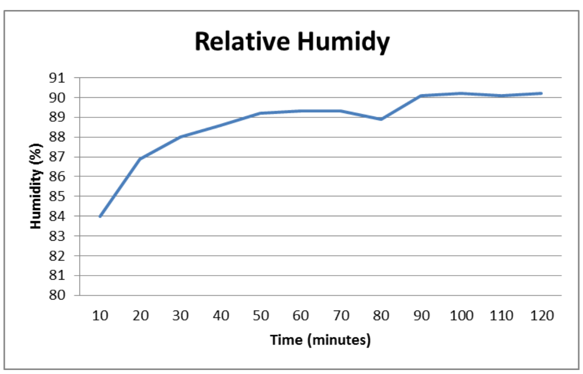
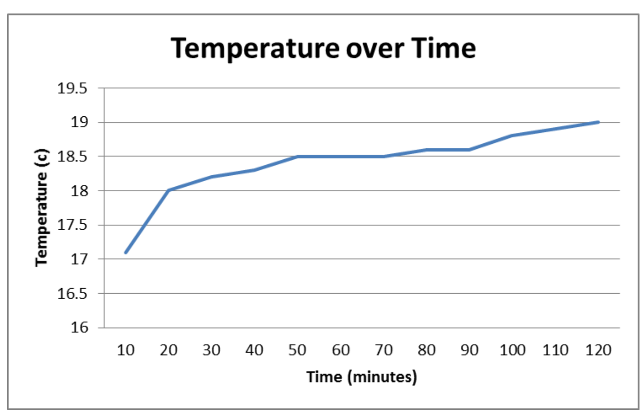
NSF Carbon Sequestration

2013 Trial

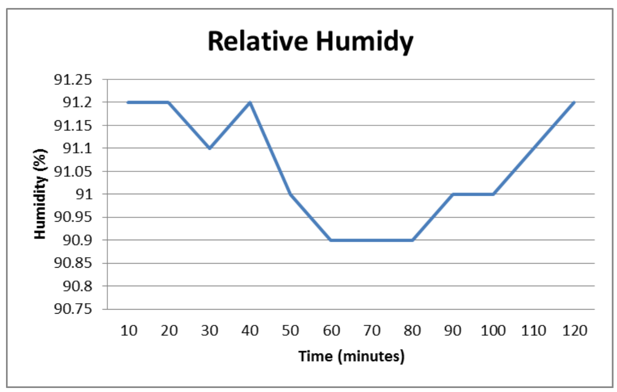
The project scope to optimize carbon sequestration of concrete masonry units was performed on Feb 5th and 6th at WCCT. This was accomplished by the installation of two flow meters which would monitor the flow rates of CO_2 and air. The results of previous testing performed in 2012, noted that the relative humidity content during the experiments exceed 75% in all test, thus no additional moisture is needed to be added to the chamber. This first series of CMU's will be tested using only air and CO_2. The relative humidity and temperature rise will be monitored as previous testing from 2012. The same concrete masonry mix design will be used as in 2012, as well as the same CMU molds, mixing time, compaction, and vibration sequence. In addition, the same cement and aggregates were also used. The flow rate meters were installed to monitor CO_2 and air distribution into the curing chamber at normal atmospheric pressure, 1atm, (10cc/scft/hr).

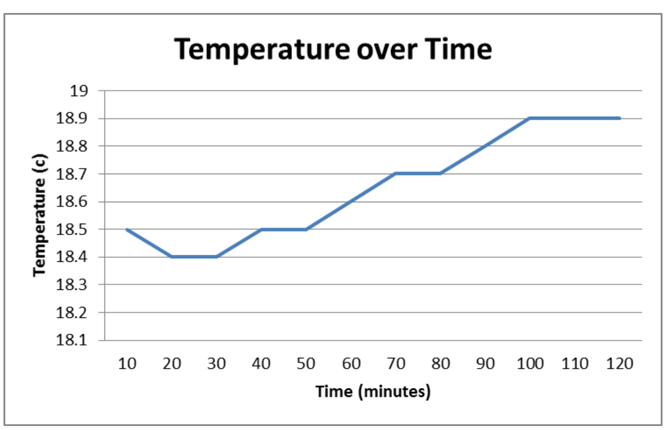
The first CMU's were placed into the curing chamber immediately after molding and a flow rate of 10cc/scft/hr for both CO_2 and air for 2 hours. See relative humidity and temperature profiles below:





It was immediately observed that the flow meters were not metering enough CO2 and air (50%/50%) to impact the curing acceleration of the CMU's to effectively increase initial strength. The relative humidity continued to increase irregardless of no addition of water to the curing chamber. Starting relative humidity, RH, was 84.0% and at the end of 2 hours of curing the relative humidity increased to 90.2%. The temperature profile increase slightly from 17.1 degrees C (62.8 degrees F) to 19.0 degrees C (66.2 degrees F) at the end of the test. Thus the conclusion from this initial run was that humidity levels are not impacted by the addition or absence of moisture at the start of curing process and optimum temperature rise is not impacted since hot water or steam is not being added initially. The second run was with 2 hour preset CMU's which were molded at the same time as above except set aside for the 2 hour period. Knowingly that the flow meters were undersized, the test continued for the comparisons of no-preset versus 2-hour preset CMU's at a flow rate of 10cc/scft or a ratio of 50%/50% addition. Noted relative humidity and temperature rise below:

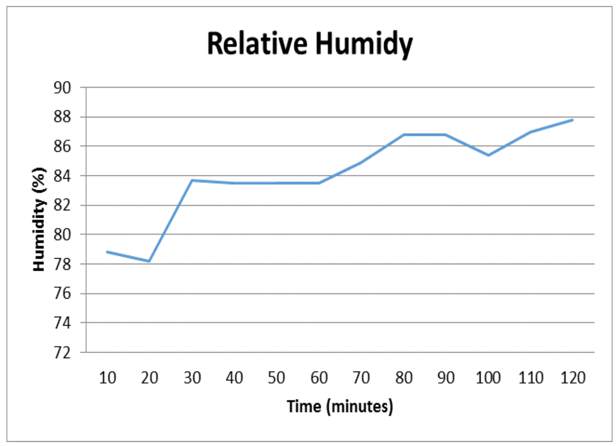


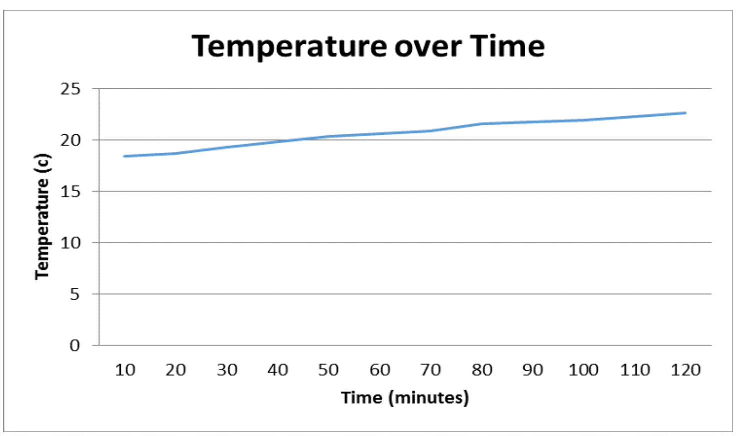


The relative humidity, RH, initial was elevated (91.2%) due to the first test, but had a general decrease of relative humidity after 60 mins leveling out at 90.9%, then increasing to 91% at end 2 hours curing.

The temperature profile started slightly higher than the first test at 18.5 degrees C (65.3 degrees F) and had a increasing trend to 18.9 degrees C (66.1 degrees F) at the end of the 2 hour test. The relative humidity, RH, again increased above 90% without the addition of moisture.

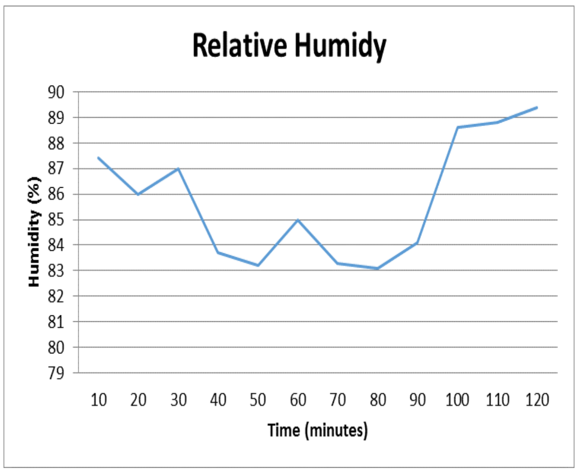
After the first day of testing it was decided to remove the flow meters due to insufficient inability addition of CO2 and air. Thus the second day of testing was controlled at a higher flow rate by opening the flow rate drectly from the CO2 and air tanks. The third run was metered at a 50%/50% ratio of CO2 and air, except at higher flow rates at normal atmopsheric pressure. Note relative humidity, RH, and temperature profiles for non-preset CMU's

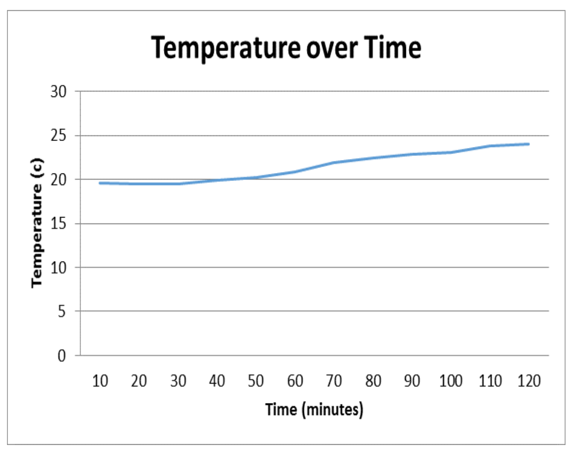




The relative humidity, RH, started at 78.8% and gradually increased to 87.8%, whereas the temperature started at 18.4 degrees c (65.3 degrees F) and only increased to 22.6 degrees C (72.5 degrees F) only an increase of 4.2 degrees C. The thermal heat of hyradration reactkon is insufficient in aiding initial strength development. Also the flow rate through the curing chamber might not be allowing the carbonation reaction to develop properly.

The final run to be evalauted at this higher flow rate addition involved CMU's which had been set aside for a 2 hour preset time. The relative humidity started at 87.4% higher due to the previous run which ended at 88%. The trend decreased for the first 90 minutes reaching the minimium of 83.1% and slowly increased to 89.4%. The temperature started 19.6 degrees C (67.2 degrees F) and finished at 24 degrees C (75.2 degrees F) at the end of 2 hours of curing at a 50%/50%, CO2 to air ratio. This final temperature was the highest of the 4 runs of non-preset or 2 hour preset CMU's, see proflies below, also the relative humidity decreased from the original 87.4% down to 83.1%, before the trend increased:





All CMU's met the requirements of ASTM C90, Standard Specification for Loadbearing Concrete Masonry Units, as specified for compressive strengths and water absorption

Discussion:

Below are the net compressive strengths for the CMU's tested on both runs:

Net Compressive strength, age	Date of Run: Feb 5th	Date of Run: Feb 6th
2 hour strength, no-preset	110 psi	330 psi
2 hour strength, 2 hour-preset	220 psi	400 psi
1-day strength, non-preset	1590 psi	1700 psi
1-day strength, 2 hour-preset	1450 psi	1660 psi
7-day strength, non-preset	3070 psi	3310 psi
7-day strength, 2 hour-preset	2790 psi	3290 psi
28-day strength, non-preset	2750 psi	3410 psi
28-day strength, 2 hour-preset	2800 psi	3670 psi
100% CO2 addition, 20 psi curing pressure	2-hr: 760 psi; 1-day: 1580 psi	7-day: 2330 psi; 28-day: 3010 psi
Normal Kiln Cured	2-hr: 200 psi; 1-day: 1660 psi	7-day: 3290 psi; 28-day: 4450 psi

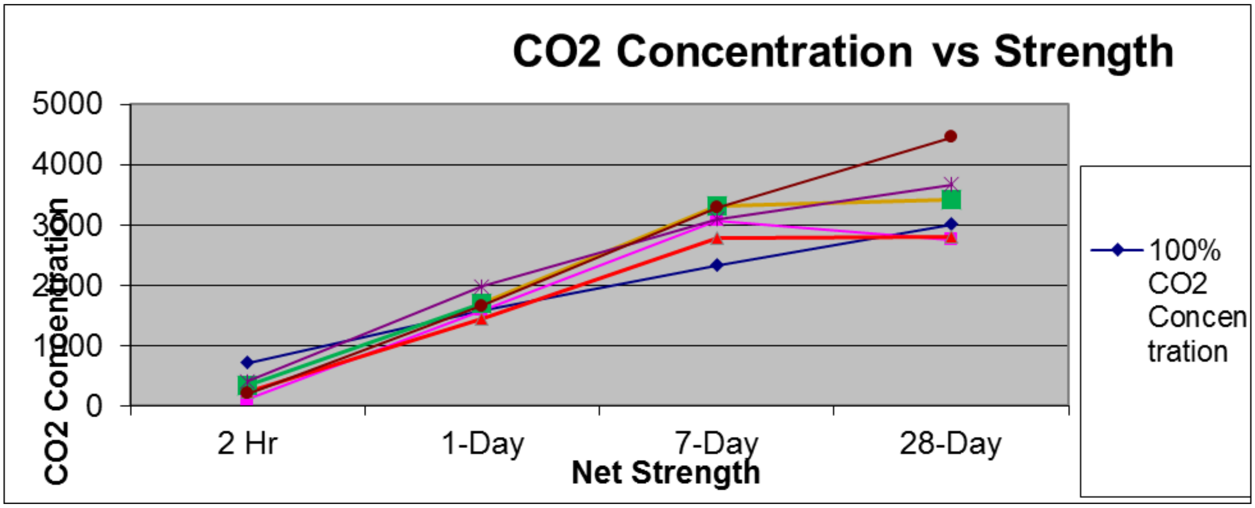
Note: Standard 28-day minimum, 1900 Net compressive strenght (psi)

Additionally the CMU's were evaluated for water absorption, see below:

Date of Run	Maxmium Water Absorption, pcf	Density (Oven Dry). pcf
Feb 5th, 2013, no preset time	6.48	138.99
Feb 5th, 2013, 2hr preset time	6.52	139.55
Feb 6th, 2013, no preset time	6.70	138.33
Feb 6th, 2013, 2hr preset time	5.97	140.68

Note: Maxmium Water Absorption, 13.0; Minimum Concrete Density, 125 pcf

The above 2-hr to 28-day net compressive strengths follow a typical strength gain trend, see below:



There are several reports discussing carbon sequestration of concrete masonry units at higher curing pressures, above 10 ps and as high as 20 psi, than normal atmospheric pressure and relative humidity between 50%-75% as optimium. This trial was to confirm CMU strength performance at normal atmospheric pressure and no additional moisture addition using only flow of CO2 and air at a blend ratio of 50%/50% through the curing chamber.

All the initial 2 hour compressive strengths conpared very similar to the traditional kiln cured CMU's, although no additional moisture was introduced into the curing chamber during the 2 hour curing time. The amount to moisture batched within the concrete mix is sufficient for curing within the chamber. The optimium relative humidity, RH, performance has been report between 50% to 75%, since water seems to prevent proper CO2 absorption into the matrix of the concrete masonry units. These runs all trended above the 75% humidity, except for the final run which trended donward for 90 minutes to a minmium of 84.1% which also had the highest temperature differential change of 4.4 degrees C, as compared to temperature rise of 1.9 degrees C, 0.4 degrees C, and 4.2 degrees C, respectively for the other runs. The heat of hydration from the concrete masonry units do not provide sufficient rise in temperature for optimium absorption of CO2 and initial strength gain performance.

Conclusions and Recommendations

The proper amount of moisture, relative humidity and of CO_2 is necessary for the pore structure to absorb CO_2 into the matrix of the concrete masonry unit for optimum carbon sequestration. In addition if the temperature profile is not trending upwards, then compressive strengths development will also be less than optimum.

Comparing the temperature profiles for the 2012 runs, all three runs maximum temperature reached was 30 degrees C (88 degrees F), regardless of curing chamber pressure of 20 psi, 10 psi, or 5 psi. Kiln cured CMU's are typically cured at 39 degrees C (102.2 degrees F) with steam. The present trial in 2013 was cured without pressure or additional moisture at a high CO_2/air rate only reached 24 degrees C (75.2 degrees F). Additional heat from either steam or hot water was needed to accelerate the heat of hydration from the CMU's. Therefore an internal heating element is recommended for the next trial which can control the temperature within the curing chamber.

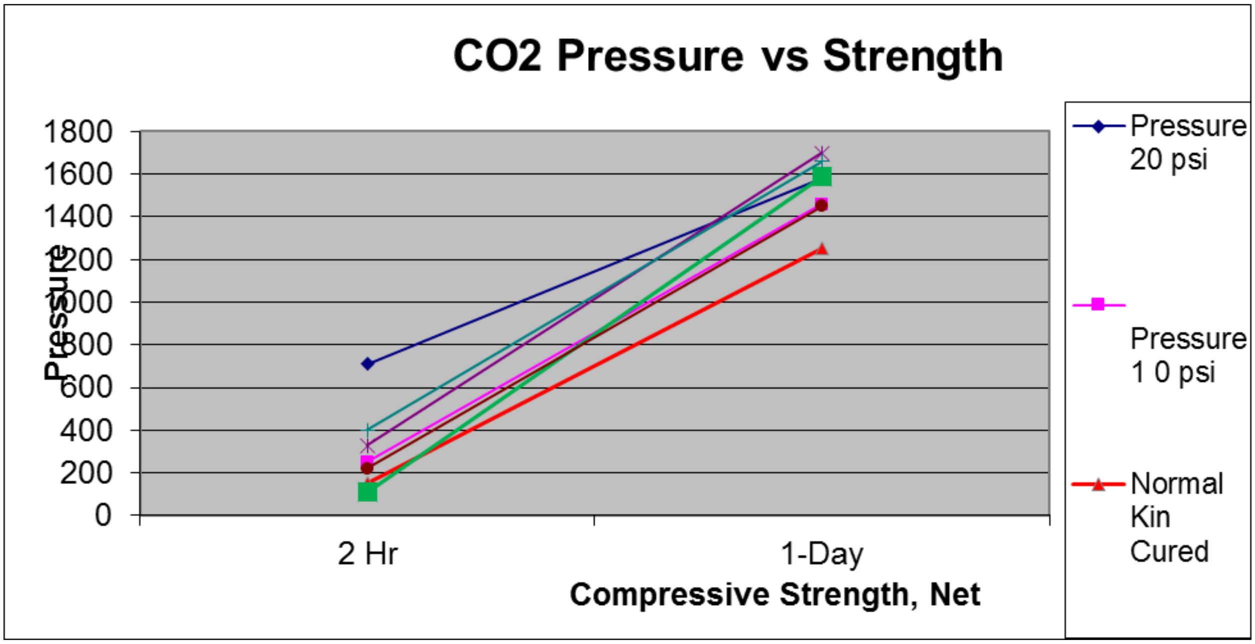
The addition of CO_2 and air at a 50%/50% ratio need correction for ambient conditions of temperature and pressure. CO_2 gas density at STP, standard temperature and pressure (0 degrees C, 32 degrees F, and 1 atm, 760 mm Hg) is 1.9769 mg/cc; thus at lab experimental temperatures of 20 degrees C (66.7 degrees F) is 1.842 mg/cc. Therefore the actual CO_2 gas addition was 42% corrected for density when added at a 50%/50%, CO_2 to air ratio, thus the actual addition ratio is 42%/58%.

It has was reported that the first two runs were at a CO_2/air addition of 10cc/scft/hr which was too low for any impact compressive strength development, whereas the last two runs were metered at a higher addition rate controlled from the CO_2/air tanks directly. Thus new flow meters to control the blend of CO_2/air are needed. The curing chamber volume has a capacity of 32 cubic feet which permits 18 blocks to be tested at any one time. Steinour's equation with this cement predicts that a 50% CO_2 uptake reacting with the calcium hydroxide from the cement hydration process, thus the amount of carbon dioxide necessary for reaction is between 0.144 lbs/cuft to 0.180 lbs/cuft of CO_2 for complete reaction to occur.

Cement hydration is composed of an aggregate of various number of chemical reactions especially for CO_2 sequestration. The reactions are immediate within the first 30 minutes of cement hydration.

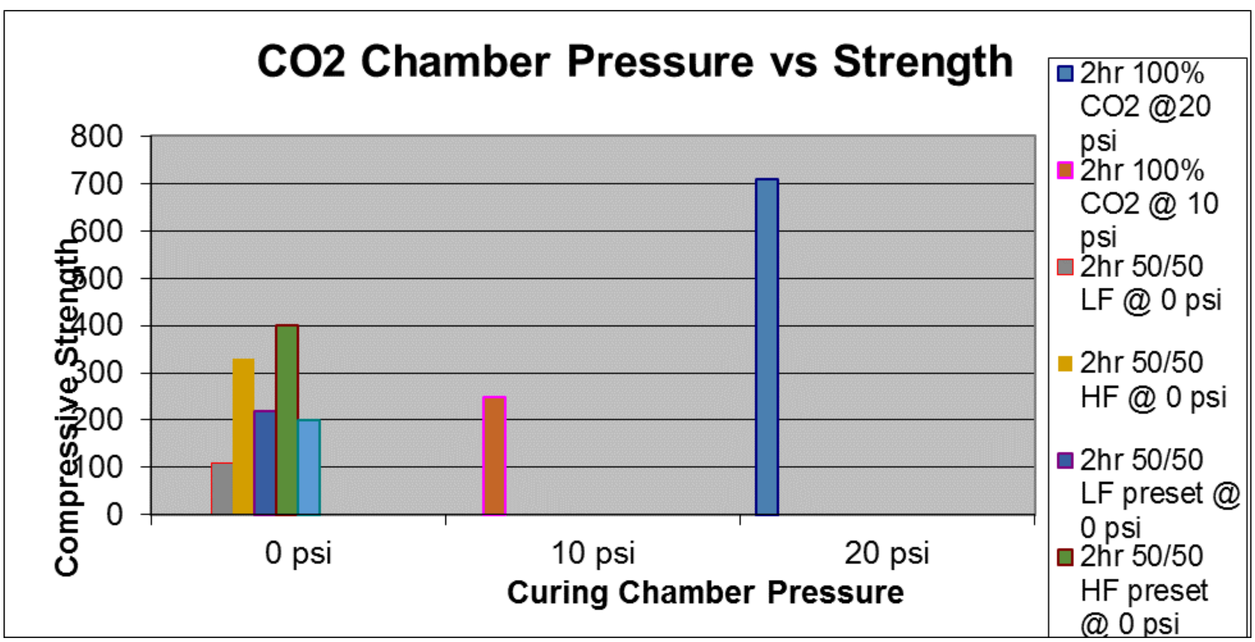
The following Graph 1 showing compressive strength development within the initial first 2 hours and 24 hours of curing:

Graph 1



This shows the strength performance between 2 hours and 24 hours of chamber curing in a 100% CO_2 atmosphere. Plotting the critical 2 hour compressive strengths cured under a CO_2/air environment at normal atmospheric pressure, 1 atms, note strength profile at zero pressure, as compared to pressure at 10 psi and 20 psi, note as below:

Graph 2



Early-age carbonation curing of concrete products result in improved early strength, increased surface hardness, and reduced surface permeability to water, also well as the potential for efflorescence. Carbonation reaction between carbon dioxide and appropriate calcium compounds result in permanent fixture of the carbon dioxide in a thermodynamically stable calcium carbonate.

Reaction in a static system is extremely rapid, but as has been shown in this analysis, moisture addition is not needed since relative humidity is typically greater than 70%. Also a two hour preset time seems to develop better 2 hour compressive strengths, as compared to no preset time interval. The addition of 50/50, CO2 to air ratio, at a high flow rate developed better compressive strengths, than the low flow rate.

Additional temperature increase is needed to continue development of optimum 2 hour compressive strengths by an external heating element. This external heating element could be installed within the curing chamber and controlled depending on the temperature monitoring of the concrete masonry units.

The flow rate of CO2 and air also needs refinement in order to optimize the 2 hour development of compressive strength at an addition flow rate of 50/50 or less than 50/50 to 25/75, CO2 to air flow rate. Theoretically the curing chambers' volume occupies 32 cubic feet and the reaction is within 30 minutes of reaction, a flow rate of 64 cubic feet/hour is necessary, in a concentrated 100% CO2, thus in a 50% or 25% CO2 addition, a flow rate of between 128 cubic feet/hour to 256 cubic feet/ hour is needed. The objective is to enhance the 2 hour compressive strength development higher than the 2 hour strength at a curing chamber of 20 psi or a compressive strength greater than 700 psi. 2 hour normal kiln cured concrete masonry units have strengths around 200 psi, whereas all of the CO2 cured CMU's range from 120 psi to 400 psi. The 42 hour compressive strengths range from 1500 psi to 1700 psi and at 28 days all CMU's compressive strengths are above 3000 psi, thus all CMU's have met the compressive strength requirement of ASTM C90, Standard Specification for Loadbearing Concrete Masonry Units.