



# “Refractory Materials and Types”



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IEEE-West Coast Cement  
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# WHAT ARE REFRACTORIES?

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**According to Ceramic Engineers**

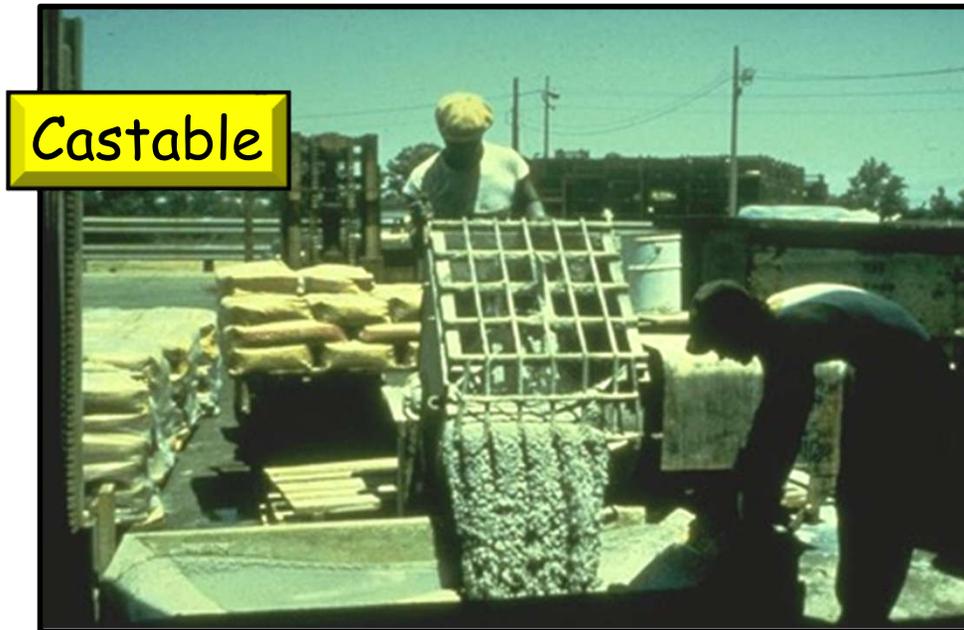
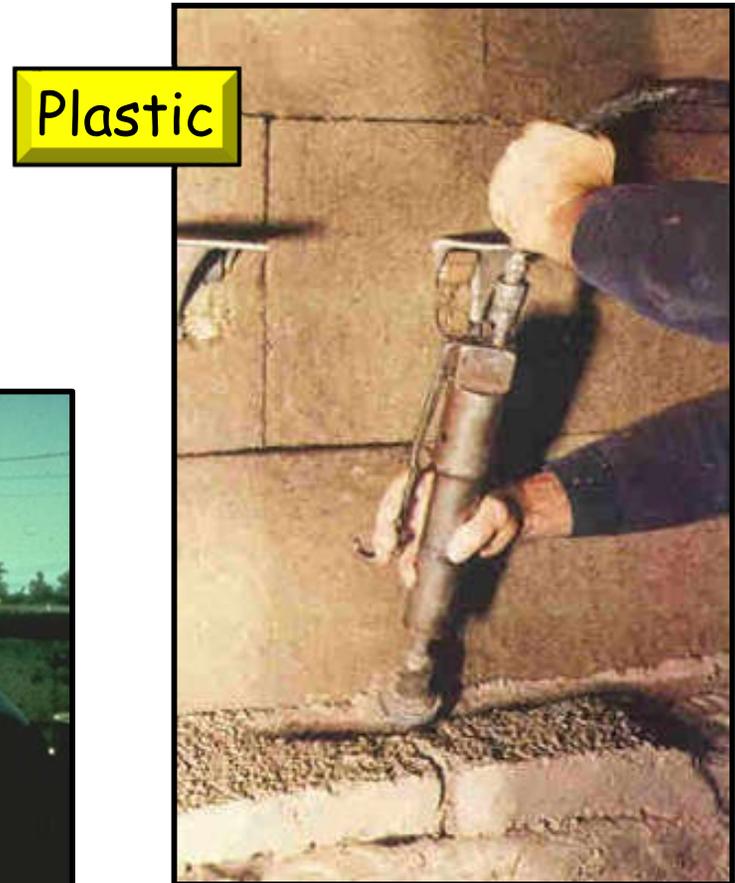
- **“Inorganic, non-metallic, Solid materials that can withstand high temperatures and be resistant to the chemical and mechanical conditions of furnace operations”**
  - **Resist High Temperature**
  - **Contain Flame and Heat**
  - **Resist Chemical Alteration**



# Refractories Forms

- **DIFFERENT FORMS**
  - **Dense Brick**
  - **Insulating Brick**
  - **Mortar**
  - **Castable**
  - **Plastic**
  - **Ceramic Fiber**
  - **Refractory Anchors,  
Ceramic**

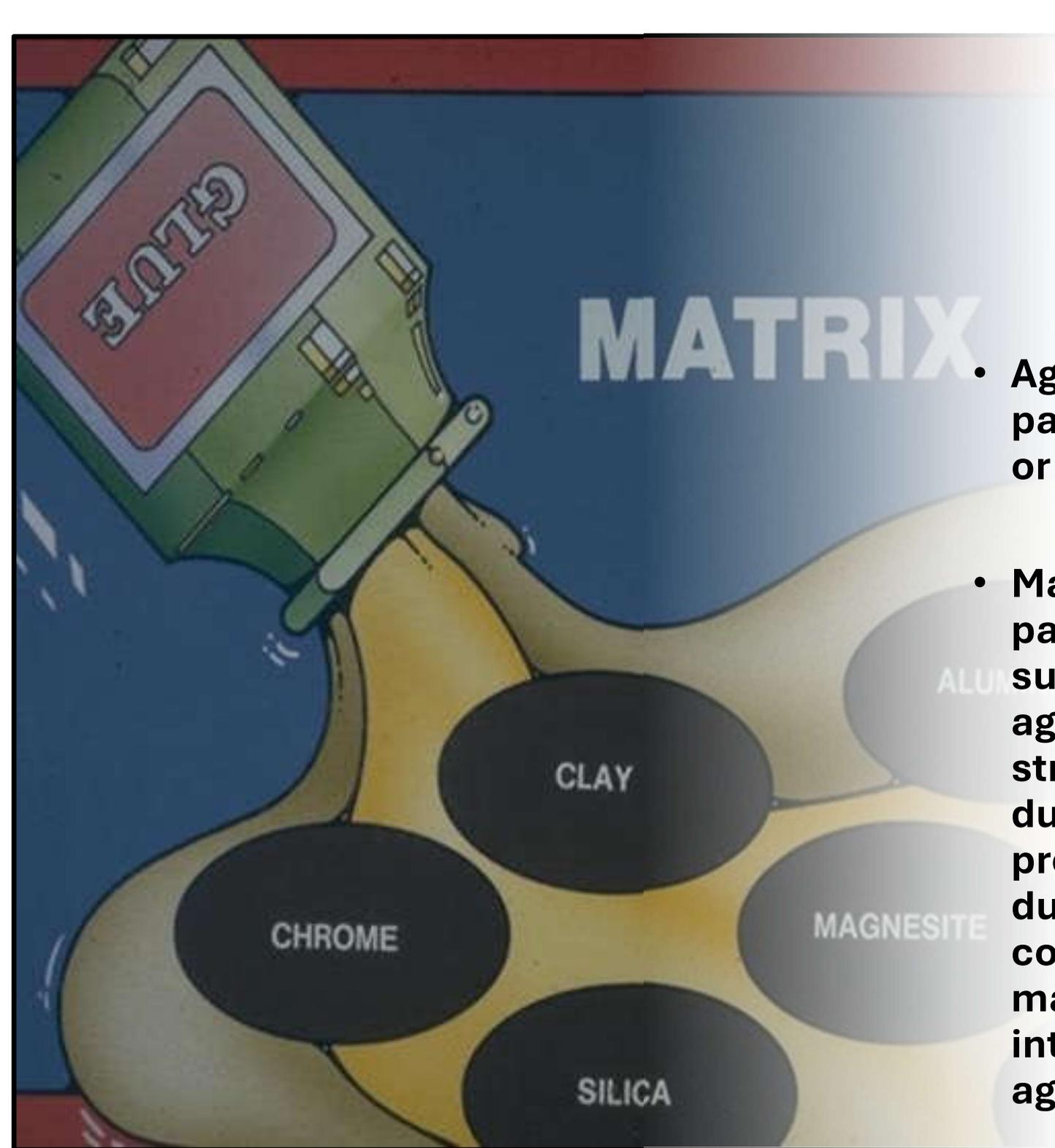
# Basic Types



# Matrix

**MATRIX**

- **Aggregate = the large particles in a brick or monolithic**
- **Matrix = the fine particles that surround the aggregate. The strength and durability of the product is primarily due to the composition of the matrix and its interaction with the aggregate**



# Types of Bonds

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## Bonding Mechanisms

**Hydraulic**



**Castables**  
**Gun mixes**  
**Shotcrete mixes**

**Chemical**



**Plastics**  
**Mortars**

**Ceramic**



**Bricks**



Refractories  
Raw  
Materials

## Raw Materials:

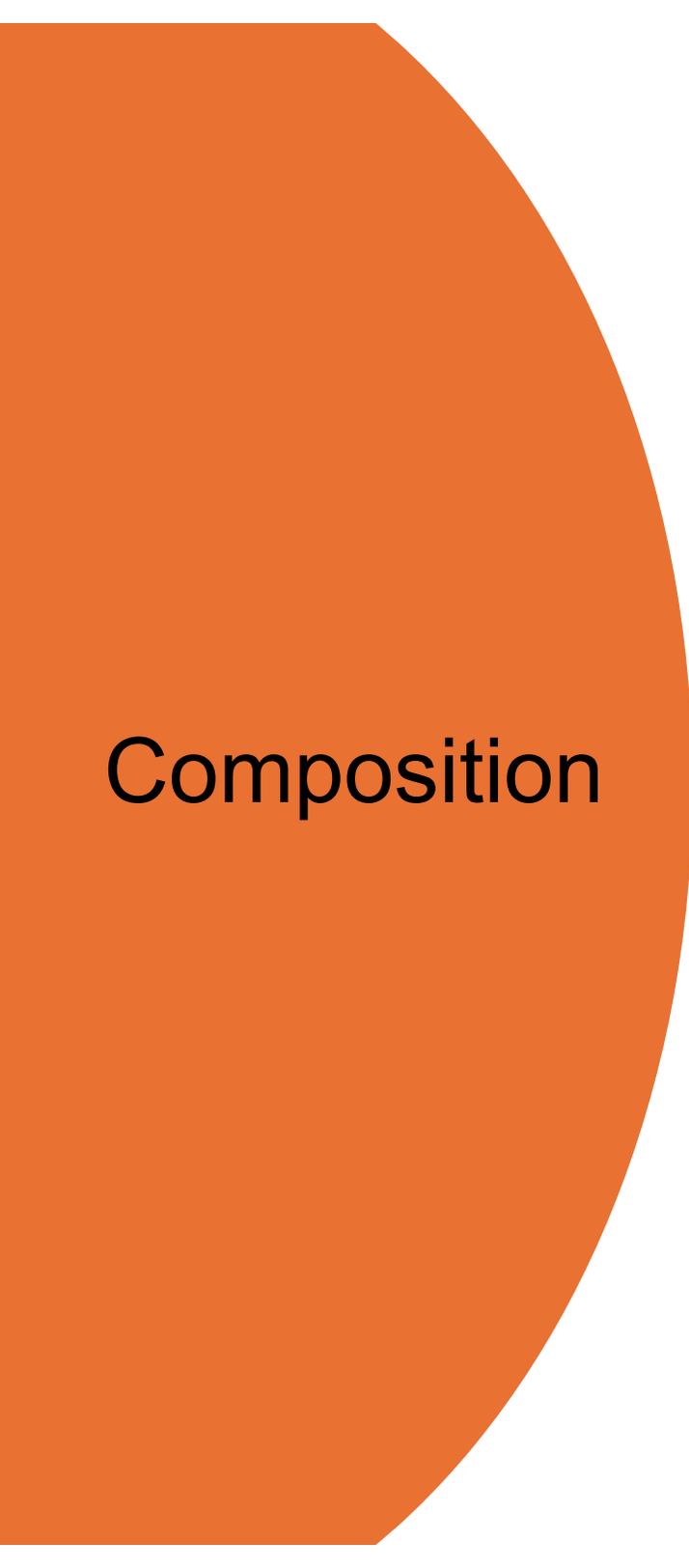
**Basic – Predominately  
Magnesia Based ( $\text{MgO}$ )**

**Acid – Predominately Alumina-  
Silica Based ( $\text{Al}_2\text{O}_3 - \text{SiO}_2$ )**

**Binders**

**Other**





## Composition

**Refractories are made of chemical compositions with various mineralogical forms. The minerals employed can be comprised of combinations of chemical compositions.**



# CHEMICAL COMPOSITIONS

## CHEMICAL SYMBOL

SiO<sub>2</sub>

Al<sub>2</sub>O<sub>3</sub>

MgO

Fe<sub>2</sub>O<sub>3</sub>

C

SiC

## CHEMICAL NAME

SILICA

ALUMINA

MAGNESIA

IRON OXIDE

CARBON

SILICON CARBIDE

## MINERALOGY

QUARTZ

CRISTOBALITE

TRIDYMITE

FUME

VITREOUS

CORUNDUM

PERICLASE

HEMATITE

DIAMOND

GRAPHITE

SILICON CARBIDE

# Purity

## Chemical Purity

In most cases, higher purity also means....

- Higher Priced Ingredients
- Higher Temperature Resistance
- Higher Chemical Resistance
- Higher Density
- Higher Strength
- Higher Performance
- Higher Selling Price

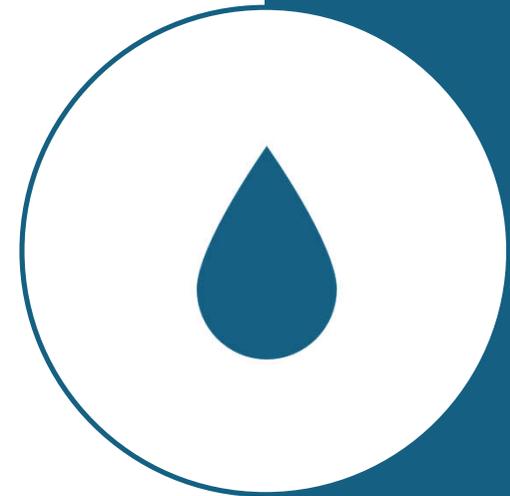


# Impurities

**Tend to Reduce the Service Temperature Limit of Both Basic and Acidic Systems. Commonly Referred to as Fluxes – Any Chemical that Lowers the Melting Point of a Material.**

**Common Fluxes to Refractory Systems Include:**

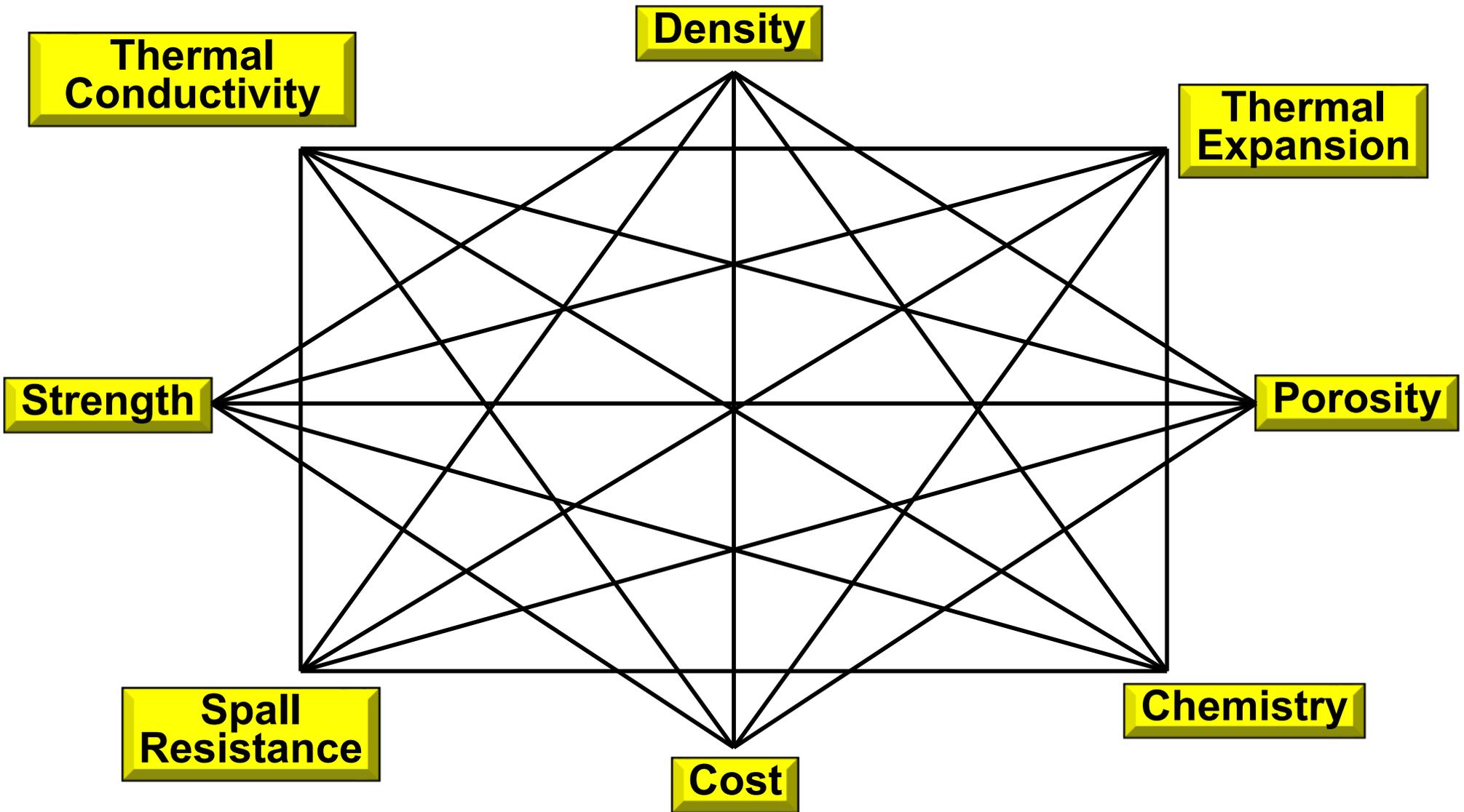
**$\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{MnO}$ ,  $\text{V}_2\text{O}_5$ ,  $\text{P}_2\text{O}_5$ ,  $\text{B}_2\text{O}_3$ ,  
 $\text{CaO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$  and Many Others**



# Raw Materials

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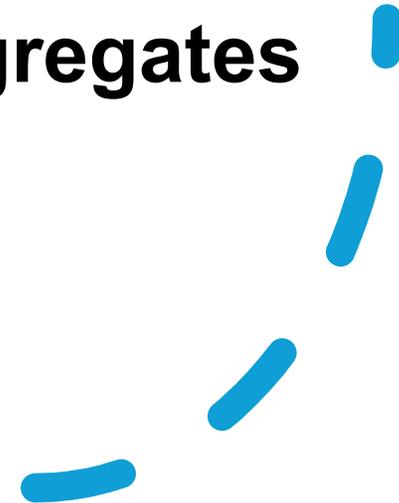
# All Properties Are Interconnected





Raw  
Materials

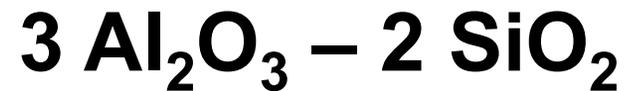
## Aggregates

- **Mullite Bearing Aggregates**
  - **Mullite Forming Aggregates**
  - **Bauxite**
  - **Alumina**
  - **Magnesia**
  - **Chromia Bearing Aggregates**
  - **Spinel**
- 

# Mullite

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**Chemical Formula**



**Synthetic Grain**

- **High Purity Sintered or Fused Grain made from High Purity Alumina and Silica**
- **Lower Purity Sintered Grain made from Calcining Clays or Blends of Clay and Bauxite**

# Raw Materials

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## Mullite Bearing Calcines

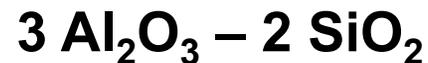
Calcine Product:	Missouri Flint	MULCOA 60	MULCOA 70
Silica	48.9	38.3	26.6
Alumina	46.6	59.0	69.2
Iron Oxide	1.1	1.2	1.2
Titania	2.3	2.3	2.8
Alkalies	0.8	0.05	0.12
Mullite	57	77	87
Cristobalite	9	23	13
Glass	32	0	0

# Mullite

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## Mullite Forming Aggregate

**Chemical Formula**



**At High Temperatures, React to Yield Mullite plus Glass plus Cristobalite**

**Kyanite's Reaction Occurs Between 2010- 2550°F and is Characterized by a 10-19 % Volume Expansion**

**Andalusite's Reaction Occurs Between 2550 - 2730°F and is Characterized by a 3-5 % Volume Expansion**

# Mullite Forming Aggregates

Calcine Product:	Kyanite	Andalusite
Silica	40.6	38.0
Alumina	57.0	60.5
Iron Oxide	0.55	0.62
Titania	0.67	0.17
Alkalies	0.42	0.15

# **Bauxite Types**

## **Bauxite**

**Bauxite - Calcined High Alumina  
Aggregate Sourced from Guyana or  
China**

**Chinese Bauxite – Diaspore-Kaolin  
Type, Calcined Using either Shaft,  
Rotary or Round Kilns.**

**Guyanese Bauxite – Gibbsitic Type,  
Calcined Using a Shaft Kiln**

# Bauxite

## Calcined Bauxite

Product:	Chinese	Chinese HD	Guyanese
Silica	6.0	3.0	6.6
Alumina	88.4	91.5	88.0
Iron Oxide	1.5	1.2	1.3
Titania	3.5	3.8	3.0
Alkalies	0.2	0.2	----
Mullite	Trace	----	Minor
Cristobalite	Major	Major	Major
Glass	Trace	Trace	Trace

# High Alumina

## Alumina Aggregates

Derived from Bauxite Ore by Chemical Processing to Form Aluminum Hydroxide

Tabular – Form Pellets of Calcined Alumina, Fire to Densify into a Sintered Aggregate

White Fused – Melt Calcined Alumina in an Electric Arc Furnace to Form a High Purity Fusion

Brown Fused – Melt Unrefined Calcined Bauxite in an Electric Arc Furnace to Form a Fusion

# Alumina Aggregates



Product:	Tabular	White Fused	Brown Fused
Silica	0.07	0.06	1.0
Alumina	99.6	99.6	95.5
Iron Oxide	0.13	0.03	0.1
Titania	--	--	2.6
Alkalies	0.26	0.17	0.1

# Magnesia

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## **Magnesia Aggregates**

**Sintered Magnesia Aggregate Derived from the Processing and Firing of Natural Magnesite**

**Sintered Magnesia Aggregate Derived from the Processing and Firing of Brine.**

**Fused Magnesia Aggregate Derived from the processing of Raw or Sintered Magnesia Sources.**

## What are Spinel?

Spinel in refractories are generally mineral compositions containing  $\text{MgO} \cdot \text{Al}_2\text{O}_3$  (aka  $\text{MgAl}_2\text{O}_4$ ), represented by the following four product types:

- Products classified as ***in-situ spinels*** have high purity  $\text{Al}_2\text{O}_3$  added to the raw material and the spinel is formed during the firing of the brick.
- Products classified as ***sintered spinels*** have preformed sintered spinel grains added to the raw materials of the brick mix.
- Products classified as ***fused spinels*** have preformed fused spinel added to the raw materials in the brick mix.
- Products classified as ***ultra high-purity spinels*** contain high purity preformed spinel grain added to the raw materials of the mixes

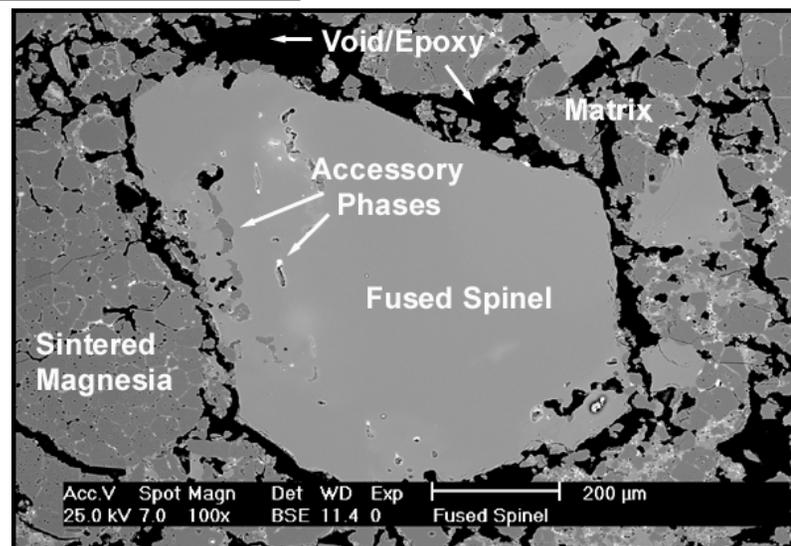
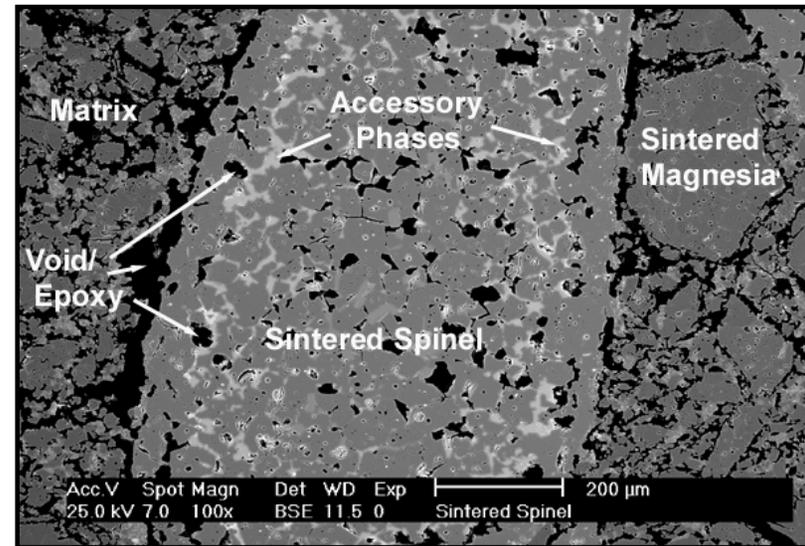
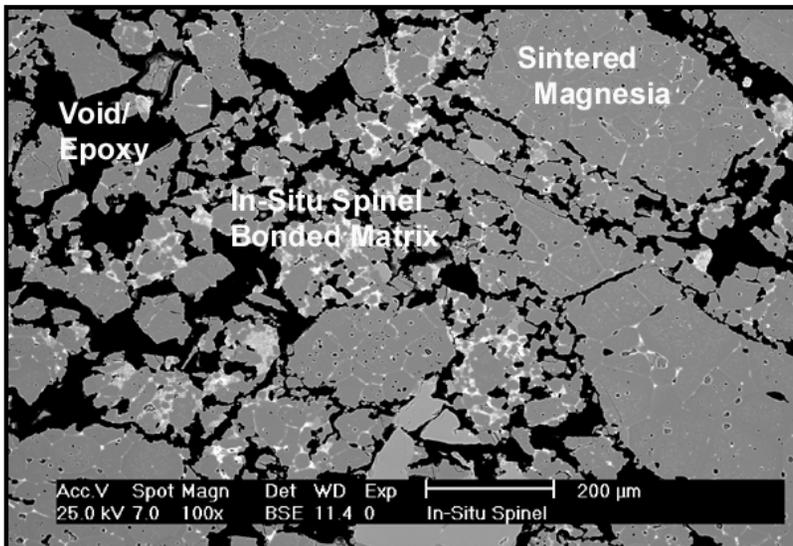
Spinel  
Encompass  
Many  
Compositions!

In mineralogy, the term spinel covers an entire group of minerals with the general formula  $AB_2O_4$ , where A may be magnesium, ferrous iron, zinc or manganese – or a combination of these. B may be aluminum, ferric iron or chromium. Therefore, in refractories, the spinel and the associated products may be referred to as:

- Alumina Rich
- Magnesia Rich
- Galaxite Spinel (Manganese Rich)
- Hercynite (Iron Rich)
- Fused/Sintered/In-Situ
- High Purity/Low Purity

A good rule of thumb is to recognize that basic brick with lime-to-silica ratios of 2 or greater have the potential for liquid formation at relatively low temperatures.

# Scanning Electron Microscope (SEM) of In-Situ, Sintered and Fused Spinel



# Other Raw Materials

## Raw Materials

### “Other”

- **Chromic Oxide**
- **Silica**
- **Fused Silica**
- **Silicon Carbide**
- **Graphite**
- **Zircon**
- **Light Weight Aggregates**

# BRICKS

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# Brick

**Brick are pressed on hydraulic or mechanical presses then fired in a tunnel kiln**



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# Hydraulic Brick Press

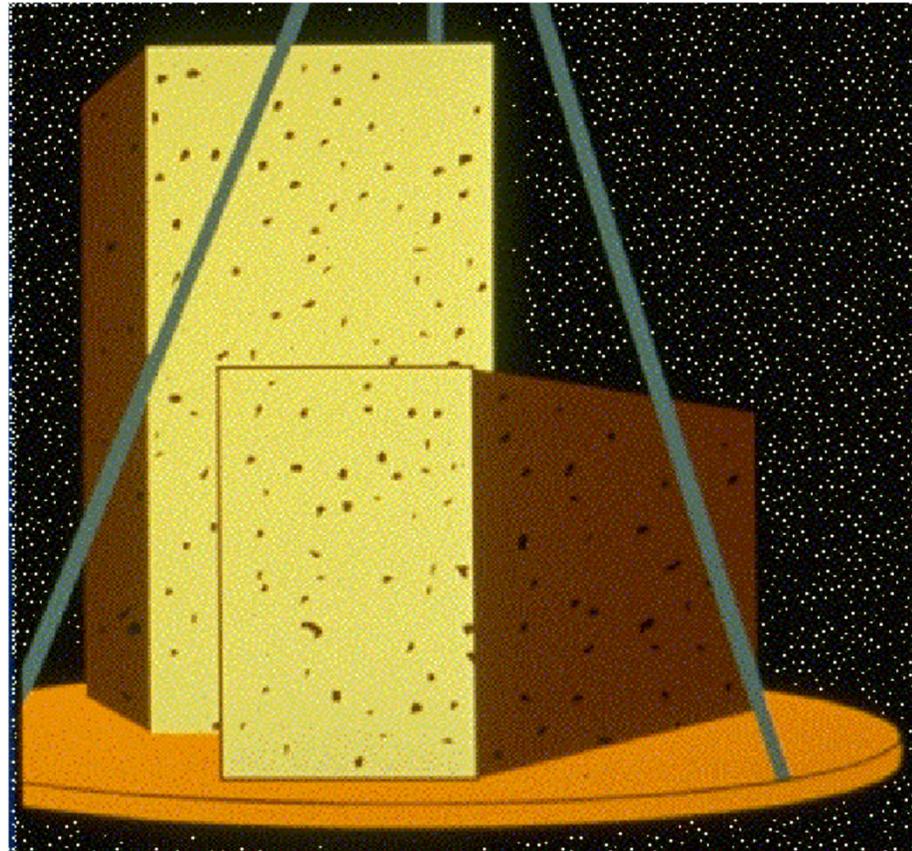


# Fired Brick

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## Brick Advantages

- Higher Density
- Lower Porosity
- Prefired
- Properties Not Installer Dependent

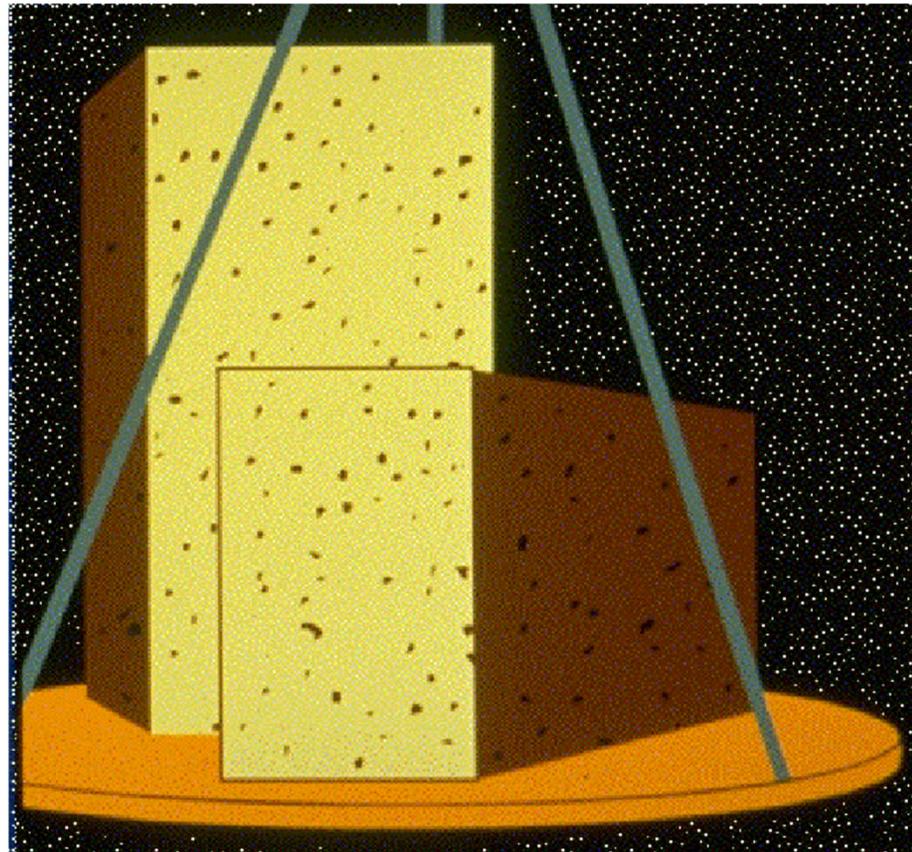


# Brick

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## Brick Disadvantages

- Skilled Masons
- Joints
- Labor Cost
- Installation Time
- Lead time



# Classification

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**The four standard classes of fireclay brick are:**

- **Super Duty**
- **High-Duty**
- **Medium-Duty**
- **Low-Duty**
- **And Semi-Silica.**

# Fireclay

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- Fireclays range from approximately 18% to 44% alumina, and from about 50% to 80% silica.
- From the standpoint of fusion temperature, super duty fire-clay brick having a PCE of approximately Cone 33, which corresponds to 3175°F does not mean that a brick with a PCE of Cone 33 can be used in furnaces operating at 3175°F.
- On the contrary, it means that at this temperature in a clean, slag free, neutral to slightly oxidizing atmosphere, this brick would be unable to support its own weight.



- **Fire-clay brick begin to soften far below their fusion temperature and under load actual deformation takes place. The amount of deformation depends upon the load, and**
- **Once started, this deformation is a slow but continuous process unless either the load or the temperature is reduced. It is for this reason that fire-clay brick are not well adapted for use in wide sprung arches in furnaces operating continuously at high temperatures.**

# Insulating Firebrick

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- IFB are lightweight insulating bricks.
- Generally, IFBs are not suitable for a working lining and heavy load-bearing structures or environments with aggressive erosion and wear.
- A majority of the IFB's are alumino-silicate refractory bricks, silicate bricks, or lightweight corundum (alumina) bricks
  - The higher the alumina content and the firing temperature of the insulating firebrick, the higher its classification temperature.
- The ASTM C155-97 classifications range from 2000°F(1100°C) with a density of 30pcf to 3200°F(1760°C) with a density of 78pcf.

# Insulating Firebrick

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- The raw materials used for IFB include clay, kaolin, kyanite, mullite, (light) chamotte, sillimanite or andalusite.
- The thermal conductivity is influenced by the ingredients as well as the total porosity, pore shape, and pore size distribution.
- IFB's total porosity is >45%
- The porosity is produced by burnout materials and water. Common burnout materials include sawdust, straw, styrene bubbles, coke, or cellulose

IFBs are normally used in applications >1,000°C (1,832°F) because, at these temperatures, they provide the most cost-effective insulation available compared to alternative insulating refractories.



**Okay what brick should I use?**

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# Summary

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**Should determine your operation and wear mechanism(s)**

- **Fireclays although they exhibit some alkali resistance do not have a wide range in operating temperature or load resistance**
- **Mullite/andalusite offer excellent alkali and thermal shock resistance and improved hot strength-could have additives such as Silicon Carbide or zirconia**
- **Bauxite does not offer good alkali resistance too many impurities but can withstand higher temperatures**
- **Tabular alumina offers excellent hot properties at elevated temperatures and in certain applications is the preferred product for chemical purity and high temperatures-ammonia reactors/carbon black**

# Monolithics

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# Monolithics

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**Monolithics come in many forms depending on the installation method and use:**

## **Physical Forms**

- **Castable**
- **Gunning Mix**
- **Vibration Cast**
- **Self-Leveling**
- **Pumping**
- **Shotcrete**

## **Bonding Mechanisms**

- **Conventional**
- **Low Cement**
- **Ultra-low Cement**
- **Lime Free or No-Cement**
- **Chemical**



# Classification of Castables

Category	Lime (CaO) Level	Cement Level
Conventional Castables	> 2.5 %	> 10%
Low Cement Castables	1.0 – 2.5 %	4 – 8 %
Ultra-Low Cement Castables	< 1.0 %	< 4 %
Cement Free Castables	< 0.2 %	No Cement

# Raw Materials Dense

- **Monolithics basically have the same raw material source as brick.**
- **Primary difference is in the binder system and additives.**
  - **Colloidal silica /cement(s)/phos**
  - **Clays**

# Raw Materials Lightweights

## Aggregates used in Lightweight or backup monolithics

- Perlite
- Pyrophyllite
- Vermiculite
- Expanded Shale
- Bubble Alumina

# Cement Bonded

**For cement-bonded castables  
and gun mixes:**

- **As cement decreases:**
  - **Density increases, porosity decreases**
  - **Modulus of rupture and crushing strengths increase**
  - **Hot modulus of rupture increases**
- **Practical service limit is where permanent linear change is +/- 1.5%**

# Castable Cement Bonded

- **Castable advantages**
  - **Set At Room Temp**
  - **Excellent properties**
  - **Reduced Heat Losses**
  - **Anchored Construction**
- **Castable disadvantages**
  - **Forms Required longer installation time**
  - **Controlled Heat-Up**
  - **Water additions critical**
  - **Materials Cost More**

NC-No  
Cement

## No-Cements-Advantages

1. **No reactions to process additives (no CaO to be attacked by sulfurs or chlorides)**
2. **Great physical properties / product performance**
3. **Reduced cure / dry-out time**
4. **Adheres / bonds to existing monolithic linings (allows “flash coating” without having to remove existing lining and / or weld new anchors to steel)**

# No-Cement Monolithics

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## Key features of NC monolithics

- **Dry-out:** With sol-gel castables, the chemical water is not formed. The moisture is easily released and dissipated through the lining. Time savings of twenty to thirty percent can be achieved in the bake out process due to more rapid moisture release.
- **The NC materials have lower permeability than comparable cement bonded castables.**

# No-Cement Monolithics

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**Hot Strength: NC's generation of castables incorporates a mullite forming binder system.**

- **No-Cement Castables achieve a 100% to 300% increase in hot modulus of rupture @ 2500°F when compared to low cement castables of equal density and mineralogy.**
- **Greater hot strengths provide less erosion by dust laden air streams at high temperatures.**

**How do I choose  
what product to use  
from so many  
variations  
available?**



# Choosing a Product

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- **Application/use**
  - **Determine what are the operating conditions you are trying to address**
    - **Alkali resistance**
    - **Abrasion**
    - **High temperature**
    - **Furnace conditions/gases**
    - **Dry-out window**
    - **Installation timeframe**
    - **Etc.**

# Choosing a Product

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- **Determine the installation method**
  - **Cast/gun/shotcrete**
    - **Casting behind forms offers the best installed properties of all other methods**
      - **Tends to be more costly and time consuming**
    - **Shotcreting offers the second best**
      - **Typically, shotcreting is used for larger installations as this is designed for serious tons/hr installations**
    - **Gunning is used for smaller installations or in areas where shotcreting is not practical**

# Gunning

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- **Gunning advantages**
  - **No Forms**
  - **Joint-Free Construction**
  - **Anchored Lining**
  - **Fast Installation-limits on tons/hr**
  
- **Gunning disadvantages**
  - **Dust**
  - **Rebounds**
  - **Skill Required**
  - **More Material Required**

# Shotcrete

- **Shotcrete advantages**
  - **Fastest Installation**
  - **Lowest Labor Cost**
  - **Minimal Rebounds and Dust**
  - **Excellent Uniformity**
- **Shotcrete disadvantages**
  - **Special Equipment**
  - **Higher Waste in lines**
  - **Space Restrictions**
  - **Limits on how far and high you can shotcrete**



# Plastics/ramming mixes

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# Plastics

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## PLASTIC REFRACTORIES

### Physical Forms

- Plastic
- Ramming Mix
- Gunning Plastic
- Patching Plaster
- Vibratable Plastic

### Bonding Mechanisms

- Clay
- Phosphate
- Resin

Plastics

**Plastics just like monolithics  
are manufactured from the  
same raw materials as brick.**



# Plastics

- **Advantages of plastics**
  - **Ready To Use**
  - **Joint-Free Construction**
  - **Anchored Construction**
  - **Thermal Shock/alkali Resistance**
  - **Not Cement Bonded**
  
- **Disadvantages of plastics**
  - **Require Heat To Set**
  - **Curing is critical**
  - **Installation Time**
  - **Shelf Life**

# Ramming

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# Plastic-Nose Ring

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# Plastic- Support

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**Expanded metal for curing  
Cooler Bullnose**



**Support overhead  
installations with wire mesh**



# Mortars

## Mortars

- **Just like plastics the raw materials they are made from are similar in composition to brick**
- **Mortar joints are used to make up for imperfections on the laying surface, make corrections in laying and bond the brick to brick**
- **Mortars are the weakest part of a brick construction.**

# Mortars-Types

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- **Heat-Setting Mortars**
  - Develop ceramic set with strong bond at furnace temperatures. Provide flexibility in expansion during initial heating.
- **Air-Setting Mortars**
  - Take a rigid set when dried due to chemical binders.
  - Maintain bond strength up to temperature at which the ceramic bond takes effect.
- **Phosphate-Bonded Mortars**
  - Often grouped with heat-setting mortars but are different.
  - Chemical reaction occurs at low temperatures, 500-600°F, between the phosphoric acid and other raw materials.
  - This reaction imparts high strength to the mortar joint.

# Comparisons

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## Service performance comparisons

	HOT MOR	T. SHOCK	POROSITY
BRICK	5	2-5	5
PHOS PLASTIC	2-3	4	3-4
GUN MIX	1	2	2
STD CASTABLE	1-2	2	2-3
LC CASTABLE	3-4	2-5	4
NO CEMENT CASTABLE	4-5	3-4	4

1=POOR / 5=EXCELLENT

# Conclusion

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- **Had enough of Refractory Materials and Types sorry to say this is only the beginning!**
- **Obviously, there is a lot to refractory understanding, and I have only skimmed the surface.**
- **There are reference manuals out there that go into more depth and explanations as to what was presented.**



*Anything that  
can go wrong  
will go wrong!*

*- Capt. Edward A. Murphy, -  
Originator of Murphy's Law*

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**Thank You!**

Questions?

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