Thermal Oxidizer Refractories

Mike Heying
Key Elements to Address for Product Selection

- Temperature Rating
- Abrasion
- Corrosion
- Thermal Shock

How the material can be installed:

- Pump cast
- Pump shotcrete
- Hand cast
- Pneumatic gunning
PRODUCTS

Proven in Thermal Oxidizers.
Full line of Conventional and Low Cement Unshaped Refractories

- Dense
- Medium Weight
- Insulating
- All Available in Low Iron (LI) for Sulfur and REDOX applications

- Plastics
- Mortars
- Dry Gunnable
- Wet Gunnable
- Vibration Castable
- Self Flow Castable
Conventional Castables and Dry Gun Grades

- MORCOCAST HS
- MORCOCAST 3000 HS
- MORCOCAST 60
- MORCOCAST 70
- MORCOCAST 85
- MORCOCAST 95

- MORCOCAST HS GUN
- MORCOGUN 60
- MORCOGUN 70
- MORCOGUN 85
- MORCOGUN 95
Insulating Castables

MORCOLITE 23 LI/GUN
MORCOLITE 60 2600 LI/GUN
MORCOLITE 75 2600 LI/GUN
MORCOLITE 80 2800 LI/GUN
MORCOLITE 50 2200 GUN
MORCOLITE 60 2500
MORCOLITE 75 2500
TURBOCAST

No-dry series of castables
TURBO Castables

- TURBOCAST 45
- TURBOCAST 50
- TURBOCAST 60
- TURBOCAST 85
- TURBOCAST 95

- TURBOGUN 45
- TURBOGUN 50
- TURBOGUN 60
- TURBOGUN 85
- TURBOGUN 95
Turbo Insulating Castables

- Turbolite 23 Li / Gun
- Turbolite 50 2200 Gun
- Turbolite 60 2600 Li Gun
- Turbolite 70 2500 Gun
- Turbolite 25x Gun
- Turbolite 60 2500
- Turbolite 75 2500
TURBOCAST ADVANTAGES

- Rapid Setting, 1 hour from time of water addition to demolding.
- High flow and densification rates when assisted by vibration.
- Fibers add to toughness and increase permeability without degrading other properties.
- NO drying or prefiring required in many uses.
- Drying Rate of less than 300°F per hour recommended. Most process heaters fire below this rate.

INCREASED PRODUCTIVITY
INCREASED PROFITS
LOWER COST
TURBOCAST HEATING TEST

- 9”x5 ½”x4 ½” heated from all sides.
- 12”x12”x5 ½” heated from one side.

[Graph showing temperature over time with annotations for chamber temperature, sample surface temperature, sample center temperature, and 250 °F per hour.]
Fast Cast (FC) Option

Select the Fast Cast option when it is desired to demold cast shapes in less than 20 minutes.

The Fast Cast Option material requires 2–3 minutes mixing and 2–3 minutes of vibration.

Material begins to self-heat and harden 15–30 minutes after water addition to cause rapid setting allowing form removal in 45–60 minutes.
DRYING SCHEDULES
DRYING and INITIAL HEATING SCHEDULE to 1000°F

- Ambient (50–90°F)
  Hold and keep covered with plastic sheet for: 24 hours minimum
- Ambient (60–90°F) to 250–300°F (120–150°C)
  Less than 50°F (25°C) per hour 4 hours
- Hold at 250–300°F (120–150°C)
  1 hour per inch (25 mm) of thickness, minimum 5 hours minimum
- 250–300°F (120–150°C) to 600–700°F (315–370°C)
  Less than 50°F (25°C) per hour 8 hours
- Hold at 600–700°F (315–370°C)
  1 hour per inch (25 mm) of thickness, minimum 5 hours minimum
- 600–700°F (315–370°C) to 1000–1050°F (540–570°C)
  Less than 50°F (25°C) per hour 6 hours
- Hold at 1000–1050°F (540–570°C)
  1 hour per inch (25 mm) of thickness, minimum 5 hours minimum
- To Operating Temperature
- Less than 75°F (42°C) per hour

- TOTAL 57 hours minimum

- NOTE: HOLD IF WATER IS STILL DRIPPING OR STEAM IS ESCAPING FROM FURNACE, DO NOT PROCEED IN PROGRAM UNTILL WATER STOPS ESCAPING
- Further heating rates should never exceed 75°F (40°C) per hour.
- Further cooling rates should never exceed 100°F (55°C) per hour.
**DRYING and INITIAL HEATING SCHEDULE to 1000°F**

**TURBO CASTABLE per API 936**

- Ambient (50–90°F)
  Hold and keep covered with plastic sheet for: 24 hours minimum
- Ambient (60–90°F) to Operating Temperature (1300°F)
  Less than 300°F (165°C) per hour 4.2 hours
- Hold at Operating Temperature
  1 hour per inch (25 mm) of thickness, minimum 5 hours minimum
- **TOTAL** 33.2 hours minimum

**NOTE:** HOLD IF WATER IS STILL DRIPPING OR STEAM IS ESCAPING FROM FURNACE, DO NOT PROCEED IN PROGRAM UNTIL WATER STOPS ESCAPING

- Further heating rates should never exceed 75°F (40°C) per hour.
- Further cooling rates should never exceed 100°F (55°C) per hour.
Comparison of Heating Rates for API Conventional (40 total hours) to TURBO (9.2 total hours)
Approved by API per manufactures instructions Dryout Index

- **TURBOCAST & TURBOGUN (300°F/hr)**
- **API Conventional Castable**

![Graph showing temperature over hours for TURBOCAST & TURBOGUN and API Conventional Castable.](image-url)
DRYING SCHEDULE to 500°F

- Ambient (50–90°F)
  Hold and keep covered with plastic sheet for: 24 hours minimum
- Ambient (60–90°F) to 250–300°F (120–150°C)
  Less than 50°F (25°C) per hour 4 hours
- Hold at 250–300°F (120–150°C)
  1 hour per inch (25 mm) of thickness, minimum 5 hours minimum
- 250–300°F (120–150°C) to 500–600°F (260–315°C)
  Less than 50°F (25°C) per hour 8 hours
- Hold at 500–600°F (260–315°C)
  1 hour per inch (25 mm) of thickness, minimum 8 hours minimum
- 500–600°F (260–315°C) to Ambient
  Less than 100°F (55°C) per hour 4 hours

- TOTAL 53 hours minimum
DRYING SCHEDULE to 500°F TURBO CASTABLE per API 560

- Ambient (50–90°F)
  Hold and keep covered with plastic sheet for: 24 hours minimum
- Ambient (60–90°F) to 500–600°F (260–315°C)
  Less than 100°F (55°C) per hour 4.5 hours
- Hold at 500–600°F (260–315°C)
  1 hour per inch (25 mm) of thickness, minimum 8 hours minimum
- 500–600°F (260–315°C) to Ambient
  Less than 100°F (55°C) per hour 4.5 hours

- TOTAL 41 hours minimum
Comparison of Heating Rates for API Conventional (70 total hours) to TURBO (27 total hours)

Approved by API per manufactures instructions Dryout Index with Alkaline Hydrolysis Fabricator Drying

- TURBO Predry for Alkaline Hydrolysis
- TURBO StartUp
- Conventional Predry for Alkaline Hydrolysis
- Conventional Startup

Temperature (°F) vs Hours
MORCOCOAT K9P

- MORCOCOAT K9P is a ceramic based latex paint, comprised of inert inorganic pigments with phosphoric acid and latex based binders and wetting agents. It develops a strong corrosion resistant coating at ambient and high temperature.

- MORCOCOAT K9P may be diluted with water prior to application. Water may be added directly to bucket and stirred in thoroughly. Stir occasionally after diluting to prevent pigment from settling. Clean the substrate of any foreign material. Apply one or more coats by trowel, brush, dip or spray. It may be applied to hot surfaces, up to 260°C (500°F). Dry before adding hot metal, heat may be applied to accelerate drying. Clean up with water.
API 560 2007 Section 14.1.12

Burner Tile Question
Burner tiles shall be supplied, pre-dried as required, so as to allow full firing after installation without further treatment. Burner tiles fabricated from water-based and hydrous materials shall be pre-dried to no less than 260°C (500°F).

- All castables, whether acid or cement bonded are water based hydrous materials.
- This is old and outdated.
- Review other items and return to this Problem.
Review of API Standard 560 and 936

Fired Heaters for General Refinery Service

ANSI/API STANDARD 560
FOURTH EDITION, AUGUST 2007

ISO 13705:2006 (Identical), Petroleum, petrochemical and natural gas industries—Fired heaters for general refinery service

Refractory Installation Quality Control—Inspection and Testing Monolithic Refractory Linings and Materials

API STANDARD 936
THIRD EDITION, NOVEMBER 2008
Refractory products with dryout requirements differing from those defined in Table 5 shall be rated by the dryout index. To provide a comparative basis, the dryout index shall be defined as the duration time in hours that is required for initial heating from 50°F to 1300°F (10°C to 710°C), including recommended heating rates and holding times. The Index shall be based on single-layer linings 5 in. (127 mm) thick, applied and dried out in accordance with this standard.

- Table 5 Dryout index—40 hours
- TURBOCAST Dryout index—9.2 hours
Table 5—Dryout of Conventional Castable Refractories

<table>
<thead>
<tr>
<th>Heating Stage</th>
<th>Refractory Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Less Than 75 lb/ft³ (1200 kg/m³)</td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial temperature to first hold⁶</td>
<td>Heat at 100°F/h (55°C/h)</td>
</tr>
<tr>
<td></td>
<td>Hold at 250°F to 300°F (122°C to 150°C)</td>
</tr>
<tr>
<td></td>
<td>Hold 1 h/in. (1 h/25 mm) of refractory thickness</td>
</tr>
<tr>
<td></td>
<td>Heat at 75°F/h (42°C/h)</td>
</tr>
<tr>
<td></td>
<td>Hold at 250°F to 300°F (122°C to 150°C)</td>
</tr>
<tr>
<td></td>
<td>Hold 1 h/in. (1 h/25 mm) of refractory thickness</td>
</tr>
<tr>
<td></td>
<td>Heat at 50°F/h (28°C/h)</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td>Hold 1 h/in. (1 h/25 mm) of refractory thickness</td>
</tr>
<tr>
<td>Ramp to next hold</td>
<td>Heat at 100°F/h (55°C/h)</td>
</tr>
<tr>
<td></td>
<td>Hold at 600°F to 700°F (318°C to 374°C)</td>
</tr>
<tr>
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<td>Ramp to next hold</td>
<td>Heat at 100°F/h (55°C/h)</td>
</tr>
<tr>
<td></td>
<td>to operating temperature</td>
</tr>
<tr>
<td></td>
<td>Heat at 75°F/h (42°C/h)</td>
</tr>
<tr>
<td></td>
<td>Hold at 1000°F to 1050°F (542°C to 565°C)</td>
</tr>
<tr>
<td></td>
<td>Hold 1 h/in. (1 h/25 mm) of refractory thickness</td>
</tr>
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<td></td>
<td>to operating temperature</td>
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<tr>
<td></td>
<td>23 hours</td>
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<tr>
<td></td>
<td>31 hours</td>
</tr>
<tr>
<td></td>
<td>40 hours</td>
</tr>
</tbody>
</table>

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**TURBOCAST**

Heat at 300°F/h (150°C/h) to operating temperature

9.2 hours
“The materials used for construction of a burner shall be chosen for strength, as well as temperature and corrosion resistance, for the anticipated service conditions. Burner components shall be designed in accordance with the minimum requirements shown in Table 15.”

<table>
<thead>
<tr>
<th>Burner Tile</th>
<th>Normal</th>
<th>&gt; 40% alumina refractory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burner Tile</td>
<td>High Intensity</td>
<td>&gt;85% alumina refractory</td>
</tr>
<tr>
<td>Oil-firing Tile</td>
<td>≤50mg/kg (V+Na)</td>
<td>≥60% alumina refractory</td>
</tr>
<tr>
<td>Oil-firing Tile</td>
<td>&gt;50mg/kg (V+Na)</td>
<td>&gt;90% alumina refractory</td>
</tr>
</tbody>
</table>

Dated information better refractories are currently available, especially when vanadium is present.
“The vendor shall state the type of protection for refractory and insulation to avoid damage from handling or weather during shipment, storage and erection.”

Missouri Refractories requests that cast parts be kept dry and not allowed to freeze if not dried to 260°C (500°F).

Parts made from TURBOCAST dry during curing and storage.
16.5.8 The following shall apply to castables.

“a) The surfaces to which castables is applied shall be kept above 7°C (45°F) and below 38°C (100°F) during installation and curing.”

“e) Each layer of the castable shall be properly air-cured after installation. To reduce the tendency for hydraulic setting castables to develop alkaline hydrolysis, an application of an impervious organic coating shall be applied to the hot-face layer immediately after placement and the same coating shall be reapplied shortly after the 24 hour cure…”

“f) Shop-installed castable shall not be handled or tested for 72 hour after installation.”

These are important but also old and outdated. Tighter temperature controls than those listed in a) are commonly used. Alkaline hydrolysis is not a problem with TURBOCAST and impervious organic coatings are NOT recommended. Impervious coatings reduce drying rates of TURBOCAST and may lead to explosive dewatering. TURBOCAST materials may be demolded and handled before 72 hours have expired.
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560 5th 11.6.2 Alkali hydrolysis in insulating castable refractory materials, (less than 100 lb/ft³).

a) To reduce the possibility of alkali hydrolysis, castables and gunning mix linings shall be dried out (add to definition) to a minimum of 260°C (500°F, hot-face temperature with heating from hot-face) for 8 hours. Linings shall be inspected for signs of alkaline hydrolysis. If found, affected material shall be removed or repaired as required. Inspection and repair shall occur immediately prior to dryout. Alternate methods for minimizing alkali hydrolysis and remediation shall be approved by the Owner/OEM/Fabricator. Linings shall be dried out before leaving fabricator. Heating/cooling rates for this dryout shall be 55°C/hour (100°F/hour) maximum.

b) Once dried out, linings shall be protected from moisture and mechanical damage.

MORCO disagrees, MORCO has never had an alkali hydrolysis issue with insulating materials. Alkali hydrolysis occurs with high iron cements lower refractory cements not used by MORCO.
17.5.2 Refractory Testing

“Installed castable linings shall undergo hammer tests to check for voids within the refractory material. For dual-layer linings, the hammer test shall be conducted on each layer after curing. Linings shall be struck with a 450 g (1 lb) machinist’s ball peen hammer over the entire surface using a grid pattern approximating the following:

- a) for arch areas: 600 mm (24 in) centres;
- b) for sidewall and floor areas: 900 mm (36 in) centres”

Good Test but rarely used.
“The contractor shall develop a dryout procedure and submit it to the owner for approval. The dryout procedure shall accommodate the refractory manufacturer’s dryout requirements of this standard. In the absence of refractory manufacturer requirements, the minimum dryout schedules in accordance with Table 5 shall apply. The dryout procedure shall include heat up/cool down rates for all control temperature indicators, location of maximum temperature difference between temperature indicators, and shall ensure adequate flow of heated air over the entire surface.”

MORCO recommended.
This section describes provisions for determining safe and cost effective dryout schedules for conventional cement bonded castables. Dryout is the initial heating of castable refractory linings in order to remove retained water from within the refractory without adversely affecting its structure or physical properties. The procedure shall be efficient and provide for cost effective execution with minimal impact on the service factor of the process unit in which the refractory is installed.

MORCO fully commits to this reasoning.
Comparison of Reactions and Water Loss for Phosphate and Calcium Aluminate based Castables during Heating

<table>
<thead>
<tr>
<th>Temperature Range</th>
<th>Phosphate Bonded</th>
<th>Calcium Aluminate (CA) Bonded (Shorthand notation—H=H₂O, C=CaO, A=Al₂O₃)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient, above 70°F (20°C) (Casting below this temperature is dangerous in both cases)</td>
<td>H₃PO₄ + Al₂O₃ → 2Al(H₃PO₄) (Aluminum Acid Phosphate, Water Soluble)</td>
<td>CA₁₀₂₅₂ → H → AH₅ + C₂AH₄ + C₂AH₅₂₅ + C₅AH₆</td>
<td>Physical water released about 50-80% of total water or activator added, approximately the same amount of water is lost for CA cement and phosphate bonded castables.</td>
</tr>
<tr>
<td>230°F (110°C)</td>
<td></td>
<td>AH₅ + C₂AH₄ + C₂AH₅₂₅ + C₅AH₆ → A + CA + CA₆</td>
<td></td>
</tr>
<tr>
<td>500°F (260°C)</td>
<td>2Al(H₃PO₄) + Al₂O₃ → Al₂(H₂PO₄)₃ + 3H₂O (Polyphosphate, Water Soluble)</td>
<td>Chemical water released remaining 20-50% of total water or 5-15% of activator added</td>
<td></td>
</tr>
<tr>
<td>950°F (500°C)</td>
<td>Al₂(H₂PO₄)₃ → Al[PO₄]₃ + 3H₂O (beta metaphosphate)</td>
<td>Chemical water released 5-15% of activator added</td>
<td></td>
</tr>
<tr>
<td>2200°F (1200°C)</td>
<td>Al[PO₄]₃ → AlPO₄ (orthophosphate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2500°F (1400°C)</td>
<td>AlPO₄ → Al₂O₃ + P₂O₅</td>
<td>A + CA + CA₂ → CA₆</td>
<td></td>
</tr>
</tbody>
</table>

The implications of the above are important to successfully dewatering castables. Castables that have not been heated are stable and non-water soluble when formed with CA cement (TURBOCAST). Conversely, castables bonded with phosphate are water soluble until heated above 950°F (500°C).

During initial drying at 230°F (110°C) both castables lose approximately 50% of the added liquid. CA bonded materials that were cast at less than 70°F (20°C) form AH₅ gel which inhibits the removal of water, reduces strength and increases the likelihood of explosive dewatering, with phosphate bonded castables only the strength is reduced.

During drying from 230°F (110°C) to 500°F (260°C) hydrates of aluminum phosphate migrate toward the surface of the cast piece forming a denser layer which inhibits removal of water if heating is excessively slow. Prior to 500°F (260°C) phosphate bonded castables are water soluble, exposure to water may cause softening and slumping, and exposure to steam leads to loss of strength and disintegration. After 650°F (350°C) phosphate bonded castables are mostly insoluble. CA cement bonded castables increase in strength from exposure to water and steam over all temperature ranges as long as the atmosphere is oxidizing.

During drying from 500°F (260°C) to 950°F (500°C) all of the remaining physical and chemical water is lost by CA cement bonded castables. This rapid loss of chemical water in addition to any remaining physical water may cause the formation of a water wall approximately 4-6" from the hot face of the casting. This water wall inhibits further removal of water and may lead to explosive dewatering. During this range only about one-fourth as much water is removed from phosphate as compared to cement bonded castables reducing the probability of forming a water wall and explosive dewatering. Permeability inducing aids such as those used in TURBOCAST greatly reduce the probability of explosive dewatering and allow heating schedules equivalent to or faster than phosphate bonded castables.

During drying from 950°F (500°C) to 2200°F (1200°C) the remaining chemical water is removed from phosphate bonded castables leading to an insoluble castable. Prior to 2200°F (1200°C) phosphate bonded castables are partially water soluble and may lose strength in wet environments due to water absorption. CA cement bonded castables are stable with highly refractory bond phases.

From 2200°F (1200°C) to 2500°F (1400°C) phosphate bonded castables are stable with highly refractory bond phases. Above 2500°F (1400°C) aluminum orthophosphate slowly breaks down liberating P₂O₅ gas and leaving a stable, strong corrosion resistant Al₂O₃ bond. CA cement bonded materials slowly convert from A, CA and CA₂ to CA₆, an extremely strong, stable bond phase with excellent corrosion resistance.
If Phosbond requires no drying—Why not TURBOCAST?

- API 560 Section 14.1.12 states that “water-based and hydrous materials shall be pre-dried to no less than 260°C (500°F).” Both Phosbond and TURBOCAST 60 Z are water based. Water contents are based on adding the prescribed amount of water or activator (68% water by mass) as per the datasheets.

- Maximum water content (% by mass) at temperatures of drying after extended drying to allow complete removal of available water.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Phosbond water %</th>
<th>TURBOCAST 60 Z water %</th>
</tr>
</thead>
<tbody>
<tr>
<td>70°F (20°C)</td>
<td>9.0</td>
<td>11</td>
</tr>
<tr>
<td>230°F (110°C)</td>
<td>4.5</td>
<td>5.5</td>
</tr>
<tr>
<td>500°F (260°C)</td>
<td>2.2</td>
<td>0</td>
</tr>
<tr>
<td>950°F (500°C)</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
All cast burner tiles even phosbond or chemical bond require drying per 14.1.12.

Refractory producers argued against this requirement for many years.

Requirement Stands.

It does not matter what type of castable or who the refractory manufacturer, tile fabricator or customer is.

MORCO TURBOCAST is known to not require firing prior to use as proven by laboratory testing, pilot plant trials and years of industrial use without a failure.
Storing Cast Refractory

- Cast TURBOCAST and PHOSCAST refractory may be stored indefinitely as cast if not allowed to freeze.
  - Freezing may cause cracking.
  - TURBOCAST and PHOSCAST may be allowed to freeze after heating above 260°C and holding above 260°C for at least 1 hour per 25 mm of thickness in thickest section.

- Air should be allowed to circulate around and through openings.
  - Sealing the part in plastic wrap may cause condensation which will lead to calcia migration to the surface in cement bonded TURBOCAST.
  - Phosphate bonded PHOSCAST may mold in the presence of moisture as phosphate is an excellent fertilizer.
  - Mold in phosphate bonded PHOSCAST and calcia migration in TURBOCAST will only damage the outer surface and should not be cause for extreme concern.
  - Exposure to intermittent moisture may increase strength. Alkaline hydrolysis should not occur unless stored exposed to salt water in dense, high purity refractory parts.

- Optimum storage conditions are in a ventilated warehouse maintained between 20 and 100°C such that air can circulate around parts.
- Parts should not be stored where they may be exposed to salt water.
<table>
<thead>
<tr>
<th>Product</th>
<th>MORCOPACK 80</th>
<th>MORCOCAST 175 3000</th>
<th>MORCOCAST 125 2500</th>
<th>MORCOLITE 88 2500</th>
<th>MORCOLITE 80 2500</th>
<th>MORCOLITE 100 668</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Extreme erosion resistant, dense castable – hand packable</td>
<td>Extreme erosion resistant heat insulating, dense castable</td>
<td>Erosion resistant heat insulating, acid resistant heavy castable</td>
<td>Medium weight heat insulating medium purity castable</td>
<td>Medium weight heat insulating high purity castable</td>
<td>Unique medium weight insulating extremely high purity castable</td>
</tr>
<tr>
<td>Maximum Hot Face Temperature (°F)</td>
<td>2300</td>
<td>3100</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
</tr>
<tr>
<td>Maximum Grain Size (Mesh)</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Bulk Density (lb/ft³)</td>
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<tr>
<td>Linear Change (%)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>230°F 1500°F</td>
<td>-0.4 to -0.1 -0.4 to +0.2</td>
<td>-0.2 to +0.0 -0.3 to +0.0</td>
<td>-0.1 to +0.1 -0.3 to -0.1</td>
<td>-0.1 to +0.1 -0.3 to -0.0</td>
<td>-0.2 to +0.0 -0.5 to -0.0</td>
<td>-0.3 to +0.0 -0.4 to -0.1</td>
</tr>
<tr>
<td>Cold Crushing Strength (psi)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Abrasion Resistance (cc)</td>
<td></td>
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</tr>
<tr>
<td>230°F 1500°F</td>
<td>6–7 2–3 3–5</td>
<td>5–7 2–4</td>
<td>7–9 3–5</td>
<td>-- --</td>
<td>-- --</td>
<td>-- --</td>
</tr>
<tr>
<td>SiO₂ (%)</td>
<td>2–4</td>
<td>&lt;0.5</td>
<td>78–80</td>
<td>37–39</td>
<td>37–39</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>CaO (%)</td>
<td>2–4</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>7–8</td>
<td>6–7</td>
<td>13–14</td>
</tr>
<tr>
<td>P₂O₅ (%)</td>
<td>5–10</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Fe₂O₃ + TiO₂ (%)</td>
<td>&lt;1</td>
<td>&lt;0.3</td>
<td>&lt;0.4</td>
<td>&lt;0.8</td>
<td>&lt;0.8</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Na₂O + K₂O (%)</td>
<td>2–4</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.9</td>
<td>&lt;0.9</td>
<td>&lt;0.2</td>
</tr>
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