Alternative Concrete Masonry Unit Utilizing Local Waste Materials

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Project Members

May 10, 2018

Dear Dr. Tuchscherer:

The team submits here with a final report in support of a research project "Alternative Concrete Masonry Unit Utilizing Local Waste Materials" to be performed under the direction of Northern Arizona University's capstone program.

Questions regarding any technical aspects of the final report should directed to either Sam Carnes or Teo Albers.

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Your consideration for the final project is greatly appreciated.

Sincerely,

Sam Carnes

Teo Albers

Enclosure: Proposal

cc: Dr. Dianne McDonnell

NORTHERN ARIZONA UNIVERSITY

Alternative Concrete Masonry Unit Utilizing Local Waste Materials

Final Design Report

CENE 486

May 10, 2018

Teo Albers
Sam Carnes

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List of Abbreviations

CMU	Concrete Masonry Unit
OHV	Off-Highway Vehicle
PSI	Pounds per Square Inch
In	Inch
Lbf	Pounds per Linear Foot

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1.0 Project Introduction

1.1 Research Goals

The goal of the project is to develop an insulated, dry stacked modular block made from local waste materials (e.g. small diameter timber, cinder). Additionally the focus of this research study is to evaluate the effects that local waste material used as aggregate has on the CMU's (concrete masonry unit) physical characteristics such as density, compressive strength, freeze-thaw capabilities in addition to the conduction of an embodied energy study concerning the effect that alternative aggregate incorporated into CMU mix has on the specimens thermal heat transference qualities.

1.2 Project Justification

Insulated modular blocks made with wood fiber aggregate are limited. The blocks that are available are not structural and simply act as formwork intended to support the hydraulic pressure of grout. Additionally due to costs the availability of current blocks relies heavily on regional availability of the necessary materials. The environmental impacts of using concrete can be reduced by using a greener alternative option within its mix. The world's yearly cement production of 1.6 billion tons accounts for about 7% of the global loading of carbon dioxide into the atmosphere [1].

1.3 Constraints & Limitations

The constraints of the research project include all CMU design mixes obtaining an insulation value of at least R-10 and a compressive strength of 1900 psi as per ASTM-C90 [2]. Additionally the block must meet all demands of modern building construction. Lastly the CMU must be constructed strictly out of local materials that have been collected from the Flagstaff area.

1.4 Objectives

The objective of the research is to develop an alternative to the markets dry stacked modular block by developing a mix that is made out of materials local to flagstaff such as small diameter timber that is left from logging companies as well as the cinders that are present within the Flagstaff area. Another objective is to assure that the designed modular block meets the minimum strength requirement and can be mass produced within a local factory.

2.0 Methodology

2.1 Material Collection

One of the main objectives of the project is to incorporate local waste material within the CMU's design mix. Due to this design constraint, all material that will be used in the CMU's concrete mix was collected locally to Flagstaff, AZ. Fine cinder was collected on-site at Cinder Hill OHV area located 13 miles northeast of downtown Flagstaff. Approximately 5.34 cubic feet of fine cinder was collected from the area. Fine cinder was considered to be anything that passed through a ⅜" sieve. After the completion of the sieve analysis a total of 3 cubic feet of fine cinder was collected to be used in the concrete mix. Block-Lite is a local masonry company that constructs and sells concrete modular blocks to be used in construction and landscaping. Block-Lite was generous enough to donate the other raw materials that were needed in the concrete mix. Raw materials that were collected from Block-Lite include, 8 cubic feet of construction sand, 3 cubic feet of course cinder, and a single bag of Portland cement having a unit weight of 94 lbs/ft^3. Course cinder is considered anything that is approximately ⅜" in diameter. Block-Lite had previously sieved all material so the sieving of the course cinder was not necessary. Small diameter timber was considered to be anything under 2" in length and 1" in diameter. The small diameter timber was collected from burn piles located near Mt. Elden in Flagstaff, AZ. For the testing phase of the project it will need approximately 160 4"x 8" plastic cylinder molds in order to pour and test the concrete mix designs per ASTM standards. The concrete molds were purchased from Gilson Company Inc. and shipped to Flagstaff, AZ. The plastic cylinders satisfy both the ASTM 192 and ASTM C470 standards.

2.2 Small Diameter Timber Analysis

Prior to being used within a concrete mix the small diameter timber must go through a mineralization process. "The objective is to impregnate the wood particles to avoid the reactions of the "cement inhibitors" after the mixing process" [3]. In order to accomplish this the small diameter timber was put through a process called the K-X treatment. The K-X treatment is used by Faswall who is a company that creates green building modular blocks using small diameter timber. The ideal size of the small diameter timber is 1/32"-½" in diameter and 3/16"-1 ½" in length [3]. Additionally the small diameter timber must be free from any dirt and dust prior to the treatment. In order to fulfil this criteria the small diameter timber was passed through a ½" sieve in order to eliminate any dirt and dust that may have been collected. After the initial sieve the small diameter timber was then sorted through selecting only the members that fit the treatments criteria. With the small diameter timber prepared the initial phase of the K-X treatment can be started. The first stage of the K-X treatment requires the small diameter timber to soak in an aluminum sulphate-water solution. The solution will close the timbers particle pores and cavities. The aluminum sulphate has “a ratio of 1.5-2% of to the amount of Portland cement used in a conventional cement mix and is diluted with 7-8 parts of water. The small diameter wood chips are required to soak for a minimum of 4 minutes and a thorough mixing of the aggregate is important. This second stage of the K-X treatment adds kaolin powder to the original solution. Kaolin is a clay mineral that will mineralize the small diameter timber creating a product that is no longer affected by degradation. The small diameter timber must be evenly coated in the kaolin powder and has a minimum soaking time of 3 minutes with consistent mixing of the aggregate throughout. It is essential that the small diameter timber has a thin even coat of kaolin powder surrounding its exterior. With the completion of the second stage the small diameter timber has now been transformed into K-X treated wood chips and can be used within a concrete mix.

2.3 Establish a Baseline Mix

In order to compare the test results of the created alternative mix designs a baseline mix will be created. Block-Lite a local brick manufacturer here in Flagstaff was generous enough to share their CMU mix ratio that they currently are using in their factory. The three alternative mix designs will be based off of the same ratios as the baseline mix with different percentages of wood aggregate replacement. The baseline design mix ratio is presented below,

- 3 part sand
- 1 part cement
- 3 part aggregate
    - 2 part fine cinder (<⅜”)
    - 1 part course cinder (⅜”)
- 0.50 water-cement ratio

2.4 Alternative Mixes

A total of three design mixes were created in order to test the effects of adding small diameter timber to a CMU mix. The three mixes will utilize different percentages of the K-X treated wood chip aggregate. Wood aggregate replacement percentages are presented below,

Table 1: Wood Aggregate Replacement Percentages

Mix Type	Wood Aggregate Replacement
Baseline	0%
Alternative #1	10%

Alternative #2	15%
Alternative #3	20%

The alternative design mixes will follow the same mix proportions as the baseline mix with the wood aggregate replacement taking place within the course cinder portion of the mix design.

2.5 Assembling the Specimens

A total of 160 specimens were constructed from the 4 mix ratios. Compressive strength testing and tensile strength testing require 10 specimens per mix in order to develop statistical significance. Specimens will be right circular cylinders measuring 8” in height and 4” in diameter per ASTM C470 [4].

2.6 Compressive Strength Test

The Compressive strength of the dry stacked modular brick will be gauged following the procedures of ASTM C39 [5]. The test method consists of applying a compressive axial load to molded cylinders until failure occurs. The compressive strength is then calculated by dividing the maximum load by the cross sectional area of the prototype. The test specimens should be allowed at a minimum 28 days to fully cure and reach its ultimate strength, however the sample specimens are removed from the moisture tight container 48 hours prior to the 28th day of the curing cycle of the samples. During the compressive testing procedure the test specimens were subjected to a compressive axial load to the molded CMU cylinders until failure occurs. The equation provided by the ASTM C39 to evaluate the maximum applied load is displayed below.

$$f_{cm} = \frac{4P_{max}}{\pi D^2}$$

Where

f_{cm} = compressive strength,(psi)
P_{Max}= maximum applied load,(lbf)
D = Specimen Diameter,(in)

2.7 Tensile Strength Test

The tensile strength of the dry stacked modular bricks was analyzed in accordance to ASTM C496 [6]. ASTM C496 is the standard testing method used for the splitting tensile strength of cylindrical concrete specimens. The procedure included the application of a diametric compressive force along the length of the cylindrical CMU specimen until compressive failure occurred [6]. In order to evaluate the splitting Tensile strength of the CMU test specimens the compressive strength value that is inputted by the testing apparatus is used in order to solve for the maximum compressive load applied by the machine onto the test specimen. Once the maximum applied load has been determined the splitting tensile strength of the specimen can be determined by inputting that load into the following equation provided by ASTM C496 in order to evaluate the splitting tensile strength of a CMU test cylinder.

$$T = \frac{2P}{\pi l d}$$

Where

T = Splitting Tensile Strength, (psi)
P = Maximum Applied Load by Testing Apparatus, (lbf)
ℓ = Length of Test Specimen, (in)
D =Diameter of Test Specimen, (in)

2.8 Freeze-Thaw Test

The Freeze-Thaw capabilities of the dry stacked CMU blocks was evaluated in accordance to the ASTM-C666 [7]. The ASTM standard states that the samples will be tested for the two most prevalent types of structural strength corrosion, internal micro cracking and surface scaling. Internal Cracking is seldom present in properly air sealed concrete, however if an unprotected dry stacked modular brick that has poor network it can theoretically lead to the ultimate failure of the dry stacked modular brick. Internal cracking takes place when a dry stack modular block has voids that are generally not filled with water but with air, however when the water seeps through the voids and freezes, internal stresses generated from the approximate 10% expansion in the waters volume as the water transitions from a liquid state to a solid. Surface scaling occurs when there is some sort of deicer (i.e. salt) present in the dry stacked modular brick. With the presence of salt, the evaporation process is much more time consuming which consequently will increase the degree of saturation for the dry stacked modular brick; since scaling is microscopic surface quality of the sample, its only influencer's is its water/cement ratio, curing techniques, as well as its final placement. The ASTM standard states that the cylinders are to be subjected to 5 - 8 freeze thaw cycles per day until the test specimens have been subjected to a total of 300 cycles. The temperature range that the CMU test specimens were subjected during one freeze thaw cycle was from 4°C to -18°C and then raising it from -18°C to 4°C. With completion of the 300 cycles the specimens were then tested for their compressive strengths.

2.9 Embodied Energy Study

The Embodied Energy Study consisted of our research focused on the energy that is typically consumed with all of the processes associated with the transportation, mining and processing of natural resources, and manufacturing. However the focus of the study was regarding the amount of energy saved when incorporating the local waste products of flagstaff into load bearing CMU design when the reduction in amount of fuel used in the transportation process of the CMU aggregates from the mine to the manufacturing plant due to the proposed woodchip and cinder mix replacement. Research further continued by evaluating the capacity of the CMU mix to resist heat flow, which is commonly referred to as the building materials R-Value. The R-value of building material is dependent on its U-factors which is a value used to quantify the heat transmission through a building material based on its individual dimensions [8]. U-Factors have an inverse relationship with R-values however both are used to estimate the heat flow under steady state conditions neglecting the effects of thermal mass. Thermal mass provides a description on the material's ability to store energy, because CMU's have a comparatively high density and specific heat in comparison to light framing alternatives they possess highly effective heat storage capabilities. Concrete masonry thermal performance depends on both its steady - state thermal characteristics (which is described by its R-value and U-Factors) as well as the unit's size, type, density, climate and exposure conditions. The R-value and U-factor relationship is described in the equation shown below [8].

$$R = \frac{1}{\sum U}$$

Where

R = CMU capacity to resist heat flow

$\sum$U = sum of individual CMU mix material heat transmission

The equation that is shown below was used to determine the thermal conductivity for concrete k_c, $k_c$is primarily dependant on the the types of aggregate used in the concrete mixture. Once the coefficient of thermal conductivity of concrete was determined a matrix of equations were used in order to obtain an accurate value of their thermal conductivity coefficients of the coarse and fine aggregate, the water, and the sand that was used in the three alternative mix designs [8].

$$K_c = 0.5e^{0.02d} \ \ (inch - pound\ units)$$

Where

K_c=thermal conductivity of concrete, (BTU * in./(h*ft^2*°F)

D = density of test specimen, (pcf)

Since the U-factors are values used to quantify the heat transmission of CMU mix design but are measured based on the volumetric quantity of each material used in the mix design but also its coefficient of thermal conductivity. The thermal conductivity of a material is a number used to quantify the rate at which heat/energy passes perpendicularly through a unit area of homogeneous material of unit thickness for a temperature difference of one degree. The U factor of each material incorporated in the mix is determined by the equation shown below [8].

$$U_i = \frac{K_i}{L_i}$$

Where

U_i = material heat transmission U-Factor for individual mix.
K_i= material's coefficient of thermal conductivity.
L_i= Length of individual particles.

The values for the coefficient of thermal conductivity for each material was determined by using standard empirical equations and establishing multiple matrices in excel in order to evaluate the thermal coefficients for the remaining mix material that did not have a well-established empirical method used by other professionals in the industry. When all of the coefficients of thermal conductivity were determined for each component of the CMU mix designs, the U-factor for each different type of material was determined by summing up the material's coefficient of thermal conductivity divided by the specimen's length. Once all of the U-factors are known for the materials incorporated into the mix equation 1.0 can be used in order to relate all of the material's different coefficient of thermal conductivity and heat transmission values to the overall R-Value for each mix design.

3.0 Results

3.1 Compressive Strength Test Results

Results of the compressive strength test for the baseline mix are presented below,

Table 2: Baseline Compressive Strength Testing Results, Raw

Specimen I.D.	D (in.)	L (in.)	V (ft^3)	M (lb.)	Unit Weight (pcf)	P_{max} (lbf)	f_{cm}(psi)
1	4.00	7.50	0.5	4.80	87.99	25761.06	2050.00
2	4.00	7.50	0.05	4.59	84.24	27154.67	2160.90
3	4.00	8.00	0.06	4.58	78.77	23122.12	1840.00
4	4.00	7.50	0.05	4.63	84.87	20734.51	1650.00
5	4.00	8.00	0.06	4.51	77.48	19477.87	1550.00
6	4.00	7.50	0.05	4.57	83.74	31040.19	2470.10

7	4.00	7.50	0.05	4.62	84.75	15205.31	1210.00
8	4.00	7.56	0.05	4.56	82.89	15833.63	1260.00
9	4.00	7.75	0.06	4.88	86.60	16336.28	1300.00
10	4.00	7.44	0.05	4.63	85.63	37831.06	3010.50

Table 3: Baseline Compressive Strength Testing Results, Summarized

Average f_{cm}(psi)	2104.50
Unit Weight (pcf)	83.82
Minimum f_{cm}(psi)	1469.35
Maximum f_{cm}(psi)	3260.02
Standard Deviation	630.96
Standard Variance	665.09
Outliers	7,8,9

Results of the compressive strength test for alternative mix design #1 are presented below,

Table 4: Alternative #1 Compressive Strength Testing Results, Raw

Specimen I.D.	D (in.)	L (in.)	V (ft^3)	M (lb.)	Unit Weight (pcf)	P_{max} (lbf)	f_{cm}(psi)
1	4.00	7.75	0.05	4.90	86.91	13988.88	1113.20
2	3.85	7.75	0.05	4.73	90.60	13099.09	1125.20
3	3.92	7.8	0.05	4.75	87.28	15981.43	1324.20
4	3.87	7.5	0.05	7.84	94.73	10141.91	862.20
5	3.78	7.45	0.04	4.67	96.68	8789.14	783.20
6	3.70	7.38	0.04	4.60	100.20	7302.83	679.54
7	3.90	7.56	0.05	4.70	89.89	13537.10	1133.85
8	3.95	7.38	0.05	4.60	87.87	16582.35	1353.20
9	3.95	7.67	0.05	4.63	85.19	10761.62	878.36
10	3.80	7.38	0.05	4.73	97.89	14473.57	1276.63

Table 5: Alternative #1 Compressive Strength Testing Results, Summarized

Average f_{cm}(psi)	1064.70
Unit Weight (pcf)	90.08
Minimum f_{cm}(psi)	726.84
Maximum f_{cm}(psi)	1654.31
Standard Deviation	292.61
Standard Variance	308.44
Outliers	3,5,6,8

Results of the compressive strength test for alternative mix design #2 are presented below,

Table 6: Alternative #2 Compressive Strength Testing Results, Raw

Specimen I.D.	D (in.)	L (in.)	V (ft^3)	M (lb.)	Unit Weight (pcf)	P_{max} (lbf)	f_{cm}(psi)
1	4.00	7.5	0.05	4.68	85.76	11136.32	886.78
2	4.00	7.5	0.05	4.66	85.44	10771.89	857.25
3	3.96	8	0.05	4.63	81.11	19930.24	1618.63
4	3.75	7.5	0.04	4.50	93.94	8208.39	743.20
5	4.00	7.5	0.05	4.65	85.24	9339.33	743.89
6	3.97	7.56	0.05	4.54	83.75	18756.03	1515.45
7	3.85	7.75	0.05	4.55	87.05	24484.54	2103.87
8	3.97	7.44	0.05	4.65	87.30	26146.04	2112.44
9	3.94	7.75	0.05	4.80	87.04	15949.85	1308.69
10	4.00	7.75	0.05	4.41	78.30	13838.09	1101.41

Table 7: Alternative #2 Compressive Strength Testing Results, Summarized

Average f_{cm}(psi)	1280
Unit Weight (pcf)	85.49
Minimum f_{cm}(psi)	743.20
Maximum f_{cm}(psi)	2112.44
Standard Deviation	598.75
Standard Variance	631.14
Outliers	1,4,5,7,8

Results of the compressive strength test for alternative mix design #3 are presented below,

Table 8: Alternative #3 Compressive Strength Testing Results, Raw

Specimen I.D.	D (in.)	L (in.)	V (ft^3)	M (lb.)	Unit Weight (pcf)	P_{max} (lbf)	f_{cm}(psi)
1	3.92	7.38	0.05	4.47	86.93	8583.29	711.20
2	3.83	7.66	0.05	4.66	91.17	10689.26	926.20
3	3.94	7.38	0.05	4.27	82.07	12824.54	1053.45
4	3.94	7.56	0.05	4.52	84.92	15637.37	1284.22
5	4.00	7.38	0.05	4.02	77.35	9536.82	783.57
6	4.00	7.45	0.05	4.76	90.61	11570.34	950.01
7	4.00	7.5	0.05	4.34	82.12	8952.34	735.47
8	3.83	7.8	0.05	4.53	82.41	11472.92	942.24
9	3.94	7.75	0.05	4.78	92.42	17394.28	1507.21
10	3.83	7.75	0.05	4.56	88.03	8207.81	711.88

Table 9: Alternative #3 Compressive Strength Testing Results, Summarized

Average f_{cm}(psi)	898.37
Unit Weight (pcf)	85.82
Minimum f_{cm}(psi)	711.20
Maximum f_{cm}(psi)	1507.21
Standard Deviation	289.78
Standard Variance	305.45
Outliers	1,4,9,10

3.2 Tensile Strength Test Results

Results of the tensile strength test for the baseline mix are presented below,

Table 10: Baseline Tensile Strength Testing Results, Raw

Specimen I.D.	D (in.)	L (in.)	T (psi)
1	4.00	7.63	176.7
2	3.94	7.50	59.7
3	4.00	7.44	78
4	3.94	7.40	143.20
5	3.94	7.40	210.45
6	3.94	7.63	55.7
7	3.94	7.50	188.23
8	3.75	7.44	196.57
9	4.00	7.50	47.7
10	4.00	7.63	156

Table 11: Baseline Tensile Strength Testing Results, Summarized

Average f_{cm}(psi)	131.23
Minimum f_{cm}(psi)	47.70
Maximum f_{cm}(psi)	210.45
Standard Deviation	64.33
Outliers	2,3,6,9

Results of the tensile strength test for alternative mix design #1 are presented below,

Table 12: Alternative #1 Tensile Strength Testing Results, Raw

Specimen I.D.	D (in.)	L (in.)	T (psi)
1	3.80	7.63	62.90
2	4.00	8.00	53.30
3	4.00	7.75	78.00
4	4.00	8.00	65.44
5	4.00	7.80	57.30
6	3.80	7.80	43.00
7	4.00	7.63	56.50
8	3.90	7.75	74.69
9	4.00	7.90	62.71
10	3.75	8.00	58.36

Table 13: Alternative #1 Tensile Strength Testing Results, Summarized

Average f_{cm}(psi)	61.22
Minimum f_{cm}(psi)	43.00
Maximum f_{cm}(psi)	78.00
Standard Deviation	10.15
Outliers	3,6

Results of the tensile strength test for alternative mix design #2 are presented below,

Table 14: Alternative #2 Tensile Strength Testing Results, Raw

Specimen I.D.	D (in.)	L (in.)	T (psi)
1	4.00	7.50	47.70
2	4.00	7.50	54.96
3	3.75	8.00	80.25
4	3.75	7.75	46.20
5	3.94	7.75	50.21
6	4.00	8.00	84.40
7	4.00	7.75	62.10
8	4.00	7.75	42.20
9	3.75	8.00	47.00
10	4.00	7.50	43.00

Table 15: Alternative #2 Tensile Strength Testing Results, Summarized

Average f_{cm}(psi)	55.80
Minimum f_{cm}(psi)	42.20
Maximum f_{cm}(psi)	84.40
Standard Deviation	15.17
Outliers	6

Results of the tensile strength test for alternative mix design #3 are presented below,

Table 16: Alternative #3 Tensile Strength Testing Results, Raw

Specimen I.D.	D (in.)	L (in.)	T (psi)
1	3.94	7.50	47.00
2	3.83	7.50	48.02
3	3.94	7.75	43.00
4	3.94	7.75	54.90
5	3.94	7.38	69.57
6	4.00	7.63	74.86
7	3.94	7.63	71.60
8	3.84	7.50	54.12
9	4.00	7.75	43.80
10	4.00	8.00	63.12

Table 17: Alternative #3 Tensile Strength Testing Results, Summarized

Average f_{cm}(psi)	56.99
Minimum f_{cm}(psi)	43.00
Maximum f_{cm}(psi)	74.86
Standard Deviation	11.98
Outliers	N/A

3.3 Freeze-Thaw Test Results

With the completion of 300 cycles the compressive strength results of the design mixes are presented below.

Table 18: Freeze-Thaw Test Results

Mix Design	Initial Unit Weight (pcf)	Final Unit Weight (pcf)	Unit Weight Difference (%)	f_{cm}(psi)
Baseline	91.80	91.80	9.52	796.20
Alternative #1	97.12	97.12	7.82	804.00
Alternative #2	97.23	97.23	13.73	843.52
Alternative #3	97.86	97.86	97.86	FAIL

3.4 Embodied Energy Study Results

Upon the completion of the Embodied Energy study the R- Values and U-Factors for each CMU mix is displayed below.

	U - Factor	R- Value
Baseline	0.08333	12
Mix # 1	0.07806	12.81
Mix # 2	0.07722	12.95
Mix # 3	0.07686	13.01

4.0 Discussion

4.1 Compressive Strength Test

With the completion of the compressive strength test it was found that none of the alternative mixes meet the strength requirement of 1900 psi. As the percentage of wood aggregate replacement increased the compressive strength of the test specimen decreased. Between the three alternatives that were tested alternative #2 featuring the 15% wood replacement was the optimal design mix as it resulted in the highest compressive strength of 1280 psi. However even with this being the most optimal design mix it still has a percent error of 33% when compared to the ASTM C90 standard of 1900 psi. Additionally the team had hypothesized that as the wood aggregate percentage increased the unit weight of the alternative would decrease creating a lighter specimen. However the increased percentage of wood aggregate had little to no effect on the overall unit weight of the alternatives. Between the four mix designs the unit weights only had a percent difference of 8%. The location of the wood aggregate replacement within the specimen as well as the size of the wood aggregate is believed to be the reason for the poor compressive strength results. Additionally these two problems are believed to also be the reason as to why the 15% wood aggregate replacement resulted in better strength results than the 10% wood aggregate replacement.

4.2 Tensile Strength Test

The tensile strength results of the three design mixes did not differ greatly with the additional increase of wood aggregate replacement. The tensile strength of the 10% replacement mix and the 20% replacement mix had strength results of 143 psi and 120 psi respectively which is only a 19% difference between the two. None of the alternatives met the ASTM C90 standard of 190 psi. Alternative #2 with 15% replacement was again the optimal design mix having a tensile strength of 143 psi and a percent error of 25% based off the 190 psi standard.

4.3 Freeze-Thaw Test

At the conclusion of the Freeze-Thaw Testing it was evident that by incorporating less desirable cinders and petrified wood chips it was evident that using these non-traditional CMU materials has a significant impact in reducing the specimen’s ability to resist frost’s damaging effects on concrete. By further increasing the percent amount of alternative aggregate incorporated the compressive strength of the specimen at the conclusion of the test will be significantly reduced. Concrete specimens that have an inadequate air-void system will be unable to prevent critical saturation by the water while the specimens are subjected to the Freeze Thaw Test.

Upon completion of subjecting the CMU testing specimens to the required 300 Freeze-Thaw cycles listed in ASTM C666 it was evident that the specimens had critical saturation present which was evident due to the specimens having a “bleeding” appearance after 48 hours of being removed from the Freeze-Thaw Testing. Bleeding may occur in CMU specimens when the average size of the coarse aggregate is slightly too large in respect to its by part mix design thus affecting the specimen’s air void system. As the specimens are subjected to the Freeze-Thaw test water enters the specimens through the air void system and when subjected to a freezing cycle these air voids expand thus enlarging the initial size of the air void system within the specimens therefore creating more weak points in the specimen which directly diminishes the mixes compressive strength.

4.4 Embodied Energy Study

The focus of the Embodied Energy study that was conducted regarding the scope of this project placed an emphasis on the reduction of energy used when incorporation local material for CMU mix design rather than the energy that is currently used when considering the amount of energy it takes in transporting the CMU aggregate materials from queries and/or mines. The thermal performance of a CMU is primarily dependent on the specimen's thermal characteristics such as its thermal mass and heat capacity. Thermal mass and heat capacity characteristics of CMU specimens is predominantly a function of the specimen's size, type, and configuration of the masonry unit in addition to its exposure to climate. The thermal mass of a material is used to describe the capability of the material to store thermal energy. Because CMU's possess relatively high density & specific heat capacities, concrete masonry building material offers a highly effective thermal storage capabilities. CMU's have exceptional heat capacity compared to alternative building materials because the heat absorption rate of masonry is much slower than other materials. Heat capacity is simply defined as the required amount of heat needed to raise the temperature of a specimens mass by one degree.

5.0 Conclusion & Recommendations

Additional research on the effects that wood aggregate has on the strength of the concrete mix should not be completed without further investigation of the small diameter timber analysis. The size of the wood aggregate had a major effect on the strength of the concrete mixes. As a result none of the designed alternatives met load bearing standards. Finding a way to minimize the size of the wood aggregate without making it as small as sawdust will increase the bond within the test specimen and will increase the concrete mixes overall strength. None of the alternative mixes researched met the standard load bearing requirements for concrete masonry units. However, the alternative mix designs that were pursued could still be used as formwork as long as they were not meant to bear any loads. Considering the poor strength results of the mix designs the usage of an alternative waste material that isn't small diameter timber may want to be investigated. Plastic fibers as well as corn husk ash are waste materials that have been used before in a concrete mix.

6.0 References

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7.0 Appendix

Appendix A: Compressive Strength Results

Baseline Mix											
Specimen I.D	D (in.)	L (in.)	(L/D)	V (in.^{3})	V (ft.^{3})	M(kg)	M (slugs)	W (lb.)	Unit-Weight (pcf)	P_{max} (lbf)	f_{cm} (psi)
21	4	7.5	1.9	94.2	0.1	2.2	0.1	4.8	88.0	25761.1	2050.0
23	4	7.5	1.9	94.2	0.1	2.1	0.1	4.6	84.2	27154.7	2160.9
30	4	8	2.0	100.5	0.1	2.1	0.1	4.6	78.8	23122.1	1840.0
34	4	7.5	1.9	94.2	0.1	2.1	0.1	4.6	84.9	20734.5	1650.0
25	4	8	2.0	100.5	0.1	2.0	0.1	4.5	77.5	19477.9	1550.0
22	4	7.5	1.9	94.2	0.1	2.1	0.1	4.6	83.7	31040.2	2470.1
33	4	7.5	1.9	94.2	0.1	2.1	0.1	4.6	84.8	15205.3	1210.0
29	4	7.5625	1.9	95.0	0.1	2.1	0.1	4.6	82.9	15833.6	1260.0
28	4	7.75	1.9	97.4	0.1	2.2	0.2	4.9	86.6	16336.3	1300.0
35	4	7.4375	1.9	93.5	0.1	2.1	0.1	4.6	85.6	37831.1	3010.5

Mix Design # 1											
Specimen I.D	D (in.)	L (in.)	(L/D)	V (in.^{3})	V (ft.^{3})	M(kg)	M (slugs)	W (lb.)	Unit-Weight (pcf)	P_{max} (lbf)	f_{cm} (psi)
13	4	7.75	1.9375	97.38937226	0.05635959	2.22	0.152118396	4.89821	86.910	13988.88	1113.20
18	3.85	7.75	2.012987013	90.22212315	0.052211877	2.144	0.146910739	4.73053	90.602	13099.09	1125.20
14	3.92	7.8	1.989795918	94.13619024	0.054476962	2.155	0.147664479	4.7548	87.281	15981.43	1324.20
9	3.87	7.5	1.937984496	88.22122315	0.051053949	2.192	0.150199786	4.83643	94.732	10141.91	862.20
25	3.78	7.45	1.970899471	83.60451923	0.048382245	2.12	0.145266216	4.67757	96.680	8789.14	783.20
32	3.7	7.375	1.993243243	79.29674382	0.045889319	2.084	0.142799431	4.59814	100.201	7302.83	679.20
19	3.9	7.5625	1.939102564	90.34091462	0.052280622	2.13	0.145951434	4.69964	89.893	13537.10	1133.20
24	3.95	7.375	1.867088608	90.37453948	0.052300081	2.083	0.142730909	4.59594	87.876	16582.35	1353.20
10	3.95	7.666	1.940759494	93.94050436	0.054363718	2.099	0.143827258	4.63124	85.190	10761.62	878.20
5	3.8	7.375	1.940789474	83.64097741	0.048403343	2.147	0.147116305	4.73715	97.868	14473.57	1276.20

Mix Design # 2											
Specimen I.D	D (in.)	L (in.)	(L/D)	V (in.^{3})	V (ft.^{3})	M(kg)	M (slugs)	W (lb.)	Unit-Weight (pcf)	P_{max} (lbf)	f_{cm} (psi)
24	4	7.5		94.24777961	0.054542	2.12	0.145266	4.677572155	85.76	11136.32	886.20
28	4	7.5		94.24777961	0.054542	2.112	0.144718	4.65992094	85.44	10771.89	857.20
18	3.96	8		98.53039871	0.05702	2.096	0.143622	4.624618508	81.11	19930.24	1618.20
33	3.75	7.5		82.83496255	0.047937	2.041	0.139853	4.5032664	93.94	8208.39	743.20
29	4	7.5		94.24777961	0.054542	2.107	0.144375	4.64888893	85.24	9339.33	743.20
[29]	3.97	7.5625		93.61302572	0.054174	2.056	0.140881	4.53636243	83.74	18756.03	1515.20
25	3.85	7.75		90.22212315	0.052212	2.06	0.141155	4.545188038	87.05	24484.54	2103.20
19	3.97	7.4375		92.06570298	0.053279	2.108	0.144444	4.651095332	87.30	26146.04	2112.20
13	3.94	7.75		94.4896037	0.054682	2.157	0.147802	4.759209028	87.04	15949.85	1308.20
34	4	7.75		97.38937226	0.05636	2	0.137044	4.41280392	78.30	13838.09	1101.20

Mix Design # 3											
Specimen I.D	D (in.)	L (in.)	(L/D)	V (in.^{3})	V (ft.^{3})	M(kg)	M (slugs)	W (lb.)	Unit-Weight (pcf)	P_{max} (lbf)	f_{cm} (psi)
34	3.92	7.375		89.00697474	0.051508666	2.027	0.138893689	4.47238	86.83	8583.29	711.20
4	3.833333	7.66		88.40398094	0.051159711	2.114	0.144855085	4.66433	91.17	10689.26	926.20
17	3.9375	7.375		89.80345377	0.051969591	1.933	0.132452639	4.26497	82.07	12824.54	1053.20
18	3.9375	7.5625		92.08659243	0.053290852	2.051	0.140538212	4.52533	84.92	15637.37	1284.20
30	3.9375	7.375		89.80345377	0.051969591	1.822	0.12484672	4.02006	77.35	9536.82	783.20
3	3.9375	7.45		90.71670923	0.052498096	2.156	0.147733001	4.757	90.61	11570.34	950.20
33	3.9375	7.5		91.32554621	0.052850432	1.967	0.134782381	4.33999	82.12	8952.34	735.20
32	3.9375	7.8		94.97856806	0.054964449	2.053	0.140675255	4.52974	82.41	11472.92	942.20
22	3.8333	7.75		89.44111449	0.051759904	2.168	0.148555262	4.78348	92.42	17394.28	1507.20
28	3.8333	7.75		89.44111449	0.051759904	2.065	0.141497517	4.55622	88.03	8207.81	711.20

Appendix B: Splitting Tensile Strength Results

Baseline Mix				
Specimen I.D	D (in.)	P_{max} (lbf)	*L (in.)*	*T (psi.)*
16	4	8471.122	7.63	176.7
17	3.94	2771.097	7.5	59.7
18	4	3646.258	7.44	78
19	3.94	6558.293	7.4	143.2
24	3.94	9638.218	7.4	210.45
26	3.94	2630.243	7.63	55.7
27	3.94	8737.078	7.5	188.23
35	3.75	8614.723	7.44	196.57
36	4	2247.81	7.5	47.7
11	4	7478.75	7.63	156

Mix Design # 1				
Specimen I.D	D (in.)	P_{max} (lbf)	*L (in.)*	*T (psi.)*
4	3.8	2862.82	7.625	62.9
5		0		53.3
15	4	3798.186	7.75	78
23		0		65.44
27	4	2835.209	7.875	57.3
28	4	2127.644	7.875	43
29	3.8	2571.531	7.625	56.5
31	4	3637.006	7.75	74.69
33	4	2758.13	7	62.71
34		0		58.36

Mix Design # 2				
Specimen I.D	D (in.)	P_{max} (lbf)	*L (in.)*	*T (psi.)*
16	4	2247.81	7.5	47.7
17	4	2589.929	7.5	54.96
19		0		80.25
20	3.75	2109.089	7.75	46.2
22	3.9375	1222.788	3.9375	50.21
26	4	2121.203	4	84.4
27	4	1560.743	4	62.1
30	4	1060.602	4	42.2
31	3.75	1038.198	3.75	47
32		0		43

Mix Design # 3				
Specimen I.D	D (in.)	P_{max} (lbf)	*L (in.)*	*T (psi.)*
16	3.9375	2162.048	7.4375	47
21	3.8333	2204.726	7.625	48.02
23	3.9375	1994.666	7.5	43
24	3.9375	2504.233	7.375	54.9
25	3.9375	3280.97	7.625	69.57
26	3.9375	3530.45	7.625	74.86
27	3.8333	3287.347	7.625	71.6
29	3.9375	2552.337	7.625	54.12
31		0		43.8
35	3.9375	2927.984	7.5	63.12

Appendix C: Embodied Energy Study Results

Baseline Mix :

Specimen I.D	M	W	L	D	V total	V total	V sand	V gravel	V Fine Cinders	V woodchips	V Fine Cinders	V water	V aggregate	ρ	K concrete	K aggregate	K gravel	K sand	R - Factor	R - Factor	R - Factor	R - Factor	U - Value	R - Factor
	(kg.)	(lb.)	(in.)	(in.)	(in.³)	(ft.³)	(in.³)	(in.³)	(in.³)	(in.³)	(in.³)	(in.³)	(ft.³)	(lb./ft.³)	('in./(h'ft2	BTU'in./(h'ft2	(BTU'in./(h'ft2 °F)	(BTU'in./(h'ft2 °F)	Course Aggregate	Fine Aggregate	Concrete	Wood	CMU	CMU
	2.2	4.85	7.5	3.9	89.59	0.05	41.35	13.78	27.57	0.00	27.57	6.89	0.04	93.54	2.75	0.04	0.62	1.00	10.71	7.14	2.73	7.50	0.085665569	12
	2.099	4.63	7.65	3.95	93.74	0.05	43.27	14.42	28.84	0.00	28.84	7.21	0.04	85.30	2.75	0.04	0.62	1.00	10.71	7.14	2.78	7.65		
	2.132	4.7	7.95	3.9	94.97	0.05	43.83	14.61	29.22	0.00	29.22	7.31	0.04	85.52	2.75	0.04	0.62	1.00	10.71	7.14	2.89	7.95		
	2.122	4.68	7.667	3.85	89.26	0.05	41.20	13.73	27.46	0.00	27.46	6.87	0.04	90.57	2.75	0.04	0.62	1.00	10.71	7.14	2.79	7.67		
	2.06	4.54	7.85	3.9	93.78	0.05	43.28	14.43	28.85	0.00	28.85	7.21	0.04	83.69	2.75	0.04	0.62	1.00	10.71	7.14	2.85	7.85		
	2.043	4.5	7.667	3.9	91.59	0.05	42.27	14.09	28.18	0.00	28.18	7.05	0.04	84.98	2.75	0.04	0.62	1.00	10.71	7.14	2.79	7.67		
	2.091	4.61	7.25	3.95	88.84	0.05	41.00	13.67	27.34	0.00	27.34	6.83	0.04	89.66	2.75	0.04	0.62	1.00	10.71	7.14	2.64	7.25		
	2.109	4.65	7	3.95	85.78	0.05	39.59	13.20	26.39	0.00	26.39	6.60	0.04	93.66	2.75	0.04	0.62	1.00	10.71	7.14	2.55	7.00		
	2.212	4.88	7.5	3.95	91.91	0.05	42.42	14.14	28.28	0.00	28.28	7.07	0.04	91.69	2.75	0.04	0.62	1.00	10.71	7.14	2.73	7.50		
	2.066	4.55	7.45	3.95	91.29	0.05	42.14	14.05	28.09	0.00	28.09	7.02	0.04	86.21	2.75	0.04	0.62	1.00	10.71	7.14	2.71	7.45		
																			10.71	7.14	2.74	7.55		
																				8.928428571				

Mix Design # 1 :

Specimen I.D	M	W	L	D	V total	V total	V sand	V gravel	V Fine Cinders	V woodchips	V Fine Cinders	V water	V aggregate	ρ	K concrete	K aggregate	K gravel	K sand	R - Factor	R - Factor	R - Factor	R - Factor	U - Value	R - Factor
	(kg.)	(lb.)	(in.)	(in.)	(in.³)	(ft.³)	(in.³)	(in.³)	(in.³)	(in.³)	(in.³)	(in.³)	(ft.³)	(lb./ft.³)	('in./(h'ft2	BTU'in./(h'ft2	(BTU'in./(h'ft2 °F)	(BTU'in./(h'ft2 °F)	Course Aggregate	Fine Aggregate	Concrete	Wood	CMU	CMU
	2.064	4.55	7.5	3.9	89.594	0.052	41.351	13.784	27.567	13.439144	14.128	6.892	0.0398835	87.7621657	2.75	0.035	0.624	1	10.714	7.142857143	2.72727273	7.5	0.078091071	12.81
	2.07	4.56	7.65	3.95	93.744	0.054	43.267	14.422	28.844	14.061666	14.783	7.211	0.041730964	84.1206917	2.75	0.035	0.624	1	10.714	7.142857143	2.78181818	7.65		
	2.042	4.5	7.95	3.9	94.970	0.055	43.832	14.611	29.222	14.245493	14.976	7.305	0.042276511	81.9119965	2.75	0.035	0.624	1	10.714	7.142857143	2.89090909	7.95		
	2.073	4.57	7.667	3.85	89.256	0.052	41.195	13.732	27.463	13.388381	14.075	6.866	0.03973285	88.4790592	2.75	0.035	0.624	1	10.714	7.142857143	2.788	7.667		
	2.025	4.46	7.85	3.9	93.775	0.054	43.281	14.427	28.854	14.066304	14.788	7.213	0.041744731	82.264843	2.75	0.035	0.624	1	10.714	7.142857143	2.85454545	7.85		
	2.132	4.7	7.667	3.9	91.589	0.053	42.272	14.091	28.181	13.738389	14.443	7.045	0.040771573	88.6789698	2.75	0.035	0.624	1	10.714	7.142857143	2.788	7.667		
	2.081	4.59	7.25	3.95	88.843	0.051	41.004	13.668	27.336	13.326415	14.010	6.834	0.039548953	89.2335146	2.75	0.035	0.624	1	10.714	7.142857143	2.63636364	7.25		
	2.092	4.61	7	3.95	85.779	0.050	39.590	13.197	26.394	12.866884	13.527	6.598	0.038185196	92.9089528	2.75	0.035	0.624	1	10.714	7.142857143	2.54545455	7		
	2.11	4.65	7.5	3.95	91.906	0.053	42.418	14.139	28.279	13.785947	14.493	7.070	0.04091271	87.4611366	2.75	0.035	0.624	1	10.714	7.142857143	2.72727273	7.5		
	2.132	4.7	7.45	3.95	91.294	0.053	42.136	14.045	28.090	13.69404	14.396	7.023	0.040639958	88.9661614	2.75	0.035	0.624	1	10.714	7.142857143	2.70909091	7.45		
																			10.714	7.142857143	2.74487273	7.55		
																						1.13		
																				8.928428571				

Mix Design # 2 :

Specimen I.D	M	W	L	D	V total	V total	V sand	V gravel	V Fine Cinders	V woodchips	V Fine Cinders	V water	V aggregate	ρ	K concrete	K aggregate	K gravel	K sand	R - Factor	R - Factor	R - Factor	R - Factor	U - Value	R - Factor
	(kg.)	(lb.)	(in.)	(in.)	(in.³)	(ft.³)	(in.³)	(in.³)	(in.³)	(in.³)	(in.³)	(in.³)	(ft.³)	(lb./ft.³)	('in./(h'ft2	BTU'in./(h'ft2	(BTU'in./(h'ft2 °F)	(BTU'in./(h'ft2 °F)	Course Aggregate	Fine Aggregate	Concrete	Wood	CMU	CMU
	2.2	4.85	7.5	3.9	89.594	0.052	41.351	13.784	27.567	17.918859	9.649	6.892	0.0398835	93.5449441	2.75	0.035	0.624	1	10.714	7.142857143	2.72727273	7.5	0.075854554	13.18
	2.099	4.63	7.65	3.95	93.744	0.054	43.267	14.422	28.844	18.748888	10.096	7.211	0.041730964	85.2991942	2.75	0.035	0.624	1	10.714	7.142857143	2.78181818	7.65		
	2.132	4.7	7.95	3.9	94.970	0.055	43.832	14.611	29.222	18.993991	10.228	7.305	0.042276511	85.5222216	2.75	0.035	0.624	1	10.714	7.142857143	2.89090909	7.95		
	2.122	4.68	7.667	3.85	89.256	0.052	41.195	13.732	27.463	17.851175	9.612	6.866	0.03973285	90.57046	2.75	0.035	0.624	1	10.714	7.142857143	2.788	7.667		
	2.06	4.54	7.85	3.9	93.775	0.054	43.281	14.427	28.854	18.755073	10.099	7.213	0.041744731	83.6867044	2.75	0.035	0.624	1	10.714	7.142857143	2.85454545	7.85		
	2.043	4.5	7.667	3.9	91.589	0.053	42.272	14.091	28.181	18.317852	9.863	7.045	0.040771573	84.9770804	2.75	0.035	0.624	1	10.714	7.142857143	2.788	7.667		
	2.091	4.61	7.25	3.95	88.843	0.051	41.004	13.668	27.336	17.768554	9.568	6.834	0.039548953	89.6623157	2.75	0.035	0.624	1	10.714	7.142857143	2.63636364	7.25		
	2.109	4.65	7	3.95	85.779	0.050	39.590	13.197	26.394	17.155845	9.238	6.598	0.038185196	93.6639491	2.75	0.035	0.624	1	10.714	7.142857143	2.54545455	7		
	2.212	4.88	7.5	3.95	91.906	0.053	42.418	14.139	28.279	18.381262	9.898	7.070	0.04091271	91.6891157	2.75	0.035	0.624	1	10.714	7.142857143	2.72727273	7.5		
	2.066	4.55	7.45	3.95	91.294	0.053	42.136	14.045	28.090	18.258721	9.832	7.023	0.040639958	86.2120495	2.75	0.035	0.624	1	10.714	7.142857143	2.70909091	7.45		
																			10.714	7.143	2.745	7.548		
																			8.929			1.50968		

Mix Design # 3 :

Specimen I.D	M	W	L	D	V total	V total	V sand	V gravel	V Fine Cinders	V woodchips	V Fine Cinders	V water	V aggregate	ρ	K concrete	K aggregate	K gravel	K sand	R - Factor	R - Factor	R - Factor	R - Factor	U - Value	R - Factor
	(kg.)	(lb.)	(in.)	(in.)	(in.³)	(ft.³)	(in.³)	(in.³)	(in.³)	(in.³)	(in.³)	(in.³)	(ft.³)	(lb./ft.³)	('in./(h'ft2	BTU'in./(h'ft2	(BTU'in./(h'ft2 °F)	(BTU'in./(h'ft2 °F)	Course Aggregate	Fine Aggregate	Concrete	Wood	CMU	CMU
	2.2	4.85	7.5	3.9	89.594	0.052	41.351	13.784	27.567	22.398574	5.169	6.892	0.0398835	93.5449441	2.75	0.035	0.624	1	10.714	7.142857143	2.72727273	7.5	0.075854554	13.183
	2.099	4.63	7.65	3.95	93.744	0.054	43.267	14.422	28.844	23.436109	5.408	7.211	0.041730964	85.2991942	2.75	0.035	0.624	1	10.714	7.142857143	2.78181818	7.65		
	2.132	4.7	7.95	3.9	94.970	0.055	43.832	14.611	29.222	23.742488	5.479	7.305	0.042276511	85.5222216	2.75	0.035	0.624	1	10.714	7.142857143	2.89090909	7.95		
	2.122	4.68	7.667	3.85	89.256	0.052	41.195	13.732	27.463	22.313968	5.149	6.866	0.03973285	90.57046	2.75	0.035	0.624	1	10.714	7.142857143	2.788	7.667		
	2.06	4.54	7.85	3.9	93.775	0.054	43.281	14.427	28.854	23.443841	5.410	7.213	0.041744731	83.6867044	2.75	0.035	0.624	1	10.714	7.142857143	2.85454545	7.85		
	2.043	4.5	7.667	3.9	91.589	0.053	42.272	14.091	28.181	22.897315	5.284	7.045	0.040771573	84.9770804	2.75	0.035	0.624	1	10.714	7.142857143	2.788	7.667		
	2.091	4.61	7.25	3.95	88.843	0.051	41.004	13.668	27.336	22.210692	5.126	6.834	0.039548953	89.6623157	2.75	0.035	0.624	1	10.714	7.142857143	2.63636364	7.25		
	2.109	4.65	7	3.95	85.779	0.050	39.590	13.197	26.394	21.444806	4.949	6.598	0.038185196	93.6639491	2.75	0.035	0.624	1	10.714	7.142857143	2.54545455	7		
	2.212	4.88	7.5	3.95	91.906	0.053	42.418	14.139	28.279	22.976578	5.302	7.070	0.04091271	91.6891157	2.75	0.035	0.624	1	10.714	7.142857143	2.72727273	7.5		
	2.066	4.55	7.45	3.95	91.294	0.053	42.136	14.045	28.090	22.823401	5.267	7.023	0.040639958	86.2120495	2.75	0.035	0.624	1	10.714	7.142857143	2.70909091	7.45		
																			10.714	7.143	2.745	7.548		