

Refractory Concrete: Abstract of State-of-the-Art Report

Reported by ACI Committee 547

This abstract first appeared in *Concrete International: Design & Construction*, V. 1, No. 5, May 1979, pp. 62-77. The full report is available as a separate publication in 8 1/4 x 11 in., paper cover format, consisting of 224 pages. Contents listed on this page represent only the sections of the report covered in this abstract.

Refractory concretes are currently used in a wide variety of industrial applications where py-reprocessing and/or thermal containment is required. The service demands of these applications are becoming increasingly severe and this, combined with the constant demand for refractories with enhanced service life and more efficient means of installation, has resulted in an ever expanding refractory concrete technology. ACI Committee 547 has prepared this state-of-the-art report in order to meet the need for a better understanding of this relatively new technology.

The report presents background information and perspective on the history and current status of the technology. Composition and proportioning methods are discussed together with a detailed review of the constituent ingredients. Emphasis is placed on proper procedures for the installation, curing, drying, and firing. The physical and engineering properties of both normal weight and light weight refractory concretes are reported, as are state-of-the-art construction details and repair/maintenance techniques. Also included is an in-depth review of a wide variety of applications together with the committee's assessment of future needs and developments.

Keywords: abrasion; accelerating agents; admixtures; **aggregates**; aluminate cement and concretes; anchorage (structural); cement-aggregate reactions; chemical analysis; construction; corrosion; curing; drying; failure mechanisms; formwork (construction); hydration; insulating concretes; kilns; **lightweight concretes**; mechanical properties; **mix proportioning**; packaged concrete; **physical properties**; placing; pumped concrete; quality control; refractories; **refractory concretes**; reinforcing materials: repairs; research; shotcrete; spalling; structural analysis; temperature; thermal properties; water; welded wire fabric.

Contents of summary

Chapter 1 -Introduction, p. 547R-2

- 1.1 - Objective of report
- 1.2 - Scope of report
- 1.3 - Nomenclature
- 1.6 - Non-hydraulic setting refractories

Chapter 2 -Criteria for refractory concrete selection, p. 547R-5

- 2.1 - Introduction
- 2.2 - Castables and field mixes
- 2.5 - Load bearing considerations
- 2.7 - Corrosion influences
- 2.10 - Abrasion and erosion resistance

Chapter 3 -Constituent ingredients, p. 547R-6

- 3.2 - Binders
- 3.3 - Aggregates
- 3.4 - Effects of extraneous materials

Chapter 4 -Composition and proportioning, p. 547R-7

- 4.1 - Introduction
- 4.3 - Field mixes
- 4.4 - Water content

Chapter 5 -Installation, p. 547R-8

- 5.1 - Introduction
- 5.2 - Casting
- 5.3 - Shotcreting
- 5.4 - Pumping and extruding
- 5.5 - Pneumatic gun casting
- 5.8 - Finishing

Chapter 6 -Curing, drying, firing, p. 547R-9

- 6.1 - Introduction
- 6.2 - Bond mechanisms
- 6.3 - Curing
- 6.4 - Drying
- 6.5 - Firing

Chapter 7 -Properties of normal weight refractory concretes, p. 547R-10

- 7.1 - Introduction
- 7.2 - Maximum service temperature
- 7.4 - Shrinkage and expansion
- 7.5 - Strength
- 7.6 - Thermal conductivity
- 7.10 - Specific heat

Chapter 8 -Properties of lightweight refractory concretes, p. 547R-11

- 8.1 - Introduction
- 8.4 - Shrinkage and expansion
- 8.5 - Strength
- 8.6 - Thermal conductivity
- 8.10 - Specific heat

Chapter 9 -Construction details, p. 547R-12

- 9.1 - Introduction
- 9.2 - Support structure
- 9.3 - Forms
- 9.4 - Anchors
- 9.5 - Reinforcement and metal embedment
- 9.6 - Joints

Chapter 10 -Repair, p. 547R-13

- 10.1 - Introduction
- 10.2 - Failure mechanisms
- 10.3 - Surface preparation
- 10.4 - Anchoring and bonding
- 10.5 - Repair materials
- 10.6 - Repair techniques

Chapter 11 -Applications, p. 547R-15

- 11.1 - Introduction

Chapter 12 - New developments and future use of refractory concrete, p. 547R-15

- 12.1 - Introduction
- 12.2 - New developments
- 12.3 - Research requirements

Copyright ©1979, American Concrete Institute
All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by any electronic or mechanical device, printed or written or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.

Discussion of this committee report may be submitted in accordance with general requirements of the ACI Publication Policy to ACI Headquarters, P.O. Box 19150, Detroit, Michigan 48219. Closing date for submission of discussion is November 1, 1979.

Chapter 1 -Introduction

1.1 Objective of report

The objective of this report is to provide a source of information on the many facets of refractory concrete technology. The report is intended as a unified and objective source of information to aid the engineer or consumer in categorizing and evaluating monolithic refractory concrete technology and the many materials and processes available today. It is not intended to be a specification or standard, and should not be quoted or used for that purpose.

1.2 Scope of report

Refractory concrete is concrete suitable for use at temperatures up to about 3400 F (1870 C). It consists of a graded refractory aggregate bound by a suitable cementing medium. This report is concerned with refractory concrete in which the binding agent is a hydraulic cement, and does not consider concretes which use waterglass (sodium silicate), phosphoric acid, or phosphates as a principal cementing agent. It covers all facets of refractory concrete installation and use, including the properties of individual ingredients and concretes, placing techniques, methods of curing and firing, repair procedures, construction details, and current and future applications.

1.3 Nomenclature

The following definitions ^{1,2} are used in this report:

ACID REFRACTORIES – Refractories containing a substantial amount of silica that may react chemically with basic refractories, basic slags, or basic fluxes at high temperatures.

APPARENT POROSITY (ASTM C20) – The relationship of the volume of the open pores in a refractory specimen to its exterior volume, expressed as a percentage.

BASIC REFRACTORIES – Refractories whose major constituent is lime, magnesia, or both, and which may react chemically with acid refractories, acid slags, or acid fluxes at high temperatures. (Commercial use of this term also includes refractories made of chrome ore or combinations of chrome ore and dead burned magnesite).

CALCIUM ALUMINATE CEMENT – The product obtained by pulverizing clinker which consists of hydraulic calcium aluminates formed by fusing or sintering a suitably proportioned mixture of aluminous and calcareous materials.

CASTABLE REFRACTORY – A proprietary packaged dry mixture of hydraulic cement and specially selected and proportioned refractory aggregates which, when mixed with water, will produce refractory concrete or mortar.

CERAMIC BOND – The high strength bond which is developed between materials, such as calcium aluminate cement and refractory aggregates, as a result of thermochemical reactions which occur when the materials are subjected to elevated temperature.

EXPLOSIVE SPALLING – A sudden spalling which occurs as the result of a build-up of steam pressure caused by too rapid heating on first firing.

GROG – Burned refractory material, usually calcined clay or crushed brick bats.

HEAT RESISTANT CONCRETE – Any concrete which will not disintegrate when exposed to constant or cyclical heating at any temperature below which a ceramic bond is formed.

HIGH ALUMINA CEMENT – See calcium aluminate cement.

NEUTRAL REFRACTORIES – Refractories that are resistant to chemical attack by both acid and basic slags, refractories, or fluxes at high temperatures.

REFRACTORY AGGREGATE – Materials having refractory properties which form a refractory body when bound into a conglomerate mass by a matrix.

REFRACTORY CONCRETE – Concrete which is suitable for use at high temperatures and contains hydraulic cement as the binding agent.

SOFTENING TEMPERATURE – The temperature at which a refractory material begins to undergo permanent deformation under specified conditions. This term is more appropriately applied to glasses than to refractory concretes.

THERMAL SHOCK – The exposure of a material or body to a rapid change in temperature which may have a deleterious effect.

1.6 Non-hydraulic setting refractories⁵

The following discussion, while not pertinent to the main theme of the report, will be of some interest and use to the reader.

1.6.1 Refractory brick – High quality brick, known as firebrick, with unique chemical and physical properties is obtained by blending different types of clay and other ingredients and by varying both the method of processing and the burning temperatures. In addition to the many varieties of fireclay brick, high alumina, insulating, silica, fused aggregate, and basic firebrick have been developed. Refractory brick remains a major construction material for applications in which heat containment and control is necessary and in many instances, is the only satisfactory solution to a specific problem.

Brick has a number of disadvantages when compared to monolithic refractories. These disadvantages include multiple joints, complicated anchoring, higher placement costs, more difficult repair procedures, the need to maintain expensive inventories of special or scarce items, a certain inflexibility in structural design, and higher fuel requirements during manufacture.

1.6.2 Plastics and ramming mixes – Plastic refractories and ramming mixes are refractories which are tamped or rammed in place and are used for monolithic construction, for repair purposes, and for molding special shapes. These materials find extensive use in industry. They usually employ a clay, alumina, magnesite, chrome, silicon carbide, or graphite base, and are blended with a binder. Heat setting mixes are likely to contain fireclay or phosphoric acid as a binder. Air or cold-setting mixes generally contain fireclay and sodium silicate as the binder. Compared to ramming mixes, plastic refractories have higher moisture contents and therefore, higher plasticity.

TABLE 2.1a - Characteristics of normal weight refractory concretes

Full document details: ACI 547R-79 (1997)

PRODUCT DESCRIPTION	TABULAR A1.0, HIGH PURITY BINDER		GENERAL PURPOSE 2800F	HIGH STRENGTH 2800 F GUN	EROSION/ ABRASION RESISTANT	2800 F STEEL MILL		STANDARD	HIGH STRENGTH	COARSE HIGH STRENGTH 2350 F	COARSE HIGH STRENGTH 2600 F	LOW IRON HIGH STRENGTH
	HIGH STRENGTH	3000E										
Recommended Service Temperature max., Deg. F	3400	3000	2800	2800	2400	2800	2600		2500	2350	2600	2600
ASTM Class (C-401)	G	E	-	-	B	D	C		C	B	C	C
Water Required for Mixing, Percent by Weight	8-11	8-12	10-12	(3)	10-12.5	10-13	15-21		14.0-15.5	11-14	3.5-11	14-16
Material Required (1) lbs. per cu. ft., lbs. per bag	160-165	140-145	129-133	129-133	125-130	125-131	108-114		120-124	126-130	137-142	118-120
Method of Application (2)	C-T-S	C-T-S-E	C-T	S	C-T-S	C-E	C-T-E		C-T-S-E	C	C	C-T-S-E
Bulk Density, 220 F	165	178	139	147	135	143	134	136	112	121	126	133
Heated to 1000 F	159	169	138	146	129	134	132	133	108	117	126	129
temperature of: 1500 F	161	174	138	146	129	134	130	133	108	114	120	122
then cooled 2000 F	161	174	137	146	127	135	130	133	108	115	124	129
pcf 2550 F	165	176	139	150	127	130	130	133	108	115	140	141
2732 F	160	169	138	146	128	135	124	132	111	114	133	138
3000 F	165	167	136	149	128	138	128	138			121	123
Total Linear Change % Heated to temp. of: then cooled (Note: Linear change figures are "TOTAL" in all cases and include percent of drying shrinkage occurring in conversion from wet "as cast" to "as dried" state)	220 F 1000 F 1500 F 2000 F 2550 F 2732 F 3000 F	0.0 to -0.5 -0.1 to -0.5 -0.1 to -0.5 -0.1 to -0.3 -0.4 to -1.3 -0.7 to -1.4 -0.6 to -1.1	-0.1 to -0.6 -0.1 to -0.6 -0.2 to -0.6 -0.2 to -0.7 -0.5 to -1.1 -0.2 to +0.3 +0.1 to +0.7	-0.1 to -0.4 -0.2 to -0.3 -0.1 to -0.5 -0.3 to -0.7 -0.8 to +1.3 -0.5 to +1.0	-0.2 to -0.6 -0.2 to -0.5 -0.1 to -0.5 -0.1 to -0.9 -0.5 to +0.2 -0.8 to +0.8	-0.2 to -0.7 -0.2 to -0.6 -0.2 to -0.6 -0.2 to -0.5 -0.1 to -0.6	-0.3 to -0.4 -0.3 to -0.4 -0.2 to -0.4 -0.2 to -0.5 +1.7 to +2.2 +1.3 to +2.4	-0.1 to -0.5 -0.2 to -0.5 -0.1 to -0.7 -0.4 to -0.8 -1.2 to +0.3	-0.1 to -0.5 -0.2 to -0.5 -0.1 to -0.9 -	-0.1 to -0.5 -0.3 to -0.6 -0.4 to -0.6 -0.3 to -0.5	0.0 to -0.3 - 0.0 to -0.3 -0.1 to -0.5 -0.1 to +1.7	-0.2 to -0.4 -0.4 to -0.5 -0.4 to -0.5 -0.5 to -0.7 -0.1 to +0.5 -
Modulus of Rupture, psi Heated to temperature of: then cooled	220 F 1000 F 1500 F 2000 F 2550 F 2732 F 3000 F	1600 - 2590 1820 - 2320 1450 - 2120 930 - 1400 1280 - 2615 1290 - 2707 790 - 1280	450 - 840 350 - 570 290 - 580 340 - 590 820 - 2050 1260 - 2400 1685 - 4620	360 - 800 370 - 650 230 - 680 390 - 780 1000 - 2450 1110 - 2260	400 - 840 320 - 680 530 - 840 500 - 970 1300 - 3030 2290 - 3740	1260 - 2000 945 - 1240 1020 - 1865 1000 - 1385	445 - 745 175 - 310 145 - 295 145 - 270 1245 - 2605 2095 - 2930	310 - 520 200 - 270 150 - 200 130 - 240 820 - 1780	820 - 1170 300 - 590 300 - 560 300 - 460	975 - 1030 535 - 710 400 - 560 405 - 465	810 - 1015 - 300 - 415 310 - 395 520 - 910	1020 - 1250 395 - 440 370 - 570 385 - 605 370 - 2390
Cold Crushing Strength, psi Heated to temperature of: then cooled	220 F 1000 F 1500 F 2000 F 2550 F 2732 F 3000 F	5180 - 10230 8170 - 9160 7280 - 9395 3030 - 10000 6180 - 11000 4330 - 10115 3320 - 5325	1030 - 2160 1070 - 2250 950 - 2250 980 - 2050 3280 - 4640 4280 - 5620 5870 - 10000	1420 - 3780 1490 - 2950 1110 - 2770 1330 - 2920 3200 - 7930 5280 - 12100	1190 - 2620 1400 - 3000 1690 - 3340 1160 - 3105 4250 - 11390 7140 - 13175	4510 - 7910 3810 - 6480 4410 - 7110 3620 - 5375	4280 - 3145 645 - 1400 540 - 1260 560 - 915 3021 - 3765 - -	990 - 1570 685 - 1030 630 - 840 640 - 850 3200 - 5490 - -	2410 - 3800 1470 - 2210 1530 - 2090 1450 - 2070	3450 - 3870 1800 - 229 1775 - 2325 1480 - 2225	2150 - 3580 - 1450 - 1590 1050 - 1340 1470 - 2280	3075 - 5470 2995 - 3795 2425 - 2845 1500 - 2105 3735 6970
Thermal Conductivity Btu/in/hr-sq.ft.-Deg F at Mean Temperature of:	500 F 1000 F 1500 F 2000 F	9.87 9.46 9.36 9.57	6.47 6.15 5.80 5.72	5.35 5.35 5.40 5.65	4.60 5.00 5.40 5.80	5.24 5.10 5.10 5.18	4.78 5.12 5.50 5.88	4.00 4.33 4.68 5.02	4.10 4.48 4.85 5.19	4.48 4.85 5.30 5.73	7.25 7.40 7.65 7.85	4.60 5.00 5.40 5.80
Chemical Analysis percent												
SiO ₂		0.03	29.73	47.58	47.31	32.06	43.19	43.71	44.35	34.64	4.18	46.08
Al ₂ O ₃ , TiO ₂		93.65	65.16	48.31	46.73	59.23	46.70	40.03	38.68	57.69	55.66	31.86
Fe ₂ O ₃ , FeO		0.27	1.15	1.47	1.37	0.91	3.05	4.22	4.78	1.30	1.19	2.57
CaO, MgO		5.52	2.48	1.47	3.25	6.89	6.09	9.03	11.31	5.63	2.96	17.08
Alkalies		0.11	0.39	0.82	0.84	0.59	0.69	1.22	0.74	0.42	0.45	1.14
Ignition Loss		0.30	0.66	0.15	0.47	-	Trace	1.14	0.11	0.27	0.11	0.67

Note: All measurements except thermal conductivity taken at room temperature.

SI conversion factors
Deg F = 1.8 C + 32
1 pcf = 16.02 kg/m³
1 lb = 0.4536 kg
1 psi = 0.006895 MPa
1 Btu-in./hr-sq ft = deg F

TABLE 2.1b— Characteristics of lightweight insulating refractory concretes

COMMERCIAL PRODUCT DESCRIPTION	HIGH ALUMINA LOW IRON	GENERAL PURPOSE	LIGHT- WEIGHT 2250 F	LIGHT- WEIGHT 1800 F	VERMICULITE BASE VERY LIGHT- WEIGHT
Recommended Service Temp. max., Deg. F	3000	2500	2250	**1800	1600
ASTM Class (C 401)	Q	Q	P&O	N	Special
Water Required for Mixing, Percent by Weight	24-27.5	38-47	40-47	46-55	176
Materials Required, lbs. per cu. ft.	87-92	80-85	48-50	46-48	24
Method of Application*	C-S-E	C-T-S-E	C-T-S-E	C-S-E	C-T-E
Bulk Density, lbs. per cu. ft., 220 F	92-96	86-90	51-53	48-54	21-25
Heated to 1500 F	90-91	80-83	47-48	47-54	20-25
Temp. of: 2000 F	89-92	80-84	48-49	46-52	-
then cooled 2250 F	90-91	80-82	47-49	-	-
2550 F	86-92	-	-	-	-
2910 F	88-93	-	-	-	-
Total Linear Change, Percent, 220 F	-0.2 to -0.3	-0.2 to -0.6	-0.3 to -0.4	-0.1 to -0.4	-0.2 to -0.4
Heated to 1500 F	-0.4 to -0.7	-0.4 to -0.8	-0.3 to -0.9	-1.7 to -2.0	-0.9 to -2.0
Temp. of: 2000 F	-0.6 to -0.8	-0.3 to -0.8	-0.3 to -1.1	-0.8 to -1.3	-
then cooled 2250 F	-0.4 to -0.6	-0.2 to -1.4	-0.4 to -1.4	-	-
2550 F	-0.6 to +0.8	-	-	-	-
2910 F	-0.2 to +0.2	-	-	-	-
Modulus of Rupture, psi, 220 F	265-360	190-350	100-150	200-420	15-55
Heated to 1500 F	205-225	140-230	70-90	105-140	15-50
Temp. of: 2000 F	280-315	120-250	75-115	100-205	-
then cooled 2250 F	625-640	155-315	160-170	-	-
2550 F	950-955	-	-	-	-
2910 F	1755-1835	-	-	-	-
Cold Crushing Strength, psi, 220 F	615-685	560-1040	290-450	390-750	30-70
Heated to 1500 F	550-610	830-710	160-290	295-405	20-80
Temp. of: 2000 F	450-545	460-800	130-220	200-285	-
then cooled 2250 F	800-880	500-810	270-330	-	-
2550 F	265-1415	-	-	-	-
2910 F	3535-4100	-	-	-	-
Chemical Analysis, percent					
SiO ₂	36.52	40.08	37.38	43.17	-
Al ₂ O ₃ , TiO ₂	54.63	38.13	34.79	17.68	-
Fe ₂ O ₃ , FeO	1.38	5.31	6.63	3.11	-
CaO, MgO	4.56	13.53	17.68	31.34	-
Alkalies	1.11	1.66	1.88	2.05	-
Ignition Loss	1.90	1.20	1.45	2.40	-
SO ₃					
Thermal Conductivity (k), Btu/Hr./Sq. Ft./F./In, At Mean					
Temp. of: 500 F	2.88	2.58	1.66	1.40	0.87
1000 F	3.19	2.86	1.98	1.71	1.15
1500 F	3.50	3.14	2.31	2.01	1.43
2000 F	3.82	3.42	2.63	-	-

*C-Casting; T-Troweling; S-Shotcreting; E-Extruding. All measurements except thermal conductivity taken at room temperature.

**2000 F (For back-up material)

SI conversion factors

DegF = 1.8 C + 32

1 pcf = 16.02 kg/m³

1 lb = 0.4536 kg

1 psi = 0.006895 MPa

1 Btu-in./hr-sq ft - deg F

Plastics are generally placed without use of forms. With the exception of some specialized tabular alumina castables, plastics have a somewhat higher service limit than castable refractories. Their main disadvantages are greater shrinkage and crack development. Except for phosphate bonded materials cured above 600 F (315 C), plastics generally have lower cold and hot strengths than refractory concretes. In addition, plastics tend to have a relatively low strength zone on the cool side of the lining.

Ramming mixes usually have higher density and less shrinkage than plastic refractories. With their low water content, they must be forced into place and require strong well-braced forms. Some of the dryer medium grind ramming mixes are suitable for gunning, and are used for patching and maintenance materials.

1.6.4 Gunning mixes other than refractory concretes^{12,13} – As used in this section, the term “gunning mixes” does not refer to refractory concrete and should not be confused with gunned refractory materials which produce refractory concrete. Gunning mixes are mixtures of non-hydraulic setting ingredients which are installed hot or cold, usually by the shotcrete method.

Gunning mixes generally have low rebound loss, are predominately used for patching or resurfacing brick or other refractories, have a strong internal bond, and exhibit excellent adhesion or bond to the existing refractory lining. They find extensive use in basic oxygen, electric arc and open hearth furnaces, among other applications.

Chapter 2 - Criteria for refractory concrete selection

2.1 Introduction

Refractory concrete is usually made with high alumina cement. It is not generally used as a structural material and its primary purpose is as a protective lining for steel, concrete or brick structures. It is considered a consumable material requiring replacement after an appropriate service life.

Some of the destructive forces that refractory concretes withstand are abrasion, erosion, physical abuse, high temperatures, thermal shock, hot and molten metals, clinker, slag, alkalis, mild acid or acid fumes, expansion, contraction, carbon monoxide, and flame impingement.

Refractory concretes are categorized as either normal weight or lightweight. The former are also referred to as “heavy refractory concretes” and the latter are often called “insulating refractory concretes.” [Table 2.1a](#) shows the characteristics of a typical range of normal weight refractory concretes; [Table 2.1b](#) shows the characteristics of lightweight refractory concretes.

2.2 Castables and field mixes

Refractory concretes are usually prepared at the job site from materials supplied to the user in either of two ways: (1) prepackaged so-called “refractory castables;” (2) field mixes.

Refractory castables are plant packaged mixes composed of ingredients that are weighed, blended and usually bagged in convenient sizes for shipping and handling. They require only mixing with water on the job to produce refractory concrete. Field mixes are made from material components which are proportioned and mixed on the site just prior to the addition of water.

2.5 Load bearing considerations

Most application designs of refractory concrete consider that there is a thermal gradient through the material with heat conducted from the hot face to the cold face. A cross section of the refractory will usually have a layer at the hot face that has a ceramic bond, an intermediate section with a weaker combination of ceramic and a partial hydraulic bond, and a cold face section that retains most of its hydraulic bond. Refractory concrete linings in this type of situation are usually well anchored and self-supporting.

Castables containing high proportions of coarse aggregates produce refractory concrete with good load bearing characteristics. Certain types of refractory concrete tend to have low strengths in the intermediate temperature zones [1500-2250 F (820-1230 C)] and should not be subjected to excessive mechanical abuse or dead load. Generally, lightweight concretes designed for insulating purposes should not be subjected to impact, heavy loads, abrasion, erosion or other physical abuse. Normally, both the strength and the resistance to destructive forces decline as the bulk density of the refractory concrete decreases.

There are a number of special refractory castables available which have better than average load-bearing capabilities and withstand abrasion or erosion much better than the standard types.

2.7 Corrosion influences

High temperature in combination with a corrosive environment can have a serious deleterious effect on both the concrete and the backup steel structure. Generally, the higher density, higher purity refractory concretes have better corrosion resistance than the lower density, lower purity types.

Alkalies can effect the service life of refractory concretes. The furnace charge can give off both alkalis (K_2O) and the fuel sulfur compounds (SO_2) as vapors. These can penetrate into the pores of the refractory concrete and react; their reaction products cool, solidify, and expand, sometimes causing the hot face of the refractory to peel or shear away.

In certain applications, the refractory concrete is subjected to highly reducing conditions. Low-iron refractory concretes should be used for this type of application.

2.10 Abrasion and erosion resistance

Abrasion and erosion begin with the wearing away of the weakest matrix constituent, binder, leaving the coarse or hard aggregate to eventually fall away. A hard aggregate, a high modulus of rupture, and high compressive strength at the hot face are necessary for good abrasion and erosion resistance in refractory concretes.

Chapter 3 – Constituent ingredients

3.2 Binders

The binders principally used in refractory concretes are calcium aluminate cements. However, ASTM-type portland cements can be used in some refractory applications up to an approximate maximum of 2000 F (1090 C) with selected aggregates, if special

precautions are taken to ensure a sound refractory concrete. Cyclic heating and cooling tends to disrupt portland cement concretes and adding a fine siliceous material to react with the calcium hydroxide, formed during hydration, is helpful in alleviating the problem.

Calcium aluminate (high alumina) cements are commercially available hydraulic binders. They are

TABLE 3.3a- Maximum service temperature of selected aggregates mixed with calcium aluminate cements under optimum conditions

Aggregate	Remarks	Maximum temperature	
		Deg C	Deg F
Alumina, tabular	Refractory, abrasion resistant	1870	3400
Dolomitic limestone (gravel)	Abrasion and corrosion resistant	500	930
Fireclay, expanded	Insulating, abrasion and corrosion resistant	1640	2980
Fireclay brick, crushed	Abrasion and corrosion resistant	1600	2910
Flint fireclay, calcined		1650	3000
Kaolin, calcined	Abrasion and corrosion resistant	1650	3000
Mullite		1650	3000
Perlite	Insulating	1340	2450
Sand	(Silica content less than 90 percent not recommended) Abrasion and corrosion resistant	300	570
Slag, blast furnace (air cooled)	Abrasion resistant	540	1000
Slag, blast furnace (granulated)	Insulating, abrasion and corrosion resistant	1200	2190
Trap rock, diabase	(Basic Igneous Rock-Minimal Quartz) Abrasion and corrosion resistant	1000	1830
Vermiculite	Insulating	1100	2010

TABLE 3.3b— Aggregate grading

Maximum size aggregate (except for gun placement)	1 ½ in. (3.81 cm)
Maximum size aggregate for normal gun placement	¾ in.* (0.64 cm)
Maximum size insulating crushed firebrick	1 in. (2.54 cm)
Maximum size expanded shales and clays	½ in. (1.27 cm)
Maximum size, with the above exceptions, should not be greater than 20-25 percent of the concrete minimum dimension.	
Aggregate of ½ in. (1.27 cm) or larger size:	
Retained on No. 8 Sieve =	50 percent
Passing No. 100 Sieve =	10-15 percent
Aggregate of less than ½ in. (1.27 cm) maximum size:	
Retained on No. 50 Sieve =	75 percent
Passing No. 100 Sieve =	10-15 percent

*In special cases larger sizes have been used successfully.