Basic Kiln Design

• Materials and Applications
• Methods of construction
• Equipment and controls
• Firing and ecology
Refractory Materials and Applications

- Refractories are generally defined as materials that can withstand extreme temperatures.  \((1000 \text{ + Degrees F})\)

- Refractories are capable of resisting one or more destructive forces like:
  - Heat
  - Thermal expansion
  - Abrasion
  - Pressure
  - Chemical attacks- like fluxes at high temps.
Refractory materials, as they are used in *kiln building*, fall into **six categories**:

- Firebrick
- Insulating Firebrick
- Castables
- Mortars
- Fibers
- Special Materials
Refractory materials are divided into five main groups:

1. **Oxides**: An **oxide** is a chemical compound containing at least one oxygen atom as well as at least one other element.

2. **Carbides**: In chemistry, a **carbide** is a compound composed of **carbon** and a less electronegative element.

3. **Nitrates**: An **ion** composed of one **nitrogen** and three **oxygen** atoms (NO$_3$).

4. **Borides**: In chemistry a **boride** is a chemical compound between **boron** and a less electronegative element.

5. **Elements**: A **chemical element** is a pure **chemical substance** consisting of one type of **atom** distinguished by its **atomic number**, which is the number of **protons** in its **nucleus**. The term is also used to refer to a pure chemical **substance** composed of atoms with the same number of protons.[1] Common examples of elements are **iron**, **copper**, **silver**, **gold**, **hydrogen**, **carbon**, **nitrogen**, and **oxygen**.

Clay is the most common refractory material found in nature.

- **Kaolinite/Kaolin**: Hydrated alumina silicate, Pure clay mineral
  
  Pure kaolin has one of the highest melting points of clays
  
  (3,245 degrees F)

  Low iron content

  Expensive (ex: Grolleg)

  Calcined very hot and sold as Molochite

- **Fireclay**: (Fireclay) a generic term that refers to a refractory clay.
  
  Usually fireclays contain some iron impurities.

  Med/Light duty fireclays have a PCE of about 27. Cedar Heights Fireclay

  Super duty fireclays can melt as high as cone 32. Hawthorne Bond

  There are Hundreds of different kinds of fireclays available, chemically they vary quite a bit.
Fireclay Bricks / Firebrick

Firebrick is a broad term, it refers to a brick made of primarily fireclay, these bricks vary greatly.

• Generally we use these bricks as a hot face liner to resist: glaze drips salt/soda vapor wood ash

• Firebricks have a high thermal-conductivity, so they absorb and store a lot of heat. (inefficient)

Four classifications of firebricks:

1. Super-duty, 33-34 +PCE (3,000 Degrees F.) ~about $ 3.00 each

2. High-duty, 32-33 +PCE (3,000 Degrees F.) ~your studio, fine for salt/soda or wood kiln

3. Intermediate-duty, 28 - + PCE (2,300-3,000 Degrees F.) ~generally do not want to use as posts

4. Low Duty, 28 and down PCE (2,900 -+ Degrees F.) ~generally do not want to use as post
Scope:
A super duty fireclay brick with excellent resistance to abrasion, spalling, and chemical attack. It will find use in general service applications where a super duty brick is required.

**PCE:** 33 - 34

<table>
<thead>
<tr>
<th>Chemical Analysis (Wt.% - Calcined Basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
</tr>
<tr>
<td>Al₂O₃</td>
</tr>
<tr>
<td>TiO₂</td>
</tr>
<tr>
<td>Fe₂O₃</td>
</tr>
<tr>
<td>MgO</td>
</tr>
<tr>
<td>P₂O₅</td>
</tr>
<tr>
<td>Alkalies</td>
</tr>
</tbody>
</table>

**CLASSIFICATION:**
ASTM C-27

**METHOD OF MANUFACTURE**
Dry Press

**MODULUS OF RUPTURE—PSI**
850—1200

**APPARENT POROSITY %**
16—19

**COLD CRUSHING P. S. I.**
4500—5500

**BULK DENSITY—lbs/cu ft.**
138—142
Medium duty

Scope:
Power pressed, to insure dense, strong brick.
Designed to satisfy requirements for intermediate (moderate) duty service

PCE: 29

<table>
<thead>
<tr>
<th>Chemical Analysis (Wt.% - Calcined Basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
</tr>
<tr>
<td>TiO$_2$</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
</tr>
<tr>
<td>CaO</td>
</tr>
<tr>
<td>MgO</td>
</tr>
<tr>
<td>Alkalies &amp; Trace Elements</td>
</tr>
</tbody>
</table>

CLASSIFICATION: ASTM C-27

METHOD OF MANUFACTURE: Dry Press

MODULUS OF RUPTURE—PSI: 1000—1300

APPARENT POROSITY %: 16—18.5

COLD CRUSHING P. S. I.: 3500—4500

BULK DENSITY—lbs/cu ft.: 129—133
Scope:
Power pressed, to insure dense, strong brick. Designed to satisfy general use where low temperatures are present and non-severe conditions exist.

PCE: 14—15

CLASSIFICATION: ASTM C-27

METHOD OF MANUFACTURE: Dry Press

MODULUS OF RUPTURE—PSI: 650—950

APPARENT POROSITY %: 18—21

COLD CRUSHING P. S. I.: 3500—4500

BULK DENSITY—lbs/cu ft.: 130—132

A.S.G.: 2.64
Firebricks are generally manufactured by:

- **Dry Pressing**- moist powder mix (no more than 10% H2O by weight) pressed into shape using extreme pressure (500-1500psi)

- **Stiff Mud Process**- plastic mixture (12-15% H2O by weight) that is ager fed and extruded under pressure, then cut into shape using a series of taut wires.

- **(Historically) Soft Mud Process**- a plastic mix (20-30% H2O by weight) is pushed into a wooden mold that uses sand or oil as a release.
• US Standard Straight-9” x 4 ½” x 2 ½”

• European Standard Straight-9” x 4 ½” x 3 “
Kiln builders will make the kiln layout divisible by 4.5" so they do not have to cut many bricks.
Insulating Firebrick (IFB)

• Made from a mixture of refractory materials (*primarily silica and alumina*) combined with either organic or multicellular lightweight aggregate.

• Organic material is burned out.

• Left with many little voids and the cells, it’s the *porosity or voids* that produces the insulating qualities.
Insulating Firebrick

IFB

• Weights 65-85% less than a dense firebrick.

• Low thermal-conductivity, stores and absorb very little heat.

• Not affected by a reduction atmosphere.

• Falls short withstanding chemical attacks, such as fluxes.

• There is *refractory coatings* that will slow the corrosion process down/ maybe..
IFB

• The bricks are made by either a *slip casting* or a *stiff mud process*.

• Then they are fired, cut and ground into shapes.

• US Standard Straight- 9” x 4 ½” x 2 ½”
• European Standard Straight- 9” x 4 ½” x 3”

**IFB’s are categorized by an identification a code:**

• K-20
• K-23
• BNZ-23HS
• K-26
• TC-26 HS
• JM-28
• JM-30

*about $2.50/brick*

http://www.morganthermalceramics.com/files/datasheets/6_1-14-3lowtempifb.pdf
## K-23

<table>
<thead>
<tr>
<th>Property</th>
<th>31 - 35 (497-560)</th>
<th>30 - 36 (480 - 576)</th>
<th>37 (593)</th>
<th>38 - 41 (593-641)</th>
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<tbody>
<tr>
<td>pcf (kg/m³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melting temperature, °F</td>
<td>2750 (1510)</td>
<td>2750 (1510)</td>
<td>2750 (1510)</td>
<td>2800 (1538)</td>
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<tr>
<td>Modulus of rupture, ASTM C 133</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>psi (MPa)</td>
<td>115 (0.79)</td>
<td>105 (0.72)</td>
<td>105 (0.72)</td>
<td>135 (0.93)</td>
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<tr>
<td>Cold crushing strength, ASTM C 133</td>
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<tr>
<td>psi (MPa)</td>
<td>145 (1.0)</td>
<td>125 (0.86)</td>
<td>125 (0.86)</td>
<td>200 (1.38)</td>
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<tr>
<td>Permanent linear change, %, per ASTM C 210</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>@ 2250°F (1232°C)</td>
<td>0 to -0.1</td>
<td>-0.2</td>
<td>0 to -0.1</td>
<td>-</td>
</tr>
<tr>
<td>@ 2450°F (1343°C)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.3</td>
</tr>
<tr>
<td>Deformation under hot load, % @ 10 psi, ASTM C 16</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>1½ hr @ 2000°F (1093°C)</td>
<td>0</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1½ hr @ 2200°F (1204°C)</td>
<td>0.3</td>
<td>-</td>
<td>-</td>
<td>0.1</td>
</tr>
<tr>
<td>Coefficient of thermal expansion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in/in°Fx10^-6</td>
<td>3</td>
<td>3</td>
<td>-</td>
<td>3.1</td>
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### Chemical Analysis, %

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<thead>
<tr>
<th>Component</th>
<th>38</th>
<th>38</th>
<th>38.5</th>
<th>46</th>
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</thead>
<tbody>
<tr>
<td>Alumina, Al₂O₃</td>
<td>38</td>
<td>38</td>
<td>38.5</td>
<td>46</td>
</tr>
<tr>
<td>Silica, SiO₂</td>
<td>45</td>
<td>45</td>
<td>47.5</td>
<td>37.5</td>
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<tr>
<td>Ferric oxide, Fe₂O₃</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Titanium oxide, TiO₂</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Calcium oxide, CaO</td>
<td>15</td>
<td>15</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Magnesium oxide, MgO</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
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<tr>
<td>Alkalis, as, Na₂O and K₂O</td>
<td>0.5</td>
<td>0.5</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

### Thermal Conductivity, BTU-in./hr·ft²·°F (W/m·K), ASTM C 201

<table>
<thead>
<tr>
<th>Temperature</th>
<th>BTU-in./hr·ft²·°F (W/m·K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>@ 500°F (260°C)</td>
<td>0.92 (0.13)</td>
</tr>
<tr>
<td>@ 1000°F (538°C)</td>
<td>1.14 (0.16)</td>
</tr>
<tr>
<td>@ 1500°F (815°C)</td>
<td>1.39 (0.20)</td>
</tr>
<tr>
<td>@ 2000°F (1093°C)</td>
<td>1.64 (0.24)</td>
</tr>
</tbody>
</table>

### Standard Sizes*

*Please refer to the original document for specific standard sizes.*
Insulating Board

• K-FAC Board
  - Mineral Board
  - Low cost

• Vermiculite Board

• Calcium Silicate Board

• Ceramic Fiber Board
Castables

• Generally you can find a castable that is equivalent to any kind of Firebrick, IFB, or Fiber material you may buy.

• Buy in dry form.

• Mix with very a specific water content.

• Like concrete, castables have a set time.

• It can be Poured, Slap-Trowel and Gunned.

• Vibrated and or tamped, to set and remove air bubbles.
Castables

- Much like clay, monitor the drying:
  - dry even to prevent cracks
  - cover with plastic if necessary
  - allow 24 hours of water curing before heating
  - If large surface area, scribe a line and tell the material where to crack.

- It is possible to *reinforce* the casting with stainless steel or other refractory material.
Mortars

• Used to bond units together.

• Possible to use a mortar as a gasket material.

• Mortar should withstand the same destructive forces as the units.

• Most refractory units have an appropriate mortar. Choose a mortar with the a similar chemical makeup as the unit.
Categorized into 3 groups:
- Ready mix- *air setting*
- Dry mix- *air setting*
- Dry mix- *heat setting*

Recommended Mortar thickness:
- IFB 1/32”
- Firebrick 1/16”

WE, when possible, dry-stack the bricks
- Allows the brick to be reused on other kilns.
- Allows walls to expand and move.

We Use *Sairset* (ready mix) for both IFBs and Firebricks
- About $0.60/LB
- 50lb bucket
- Trowels nicely
- Long shelf life
- Working temp up to 3000 degrees F

- *You can mix a mortar that is made of fireclay and grog.*
  - 60 Fireclay / 40 grog + .75% Darvan + water
Plastic / Ramming Mix

• Malleable wet refractory mix that can be pounded or rammed into place.

• Low shrinkage rate, good for repairs to kilns

• Good for making shapes.

• You can find a mix that is comparable to any brick you can buy.
Ceramic Fiber

- Ceramic fiber products:
  - Silica-Alumina (kaolin based)
  - Zirconium
  - Quartz and others
  - working temps up to 3000 + degrees F

- Very low Thermal Conductivity.
- Extremely efficient, saves on fuel costs
- Expensive 1” blanket- about $5.00 sq ft
- Does not stand up to chemical attacks.
- There are coating that will slow down corrosion.
- The material does have a linear shrinkage, 2-5%
- There is a chemical rigidizer available, to make the hot-face somewhat stiff and more durable.
Ceramic Fiber

Bulk fibers
- individual fibers can be up to 10” long

Blanket
- 1/2” to 2” thick, and up to 48” wide
- 1/32” to 1/4” thick

Paper

Spray mix

Mortar

Plastics

Boards
- up to 48” x 36” x 3”

Ropes
- up to 3” in diameter

Blocks

Felt

Frank A. Colson, Kiln Building with Space-Age Materials
General Fiber Construction
Ceramic fiber:

• Ceramic fibers have been around since the 1940’s

• Not until the early 1970’s it was available on a commercial market.

• The material is made by pouring molten ceramic material through a jet of steam.
Special Materials

Fused Mullite Components

Fused Zirconina Components

Fused Alumina Components

Recrystallized Silicon Carbide (ReSiC)
Resources:

• Gurcke Karl, *Bricks and Brickmaking*.
• Colson A. Frank, *Kiln Building with Space-Age Materials*.

Useful Websites on Refractories:

• hwr.com
• thermalceramics.com
• unifrax.com
• pryorgiggey.com

Great art book on bricks:

• Heeney Gwen, *Brickworks*
Artists using bricks/refractories

Per Kirkaby

Born Denmark 1938
Per Kirkeby
Gween Heeney
Carl Andre
Louis Kahn
Louis Kahn