrade temperature sensors. They provide a voltage output that is linearly proportional to the Celsius (centigrade) temperature. The TMP35/TMP36/TMP37 do not require any external calibration to provide typical accuracies of ±1°C at +25°C and ±2°C over the −40°C to +125°C temperature range.

The low output impedance of the TMP35/TMP36/TMP37 and its linear output and precise calibration simplify interfacing to temperature control circuitry and ADCs. All three devices are intended for single-supply operation from 2.7 V to 5.5 V maximum. The supply current runs well below 50 µA, providing very low self-heating—less than 0.1°C in still air. In addition, a shutdown function is provided to cut the supply current to less than 0.5 µA.

The TMP35 is functionally compatible with the LM35/LM45 and provides a 250 mV output at 25°C. The TMP35 reads temperatures from 10°C to 125°C. The TMP36 is specified from −40°C to +125°C, provides a 750 mV output at 25°C, and operates to 125°C from a single 2.7 V supply. The TMP36 is functionally compatible with the LM50. Both the TMP35 and TMP36 have an output scale factor of 10 mV/°C.

FUNCTIONAL BLOCK DIAGRAM

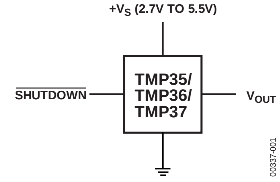


Figure 1.

PIN CONFIGURATIONS

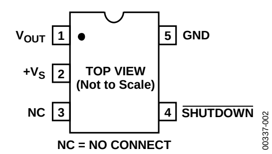


Figure 2. RJ-5 (SOT-23)

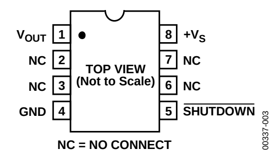


Figure 3. R-8 (SOIC_N)

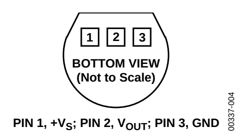


Figure 4. T-3 (TO-92)

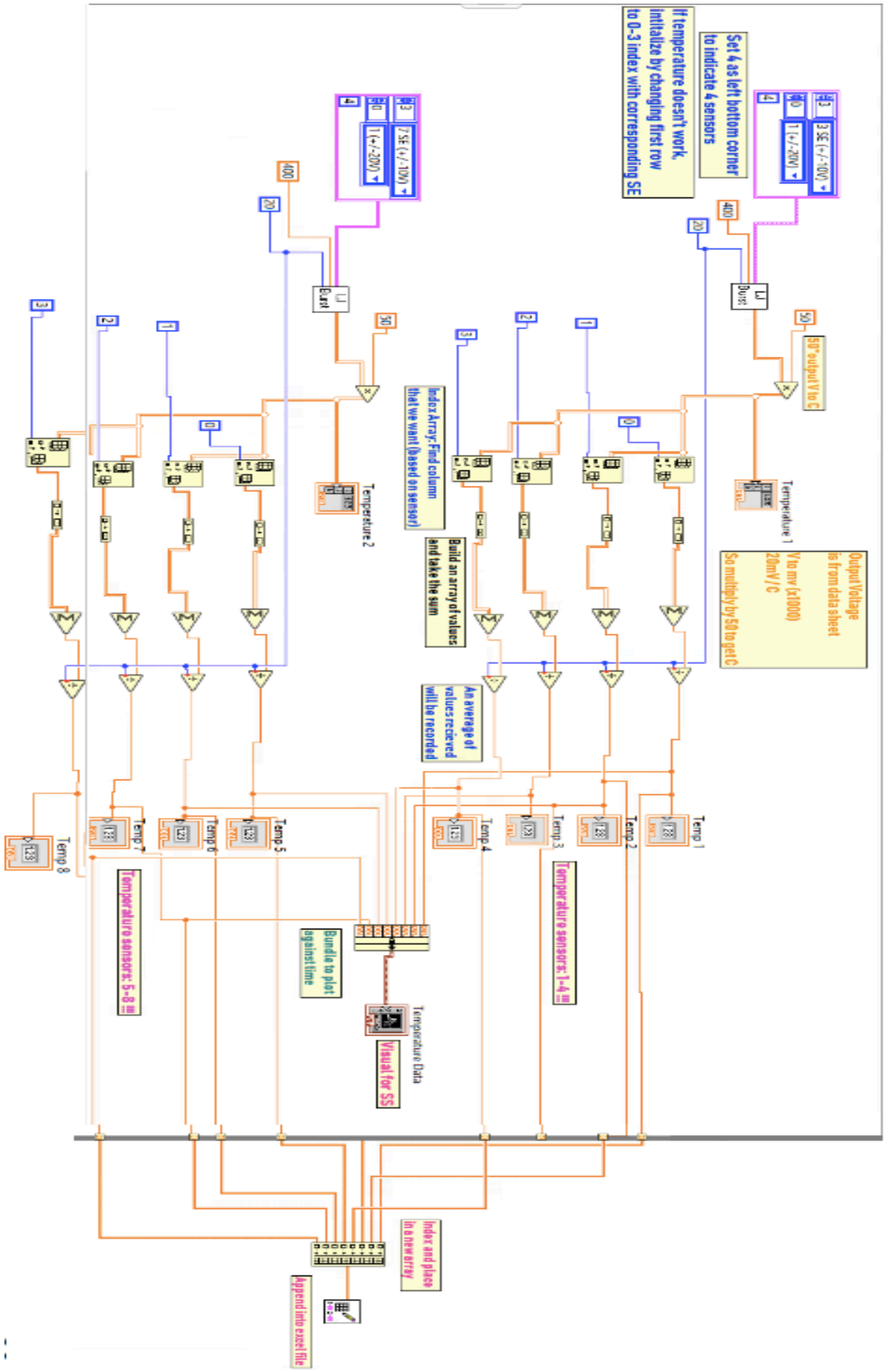
The TMP37 is intended for applications over the range of 5°C to 100°C and provides an output scale factor of 20 mV/°C. The TMP37 provides a 500 mV output at 25°C. Operation extends to 150°C with reduced accuracy for all devices when operating from a 5 V supply.

The TMP35/TMP36/TMP37 are available in low cost 3-lead TO-92, 8-lead SOIC_N, and 5-lead SOT-23 surface-mount packages.

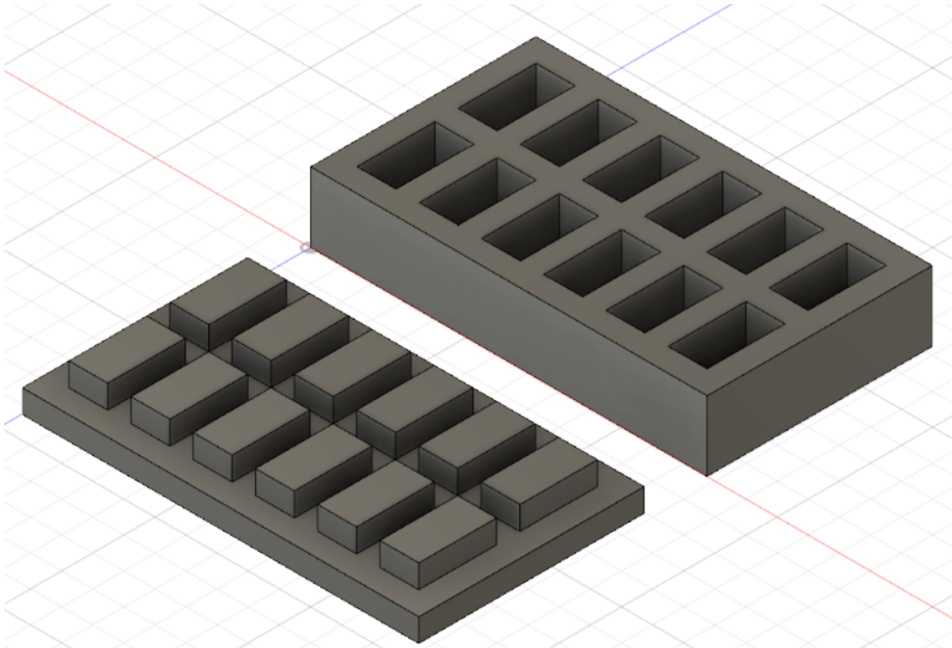
Rev. H **Document Feedback**
Information furnished by Analog Devices is believed to be accurate and reliable. However, no responsibility is assumed by Analog Devices for its use, nor for any infringements of patents or other rights of third parties that may result from its use. Specifications subject to change without notice. No license is granted by implication or otherwise under any patent or patent rights of Analog Devices. Trademarks and registered trademarks are the property of their respective owners.

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 ©1996–2015 Analog Devices, Inc. All rights reserved.
Technical Support www.analog.com

12.3 LabView Program

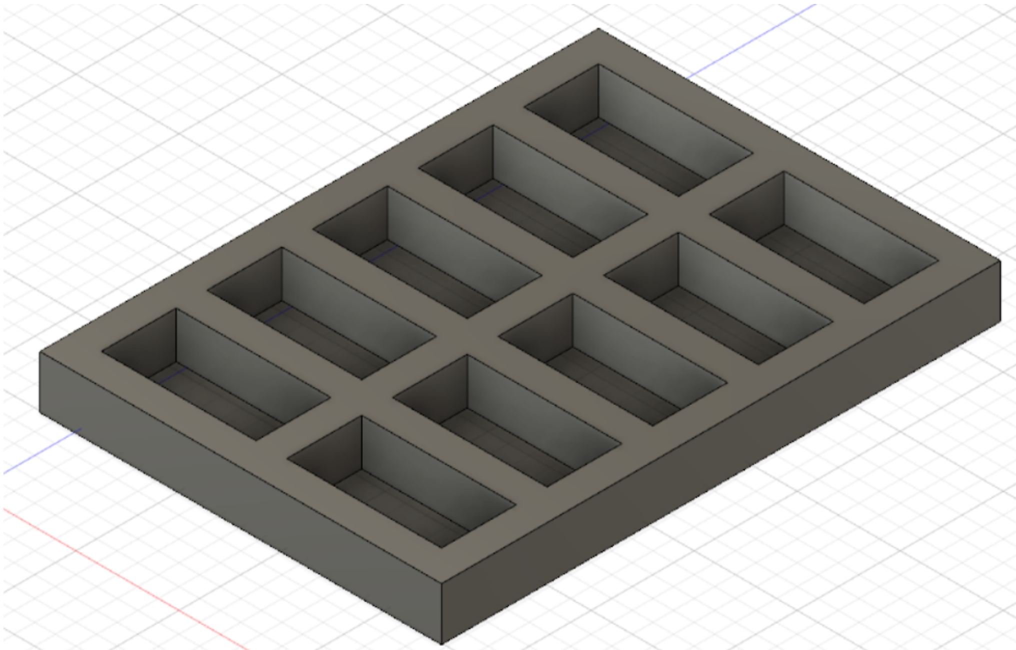


12.4 Prototype Mold



Brick Dimensions: 2 $\frac{1}{2}$" x 1 $\frac{1}{4}$" x $\frac{3}{4}$"
If made out of 1" x 8" oak, dimensions are 12 $\frac{3}{4}$" x 7 $\frac{1}{2}$" x 3" (including top)
What you will need:
2# 7 $\frac{1}{2}$" x 1 $\frac{1}{2}$" x $\frac{3}{4}$",
3# 11 $\frac{1}{4}$" x 1 $\frac{1}{2}$" x $\frac{3}{4}$"
10# 2 $\frac{1}{2}$" x 1 $\frac{1}{2}$" x $\frac{3}{4}$"
12# 2 $\frac{1}{2}$" x 1 $\frac{1}{4}$" x $\frac{3}{4}$"
2# 12 $\frac{3}{4}$" x 7 $\frac{1}{2}$" x $\frac{3}{4}$"
1 $\frac{1}{2}$" - 2" Screws
Wood glue

12.5 Full Scale Mold



Brick Dimensions: 7 $\frac{1}{2}$" x 3 $\frac{5}{8}$" x 2 $\frac{1}{4}$"
If made using 2" x 4" boards, mold dimensions are 27 $\frac{1}{8}$" x 19 $\frac{1}{2}$" x 2 $\frac{5}{8}$"
What you will need:
2# 19 $\frac{1}{2}$" x 1 $\frac{1}{2}$" x 2 $\frac{1}{4}$"
3# 24 $\frac{1}{8}$" x 1 $\frac{1}{2}$" x 2 $\frac{1}{4}$"
8# 7 $\frac{1}{2}$" x 1 $\frac{1}{2}$" x 2 $\frac{1}{4}$"
1# 27 $\frac{1}{8}$" x 19 $\frac{1}{2}$" x $\frac{3}{8}$"
2 $\frac{1}{2}$" screws

13 Appendix B

13.1 Table 1: Materials and Location

Material	**Location**
Portland Cement	Cabinet below computer
Gravel	Underneath Bench next to Sink
Insulation Test Cut-out/Left-over Insulation	Beside the fridge/ Below grinder
Recyclable Plastic	Beside grinder: in Team Jackalope drawer
Canola Oil	Team Jackalope drawer
Graphite Spray[1]	Team Jackalope drawer
Parchment Paper	Team Jackalope drawer
Concrete bricks(prototypes and large scale)	Last drawer below computer and right benchtop
Biochar and Plastic bricks(prototypes)	On right benchtop
Canvas	On right benchtop

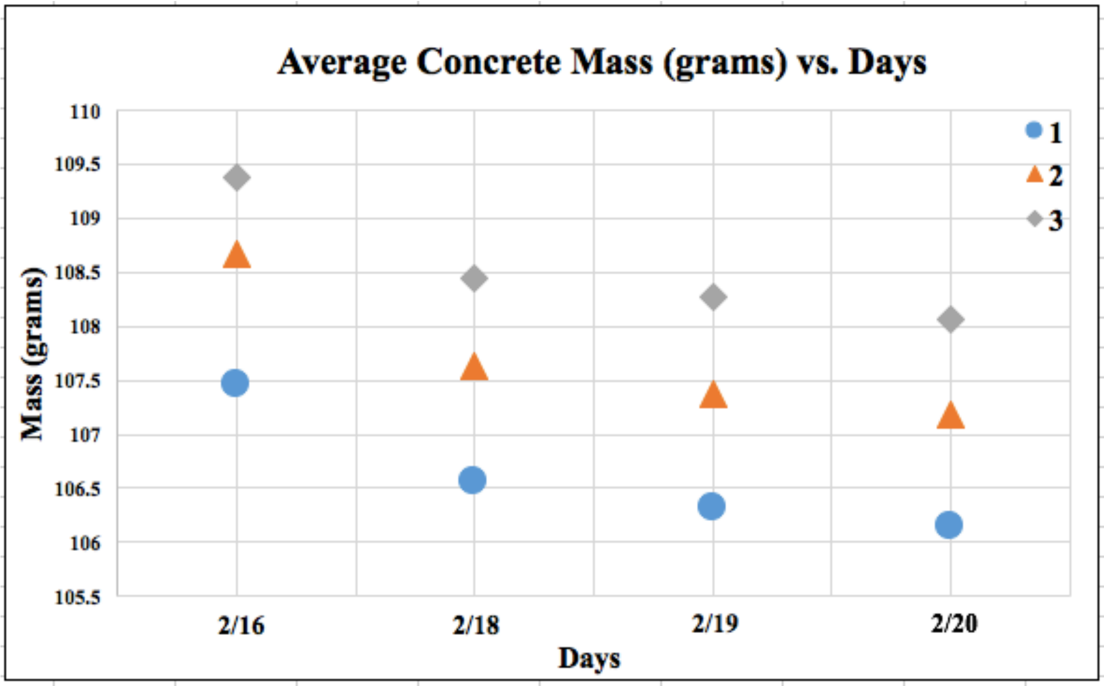
1. Spray should be returned back to GAV 111 for ChemE Car

13.2 Table 2: Equipment and Location

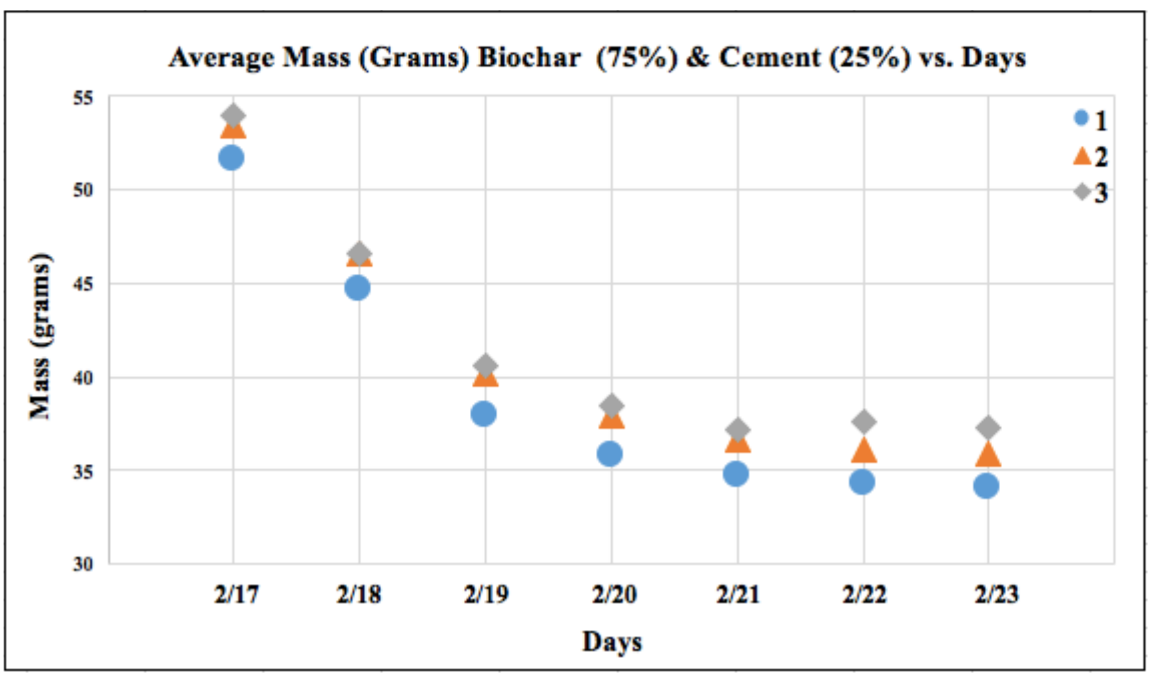
Equipment	**Location**
Grinder	On benchtop along right wall
Home Depot Buckets	Beside refrigerator (beside computer)
Liquid Nitrogen Container	Gavett 119 Left Fume Hood
Resistive heater	On benchtop next to computer
Resistive Heater Controller Box	wired to the Resistive Heater next to the computer
Stainless Steel Pot	On floor next to benchtop
Propane Tanks (5-7)	Flammability Cabinet and under fume hood
Metal Rods/Clamps	Clamps under right benchtop & metal rods in middle island drawer
Propane Torch	Team Jackalope drawer
Putty Knife	On glassware rack, benchtop,or next to sink
TMP36 Sensors (8)	On the benchtop next to the computer(still wired)
Baking trays	On right benchtop
Flammability Platform	Team Jackalope drawer
Small and Large Molds	Small mold on benchtop, large mold under benchtop
Large Scale Biochar and Cement Bricks	Offcampus (in Rochester)
Biochar and Plastic (and Additives) Prototypes	Offcampus (in Rochester)

14 Appendix C

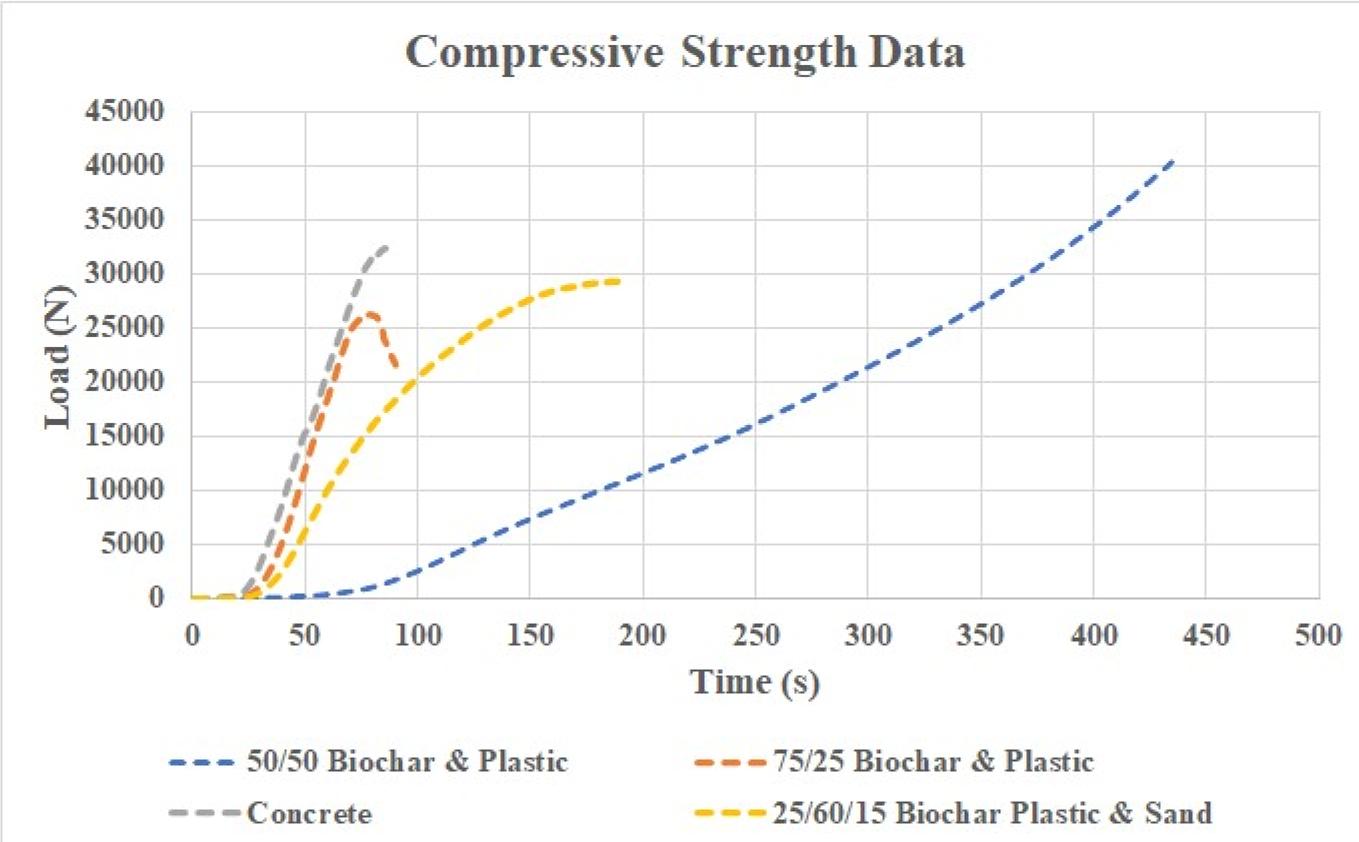
14.1 Average Mass of Concrete



14.2 Average Mass of Biochar (75%) and Cement (25%)



14.3 Output of Compression Strength Test (Raw Data)



15 Appendix D

15.1 Flammability Test SOP

Chemical Engineering Department, University of Rochester
Team Jackalope

Standard Operating Procedure

Department:	University of Rochester, Chemical Engineering
Date SOP was written:	3/2/2020
Date SOP was approved:	
Principal Investigator:	Fred Douglas Kelley
Internal Lab Safety Coordinator/Lab Manager:	Rachel Monfredo
Lab Phone:	(585) 613-1994
Office Phone:	(585) 275-7696
Emergency Contact:	Fred Douglas Kelley, Clair Cunningham *Doug Kelley: (585) 613-1994*
Location(s) covered by this SOP:	Gavett 119 or Chemistry Department *Doug Kelley: (585) 613-1994*

*Information on Propane found on SDS page: airgas.com/msds/001045.pdf

Type of SOP:

Purpose

The purpose of this Standard Operating Procedure (SOP) is to provide step by step guidance to investigating the flammability of Biochar bricks. This would ensure consistency and maintenance of testing materials and experimental conditions. In addition, to assure safety and minimize hazards.

Physical & Chemical Properties/Definition of Chemical Group

GHS ID/Chemical Name: Propane

Product type: Liquified Gas

Product use: Synthetic/Analytical Chemistry

SDS #: 001045

Classification: FLAMMABLE GASES – Category 1

GASES UNDER PRESSURE – Liquified Gas

Potential Hazards/Toxicity

- Toxic gas from plastic combustion
- CO_2 and CO from biochar combustion
    - Carbon Monoxide monitor should be placed in lab space
- Excess heat; risk of burn
- Compressed Gas (Propane tank)
- Potential splashing of melted plastic
- Potential brick explosion
- Propane tank explosion

Personal Protective Equipment (PPE)

- Laboratory-standard Goggles: in compliance with OSHA
- Kevlar Gloves: Materials are inherently flame resistant; ASTM standards-Level 2; Cut level-C protection; Ergonomic design with patent technology
- Flame Resistant lab coat: Nomex

Engineering Controls

- Propane tank valve

First Aid Procedures

Propane First Aid Measures (SDS)

- Eye contact: Immediately flush eyes with water. Remove any contact lenses. Continue to rinse for at least 10 minutes. Seek medical attention if irritation occurs
- Inhalation: Remove victim to fresh air and keep at rest in a position comfortable for breathing. If unconscious or not breathing, seek medical attention right away. Maintain open airway and loosen any tight clothing restricting breath.

- Skin Contact: Wash contaminated skin with soap and water. Removed contaminated clothing and shoes and soak in water. Get medical attention if symptoms occur. Do not rub affected area.

- Ingestion: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Seek medical attention if adverse health effects persist or are severe. If unconscious, seek medical assistance immediately. Maintain open airway and loosen any tight clothing restricting breathing.

Special Handling and Storage Requirements

- Handling of Propane Tank
  - Store propane tank outside fume hood (not in flammable cabinets)
    - Place in cabinet, isolated
- Brick storage and transportation
  - Storage: Hot bricks will be allowed to cool to room temperature under supervision or submerged in water in fume hood.
  - Bricks will be kept for potential further analysis (nothing is thrown away)
- Remove all other material from fume hood

Spill and Accident Procedure

- Ensure everyone is out of immediate danger
- Fire Extinguisher (Training REQUIRED)
- In case of carbon monixide alarm, vacate area immediately
- In case of propane leak, call the Fire Department
- In case of any serious injuries, dial 911
- Alert building manager, lab manager, and public safety
- Once situation is controlled, fill out accident report form

Medical Emergency Dial 911 or x52111 or (585) 275-3333

See attached document for Hot Work and Fire Extinguisher training individuals.

Safety Data Sheet (SDS) Location

Protocol/Procedure

1. Ensure the brick is dry and at room temperature. Set brick on metal platform with small surface area in fume hood to minimize undesired heat transfer. Ensure propane tank is in proper working condition and fire extinguisher is near the location of testing.
2. Open propane tank valve once the torch is inside the fume hood. When the torch is facing an open space in the fume hood, click on the ignition switch on the handle to create a spark at the tip of the torch and ignite the gas. Press the "hold" button to keep a steady flame without the need of constantly holding the ignition button in place. If torch does not light or if there is no propane in the tank, contact supervisor for assistance.
3. Add heat source (open flame from propane torch) to one face of the brick to mimic fire conditions. One side of the brick will be exposed to the open flame. Propane torch will be held in place by a stand orthogonal to the face of the brick. This will be direct flame contact. Start first timer. It is expected to have long flame contact.
4. End first timer with first signs of burning of the brick. First signs of burning are defined as indentation in brick face by flame. Turn off torch. Start second timer for extinguishing test.
5. End second timer when fire is extinguished and make observations. This will be determined by visual observations of the brick no longer changing size. This could be an extended period of time.

NOTE

Documentation of Training (signature of all users is required)

Principal Investigator or Lab Supervisor SOP Approval
Print name
____________________________Signature_____________________________
Approval Date:

I have read and understand the content of this SOP:

Name	Signature	Date
Brina Patel (Senior Design Member)		
Max Barton (Senior Design Member)		
Aime Laurent Twizerimana (Senior Design Member)		

Chemical Engineering Department, University of Rochester
Team Jackalope

Josh Kim (Senior Design Member)		
Fred Douglas Kelley (Principal Investigator)		
Carolyn Place (EH&S Representative)		
Mark Militello (Fire Marshall)		
Clair Cunningham (Team Advisor)		
Rachel Monfredo (Lab Manager)		