CAPILLARITY – A NEW WAY TO REPORT IRA

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The National Brick Research Center

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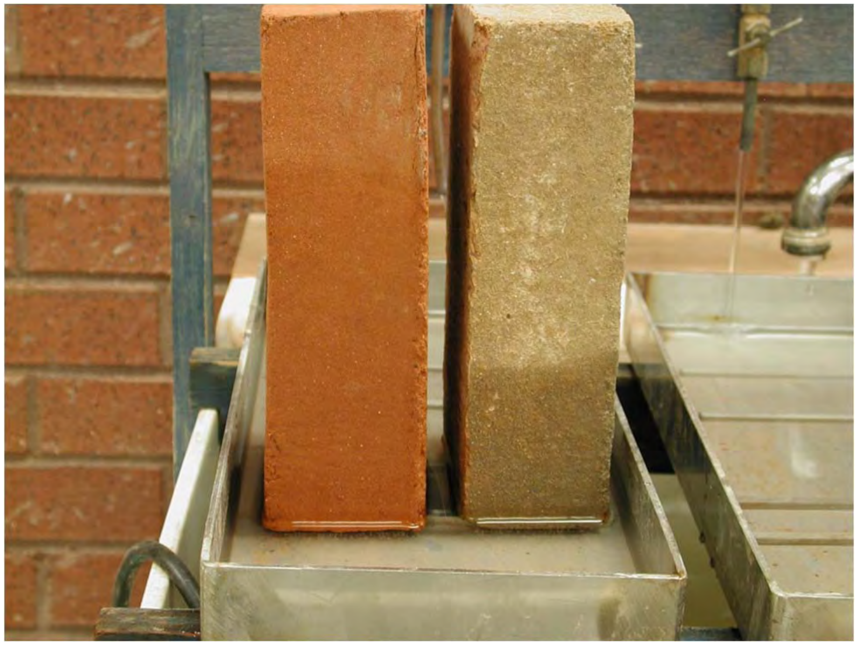
What is Capillarity?



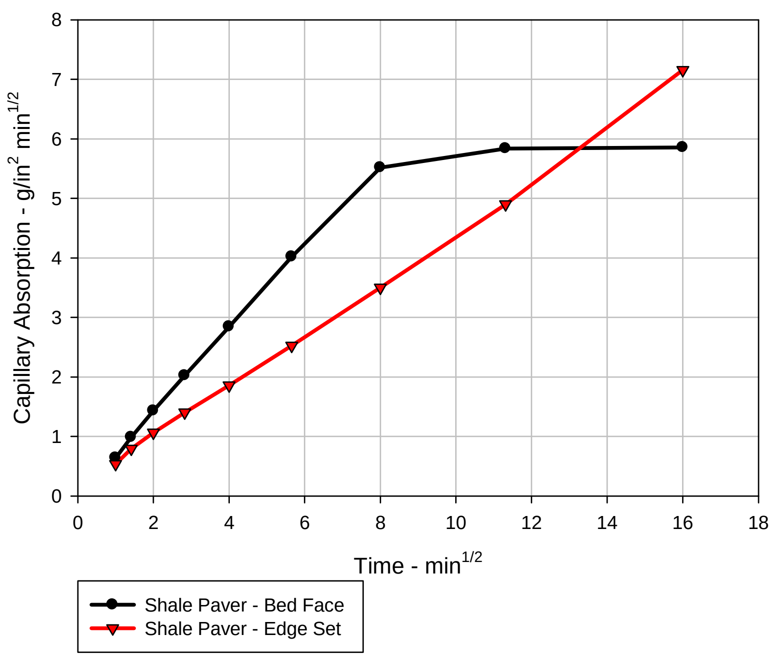
- Capillarity or Capillary Absorption is the measurement of the rate that water is absorbed by a porous solid.
- The quantity, sizes and connection of pores influence the absorption rate.
- The capillary absorption is related to the durability, porosity, pore size distribution, water absorption, and C/B ratio.
- Capillarity or Capillary Absorption is also sometimes called sorptivity or rising damp.

Measurement of Capillary Absorption

- Capillary absorption is measured like IRA, but with much more information.
- The brick is placed in a pan and a constant ¼" height of water is maintained.
- For IRA measurements, a single measurement at 1 minute is taken.
- For capillary absorption, several measurements are taken over the span of 8 to 24 hours.
  - The additional measurements allow you to calculate the rate that water is absorbed.
- Capillarity is unique in that it allows us to observe the orientation and connectivity of the pores.
  - Depending on the type of brick, we can see differences in capillary absorption parallel to the extrusion direction (bed face down) versus perpendicular due to extrusion direction (edge face down).

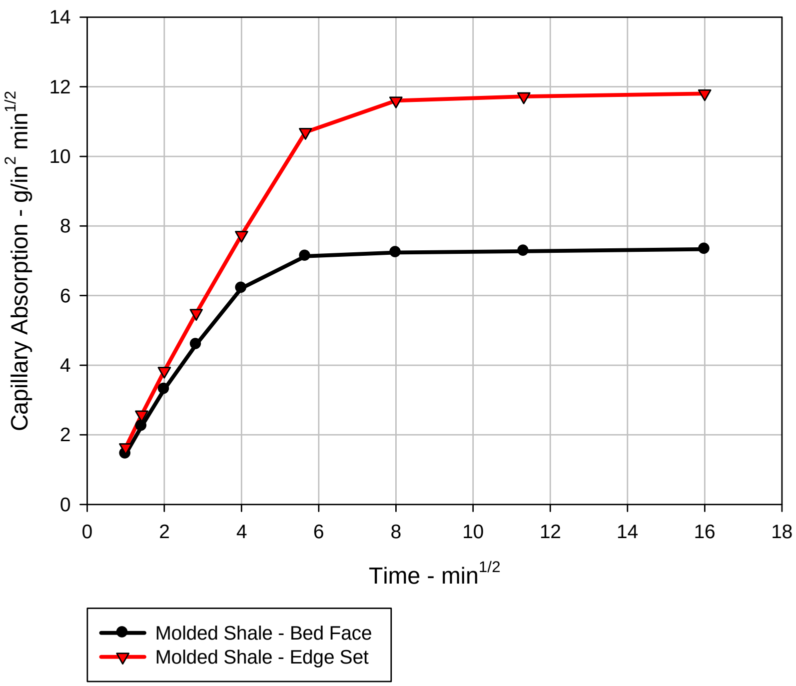
Pore Orientation and Capillary Absorption

Extruded Shale Paver



For extruded brick, it is not uncommon to see a higher absorption rate parallel to extrusion with a lower saturation level due to the alignment and connectivity of pores.

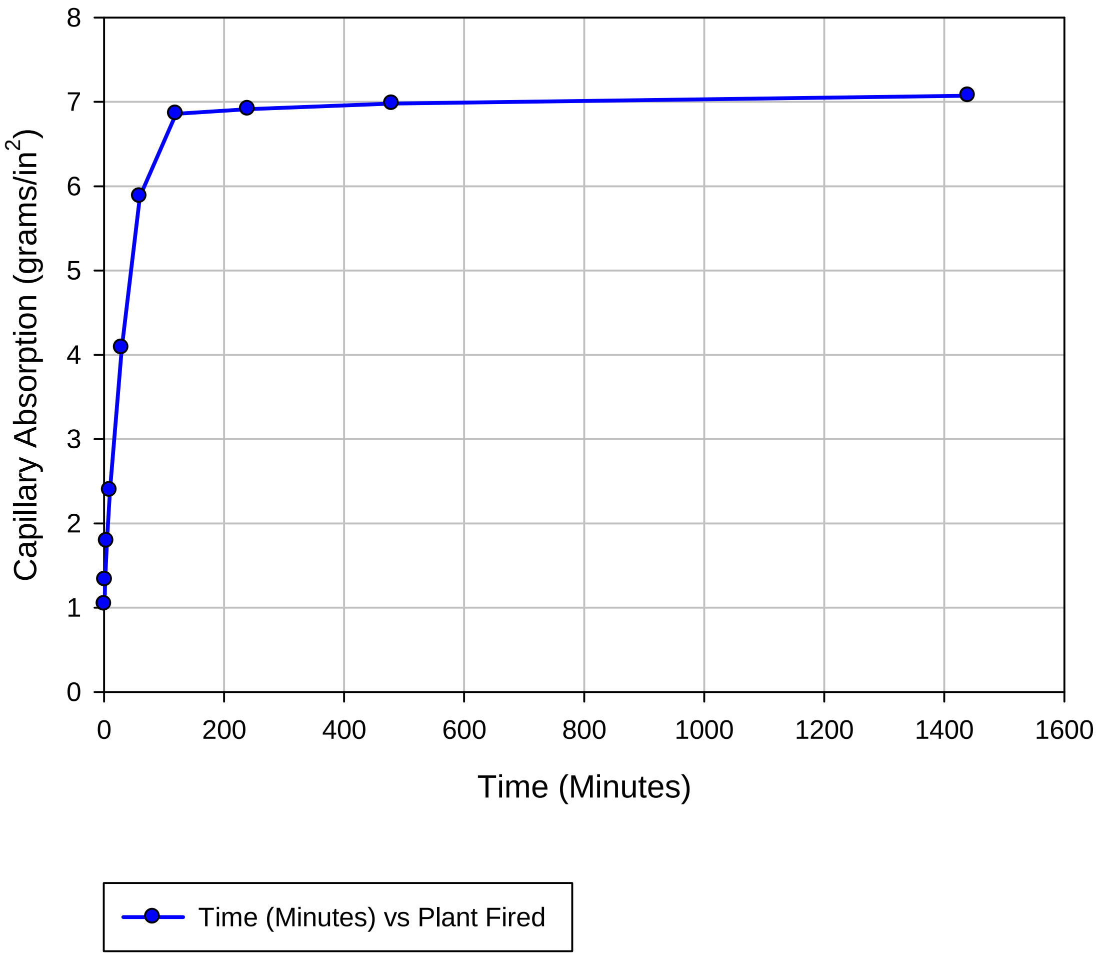
Molded Shale



For molded brick, we do not see as much difference between the orientation directions.

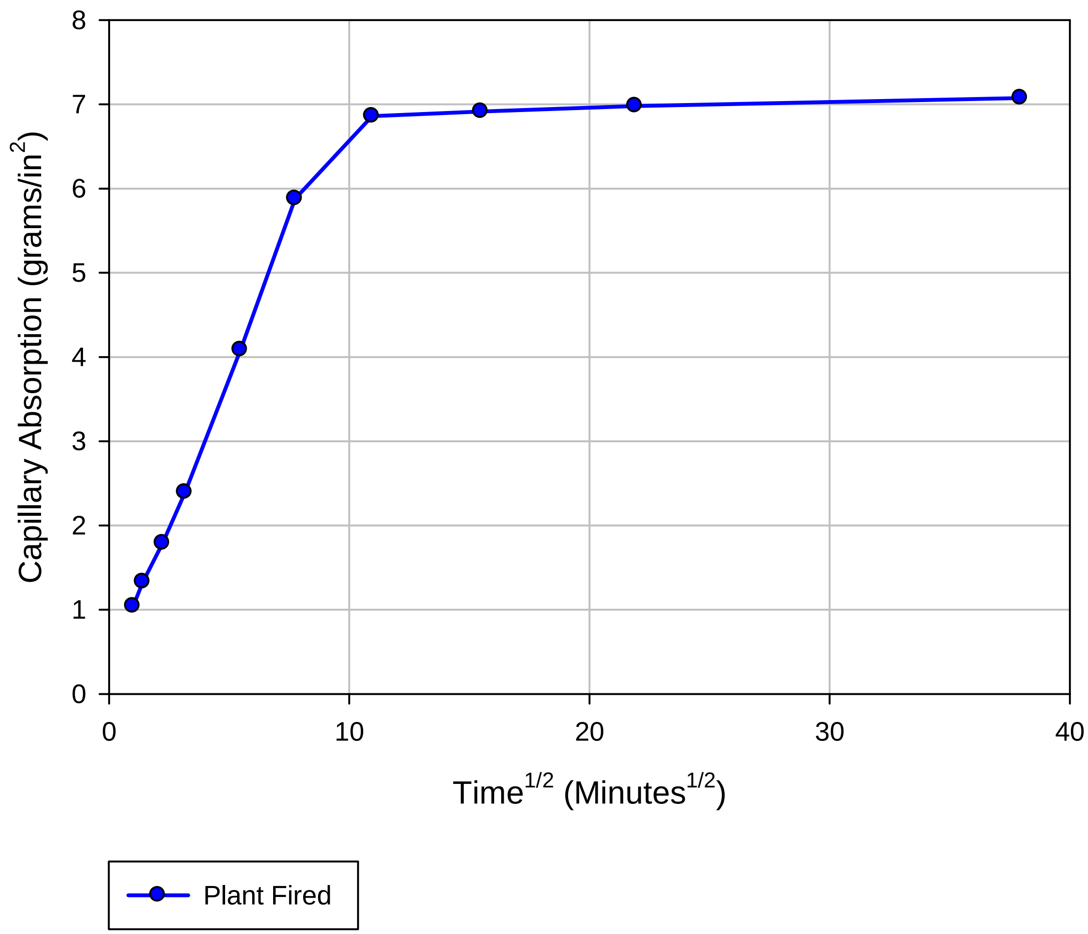
What Does Capillary Absorption Look Like?

- The capillary absorption is generally reported in units of g/in^2 while IRA is reported in units of $g/(30in^2 min)$.
- Dr. Robinson described three stages of capillary absorption.
  - Initial rapid absorption stage.
  - Declining rate stage.
  - Final stage.
- In the final stage, the brick should approach the cold water absorption value.

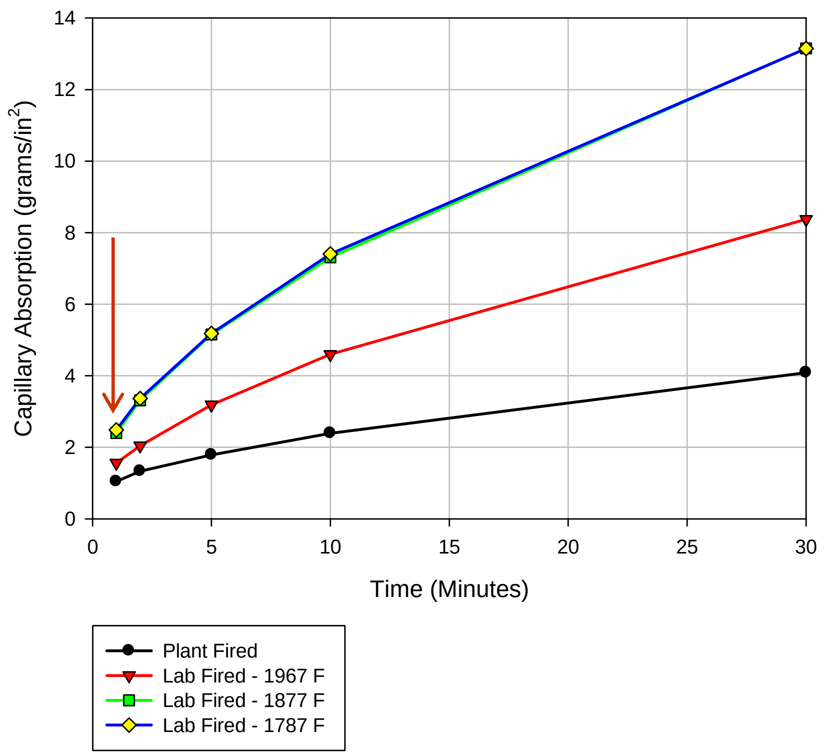


Capillary Absorption Rate

- Capillary absorption is commonly reported on a “Square Root of Time” basis.
- This linearizes the initial absorption stage and allows you to calculate an absorption rate.
- The slope of the initial stage of absorption can be calculated and is reported as the capillary absorption rate - g/(in^2 min$^{1/2}$).



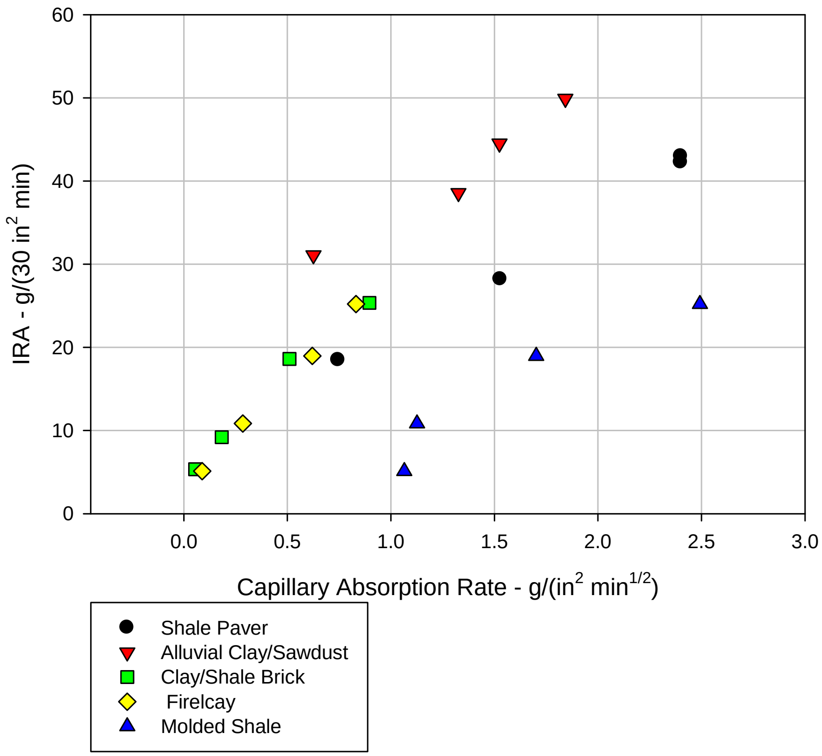
How does Capillary Absorption Compare to IRA?



- The IRA is simply the first point in the capillary absorption curve.
- While the units of IRA define it as a rate (absorption per unit area per unit time), one measurement point does not adequately define a rate.
- This imprecision and lack of information is probably one of the reasons that IRA is such a contentious issue.

How Does Capillary Absorption Compare to IRA?

- There is general agreement between the capillary absorption rate and IRA for a particular type of brick.
- We were not able to directly correlate the IRA and capillary absorption rate.
- This is due to the lack of information in the IRA measurement.



Why does Capillary Absorption Matter?

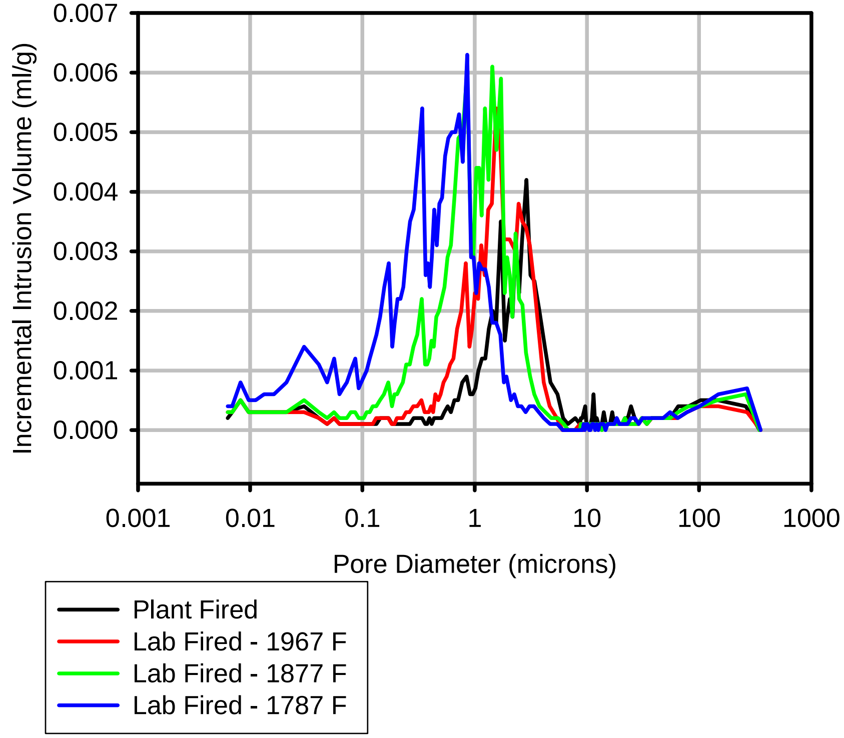
- Dr. Robinson found a relationship between capillarity and freeze thaw durability.
  - Dr. Robinson stated that durability is a function of the pore structure and the nature of the fired bond.
- For efflorescence to occur, you must have salts and the movement of water through the pores. Since capillary absorption measures how well water moves through the brick, then it must have some bearing on the efflorescence potential.
- Theoretically, the rate of capillary absorption influences the bond between brick and mortar.
  - There are several papers that say there is a relationship between IRA and flexural bond strength.
  - Yorkdale did not believe that there was a direct relationship between IRA and performance and did not feel that IRA should be included in ASTM specifications.
  - This disagreement is probably related to the lack of information contained in the IRA measurement.
  - Workmanship plays such a large role in the quality of masonry that it is hard to definitively identify the influence of other factors.
- Rising damp and moisture transfer through masonry.

The Relationship between Capillary Absorption and Other Physical Properties

Property	Capillary Absorption	Other Physical Properties
Quantity of Pores	Saturation level in capillary absorption curve	Porosity, Water Absorption, Intrusion Volume (from pore size distribution).
Size Distribution of Pores	Rate of capillary absorption	C/B ratio, pore size distribution, IRA
Orientation/Alignment of Pores	Difference in capillary absorption between the bed face and edge of a brick, rate of capillary absorption	IRA?

How does the Pore Size Distribution Evolve with Firing

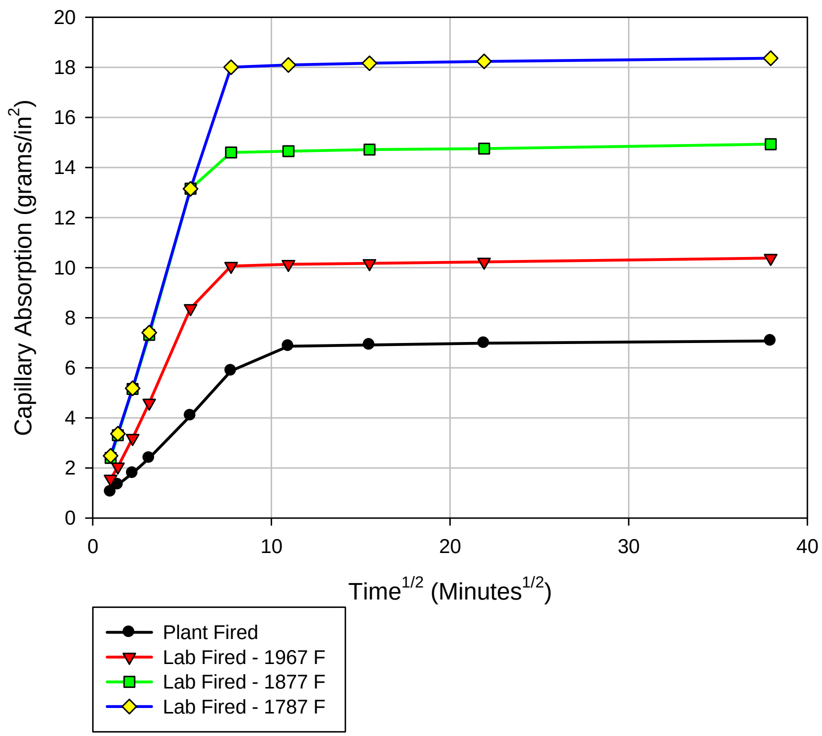
- With increased firing (more heat work), the volume of pores decreases and the average pore size shifts toward the coarser pores.
- The pore volume is represented by the area under the curve.
- The reduction in the number of small pores reduces the capillary suction.



$$H = \frac{2\sigma}{\rho g r}$$

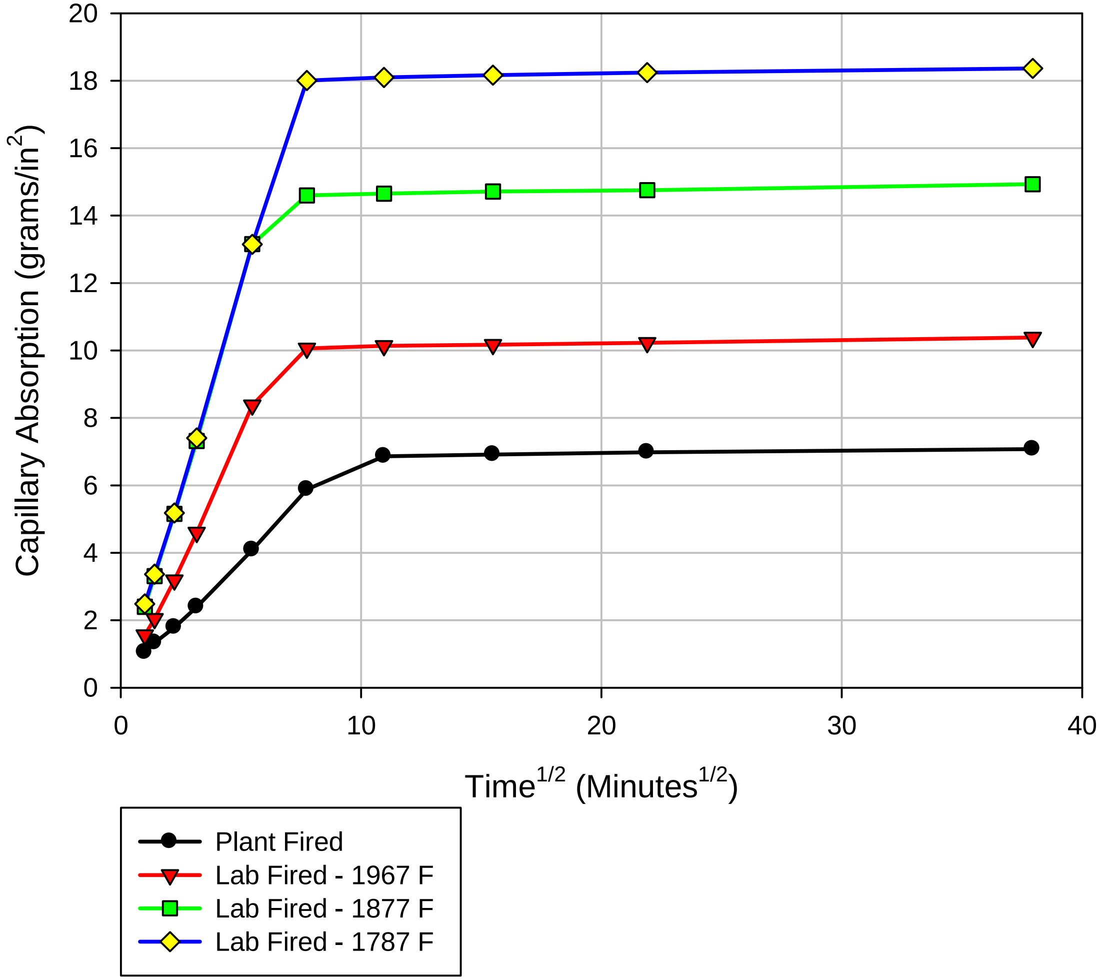
H is the capillary rise
σ is the surface tension of water
ρ is the density of water
g is the gravitational constant
r is the pore radius

The Relationship between Capillary Absorption and Pore Size



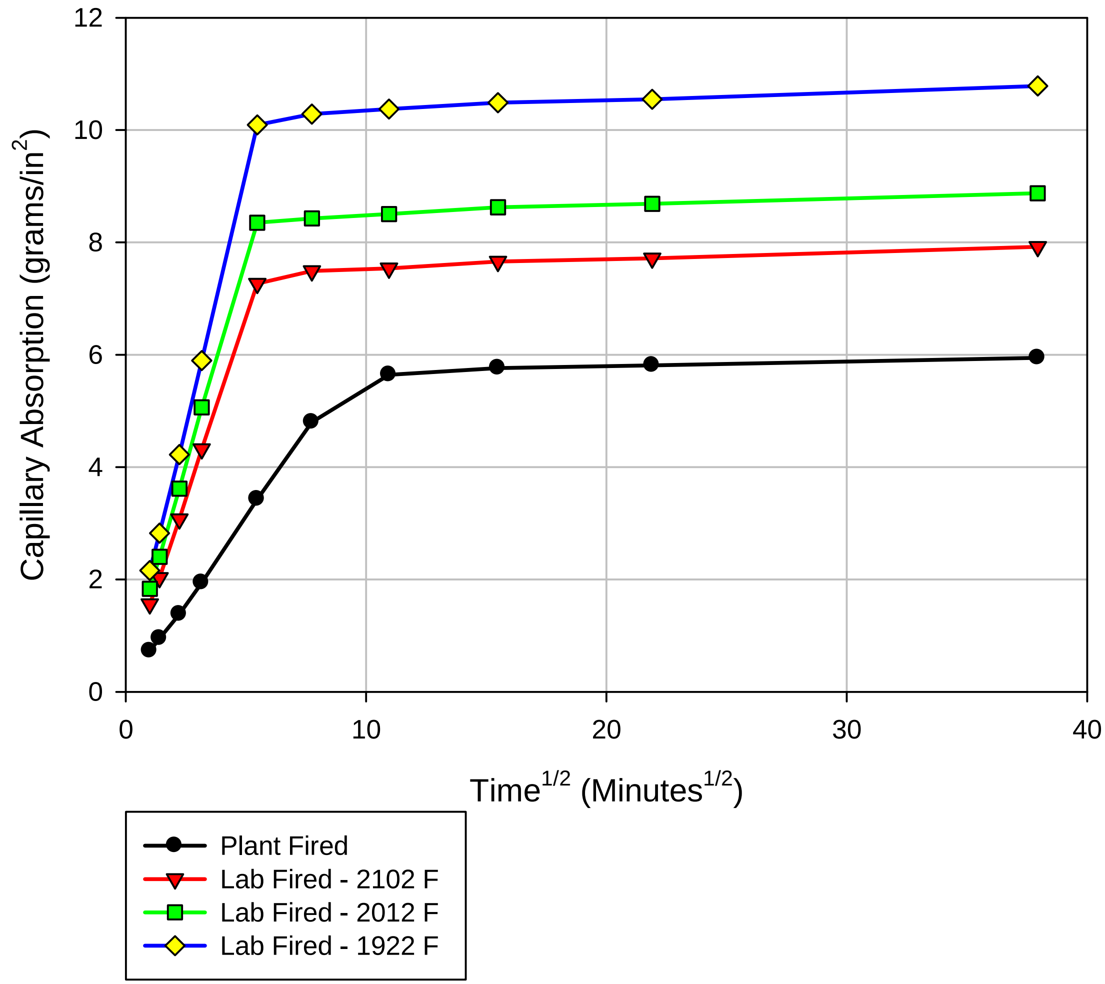
	Plant Fired	Lab Fired 1967	Lab Fired 1877	Lab Fired 1787
Porosity (%)	14.26	19.74	26.12	29.86
Pores >10µm (%)	11.8	5.2	4.1	3.7
Pores 10-1µm (%)	68.7	68.0	47.7	17.6
Pores <1µm (%)	19.5	26.9	48.2	78.7

Shale Paver

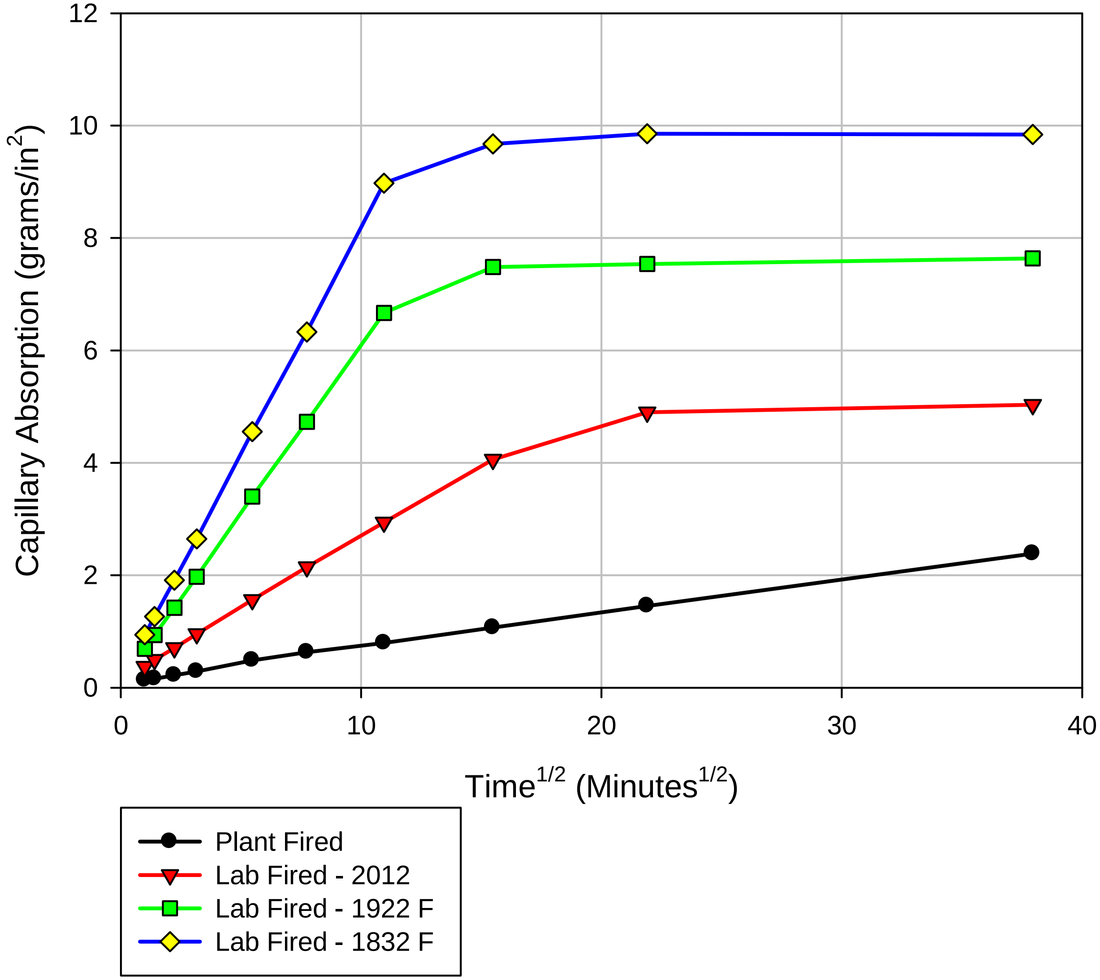


Capillary Absorption (grams/in^2)
Time$^{1/2}$ (Minutes$^{1/2}$)
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
Plant Fired
Lab Fired - 1967 F
Lab Fired - 1877 F
Lab Fired - 1787 F

Alluvial Clay/Sawdust

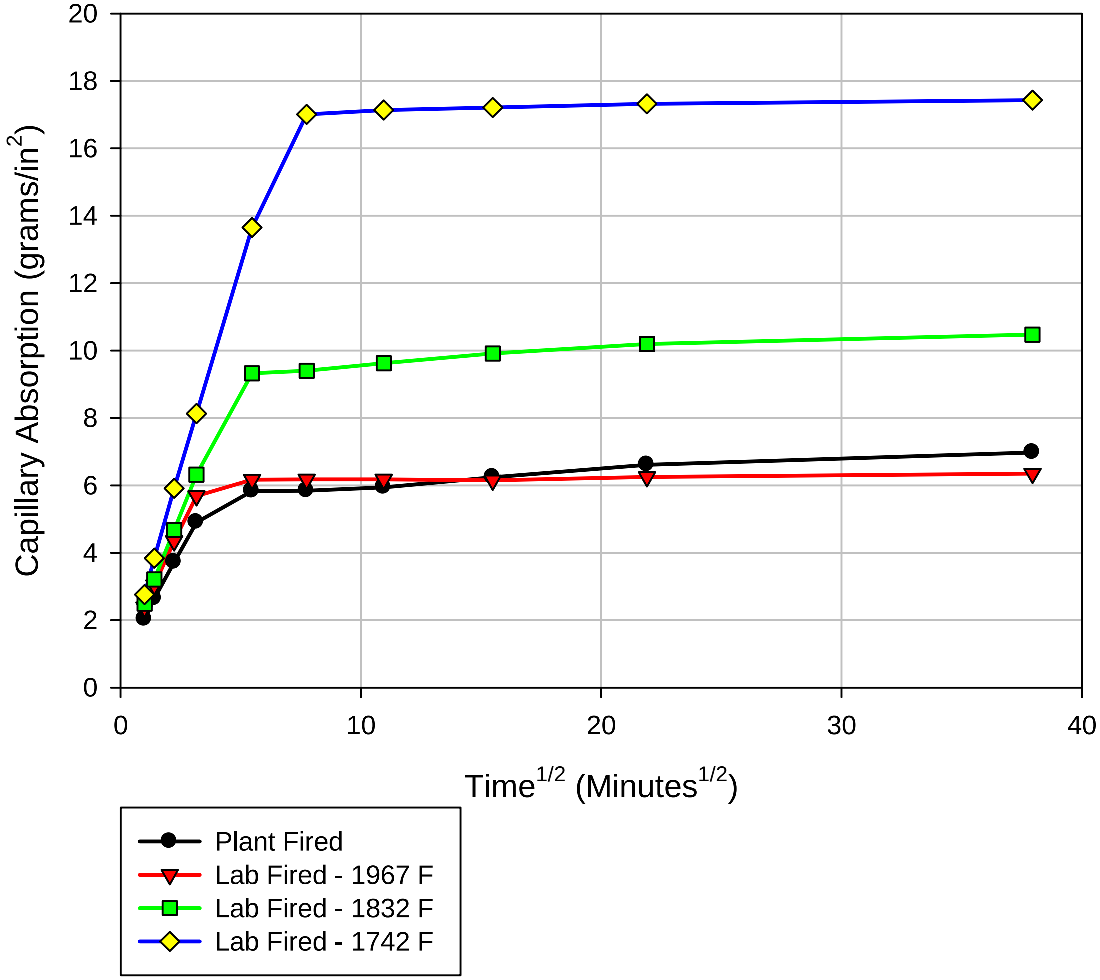


Fireclay

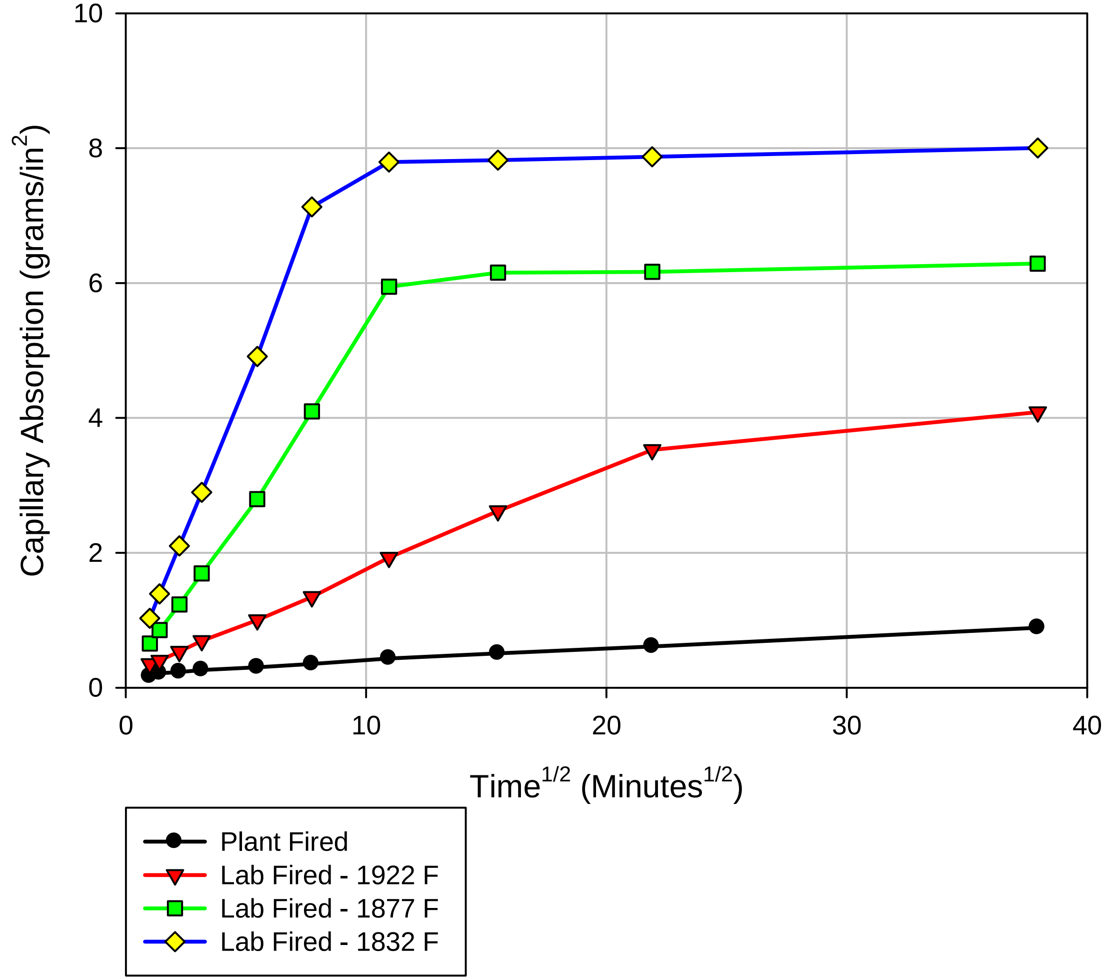


12
10
8
6
4
2
0
Capillary Absorption (grams/in^2)
0
10
20
30
40
Time^1/2 (Minutes^1/2)
Plant Fired
Lab Fired - 2012
Lab Fired - 1922 F
Lab Fired - 1832 F

Molded Shale

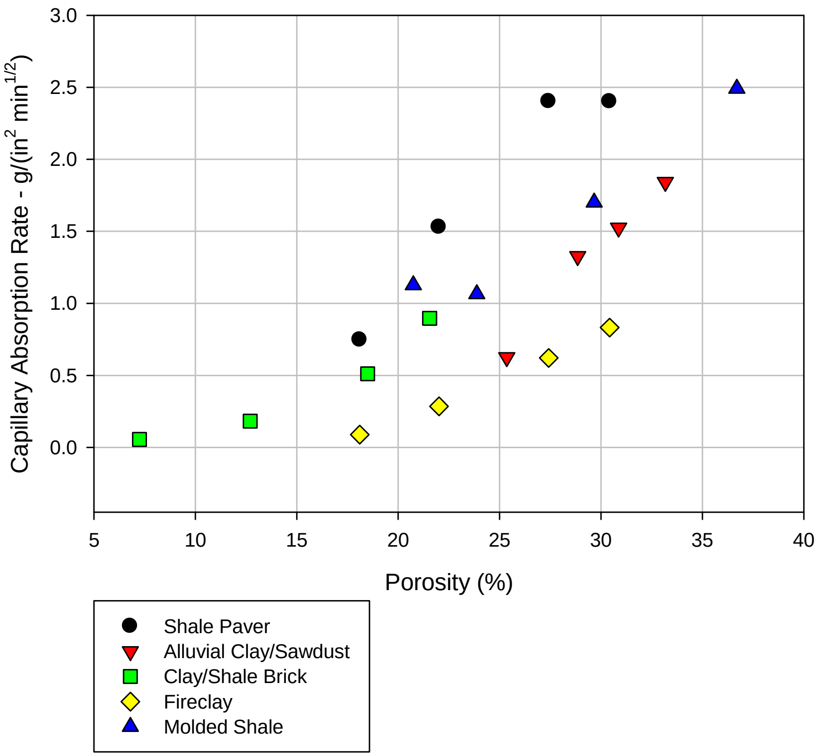


Clay/Shale



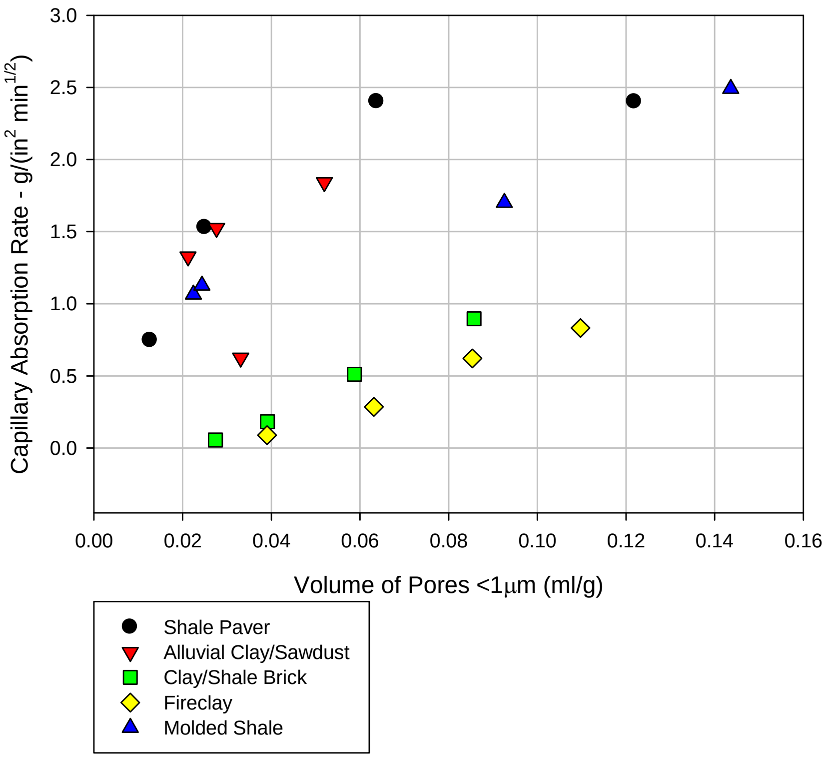
Capillary Absorption (grams/in^2)
Time$^{1/2}$ (Minutes$^{1/2}$)
0
2
4
6
8
10
0
10
20
30
40
Plant Fired
Lab Fired - 1922 F
Lab Fired - 1877 F
Lab Fired - 1832 F

Capillary Absorption Rate Trends



- Capillary absorption rate generally correlates with other physical properties, but the data must be grouped by type or source.
- This dependency on source or type illustrates the additional information about connectivity and orientation of pores that is contained in the capillary absorption rate.

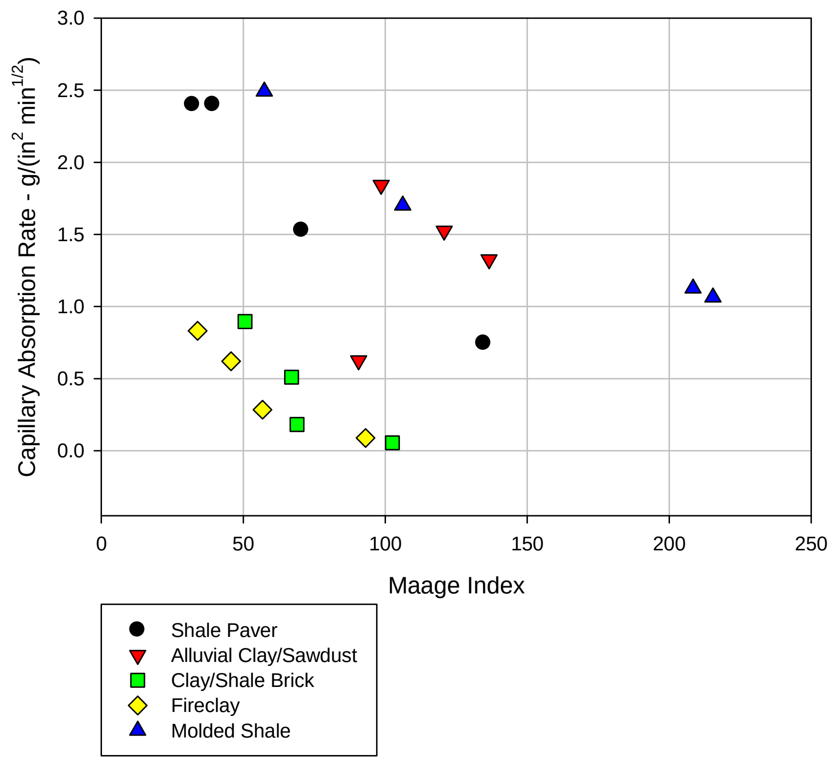
Capillarity and Fine Pores



- There is clearly a relationship between capillary absorption rate and the volume of fine pores as would be expected.
- The relationship is consistent for a particular type of brick which suggests that the connectivity and orientation of pores also play a large part in the movement of water in the pores.

Capillarity and Maage Index

- The Maage Index is sometimes used to predict durability.
- The Maage Index is unique in that both the quantity of pores and the fraction of fine pores (with higher capillary suction) are used in the calculation.
- There was a general relationship between the Maage and the capillary absorption rate, but again, the trends were only consistent for brick from the same source suggesting that the connectivity and alignment of the pores plays an important role in the movement of water.



$$F = \frac{3.2}{PV} + 2.4(P3)$$

F = Calculated Frost Index
PV = Intrusion Volume
P3 = Fraction of Pores with Diameters greater than 3µm

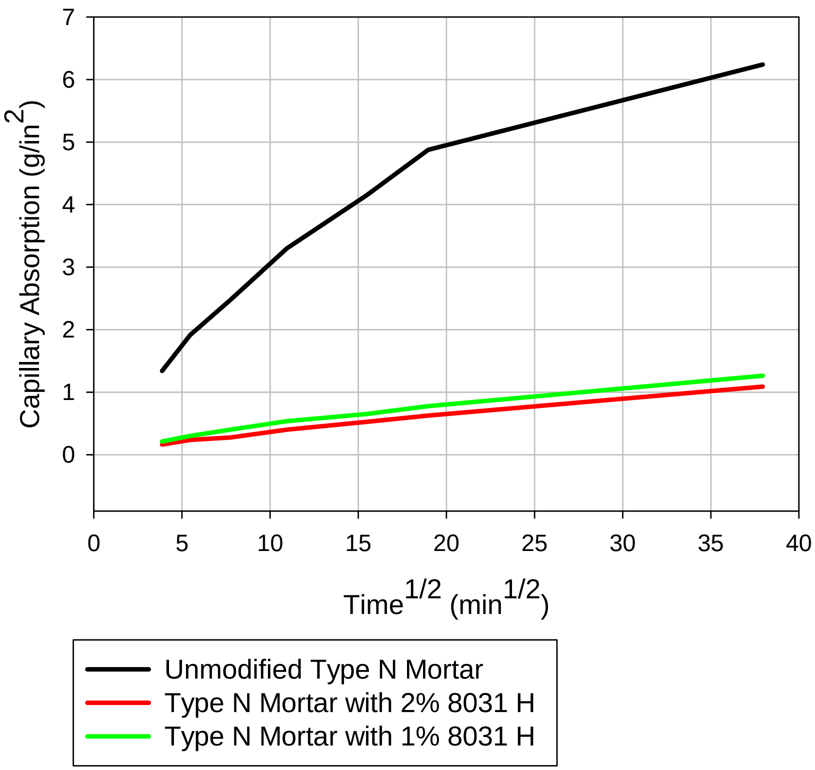
Capillary Absorption and Durability

Data grouped by Brick Type.

Should we also be looking at the effect of orientation of the pores on durability?

Brick Type	Firing	Capillary Absorption Rate – g/(in^2 min$^{1/2}$)	ASTM C 67 Freeze/Thaw Durability	Rapid Freeze/Thaw Durability – Cold Water Absorption Saturation	Rapid Freeze/Thaw Durability – Boiled Water Absorption Saturation
Shale Paver	Plant Fired	0.75	Pass	Pass	Pass
Shale Paver	Lab Fired - 1967°F	1.53	Pass	Pass	Pass
Shale Paver	Lab Fired - 1877°F	2.40	Pass	Pass	Fail
Shale Paver	Lab Fired - 1787°F	2.40	Pass	Pass	Fail
Alluvial Clay/Sawdust	Plant Fired	0.63	Pass	Pass	Pass
Alluvial Clay/Sawdust	Lab Fired - 2102°F	1.33	Pass	Pass	Pass
Alluvial Clay/Sawdust	Lab Fired - 2012°F	1.52	Pass	Pass	Pass
Alluvial Clay/Sawdust	Lab Fired - 1922°F	1.84	Pass	Pass	Fail
Clay/Shale Brick	Plant Fired	0.06	Pass	Pass	Pass
Clay/Shale Brick	Lab Fired - 1922°F	0.18	Pass	Pass	Pass
Clay/Shale Brick	Lab Fired - 1877°F	0.51	Pass	Pass	Pass
Clay/Shale Brick	Lab Fired - 1832°F	0.90	Pass	Pass	Pass
Fireclay	Plant Fired	0.09	Pass	Pass	Pass
Fireclay	Lab Fired - 2012°F	0.29	Pass	Pass	Pass
Fireclay	Lab Fired - 1922°F	0.62	Pass	Pass	Pass
Fireclay	Lab Fired - 1832°F	0.83	Fail	Fail	Fail
Molded Shale	Plant Fired	1.06	Pass	Pass	Pass
Molded Shale	Lab Fired - 1967°F	1.13	Pass	Pass	Pass
Molded Shale	Lab Fired - 1832°F	1.70	Pass	Pass	Fail
Molded Shale	Lab Fired - 1742°F	2.49	Fail	Fail	Fail

ASTM C1403 – Capillary Absorption Tests for Mortar



Conclusions/Recommendations

- Measurements of capillary absorption give us a unique measurement that reveals a great deal of information about the pore structure in a particular type of brick and how this pore structure is changed during firing.
- There is general correlation between the capillary absorption rate and IRA, but the capillary absorption rate provides much more information and should be a more reliable measurement.
- As Dr. Robinson stated, durability is a complicated function of the pore structure and the nature of the fired bond. With further review, including an attempt to incorporate orientation effects, it may be possible to use capillary absorption and other properties to develop a better durability index.

Continuing Work

- Collect capillary absorption data for the perpendicular to extrusion direction and attempt to develop an index to predict durability using these measurements.

- Correlate capillary absorption data to performance data such as masonry compressive strength, flexural bond strength and water penetration.