Permanent Linear Change Anomaly in Less Than 80 lbs/ft^3 Insulating Castables

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Contents

Executive Summary

When a cured refractory is heated to high temperatures, it goes through mineralogical phase changes that will affect the volume of the refractory measured after it has cooled down. Knowing this permanent linear change (PLC) is important because excessive shrinkage can cause cracking that can eventually cause premature failure in the refractory. However, an anomaly has been seen in the field where extended hydration time of field samples of conventional insulating castables with densities less than 80 lbs/cubic foot had a substantial impact on the dried 230°F to 1500 °F PLC when compared to pre-shipment and/or pre-qualification PLC data.

Cursory lab data indicates that after 264 hours (11 days) of hydration time, the dried 230°F to fired 1500°F PLC changes substantially. This will lead to the samples being out of specification, even though the installed refractory looked, sounded, and tested within specification. This anomaly is likely due to the microstructural changes that occur when the cement hydrates convert from the metastable C2AH8 phase to the stable C3AH6 phase over this period. This conversion results in increased porosity that allows for compaction of the minerals when they undergo phase changes during firing.

It was concluded from the data generated in this study that the PLC of insulating castable test samples was influenced by the hydration time. Even though the limited testing performed in this study showed increased PLC after 11 days, it is prudent to test samples within 7 days after placement.

Based on the reported findings, future testing should include larger scale wall panel PLC testing where heat is only applied to one face (the hot face) to see if this phenomenon is truly a problem for vessel linings Future testing should also include expanding the density range of insulation castable to see the extend that is affected by this anomaly. This includes insulating castables with density higher than 80 pcf as well as ultra-lightweight insulation castables, less than 50 pcf.

Permanent Linear Change Anomaly in Less Than 80 lbs/ft^3 Insulating Castables

1 Scope

This report documents an observed anomaly with permanent linear change (PLC) of insulating castables. The length of hydration time is shown to impact the permanent linear change when samples are subsequently fired to 816°C (1500°F). The sample preparation and testing were performed by an independent lab on behalf of API Refractory Projects Group.

2 Normative References

No other document is identified as indispensable or required for the application of this report. A list of documents associated with API 983 are included in the Bibliography.

3 Terms, Definitions, Abbreviations and Acronyms

3.1 Terms and Definitions

3.1.1
castable (refractory)
A combination of refractory grain (aggregate) and suitable bonding agent that, after the addition of a proper liquid, is installed into place to form a monolithic shape or structure that becomes rigid because of thermal or chemical action.

3.1.2
cement (refractory)
A powdery substance that is mixed with water and will harden by itself hydraulically and generally bind larger aggregates into a refractory system. Refractory cements are higher temperature materials and generally are based on calcium aluminates but can include other materials such as hydrated alumina.

3.1.3
curing
Process of bond formation in a newly installed monolithic refractory.

NOTE For hydraulic bonded castables, curing occurs at room temperature and is facilitated by an excess of water being present to react with the cement component. For phosphate-bonded plastic refractories, heating to 500 °F to 700 °F (260 °C to 370 °C) is required to form the bond.

3.1.4
density
The mass of a unit volume of a substance, usually expressed in kilograms per cubic meter (kg/m^3), grams per cubic centimeter (gm/cm^3), or pounds per cubic foot (lb/ft^3).

3.2 Abbreviations and Acronyms

CA calcium aluminate

CCS cold crush strength

MOR modulus of rupture

PLC permanent linear change

4 Background

4.1 General

Insulating castables are compositions that typically contain lightweight insulating aggregates and generally use a high percentage of calcium aluminate (CA) cement binder. Higher water percentages are required for insulating castables in order to properly wet out and hydrate the high percentage of cement binder. The densities of insulating castables range from 35 pcf to 100 pcf. They typically have K-Factors in the 1 to 4 BTU·in/hr·ft² range and are used as back-up insulation or as a hot face lining in fired heater convection sections, ducts, stacks, and breaching sections.

Permanent linear change (PLC) is the linear change in a dimensional measurement on a sample after heat treatment. Samples are typically soap samples, which are (9" x 9" x 2), although dimensions can differentiate. This soap sample is measured after curing, drying and firing and a percentage change is determined. This is important because high shrinkage or expansion can produce cracking and lead to premature failure.

An irregularity was seen in the field when the field samples of an insulating castable did not meet the dried 230°F to 1500°F PLC specification when the pre-shipment and pre-qualification testing were within specification, as well as passing visual and audio inspection of the as-installed material. Follow up analysis showed that the only difference between the field installation and the other samples was the hydration time or time before the samples saw heat. In other words, as the hydration time increases there is a point in time where the 1500 °F PLC will start to increase. This problem may be unavoidable because it is often impossible to cast, dry, and test field samples in a timely manner. The testing time is affected by logistics, the number of samples, and the testing laboratory's capacity and capability.

4.2 Why is This a Problem?

Field samples are generally sent out in batches rather than daily. This lends to increased time before the samples sees temperature and allows for more hydration time. If this happens, then installed material will be rejected and have to be torn out, even though every other test indicates that the material is good and has been installed properly.

4.3 API Sponsored Study

This problem was presented to the API 936 committee, and they agreed that it was worth looking further into this by sponsoring an independent lab to do a study. They looked at how hydration time affects dried 230°F to 1500 °F PLC on a generic 2300 °F insulating castable.

5 Test Procedure

5.1 General

An independent testing lab was selected to perform this study. They mixed, casted, and tested PLC bars per ASTM C113.

5.2 Test Preparation

A generic 2300 °F rated insulating castable was designed as shown in Table 1 and labeled API-1.

Table 1—Generic 2300 °F Insulating Castable (API-1)

Raw Material	Weight Percentage of Mix
Fireclay Aggregate	37
Perlite	23
Raw Kaolin Clay	10
50% Calcium Aluminate (CA) Cement	30

In the design of API-1, it was determined that 43.4 weight percent water was required for it to be casted. This water content produced a good ball-in-hand and had a tapped flow of 6.512 after tapping it 15 times on a flow table. 240 lbs. of API-1 mix was sent to the independent laboratory where it was blended into a uniform batch where 35-pound batches were then used in this study.

5.3 Sample Preparation

All the 35-pound batches were mixed in a 30-quart planetary mixer. Each batch had enough material to cast four shoebox molds (9” x 4.5” x 4.5”). For each batch, 32.55 weight % of the required water was placed in the mixer bowl, then the dry material was placed in the mixer bowl. The remaining 10.85 weight % of the required water was added on top of the dry mix to help prevent dust generation. The batch was then mixed for one minute on Speed 1. The speed was increased to Speed 2 and mixed another five minutes (six total minutes of mixing). The mixed material was then casted into the shoebox molds and each mold was covered in plastic sheeting to prevent water evaporation. Each shoebox mold was placed in a curing room for 24 hours. This process was repeated five times for a total of 20 shoebox molds.

After the 24-hour curing, each shoebox was cut into four 9” x 2” x 2” bars (80 total bars). Each bar was labeled according to the Batch number (1-5) and a letter (A-P) (i.e., 3F). Then the initial cured length (9” dimension) was measured with calipers for each bar and recorded. All the bars were placed into resealable plastic bags for the additional cure times. Each letter was allotted number of hours to cure at as per Table 2. Cure hours 48 and 96 were skipped because it was determined that this was too short of a cure length to see the PLC anomaly. Cure hours 72 was kept to have linear progression of the data.

Table 2—Cure Times

Letter Code	Cure Hours	Specimen Names
A	24	1A, 2A, 3A, 4A, 5A
B	72	1B, 2B, 3B, 4B, 5B
C	120	1C, 2C, 3C, 4C, 5C
D	144	1D, 2D, 3D, 4D, 5D
E	168	1E, 2E, 3E, 4E, 5E
F	192	1F, 2F, 3F, 4F, 5F
G	216	1G, 2G, 3G, 4G, 5G
H	240	1H, 2H, 3H, 4H, 5H
I	264	1I, 2I, 3I, 4I, 5I

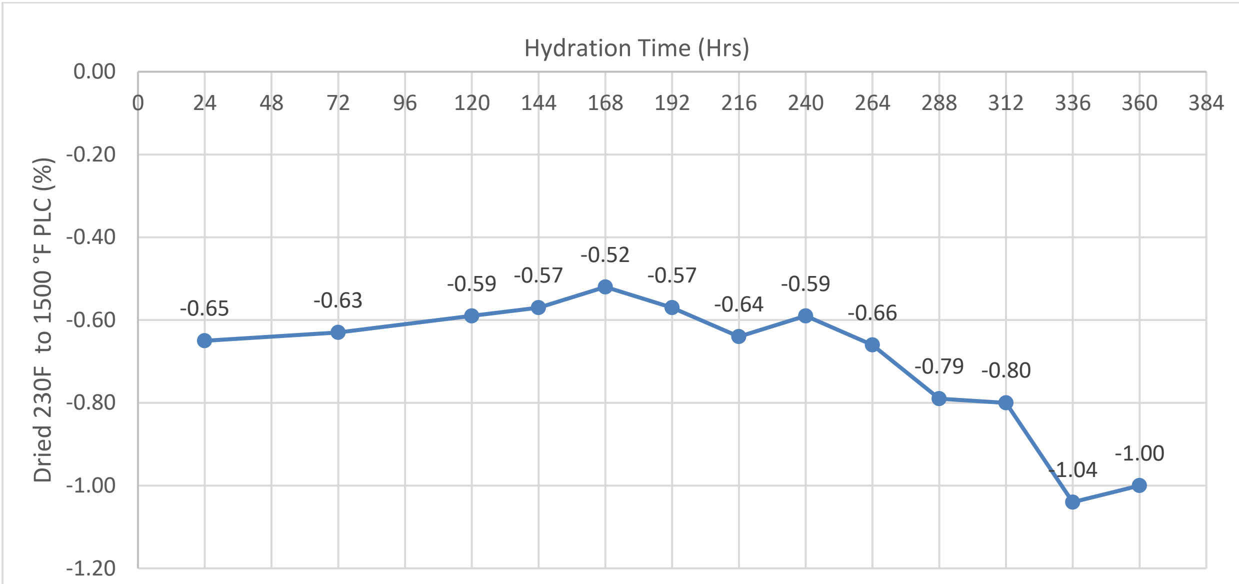
J	288	1J, 2J, 3J, 4J, 5J
K	312	1K, 2K, 3K, 4K, 5K
L	336	1L, 2L, 3L, 4L, 5L
M	360	1M, 2M, 3M, 4M, 5M
N		Extra Bars
O		Extra Bars
P		Extra Bars

5.4 Sample Testing

Each bar sample sat in the sealed plastic bags until it reached the desired total cure time. Samples were removed from the plastic bags and width, depth, length, and weight were measured according to ASTM C113 and ASTM C134. This information was used to determine the cured density. Sample bars were then oven dried to 230 °F for 20 hours. Bars were allowed to cool to room temperature and remeasured and reweighed for dried density. Bars were then fired to 1500 °F at 300 °F/hr and held at temperature for five hours. After cooling to room temperature, fired bars were remeasured and reweighed to determine fired density. Modulus of rupture (MOR) was performed on each by according to ASTM C133. Three 2” x 2” x 2” cubes were cut from each broken bar with a wet saw. These cubes were oven dried at 230 °F to remove all water from wet sawing. ASTM C133 was performed on all cubes to determine cold crush strength (CCS).

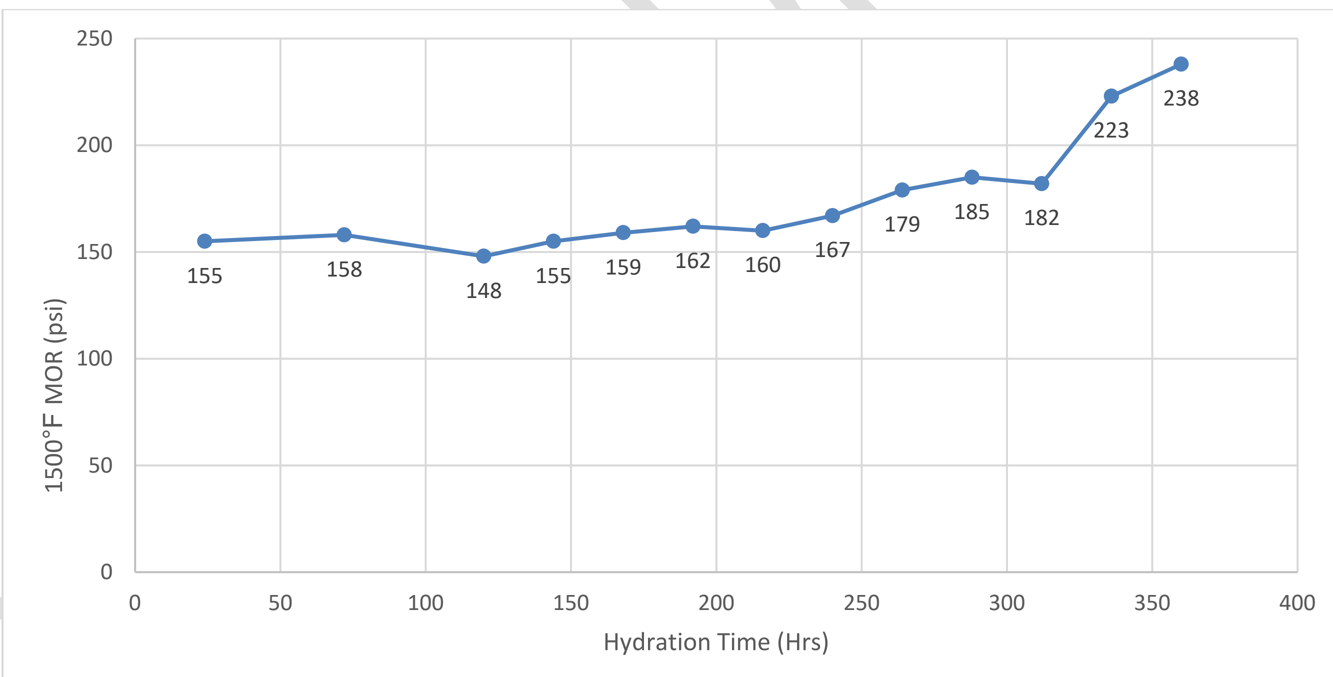
6 Results

The raw data is tabulated and shown in Annex A. Figure 1 through Figure 4 show how the hydration time effects the 1500 °F properties.



* A negative (-) PLC number designates shrinkage in the sample

Figure 1—230°F to 1500°F PLC* vs Hydration Time



* A negative (-) PLC number designates shrinkage in the sample

Figure 2—1500°F MOR vs Hydration Time

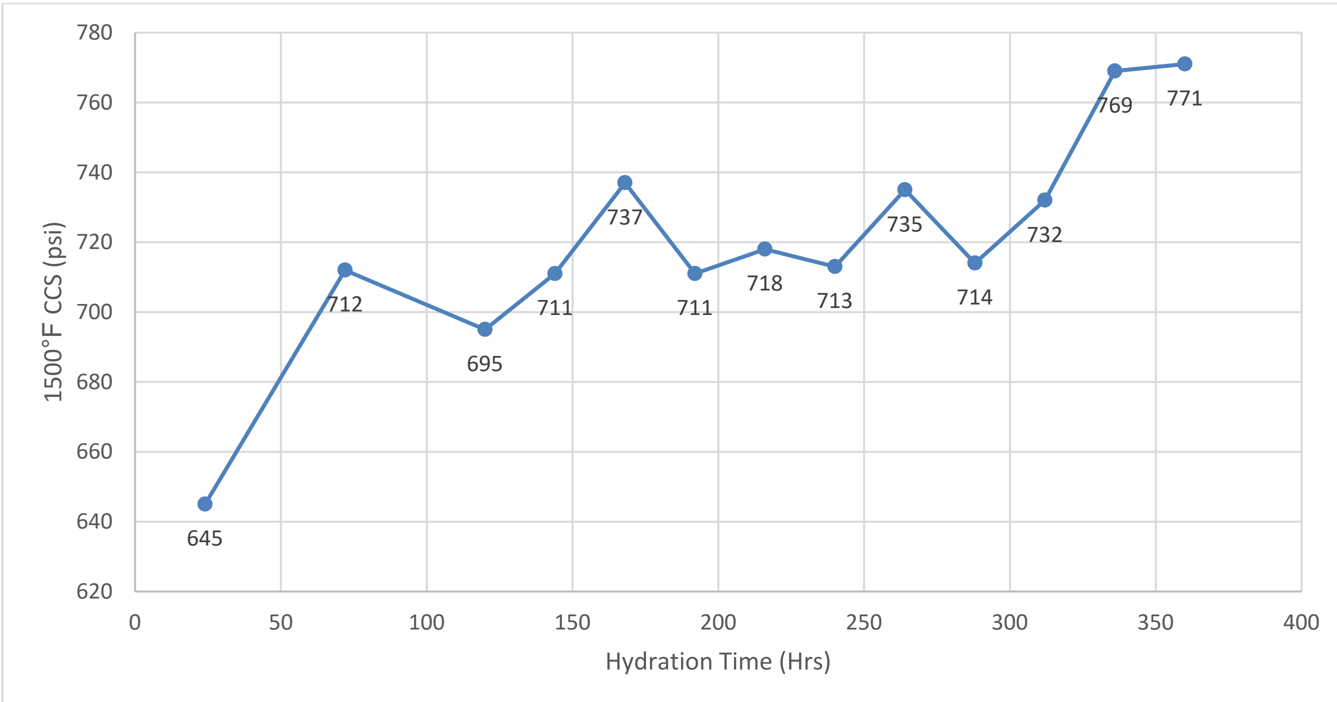


Figure 3—1500°F CCS vs Hydration Time

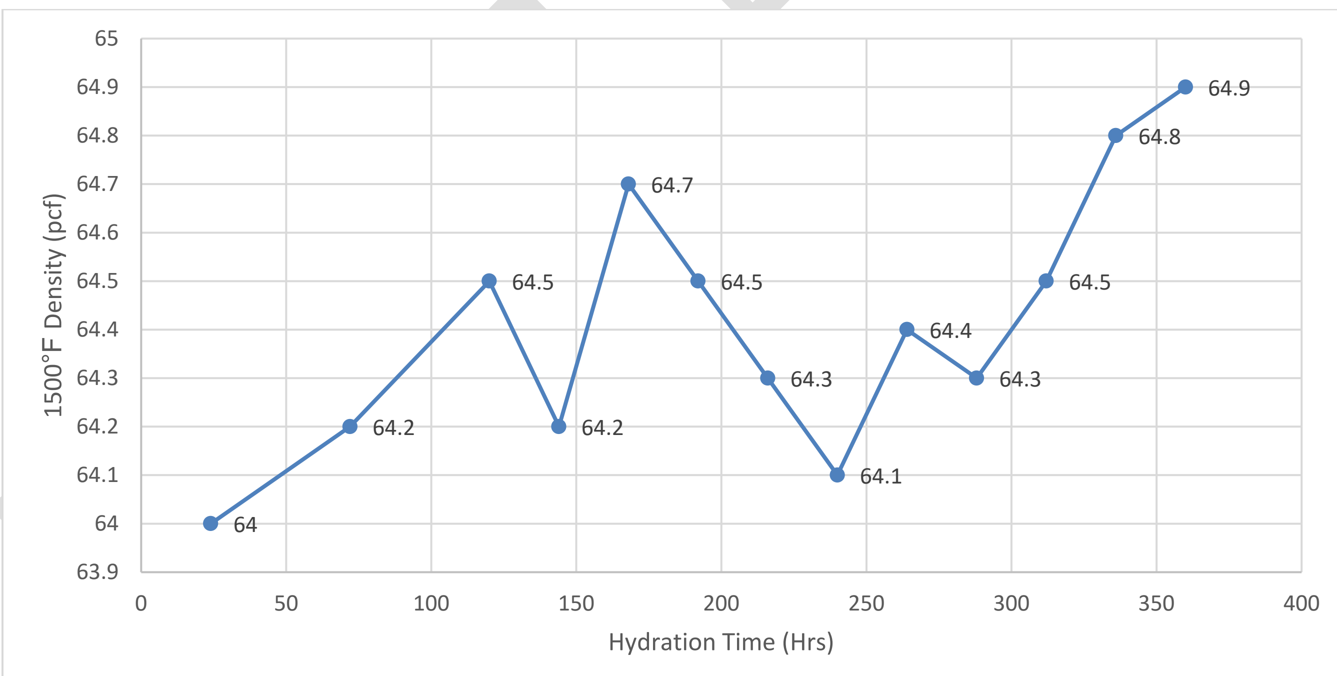


Figure 4—1500°F Density vs Hydration Time

7 Discussion of Results

As shown in Figure 1, there is a change in the 1500 °F PLC after about 264 hours (11 days) where the dried 230°F to fired 1500°F PLC went from -0.65 to -0.79 %. This change continues through 336 hours (14 days) where the PLC went from -0.65 to -1.04 %. There are also noticeable changes in the other properties, such as MOR, CCS, and density after 312 hours. It is felt that conversion causes these changes also. The density increases, which in turn increases the MOR and CCS.

8 Conclusions

It can be concluded that there is a definite effect on the 1500 °F (816 °C) PLC when the hydration time reaches a certain level in a high calcium aluminate (CA) cement containing insulating castable. CA cement phase formations are subject to an inevitable but manageable thermodynamic phenomenon called conversion [2.5]. Below 158 °F (70 °C), the hydrates (C2AH8) formed are metastable and will convert into stable hydrates (C3AH4) with time and/or temperature. This conversion phenomenon is a dissolution/precipitation process. The volume of the stable hydrates is smaller than that of the metastable ones. The loss of volume leads to an increase of porosity. It is felt that this conversion may explain the increase in shrinkage that was seen in the samples after hydrating 264 hours (11 days). The increased porosity (voids) allowed for additional compaction of the minerals that underwent phase changes during the firing process.

NOTE This study was done on one mix with one type of CA Cement. Because of this limited evaluation, a manufacturer may be conservative and recommend that samples start to be tested within seven days.

9 Recommendations

Based on the reported findings, future testing should include larger scale wall panel PLC testing where heat is only applied to one face (the hot face) to see if this phenomenon is truly a problem for vessel linings. The panel surface area needs to be large enough to account for Thermal Expansion considerations. Future testing should also include expanding the density range of insulation castable to see the extend that is affected by this anomaly. This includes insulating castables with density higher than 80 pcf as well as ultra-lightweight insulation castables, less than 50 pcf.

Annex A
(informative)

Tabulated Test Results

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
24	1	1	1A	88.3	68.5	63.2	9.080	9.080	9.072	9.014	0.00	-0.09	-0.64	-0.73	149	612
24	1	1	2A	90.3	70.1	64.4	9.070	9.070	9.062	9.007	0.00	-0.09	-0.61	-0.69	164	700
24	1	1	3A	89.5	68.9	64.3	8.974	8.974	8.968	8.906	0.00	-0.07	-0.69	-0.76	148	630
24	1	1	4A	89.3	68.9	64.0	8.991	8.991	8.981	8.919	0.00	-0.11	-0.69	-0.80	154	593
24	1	1	5A	89.4	69.6	63.9	9.062	9.062	9.056	9.000	0.00	-0.07	-0.62	-0.68	161	692
			Averages	89.4	69.2	64.0				Averages	0.00	-0.08	-0.65	-0.73	155	645

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
72	3	1	1B	90.2	70.1	64.0	9.052	9.052	9.046	8.988	0.00	-0.07	-0.64	-0.71	178	723
72	3	1	2B	89.8	70.2	64.2	9.067	9.066	9.061	9.003	-0.01	-0.06	-0.64	-0.71	151	777
72	3	1	3B	90.7	70.7	65.0	9.024	9.024	9.017	8.964	0.00	-0.08	-0.59	-0.66	158	726
72	3	1	4B	89.7	69.5	63.3	8.898	8.898	8.892	8.841	0.00	-0.07	-0.57	-0.64	142	691
72	3	1	5B	90.4	70.0	64.8	9.068	9.068	9.062	8.998	0.00	-0.07	-0.71	-0.77	159	642
			Averages	90.2	70.1	64.2				Averages	0.00	-0.07	-0.63	-0.70	158	712

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
120	5	1	1C	90.7	70.0	64.2	9.049	9.049	9.039	8.974	0.00	-0.11	-0.72	-0.83	147	748
120	5	1	2C	90.0	69.5	64.3	9.048	9.048	9.038	8.985	0.00	-0.11	-0.59	-0.70	167	750
120	5	1	3C	89.4	69.2	64.3	9.095	9.095	9.088	9.037	0.00	-0.08	-0.56	-0.64	139	639
120	5	1	4C	89.6	70.0	64.3	9.098	9.098	9.088	9.040	0.00	-0.11	-0.53	-0.64	136	647
120	5	1	5C	90.1	69.9	65.5	9.011	9.011	9.004	8.956	0.00	-0.08	-0.53	-0.61	153	689
			Averages	90.0	69.7	64.5				Averages	0.00	-0.10	-0.59	-0.68	148	695

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
144	6	1	1D	88.9	69.4	63.0	9.036	9.036	9.026	8.981	0.00	-0.11	-0.50	-0.61	148	752
144	6	1	2D	90.0	69.4	63.5	9.087	9.087	9.076	9.022	0.00	-0.12	-0.59	-0.72	159	694
144	6	1	3D	90.1	70.0	64.1	9.085	9.085	9.075	9.016	0.00	-0.11	-0.65	-0.76	178	700
144	6	1	4D	90.1	70.3	64.7	9.103	9.103	9.094	9.047	0.00	-0.10	-0.52	-0.62	145	695
144	6	1	5D	90.5	70.6	65.7	9.065	9.065	9.057	9.005	0.00	-0.09	-0.57	-0.66	142	713
			Averages	89.9	70.0	64.2				Averages	0.00	-0.11	-0.57	-0.67	155	711

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
168	7	1	1E	89.7	69.9	63.8	9.068	9.068	9.059	9.009	0.00	-0.10	-0.55	-0.65	160	696
168	7	1	2E	89.3	69.7	63.5	9.071	9.071	9.063	9.019	0.00	-0.09	-0.49	-0.57	161	712
168	7	1	3E	91.3	71.1	65.3	9.064	9.064	9.056	9.007	0.00	-0.09	-0.54	-0.63	157	747
168	7	1	4E	90.6	70.6	65.0	8.859	8.859	8.851	8.806	0.00	-0.09	-0.51	-0.60	160	759
168	7	1	5E	91.1	71.5	65.7	9.001	9.001	8.993	8.947	0.00	-0.09	-0.51	-0.60	156	768
			Averages	90.4	70.6	64.7				Averages	0.00	-0.09	-0.52	-0.61	159	737

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
192	8	1	1F	89.9	69.6	63.9	9.070	9.070	9.058	8.999	0.00	-0.13	-0.65	-0.78	150	711
192	8	1	2F	89.9	70.2	64.4	9.053	9.053	9.044	8.993	0.00	-0.10	-0.56	-0.66	154	701
192	8	1	3F	90.5	70.9	64.7	9.049	9.049	9.040	8.995	0.00	-0.10	-0.50	-0.60	181	681
192	8	1	4F	90.1	70.1	64.7	8.970	8.970	8.959	8.907	0.00	-0.12	-0.58	-0.70	164	715
192	8	1	5F	90.3	70.4	64.6	9.016	9.016	9.008	8.957	0.00	-0.09	-0.57	-0.65	161	749
			Averages	90.2	70.2	64.5				Averages	0.00	-0.11	-0.57	-0.68	162	711

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
216	9	1	1G	89.7	69.7	63.9	9.085	9.085	9.085	9.021	0.00	0.00	-0.70	-0.70	158	675
216	9	1	2G	90.0	70.2	63.7	9.054	9.054	9.054	8.992	0.00	0.00	-0.68	-0.68	182	759
216	9	1	3G	91.2	70.7	63.8	9.093	9.093	9.093	9.029	0.00	0.00	-0.70	-0.70	154	763
216	9	1	4G	89.4	70.1	64.3	8.992	8.992	8.982	8.930	0.00	-0.11	-0.58	-0.69	150	661
216	9	1	5G	90.5	70.7	65.9	9.003	9.003	8.993	8.945	0.00	-0.11	-0.53	-0.64	158	732
			Averages	90.2	70.3	64.3				Averages	0.00	-0.04	-0.64	-0.69	160	718

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired		Cured - Dried	Dried - Fired	Green - Fired		
240	10	1	1H	90.2	69.9	63.6	9.036	9.036	9.029	8.979	0.00	-0.08	-0.55	-0.63	172	787
240	10	1	2H	90.0	70.4	64.2	9.059	9.059	9.050	9.000	0.00	-0.10	-0.55	-0.65	174	780
240	10	1	3H	90.3	70.1	64.0	9.057	9.057	9.047	8.996	0.00	-0.11	-0.56	-0.67	160	687
240	10	1	4H	89.8	69.9	64.3	9.014	9.014	9.006	8.946	0.00	-0.09	-0.67	-0.75	158	643
240	10	1	5H	90.6	70.0	64.6	9.025	9.025	9.017	8.961	0.00	-0.09	-0.62	-0.71	170	668
			Averages	90.2	70.0	64.1				Averages	0.00	-0.09	-0.59	-0.68	167	713

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
264	11	1	1I	88.1	69.0	63.7	9.092	9.092	9.084	9.022	0.00	-0.09	-0.68	-0.77	185	709
264	11	1	2I	90.0	70.3	64.6	9.061	9.060	9.050	8.988	-0.01	-0.11	-0.69	-0.81	189	753
264	11	1	3I	90.3	70.7	64.4	9.083	9.083	9.072	9.009	0.00	-0.12	-0.69	-0.81	171	764
264	11	1	4I	90.1	70.3	64.6	9.109	9.109	9.099	9.045	0.00	-0.11	-0.59	-0.70	176	763
264	11	1	5I	89.7	69.9	64.6	9.030	9.030	9.018	8.962	0.00	-0.13	-0.62	-0.75	172	688
			Averages	89.6	70.0	64.4				Averages	0.00	-0.11	-0.66	-0.77	179	735

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
288	12	1	1J	89.5	69.4	64.0	9.095	9.095	9.085	9.020	0.00	-0.11	-0.72	-0.82	179	797
288	12	1	2J	89.7	69.8	64.4	9.072	9.072	9.062	8.999	0.00	-0.11	-0.70	-0.80	167	687
288	12	1	3J	90.3	69.8	64.4	9.106	9.106	9.095	9.025	0.00	-0.12	-0.77	-0.89	198	695
288	12	1	4J	90.8	70.3	64.8	9.110	9.110	9.101	9.020	0.00	-0.10	-0.89	-0.99	200	699
288	12	1	5J	89.7	69.4	64.0	9.010	9.010	8.998	8.920	0.00	-0.13	-0.87	-1.00	178	693
			Averages	90.0	69.7	64.3				Averages	0.00	-0.11	-0.79	-0.90	185	714

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
312	13	1	1K	89.0	70.2	63.9	9.109	9.109	9.097	9.024	0.00	-0.13	-0.80	-0.93	180	715
312	13	1	2K	90.6	71.4	65.4	9.074	9.074	9.062	8.994	0.00	-0.13	-0.75	-0.88	180	758
312	13	1	3K	90.5	70.7	65.1	9.009	9.009	8.997	8.926	0.00	-0.13	-0.79	-0.92	171	738
312	13	1	4K	89.5	69.7	64.1	9.056	9.055	9.045	8.974	-0.01	-0.11	-0.78	-0.91	192	722
312	13	1	5K	89.8	70.3	64.5	9.071	9.071	9.062	8.983	0.00	-0.10	-0.87	-0.97	188	728
			Averages	89.9	70.5	64.6				Averages	0.00	-0.12	-0.80	-0.92	182	732

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
336	14	1	1L	90.3	71.2	65.7	9.103	9.103	9.093	9.013	0.00	-0.11	-0.88	-0.99	196	807
336	14	1	2L	90.5	70.5	65.6	9.071	9.071	9.060	8.954	0.00	-0.12	-1.17	-1.29	223	813
336	14	1	3L	90.5	70.6	65.0	9.036	9.036	9.026	8.938	0.00	-0.11	-0.97	-1.08	205	748
336	14	1	4L	89.4	70.4	64.6	9.034	9.034	9.025	8.937	0.00	-0.10	-0.98	-1.07	255	737
336	14	1	5L	89.3	69.4	63.3	9.005	9.005	8.995	8.885	0.00	-0.11	-1.22	-1.33	238	741
			Averages	90.0	70.4	64.8				Averages	0.00	-0.11	-1.04	-1.15	223	769

Curing Time		Number of Samples	Sample Number	Density pcf			PLC								MOR psi	CCS psi
							Bar Length in				PLC %					
Hours	Days			Cured	Dried	Fired	Green	Cured	Dried	Fired	Green - Cured	Cured - Dried	Dried - Fired	Green - Fired		
360	15	1	1M	91.3	71.2	65.9	9.102	9.102	9.091	9.004	0.00	-0.12	-0.96	-1.08	237	750
360	15	1	2M	88.9	69.7	64.4	9.064	9.064	9.054	8.963	0.00	-0.11	-1.01	-1.11	243	813
360	15	1	3M	90.8	70.8	65.3	9.098	9.098	9.088	8.980	0.00	-0.11	-1.19	-1.30	238	796
360	15	1	4M	89.8	70.7	65.2	9.023	9.023	9.012	8.910	0.00	-0.12	-1.13	-1.25	231	741
360	15	1	5M	89.2	70.0	63.8	9.003	9.003	8.993	8.928	0.00	-0.11	-0.72	-0.83	241	757
			Averages	90.0	70.5	64.9				Averages	0.00	-0.11	-1.00	-1.11	238	771

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