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DEFORMATION OF INSULATING FIREBRICK UNDER LOAD*

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ABSTRACT

An electrically heated furnace and a method to apply loads to full-size insulating firebrick heated throughout to thermal equilibrium are described. Sixteen commercial brands of insulating firebrick of various use limits were tested under several loads over a range of temperatures. No correlation was found to exist between the weight and the resistance to hot loading or between the cold crushing strength and the hot load-bearing capacity.

I. Object

The object of this work was to devise a suitable test procedure to measure the relative load-bearing resistance of insulating firebrick at various loads and temperatures. For convenience as a routine laboratory test, similar to the corresponding test for dense fireclay refractories, the test was made of such duration that it could be run in an eight-hour day. A test of this short duration, however, would not give sufficient information for complete engineering or design purposes because the rate of deformation decreases as the time of test is continued and a uniform rate is not established until the sample has been under load for several days. Obviously such long-time tests are not justified unless some special design features are being investigated in connection with hot-load deformation. The foregoing remarks apply equally to insulating firebrick and dense firebrick.

The question of load-bearing resistance of insulating firebrick for ordinary wall constructions usually is unimportant. The temperature gradient through a lightweight insulating brick is so steep that the cool portion is able to carry the load even though the hot face has exceeded its load-temperature limit. There are many applications, however, in which insulating firebrick must withstand load conditions, such as insulated sprung arches of wide span, floors and car bottoms, metal holding furnaces, and parts of furnaces wherein insulating firebrick have been substituted for dense firebrick to reduce the weight of the furnace structure. The insulating brick in the latter case are sometimes heated on both sides so that the load-temperature conditions have been severe.

After selecting a suitable test procedure, the further object was to study the relationship of cold crushing strength and of bulk density to the load-carrying capacity when the brick are hot. To determine this relationship, sixteen brands of commercial insulating

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firebrick with widely differing properties were tested under the selected test procedure.

II. Method

Before establishing a test procedure, previous work by Phelps[1] was reviewed. He concluded that test brick should not be loaded when heated on all sides because the deformation is greater under these conditions than is encountered in normal wall construction wherein the high temperature is confined to one face of the brick only. For this reason, Phelps has recommended loading a wall which is heated on one face only. Because the cold part of the wall in this case supports the load, it is obvious that a test of this type cannot supply any information concerning the load-temperature conditions under which plastic flow results. It is also obvious that no relationships can be determined from such a test. For this reason, a test to be of value for the work outlined must be conducted on a sample which is heated on all sides.

In previous work on "soaking" heat load tests, the load was applied during a one and one-half hour soaking period. It was apparent that the center of the brick would not reach equilibrium until the temperature had been held for some time, thus reducing the effective loading time of the test. A variation in heating-up time would also cause a change in the temperature lag between the inside and outside of the test brick. To eliminate these two factors, the furnace temperature was balanced long enough to bring the inside of the test brick to equilibrium before the load was applied and then the load was applied for one and one-half hours.

To determine the temperature relation between the inside and outside of the test brick, thermocouples were placed in the center of the brick to determine how long a temperature-holding period would be required to bring the center to equilibrium conditions. Figure 1 shows the time-temperature relation between the inside and outside on a normal heating schedule. From these results, the furnace was brought up to the test temperature, the temperature was balanced for one hour, and the load was applied for one and one-half hours in all test runs.

[1] S. M. Phelps, "Properties of Insulating Refractories: I, Behavior Under Load at High Temperatures," *Amer. Refrac. Inst. Tech. Bull.*, No. 61, 6 pp. (December, 1935).

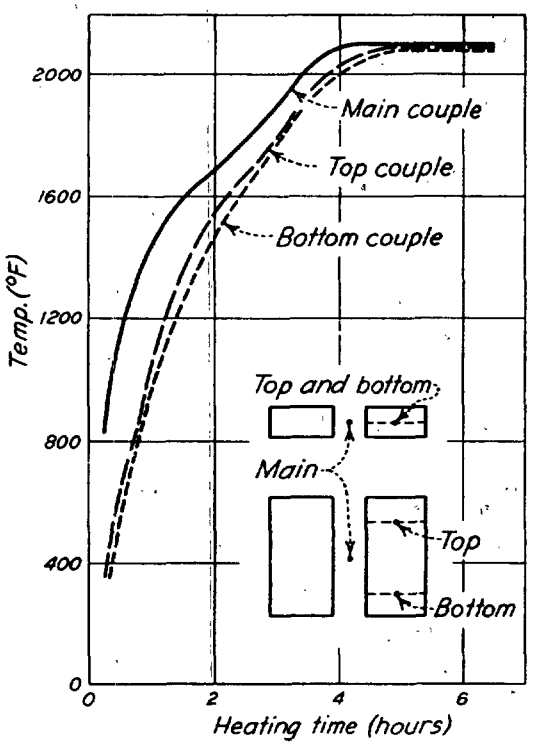

FIG. 1.—Temperature vs. heating time during load testing of insulating firebrick.

III. Load Test Furnace

The furnace used in these tests had been used previously for testing dense firebrick (Figs. 2 and 3). It consists essentially of a rectangular furnace chamber heated by six 3/4-inch Globar elements. Loading is accomplished by means of load beams with suitable knife edges and supports to reduce friction and arranged to give accurate vertical loading on the test brick. The lining of the furnace chamber is of insulating firebrick to reduce the heating-up time and to maintain a uniform temperature. In Fig. 2, four sighting windows are shown in the furnace casing, and opposite them are two reading telescopes, one of which has a filar micrometer eyepiece. This arrangement permits accurate measurement of subsidence of the test brick while at test temperature. When long-time tests are run, this method of measurement is necessary, but in the short-time test described here, the deformation was determined by measuring the test

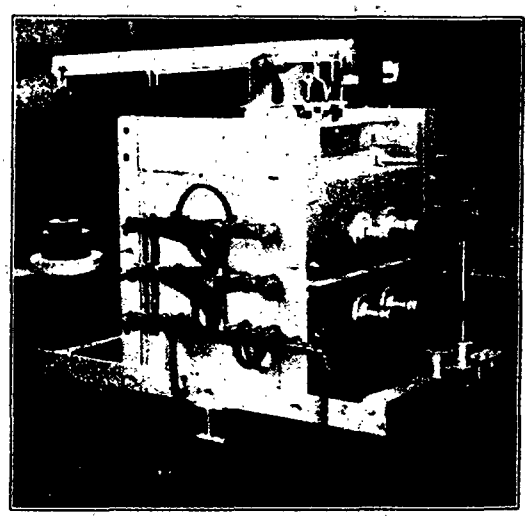

FIG. 2.—Electrically heated load test furnace.

brick before the run and again after the test was completed.

Furnace temperatures were measured by a platinum-platinum-rhodium thermocouple placed midway between the two test brick and protected by the usual porcelain tube.

IV. Procedure

The sample brick were measured carefully for length and were set in a vertical position on the $4^1/_2$- by $2^1/_2$-inch face. A fireclay brick was set upon this sample as a spacer and the loading assembly was completed (see Figs. 2 and 3). A slotted section of I-beam was used for the middle knife-edge support. The furnace was heated up, as shown in Fig. 1, held at test temperature for one hour, and then loaded by slowly lowering the unloaded beam onto its support and by applying the weights gradually. The temperature was maintained for one and one-half hours, after which the furnace was shut down and the samples were allowed to cool to room temperature under load.

TABLE I

TEST DATA ON COMMERCIAL INSULATING FIREBRICK

Brand	Use limit (°F)	Weight (lb./9 in.-straight)	Modulus of rupture (lb./sq. in.)	Cold crushing strength (lb./sq. in.)
A	2000	1.72–1.82	95	120
B	"	2.21–2.75	197	172
C	"	1.64	71	104
D	"	2.27–2.32	107	559
O	"	1.88	106	176
E	2200	1.87–1.96	165	193
F	"	2.71–3.07	224	377
G	"	2.27	129	208
N	"	2.44	66	235
I	2500	2.40–2.63	196	248
J	"	2.76	251	408
K	2600	2.30–2.50	133	128
L	"	2.68–2.80	203	372
S	"	2.40	127	196
M	2800	2.42–2.48	140	150
T	2900	2.90	235	220

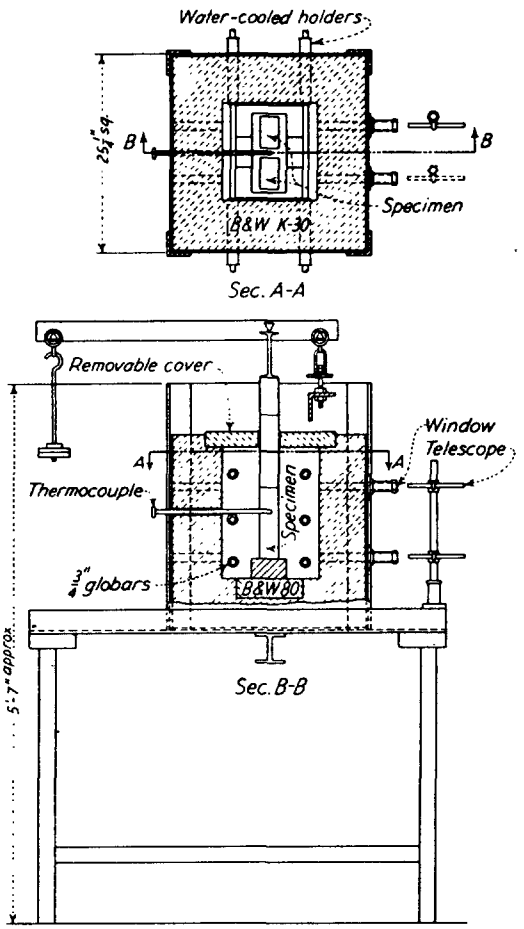

FIG. 3.—Electrically heated load test furnace.

TABLE II

LOAD TEST RESULTS

Fire-brick brand	1900°F.		2000°F.			2100°F.			2200°F.			2300°F.		
	10 lb.	25 lb.	10 lb.	25 lb.	40 lb.	10 lb.	25 lb.	40 lb.	10 lb.	25 lb.	40 lb.	10 lb.	25 lb.	40 lb.
A			0.1%	0.1%	0.1%	0.0%	0.2%	0.3%	0.4%	0.7%	1.1%	1.1%	2.7%	Failed
B	0.1%	1.6%	0.6	8.3										
C	0.1	Failed	1.0	Failed										
D			0.9	1.3	2.5	2.5	2.9	4.9	3.8	Failed				
O			Failed											
E			0.1	0.0	0.1	0.0	0.1	0.2	0.1	0.1	0.4	1.6	2.6	Failed
F			0.1	0.4	1.8	0.2	2.5	7.6	2.5	Failed				
G			0.1	1.8	7.6	1.5	Failed							
N			Failed											
I			0.1	0.8	1.2	0.2	2.0	Failed	1.9	Failed				
J				0.2	0.2	0.0	0.2	0.7	0.1	1.7	Failed			
K						0.3	0.4	0.6	0.3	1.0	2.9	1.4	Failed	
L			0.0	0.2	0.4	0.1	0.9	1.6	0.9	1.2	5.5			
S			0.1	0.1	0.2	0.2	0.3	0.8	0.4	2.9	8.2			
M						0.0	0.4	0.9	0.1	1.0	3.9	0.4	1.3	Failed
T				0.1	0.2	0.2	0.1	0.4	0.2	0.4	0.6	0.3	0.8	0.9
No. 1											0.4			Failed
No. 2											0.2			

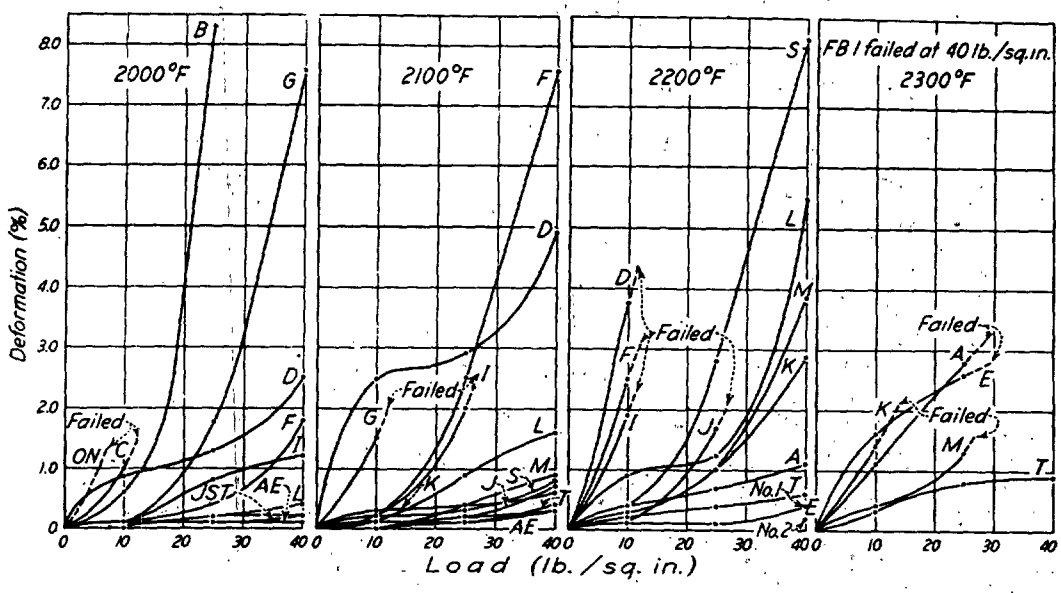

FIG. 4.—Deformation of insulating firebrick under load.

V. Samples Tested

Sixteen brands of commercial insulating firebrick were chosen to be representative of the various temperature groups The use limit, cold strength, and bulk density of these brick are listed in Table I. Two brands of dense second-quality fireclay brick were included for purposes of comparison.

VI. Results

The results obtained are shown in Table II. The loads were taken as 10 lb., 25 lb., and 40 lb. per square inch and the temperatures were 1900°, 2000°, 2100°, 2200°, and 2300°F. The deformation values are also shown in Fig. 4.

VII. Conclusions

There is no apparent relation from these results between cold strength and plastic flow. It might be concluded that a dense strong brick usually would carry more load when heated than the lighter and more fragile brands. This is not the case, however, inasmuch as some of the brands with the best load-bearing capacity are also among the lightest brands tested. The bulk density and cold strength, in general, do not indicate whether or not the brick structure is capable of withstanding hot-load conditions.

One point of considerable interest is that some brands of insulating firebrick can actually carry more load at the same test temperature than the two samples of dense firebrick tested. It is surprising that a refractory structure which consists of 80% solids will not stand as much actual loading as another refractory structure containing only 20% solids.

REFRACTORIES DIVISION
BABCOCK & WILCOX COMPANY
NEW YORK, N. Y.

APPLICATION-B&W FIREBRICK

Steam Generators

Selection of Refractories for #6 Oil Fired Furnaces

A common phenomena observed in furnaces fired with #6 fuel oil is slag formation on the surface of the brick. The average operator refers to "melting" of the brick.

Actually a reaction is taking place between the brick and impurities in the fuel oil which result in lowering the melting point of the exposed surface. Although the impurities may be well under 1%, the total weight of oil introduced into a furnace may be hundreds or thousands of pounds per hour and the weight of impurities can build up rapidly.

Usually there will be a period of operation with no slag followed by a gradual build-up as the concentration becomes sufficiently high to permit lowering of the melting point of the exposed face.

The attached article "Petroleum Ash Components and Their Effect on Refractories" by Jones and Hardy covers the basic factors involved in slagging of furnace walls, the impurities which are responsible for the effects, and proposed remedies by improved selection of refractories. We disagree with their conclusion on the use of basic brick because such brick will spall severely in the average industrial or boiler furnace service.

We do agree with the use of higher alumina content bricks. The Navy has been using B&W Allmul in their severe duty furnaces of older design for some years because slagging can be eliminated by their use. However, Allmuls should not be used if NaO_2 is present in substantial quantities in the ash because a nephelite formation may result with a marked expansion increase.

B&W Kaomul has shown a definite improvement over brick such as superduty of regular or high burned variety. B&W Kao-70 would be good for such service although 70% alumina brick of 25-30% porosity would not do as well.

Wash coatings of B&W Mulset or B&W Chrome Mortar applied to new brick of high duty or superduty grade will postpone slag formation for a period of a few weeks. To be of permanent value they must be reapplied every month or so before slag formation has started.

Petroleum Ash Components and Their Effect on Refractories

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While the ash content of petroleum is extremely small, varying from less than 0.001 to about 0.05% of the crude, this material is nonvolatile and concentrates in residual fractions marketed as heavy fuel oil. A study was made of the reactivity of these residual ash components on the refractories used in industrial furnaces. In addition, the ashes from various crudes were analyzed. Petroleum ashes containing vanadium are very destructive to fireclay brick upon direct contact at high temperatures. The alkaline earth and alkali metals (particularly sodium) and certain other metals will also lower the fusion point of refractories but are not as destructive as ash which includes vanadium. Fuel oils derived from most crudes contain ash which is potentially destructive to refractories in furnaces of improper design, as shown by the ash analysis of 25 crudes. The importance of proper furnace design is emphasized, particularly as to the selection of refractory brick resistant to attack by ash components.

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ONE of the chief advantages usually associated with petroleum fuels is the absence of the ash disposal problem. The ash in a petroleum crude is indeed small, varying from less than 0.001 to about 0.05% of the crude. This material, however, is nonvolatile and concentrates in residual fractions marketed as heavy fuel oil. When large quantities of such fuels are burned, troublesome deposits may build up despite the low ash content of petroleum. Some of these ash residues are very reactive and under certain conditions have been known to cause severe damage to equipment. For example, this is of particular concern in the operation of gas turbines, where accumulations on the turbine blades cannot be tolerated. In addition to reducing clearances and disturbing the balance of turbine rotors, ash deposits can cause severe damage by corrosion. A more common example is the corrosion found in industrial boilers, where, under certain conditions, ash residues can cause severe damage to boiler tubes and to the refractory brickwork.

The present paper deals with the effects of these residual ash components on the refractories used in industrial furnaces. Individual components of a typical ash have been evaluated to isolate the chief offenders and the resistance to damage of several typical refractory bricks has been studied. In addition, the analyses of the ash found in a number of crudes are presented to show the distribution of the harmful components.

EFFECT OF ASH COMPONENTS ON REFRACTORIES

In many oil-fired furnaces where there is a direct impingement of flame on the refractory, the firebrick becomes coated with a thin glassy substance. This has been attributed to actual fusion of the refractory. However, one investigation has shown (*2*) that the surface temperature of the brick, even with direct flame impingement, is not high enough to cause fusion; the coating on the wall was, rather, the ash originating in the oil or a slag formed by the reaction of the ash and the refractory. In the particular furnace investigated, the major cause of failure of the refractories was spalling. The investigation showed that this spalling was caused by the formation of slag which was absorbed into the brick. When the temperature of the furnace changed, because of a change in the firing rate, cracks and spalling of the brick resulted from the differential expansion of the brick and the slag.

Another type of refractory failure led to the present investigation. This was a case of certain ships in trans-Atlantic service each firing four marine boilers with approximately 10,000 barrels of fuel oil per round trip. The brick work at and below the area of flame impingement had a glazed surface marked by numerous vertical channels where rivulets of molten slag had run down to the furnace floor. The damage was so severe that during each round trip about $1^1/_2$ tons of slag accumulated on the floor of each boiler. This slag was in a molten state under furnace conditions at sea but solidified when the boiler load was reduced in port. Every four trips the accumulation of about 10 inches of this hard, glassy slag had to be removed laboriously by chipping.

Analyses of this slag and of furnace dust collected on the radiant section tubes of the boiler are shown in Table I.

Table I. Analysis of Slag and Furnace Dust

Analysis, Wt. %	Slag from Boiler Furnace Floor	Dust from Radiant Section Boiler Tubes
Vanadium (as V_2O_5)	12.5	35.3
Refractory materials[a]	80.9	7.8
Other metals[b]	2.3	6.9
Alkali metals, sulfur, and halogens	3.6	47.0
Ignition loss	Nil	2.8
Fusion point, ° F.	2199	1400

[a] Alumina, silica, etc.
[b] Including iron, molybdenum, nickel, cobalt, tin, and zinc.

The dust from the radiant section boiler tubes should be fairly representative of the ash content of the fuel oil. This dust contained high percentages of vanadium and alkali metals, particularly sodium. Slag from the furnace floor also contained relatively high percentages of vanadium, but the amount of refractory materials (alumina, silica, etc.) was about tenfold higher than in the dust from the tubes. It is quite evident from these analyses that the fuel oil ash reacted with the refractory material and lowered its fusion point. Fusion point measurement on the slag showed that it melted at about 2200° F., which is far below the softening point of the refractory material used.

There are many factors which probably contribute to failures of the type observed in these marine boilers. Among these are flame impingement on the wall, which increases wall temperatures to around 2800° F.; furnace atmosphere, which is known to be severely detrimental to furnace refractories when a high concentration of carbon monoxide is present; the composition of the refractory used; the furnace design; and the composition and quantity of the fuel oil ash. Of these, the last is the only factor over which fuel oil suppliers have any degree of control. Proper furnace design and choice of refractory materials will reduce chemical attack from any type of petroleum ash, but particular care should be taken when fuel oil containing the more reactive ash components is burned. For this reason it was felt that a determination of the chemical components of petroleum ash actually responsible for the destruction of refractories would be useful. The effects of ash components on fusion point of firebrick and chemical reactivity of the slags produced were chosen for investigation.

Experimental. Petroleum ash for fusion experiments was prepared by distilling crude to coke, burning the coke in a stainless steel furnace, grinding to 60 mesh, finally igniting in platinum or silica dishes in an electric furnace, and again grinding to 200 mesh in an agate mortar. Iron introduced by crushing and grinding the original coke was removed by a magnet.

The fusion point determinations were carried out in a gas-fired furnace as in the ASTM procedure D-271-48 for the fusibility of coal ash. Ground refractory brick and completely oxidized ash or ash component were used in the determinations. The desired mixture of the two was moistened with a 10% dextrin solution and worked into a plastic mass. The mass was then molded into small triangular pyramids $^3/_4$ inch high and $^1/_4$ inch wide at the base. These "cones" were then dried in an oven and mounted on a refractory base composed of equal parts of kaolin and calcined alumina moistened and worked into a small plate as specified in the ASTM procedure. Usually five or six cones of the same material were mounted to ensure accurate observations.

The mounted cones were placed in the furnace and the temperature was gradually increased at a uniform rate. The fusion or softening point was taken as the temperature at which the cone fused into a hemisphere of homogeneous slag. In addition to the fusion temperature, the destructive action of the slag on the kaolin-alumina base was also noted. In the following discussions this destructive action (or reactivity) of the slag formed by fusion of the mixture is reported as follows:

1. Complete decomposition. The slag reacted with the entire kaolin-alumina baseplate causing it to fuse completely.
2. Extensive, considerable, slight, and evident decomposition. The slag reacted with the kaolin-alumina base in varying degrees ranging from fusion of a large area to a minor attack around the base of the spherical lump of original slag.
3. No decomposition. The slag formed a spherical lump with no evidence of attack on the base.

These observations are necessarily qualitative in nature. However, they are thought to be quite significant in the evaluation of the chemical reactivity of the slag since the kaolin-alumina mixture is typical of refractory materials. These qualitative observations of the chemical reactivity were made at the fusion point of the sample under test. The severity of chemical attack probably increases with temperature and, thus, a slag having a low fusion point but showing a slight evidence of chemical attack may actually be very reactive under higher temperature furnace conditions.

Table II. Fusion Point and Chemical Reactivity of Undiluted Petroleum Ashes

Ash Source	Fusion Point, ° F.	Reactivity with Kaolin-Alumina Base at Fusion Point
Lagunillas crude	2760	Complete decomposition
Quiriquire crude	2445	Some decomposition
West Texas crude	2400	Considerable decomposition
East Texas, West Texas, Talco crude mixture	2155	Considerable decomposition

Discussion of Results. Table II shows the fusion point and the chemical reactivity of undiluted petroleum ashes from a number of crude sources. The fusion point of these pure ashes varied from about 2100° to 2800° F., and all resulted in considerable decomposition of the kaolin-alumina base at the fusion temperature of the ash.

Table III. Fusion Point and Chemical Reactivity of Vanadium- and Sodium-Containing Mixtures

Mixture[a], %	Fusion Point, ° F.	Reactivity with Kaolin-Alumina Base at Fusion Point
Firebrick, 100	Above 2800	No decomposition
V_2O_5, 100	1274[b]	...
V_2O_5, 10; firebrick, 90	Above 2855	No decomposition
V_2O_5, 50; firebrick, 50	2685	Evident decomposition
V_2O_5, 80; firebrick, 20	1290	Evident decomposition
$NaVO_3$, 10; firebrick, 90	2640	Slight decomposition
$NaVO_3$, 50; firebrick, 50	2620	Evident decomposition
$NaVO_3$, 80; firebrick, 20	Approx. 1800	Extensive decomposition

[a] Employing Pennsylvania fireclay brick containing 39% Al_2O_3.
[b] From (*1*).

These data show that chemical reactivity is not limited to the ash from one crude source but is typical of the ash from a wide variety of crudes. The ash from the Lagunillas crude completely destroyed the kaolin-alumina base but the ash from other crudes showed considerable reactivity even though their fusion points were lower.

Table IV. Fusion Point of Brick with Alkali and Alkaline Earth Metals

(Mixture, 50% compound and 50% Pennsylvania fireclay brick)

Compound	Fusion Point, ° F.
$MgSO_4$	2530
MgO	Above 2900
$CaSO_4$	2320
$CaCO_3$	2300
NaCl	2670
Na_2SO_4	1950
K_2SO_4	2740
Na_2CO_3	1840

The presence of high concentrations of vanadium and sodium in the ash causing damage to the marine boiler refractories described above, suggested that these metals are particularly destructive. Consequently, 10, 50, and 80% mixtures of vanadium pentoxide and of sodium metavanadate with fireclay brick were tested for fusion point and chemical reactivity. The data are shown in Table III. All compositions except the one containing 10% vanadium pentoxide showed a marked reduction in the fusion point of the brick. This effect increased, as might be expected, with the vanadium content. Sodium metavanadate in low concentrations (10%) is evidently more active than the vanadium pentoxide in reducing the fusion point, but in high concentrations, vanadium pentoxide is the more destructive. In all cases where fusion occurred there was evidence of chemical attack on the kaolin-alumina base. This reactivity increased with the concentration of the vanadium compound even though the fusion temperature at which the attack was observed decreased. If anything, the sodium vanadate was more destructive to the kaolin-alumina base than was the pure vanadium pentoxide. It may be concluded from these data that vanadium compounds in general are reactive with refractory materials and will cause significant reduction of the fusion point of such materials. The slags formed are very reactive with certain other refractories. These effects are accelerated by the presence of sodium compounds.

Another large class of compounds present in petroleum ashes is the alkali and alkaline earth metals. The effect of their salts on firebrick is shown in Table IV. Salts of magnesium, calcium, sodium, and potassium all lower the fusion point of the brick, with sodium being by far the worst offender. The potassium compound tested was not nearly as harmful as the sodium compounds. This observation was confirmed by tests using brick of other compositions. In no case was there any evidence of chemical attack on the kaolin-alumina base by the slags formed by the alkaline earth metals, indicating that these slags are not chemically active.

The anions evidently play some role in determining the extent to which metals damage refractories. The carbonates and the sulfates appear to be particularly potent in lowering fusion point while chlorides (at least in the case of sodium) are considerably less harmful. Substitution of magnesium oxide for magnesium sulfate eliminated the effect entirely.

The effect of a number of other metals known to occur in petroleum was determined in 50-50 mixtures of the oxide of the metal and firebrick. The data for the effect of various metal oxides on a fireclay brick are shown in Table V. Iron, tin, and lead are shown here to be detrimental to the firebrick. The remainder of the metals tested are either not destructive at the temperatures measured or only very slightly destructive. In no case was there any evidence of chemical attack on the kaolin-alumina base.

So far, the data have shown the effect of the components of petroleum ash on a single refractory brick. Table VI shows the effect of a typical ash on a number of different bricks. This table gives the chemical composition of the bricks investigated and the fusion point of 50-50 mixtures of these bricks with a petroleum ash derived from Lagunillas crude. Also included is the reactivity of the slags formed with the alumina-kaolin base used to support the test cones.

In Table VI, the types of brick are arranged in order of increasing cost (with the possible exception of some of the fireclay bricks, which are approximately the same grade). As a class, the fireclay bricks are subject to damage by petroleum ash containing vanadium. The reduction in their fusion points does not appear to bear any relation to the alumina content of the fireclay brick and is probably a function of the other constituents of the clay used. The method of manufacture which affects the porosity of the brick may also play an important part. The slags formed by the fusion of these firebricks were all chemically reactive to the kaolin-alumina base. Generally, fireclay brick as a class should not be used in furnaces where vanadium-bearing fuel oils are burned and there is direct impingement of flame on the refractory.

The high alumina bricks, however, appear to be suitable for use in furnaces where such conditions occur. The fusion point

Table V. Fusion Point of Brick with Various Metal Oxides

(Mixture, 50% oxide and 50% Pennsylvania fireclay brick)

Oxide	Fusion Point, ° F.
NiO	2835
Co_3O_4	2555
Fe_2O_3	2125
SnO_2	2100
ZnO	Above 2910
TiO_2	2855
Sb_2O_3	Above 2900
PbO	2230
Cr_2O_3	2900

Table VI. Effect of Petroleum Ash on Various Refractory Bricks

(Mixture, 50% Lagunillas ash and 50% commercial brick)

Composition and Type of Brick[a]	Fusion Point, ° F.	Reactivity with Kaolin-Alumina Base at Fusion Point
Fireclay brick		
New Jersey clay, 15% Al_2O_3	2710	Considerable decomposition
New Jersey clay, 25% Al_2O_3	2670	Some decomposition
Pennsylvania clay, 39% Al_2O_3	2695	Complete decomposition
Missouri clay, 44% Al_2O_3	2670	Complete decomposition
Georgia kaolin, 45% Al_2O_3	2555	Some decomposition
High alumina brick		
60% Al_2O_3	2800	In these tests the ash melted and ran into the base causing considerable damage before the fusion point of the mixture was reached
70% Al_2O_3	2940	
80% Al_2O_3	Above 3000	
Magnesia brick		
Firebonded, 82–85% MgO	Above 2855	Some damage to the base by melting of the ash; no slag formed
Chemically bonded[b]	Above 2910	
Firebonded, 90%+ MgO[c]	Above 2900	

[a] Classes and individual brick other than fireclay as listed in order of increasing cost.
[b] Contained some chrome ore.
[c] Contained 2.5% Fe_2O_3.

Table VII. Analyses of Oil-Soluble Ash in Crude Oils

	Ash, Wt.%	Chemical, Wt. % on Ash									Spectrographic	
		NiO	Na_2O	SiO_2	V_2O_5	Fe_2O_3	Al_2O_3	CaO	MoO_3	SO_3	Trace, 0.1–1.0 wt.% on ash	Present, <0.1 wt.% on ash
Louisiana and Mississippi crudes												
North Louisiana	0.0044	1.7	46.5	..	4.3	3.3	..	2.8	...	42.9	Al, Mg	Sr, Pb, Mn
Central Louisiana	0.0008	6.9	43.1	..	10.6	7.0	..	..	..	23.0	Si, Al, Ca, Mg	Cr, Cu, Ag, Pb, Mn
South Louisiana	0.0010	17.2	9.2	3.4	5.0	15.8	..	..	...	36.4	Al, Ca	Cr, Cu, Ag, Pb, Mn, Mg, Co
Southwest Louisiana	0.0005	4.2	13.4	8.8	0.3	29.0	1.9	11.0	.	12.8	Ni, Ag, Pb	Cr, Cu, Mn, Mg, Ti
Louisiana-Mississippi	0.0011	0.1	61.7	..	0.1	2.7	1.1	6.1	.	42.1	Cu, Si	Ag, Pb, Mg, Mn, Sr
Heidelberg-Eucutta (Miss.)	0.0319	2.4	16.3	..	8.6	0.8	..	..	...	50.7	Fe, Ca, Mo	Cu, Mg
011a (La.)	0.0100	7.2	35.6	..	..	1.0	..	..	...	59.6	V, Al, Ca	Cu, Mg, Sr, Co
Texas crudes												
Conroe	0.0007	..	42.0	7.1	0.2	16.5	2.7	13.2	...	28.9	Ni, Pb	Cr, Cu, Mn, Mg, Ti, B
Yates-Pecos	0.0022	15.1	4.1	11.7	63.3	0.7	12.1	1.1	1.4	16.4	Ca	Cr, Pb, Mg, K
Imogene–West Texas	0.0066	3.3	33.1	7.0	23.0	1.9	2.4	..	...	30.3	Ca, Mo	Cu, Cr
East Texas	0.0036	3.1	46.1	4.9	6.0	2.0	7.0	..	..	43.4	Ca, Co	Cu, Pb, Mg
Talco	0.0109	3.0	22.8	..	14.5	2.7	..	..	..	42.0	Al, Ca	Cr, Cu, Mg
Salt Flat	0.0026	7.0	5.9	3.7	56.9	9.4	11.4	..	.	13.1	Ca	Cr, Cu, Pb, Mn, Mg
Coastal heavy	0.0073	4.0	33.2	..	2.3	1.5	..	..	...	55.2	Ca	Al, Cu, Pb, Mg, Co
Refugio light	0.0005	17.9	7.7	3.9	24.1	9.8	2.2	..	...	10.0	Ca, B	Cr, Cu, Pb, Mn, Mg, Mo
Midcontinent and Western crudes												
Illinois-Indiana	0.0075	2.3	28.6	..	9.1	2.2	..	..	...	47.7	Al, Ca	Cu, Pb, Mg, Mn
Louden (Ill.)	0.0014	5.6	16.7	0.9	15.6	5.8	1.1	8.6	...	41.8	...	Cr, Cu, Pb, Mg, Mn, Sr
Oklahoma-Kansas	0.0049	2.0	33.3	7.0	10.9	1.0	3.3	2.8	...	38.7	...	Cr, Cu, Pb, Mg, Mn
Big Horn mixture (Wyo.)	0.0044	10.4	3.0	4.3	64.9	2.6	3.2	..	...	14.6	Ca	Cr, Cu, Pb, Mg, Mo
Venezuelan crudes												
Quiriquire	0.0236	3.2	10.0	..	23.7	1.2	2.1	33.2	...	31.5	Si, Cu, Mo	Cr, Mg, Pb
San Joaquin	0.0005	3.6	29.5	16.9	11.7	12.8	3.5	..	...	15.4	...	...
Jusepin	0.0160	1.6	23.1	4.8	16.5	4.2	0.5	..	...	41.0	Cu, Ca	Mg
Lagunillas	0.0348	3.0	8.7	11.2	59.9	0.4	1.3	..	...	0.2	...	...
La Rosa medium	0.0394	3.2	12.6	10.7	60.2	0.3	..	..	...	0.2	...	...
Tia Juana	0.0388	2.5	14.3	19.3	61.8	0.9	1.3	1.5	...	0.7	...	...

of mixtures of these bricks and petroleum ash increases with the alumina content, but even the bricks of the lowest alumina content fuse only at or above 2800° F., the temperature level of furnace walls with flame impingement. When these bricks were tested, little or no slag was formed but the ash tended to melt away from the mix, leaving the cone structure intact. It appears, therefore, that no reactive slag would be formed.

The magnesia bricks are at least the equivalent of the high alumina brick and are probably suitable for even more severe service. None of these bricks fused with the petroleum ash. They are, however, more expensive than high alumina brick and would probably be used in only the most severe service.

Summation. In brief, it may be concluded that petroleum ashes containing vanadium are very destructive to fireclay brick upon direct contact at high temperatures. The alkaline earth and alkali metals (particularly sodium) and certain other metals will lower the fusion point of refractories, but are not as destructive as ashes which include vanadium. In these cases the damage is probably limited to the surface and will usually cause a hard, glassy film on the brick which may result in failure by spalling if the brick is porous. The attack of vanadium compounds is much more extensive. In such cases, extensive damage may occur from the fluxing action of the slag. There are several means of preventing or controlling such damage. When flame impingement cannot be eliminated, damage could be minimized by cooling the refractory. In cases where this is impossible, the proper selection of refractory brick will go far in eliminating destruction from petroleum ash.

ANALYSES OF ASH OF CRUDES

In view of the conclusions reached in the first part of this paper, information is required as to whether the metals reactive with refractories occur in most crudes or whether the problem is peculiar to only a few crude sources. In order to answer this question, the analyses of 25 different crudes for their ash components are presented. These crudes were procured, sampled, and analyzed under controlled conditions. The importance of vanadium compounds makes a knowledge of vanadium content of crude samples particularly pertinent. Vanadium analyses are available on a considerable number of crudes, and these are included as a separate listing. The data on the systematic study and the vanadium content of various crudes (all independent analyses) are given in Tables VII and VIII, respectively. The remainder of the discussion in this paper will be confined to the analyses obtained in the systematic study of the 25 crude samples.

Table VIII. Vanadium Content of Various Crudes

Texas crudes	Wt. % as V_2O_5
Light Refugio	0.0001
Coastal mixture	0.0001
Talco	0.0011
West Texas	0.0016
California crudes	
Ventura Ave.	0.0045
Signal Hill	0.005
Lompoc	0.0067
San Joaquin	0.008
Las Flores	0.019
Bradley Sands	0.024
Orcutt	0.029
Santa Maria	0.036
Purisma	0.039
Nicolai	0.044
Oxnard	0.072
Illinois crude	
Louden	0.0001
Canadian crudes	
Leduc	<0.0001
Redwater	<0.0001
Mexican crudes	
Poza Rica	0.0019
El Plan	0.0024
El Burro	0.0037
Tonala	0.0038
Naranjos	0.0072
Filisola	0.0111
Panuco	0.0138
Venezuelan crudes	
Jusepin	0.003
Quiriquire	0.007
Oficina heavy	0.023
Lagunillas light	0.027
Tia Juana	0.030
La Rosa light	0.037
Pedernalles	0.040
Amacuro	0.050
Lagunillas heavy	0.057
Colombian crude	
Colombian	0.018
Arabian crude	
Abqaiq	<0.0001

The ash content of petroleum fuels may be derived from a number of different sources. These include the following:

1. The oil-soluble compounds which are present in the crude itself
2. The water-soluble compounds which are usually salts and occur in solution in water originating with the crude (on distillation these water-soluble compounds are left behind in the residual fractions as suspended salts)
3. Ash compounds from corrosion caused by the reaction of naphthenic and other acids present in the crude with the metal tanks and pipelines (like the oil-soluble ash, these are usually present as soluble matter in the residual fractions)
4. From contamination with scale, salt water, etc.
5. Caustic, carbonates, etc., injected into distillation equipment for control of corrosion or to neutralize acids

Sources 2 to 5 are variable and individual determinations are meaningless because of this variation. For this reason the systematic study was limited to the determination of the oil-soluble constituents of petroleum ash. This had a further advantage of concentrating the vanadium content of the crude since vanadium usually occurs as an oil-soluble metallo-organic compound. The vanadium determinations of these crudes should therefore be particularly accurate.

In order to avoid contamination, the crude samples were obtained from points as close to the producing wells as possible. In the case of individual crudes, specially cleaned glass containers were sent to the collection points and samples were taken under controlled conditions to avoid any possible contamination. In the case of crude mixtures from several different sources, the samples were taken from the pipeline carrying these mixtures.

Since the object of the survey was to determine the oil-soluble metallic compounds present in the crudes, each sample was paper filtered to remove suspended matter and water. Tests showed that this procedure removed all traces of water and any compounds not soluble in oil. Each filtered crude was reduced to coke by burning at as low a temperature as possible. The coke thus produced was ignited at 1000° F. in platinum dishes to produce at least 100 mg. of ash. This procedure was repeated until consistent results were obtained. Ash contents and analyses are given in Table VII.

Each of the ash samples was analyzed semiquantitatively in an emission spectrograph. This analysis reports the metals present in the ash as major (10 to 100%), minor (1 to 10%), trace (0.1 to 1%), and present (below 0.1%). Quantitative chemical analyses for all metals present in concentrations above 1% were made. These are reported in Table VII as the oxides. Sulfur determinations were also made and are reported as SO_3 content, but no analyses were made for other possible anions. Table VII also contains a list of the trace and present metals according to the semiquantitative spectrographic analysis.

The results are best summarized in Table IX which is based on the semiquantitative spectrographic analysis of the crudes. This table shows the percentage of this group of crudes containing each metal at various concentration levels.

Table IX. Summary of Semiquantitative Spectrographic Analyses of Crudes

	Percentage of Crudes Showing Concentrations of				
Element[a]	Major (10%)	Minor (1.0–10%)	Trace (0.1–1.0%)	Present (0.1%)	Not present
Sodium	90	10	..	..	..
Vanadium	80	20	5	..	..
Iron	30	70	5	..	..
Nickel	45	45	15	..	..
Aluminum	5	60	30	5	5
Silicon	15	50	15	..	25
Calcium	..	40	60	..	..
Molybdenum	..	5	15	10	70
Copper	..	..	15	75	10
Magnesium	..	..	10	85	5
Lead	..	..	10	65	25
Silver	..	..	5	15	80
Chromium	..	..	..	70	30
Manganese	..	..	..	50	50

[a] Cobalt, strontium, boron, titanium, potassium, and platinum appeared as present in 20% or less of the samples; no other elements were reported.

In general the quantitative results shown in Table VII check the semiquantitative results in Table IX quite well. Sodium and vanadium are shown to occur in the ash of most crudes in concentrations above 10% and in the ash of the remaining crudes in concentrations above 1%. There are only a few cases where vanadium is below 1%. The next most prevalent elements are iron, nickel, aluminum, silicon, and calcium. Over half the crudes investigated contain traces of copper, magnesium, lead, chromium, and manganese, while a number of other elements such as cobalt, strontium, boron, titanium, potassium, platinum, silver, and molybdenum are present in isolated samples.

These data show that fuel oils derived from most crudes contain ash which is potentially destructive to refractories. The extent of actual attack in any given furnace will, of course, depend on the concentration of ash in the fuel oil but in time the ash from most crude sources will damage refractories in furnaces of improper design. The importance of proper furnace design is emphasized, particularly as to the selection of refractory brick resistant to attack by ash components.

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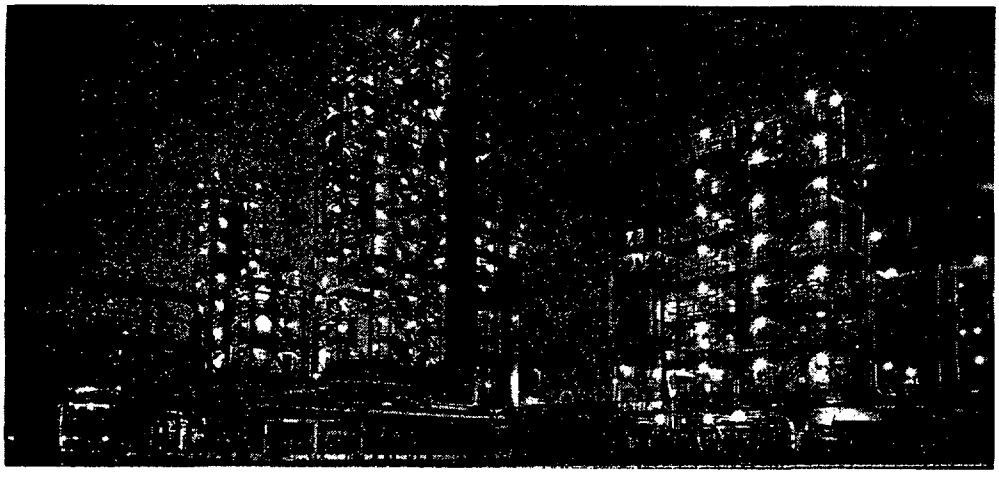
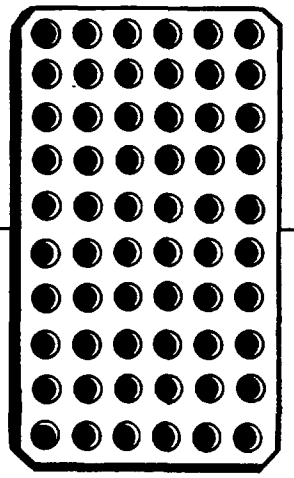


Bayway Refinery at Night

COURTESY STANDARD OIL CO. N. J.

Refractories: What They Are, How They Are Made, and What They Are Used For



Refractories are important to an engineer. They not only meet his needs for heat resisting materials, but also provide him materials that will withstand such effects as abrasion, thermal shock, pressure, corrosion, and erosion. Through the years, a wide variety of refractory materials have been developed. Each has definite physical properties. This requires that an engineer be careful in his selection of a refractory for a specific application. The environment in which a refractory will be placed first must be taken into account, then the refractory selected that has the physical properties necessary to withstand that environment. Along with an increase in the number of refractories have come improved methods for their manufacture. Manufacturing methods have evolved from hand molding to the currently used thixotropic casting process developed by AC Spark Plug Division.

FIRE is the basis of modern industrial life. The industrial use of fire is joined to important economic considerations which, besides fuel costs, include the cost of constructing and maintaining installations in which fires are contained. Furnaces, kilns, and other heat treating equipment require construction materials that will withstand the effects of heat, flame erosion, and other conditions created by the industrial use of fire and other heat producing means.

The need for heat and fire resistant materials has led to the development of a class of products known as *refractories*. Broadly defined, refractories are materials capable of resisting heat over a wide temperature range. In addition to resisting heat, however, a refractory often is required to resist corrosion, thermal gradients, thermal shock, load, and abrasion; attack by molten glass, metals, and slags; and attack by atmospheres, either reducing or oxidizing, or both.

The first refractory materials used in this country were naturally occurring materials such as mica-schist or siliceous rock. Today, the majority of refractory bricks and other shapes are manufactured from fireclays (either bauxitic, kaolin, or flint types), silica minerals, magnesite, alumina, chromite, olivine, and graphite. Another class of present day refractories, called super refractories, is manufactured from electric furnace materials or materials that are heated to high temperatures by other means. These materials include silicon carbide, fused alumina, mullite, fused magnesia, stabilized zirconia, and fusion cast refractories.

Value of Refractory Determined by its Physical Properties

The ability of a refractory material to withstand various service conditions is determined to a large extent by its chemical composition and physical properties. The most commonly determined physical properties for refractory materials are as follows:

- Pyrometric Cone Equivalent
- Average bulk density
- Weight of a 9 in. by 4½ in. by 2½ in. brick
- Porosity
- Permeability
- Mean specific heat
- Mean coefficient of expansion
- Thermal conductivity
- Modulus of rupture
- Load test (heated)
- Compressive strength
- Abrasion resistance
- Corrosion resistance
- Thermal shock resistance
- Maximum recommended temperature.

Refractories, such as refractory brick (Table I[1]), are tailored to have the maximum desired physical properties required for a specific application. For example, a refractory to be used in contact with molten metal will generally be dense, impermeable, and resistant to abrasion and corrosion (Table II). It also will have low porosity, a relatively high termal conductivity, a high modulus of rupture, and high thermal shock resistance. On the other hand, an insulating refractory to be used as back-up in a location where it does not come into contact with metal or flame impingement will be porous, permeable, rather soft and non-resistant to abrasion, have a low thermal conductivity, a relatively low modulus of rupture, and moderate to good thermal shock resistance (Table III).

The desired physical properties in refractories are obtained by the selection and preparation of suitable materials; by the manufacturing process used; and by providing variations in composition, grain size, molding pressures, water content, and firing temperature.

Physical Properties Explained

An explanation of the meaning and importance of the physical properties of refractories is necessary to understand their significance to the industry and to the user.

Pyrometric Cone Equivalent

When a solid material is transformed

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AC Spark Plug
Division

Physical properties an important factor when selecting a refractory

to a liquid by means of heat, the transition may be referred to as the melting point, fusion temperature, or softening temperature. Most commercial refractories do not have true melting points, because they soften progressively over a temperature range within which the refractory contains both crystalline material and a liquid melt. The melting points of the various crystalline components of a refractory, plus the amount and viscosity of any liquid which is formed, will determine the ability of a refractory to remain rigid at high temperatures.

The melting behavior of refractories varies greatly at high temperatures. Those refractories consisting almost entirely of pure oxides in crystalline form, such as silica (SiO_2), corundum (Al_2O_3), and magnesite (MgO), have a relatively narrow melting range. Fireclay refractories and other refractories containing several oxides with various impurities fuse and soften gradually over a relatively wide range of temperatures.

The high temperature softening behavior of fireclay and high-alumina refractories is determined by the *Pyrometric Cone Equivalent* (P.C.E.) evaluation. This method consists of comparing test cones, made from a ground sample of the material to be tested, with standard cones having known time-temperature softening values. Both the test cones and standard cones are numbered, then mounted in a ceramic plaque at a slight angle to the vertical (Fig. 1). The plaque is heated at a definite rate until the test cones soften and bend. The number of the standard cone whose tip touches the plaque at the same time as the tip of the test cone is reported as the P.C.E. value of the test cone.

TYPE	CLASS	CHARACTERISTICS
FIRE CLAY	SUPERDUTY	HIGHEST REFRACTORINESS OF ANY FIRE CLAY BRICK. STABILITY OF VOLUME AT HIGH TEMPERATURES. LOW THERMAL EXPANSION. EXCELLENT TO GOOD RESISTANCE TO THERMAL SPALLING. GOOD LOAD-BEARING PROPERTIES. FAIR RESISTANCE TO ACID SLAGS; MODERATE RESISTANCE TO BASIC SLAGS.
FIRE CLAY	(1) HIGH-DUTY (2) MEDIUM-DUTY (3) LOW-DUTY	THE CHEMICAL AND PHYSICAL PROPERTIES OF FIRE CLAYS VARY BETWEEN WIDE LIMITS; HENCE, FIRE CLAY BRICK WITH WIDELY VARYING COMBINATIONS OF PROPERTIES ARE AVAILABLE. MOST HIGH-DUTY FIRE CLAY BRICK HAVE RELATIVELY LOW THERMAL EXPANSION, FAIR SPALLING RESISTANCE AND THERMAL INSULATION VALUE; FAIR RESISTANCE TO ACID SLAGS AND FLUXES; AND RELATIVELY LOWER RESISTANCE TO BASIC SLAGS AND FLUXES.
FIRE CLAY	SEMI-SILICA	RIGIDITY UNDER LOAD AND VOLUME STABILITY AT HIGH TEMPERATURES. MODERATE THERMAL EXPANSION. EXCELLENT RESISTANCE TO STRUCTURAL SPALLING. HIGH TEMPERATURE OF INCIPIENT VITRIFICATION. HIGH RESISTANCE TO PENETRATION AND ATTACK BY VOLATILE ALKALIES OR FUMES, WITHIN ITS TEMPERATURE RANGE.
HIGH-ALUMINA	(1) 45-48% ALUMINA (2) 50% ALUMINA (3) 60% ALUMINA (4) 70% ALUMINA (5) 80% ALUMINA (6) 85% ALUMINA (7) 90% ALUMINA (8) MULLITE (9) CORUNDUM	HIGH REFRACTORINESS INCREASING WITH INCREASED ALUMINA CONTENT. THERMAL EXPANSION LOW UP TO 80 PER CENT Al_2O_3; HIGHER ABOVE 80 PER CENT Al_2O_3. HIGH MECHANICAL STRENGTH AND EXCELLENT LOAD-BEARING PROPERTIES AT HIGH TEMPERATURES. FAIR TO EXCELLENT RESISTANCE TO SPALLING. HIGH RESISTANCE TO CORROSION BY MANY BASIC SLAGS AND FLUXES; FAIR RESISTANCE TO ACID SLAGS.
SILICA	(1) SUPERDUTY REGULAR HOT PATCH (2) CONVENTIONAL REGULAR HOT PATCH (3) LIGHTWEIGHT	MELTING TEMPERATURE ONLY SLIGHTLY BELOW THAT OF PURE SILICA. HIGH MECHANICAL STRENGTH AND RESISTANCE TO ABRASION AT HIGH TEMPERATURES. FAIRLY HIGH THERMAL EXPANSION. NOT SUBJECT TO THERMAL SPALLING ABOVE 1,200 F. MOST SILICA BRICK HAVE POOR RESISTANCE TO THERMAL SPALLING BELOW 1,200 F. HOT-PATCH BRICK HAVE HIGH RESISTANCE TO SPALLING FOR THIS TYPE OF REFRACTORY. LIGHTWEIGHT SILICA BRICK HAVE ONLY ABOUT HALF THE THERMAL CONDUCTIVITY OF REGULAR SILICA BRICK. HIGH RESISTANCE TO CORROSION BY ACID SLAGS, AND TO IRON OXIDE IN AN OXIDIZING ATMOSPHERE. READILY ATTACKED BY BASIC SLAGS.
SILICON CARBIDE	(1) BONDED (2) RECRYSTALLIZED	HIGH REFRACTORINESS. HIGH STRENGTH AT FURNACE TEMPERATURES. HIGH THERMAL CONDUCTIVITY. LOW THERMAL EXPANSION. HIGH RESISTANCE TO SPALLING. SUSCEPTIBILITY TO OXIDIZATION AT CRITICAL TEMPERATURES.
ZIRCON	———	HIGH REFRACTORINESS. MODERATELY HIGH THERMAL CONDUCTIVITY. HIGH RESISTANCE TO SOME ALKALINE FLUXES. LOW THERMAL EXPANSION.
INSULATING	(1) 1,600 F (2) 2,000 F (3) 2,300 F (4) 2,600 F (5) 2,800 F (6) 3,000 F (7) 3,300 F	DENSITIES AND THERMAL CONDUCTIVITIES RANGE FROM VERY LOW TO MODERATE; HIGHER FOR THE HIGHER TEMPERATURE CLASSES. LOW THERMAL EXPANSION. VERY HIGH RESISTANCE TO THERMAL SPALLING.
MAGNESITE (PERICLASE)	A. REGULAR (1) FIRED (2) CHEMICALLY BONDED B. SPINEL BONDED (1) FIRED (2) CHEMICALLY BONDED	EXTREMELY HIGH REFRACTORINESS AND HIGH THERMAL CONDUCTIVITY. HIGH THERMAL EXPANSION. THE SPINEL-BONDED BRICK HAVE SUPERIOR RESISTANCE TO THERMAL SHOCK. GOOD RESISTANCE TO CORROSION BY BASIC SLAGS; POOR RESISTANCE TO SILICEOUS SLAGS.
CHROME	(1) FIRED (2) CHEMICALLY BONDED	MODERATE THERMAL EXPANSION AND THERMAL CONDUCTIVITY. HIGH RESISTANCE TO CORROSION BY BASIC AND MODERATELY ACID SLAGS AND FLUXES. IN GENERAL, BASIC SLAGS DO NOT ADHERE TO CHROME BRICK. UNDER CERTAIN CONDITIONS, IRON OXIDE IS ABSORBED AND CAUSES A DAMAGING EXPANSION.
MAGNESITE-CHROME	(1) FIRED (2) CHEMICALLY BONDED	RELATIVELY HIGH THERMAL EXPANSION. HIGH MECHANICAL STRENGTH AND STABILITY OF VOLUME AT HIGH TEMPERATURES. HIGH RESISTANCE TO CORROSION BY BASIC SLAGS.
CHROME-MAGNESITE	(1) FIRED (2) CHEMICALLY BONDED	RELATIVELY HIGH THERMAL EXPANSION. HIGH MECHANICAL STRENGTH AND STABILITY OF VOLUME AT HIGH TEMPERATURES. HIGH RESISTANCE TO CORROSION BY BASIC SLAGS.
FORSTERITE	(1) FIRED (2) CHEMICALLY BONDED	HIGH REFRACTORINESS. EXCELLENT STRENGTH AT HIGH TEMPERATURES. RELATIVELY HIGH THERMAL EXPANSION. MODERATE THERMAL CONDUCTIVITY. EXCELLENT RESISTANCE TO CORROSION BY VOLATILE ALKALIES AND GLASS-BATCH CARRY-OVER. FAIR RESISTANCE TO MOST BASIC SLAGS; ATTACKED BY ACID SLAGS.

Table I—Listed here are characteristic properties of various types and classes of refractory brick. In general, basic refractories are less resistant to thermal shock than fireclay and high-alumina refractories. The spall resistance of some basic brick of special compositions, however, is equal to that of superduty fireclay brick. Basic brick of any class may be either metal encased or metal encased and internally plated. Such brick have better resistance to spalling than brick without the casings. Most metal-encased brick are of magnesite-chrome compositions.

PHYSICAL PROPERTIES

PHYSICAL PROPERTIES	FIRE CLAY REFRACTORIES								ALUMINA 90-99% Al_2O_3
	LOW DUTY FIRE BRICK	MEDIUM DUTY FIRE BRICK	HIGH DUTY FIRE BRICK	SUPER DUTY FIRE BRICK	50% Al_2O_3	60% Al_2O_3	70% Al_2O_3	80% Al_2O_3	
PYROMETRIC CONE EQUIVALENT, OR NOMINAL FUSION POINT (F)	19-29 2,770-3,018	29-31 3,018-3,061	32-33 3,123-3,169	33-34 3,169-3,205	34-35 3,205-3,245	36-37 3,279-3,308	37-38 3,308-3,335	38-40 3,335-3,425	37-40 3,308-3,425
AVERAGE BULK DENSITY (G PER CU CM)	1.9-2.15	1.9-2.15	1.9-2.2	2.25-2.45	2.05-2.15	2.2-2.3	2.3-2.4	2.6-2.7	2.9
WEIGHT OF 9" x 4-1/2" x 2-1/2" BRICK (LB)	7 - 8-1/2	7 - 8-1/2	7 - 8-1/2	7-1/2 - 9	7-1/2 - 9	8.2-8.5	8.4-8.8	9.5-10	10.5
POROSITY (PER CENT)	16-25	16-25	10-24	7-20	18-24	20-27	20-35	20-30	14-24
PERMEABILITY TO COLD AIR	LOW TO HIGH	LOW TO HIGH	LOW TO HIGH	MODERATE TO HIGH	MODERATE	MODERATE	VERY LOW TO LOW	VERY LOW TO LOW	*3-51
MEAN SPECIFIC HEAT	0.25-0.26 20-1,000 C	0.25-0.26 20-1,000 C	0.25-0.26 20-1,000 C	0.25-0.26 20-1,000 C	0.26-0.27 20-1,000 C	0.26-0.27 20-1,000 C	0.26-0.27 20-1,000 C	0.26-0.27 20-1,000 C	0.28 0-1,700 C
MEAN COEFFICIENT OF EXPANSION (IN. PER IN. PER C)	5.1×10^{-6} 20-1,200 C	5.1×10^{-6} 20-1,200 C	5.1×10^{-6} 20-1,200 C	5.1×10^{-6} 20-1,200 C	5.5×10^{-6} 20-1,200 C	6.5×10^{-6} 20-1,200 C	6.5×10^{-6} 20-1,200 C	7.0×10^{-6} 20-1,200 C	7.3 TO 10.2 $\times 10^{-6}$ 25-1,500 C
THERMAL CONDUCTIVITY (BTU PER HR PER SQ FT PER IN. THICKNESS PER F)	8 - 9 AT 2,000 F	9 - 10 AT 2,400 F	10 - 11 AT 2,400 F	10 - 11 AT 2,400 F	10 - 12 AT 2,400 F	10 AT 2,000 F	10.5 AT 2,000 F	12 AT 2,000 F	15-24 AT 2,200 F
MODULUS OF RUPTURE (LB PER SQ IN.)	400-1,700 AT 70 F	1,000-1,500 AT 70 F	1,000-1,600 AT 70 F	1,000-3,000 AT 70 F	1,000-1,600 AT 70 F	900-2,000 AT 70 F	1,000-2,000 AT 70 F	800-2,000 AT 70 F	1,200-4,600 AT 70 F
HOT LOAD STRENGTH SUBSIDENCE IN 1-1/2 HR TEST UNDER 25 PSI LOAD (PER CENT)	———	3 - 10% AT 2,460 F	0.5 - 7.0% AT 2,460 F	0.5 - 7.0% AT 2,640 F	4 - 7% AT 2,640 F	1.5 - 7% AT 2,640 F	0.5 - 3.0% AT 2,640 F	0.5 - 2.5% AT 2,640 F	0.3 - 2.0% AT 2,900 F
COLD CRUSHING STRENGTH (PSI)	3,000 - 5,000 AT 70 F	2,000-3,000 AT 70 F	2,000-5,000 AT 70 F	1,500-4,000 AT 70 F	3,000-6,000 AT 70 F	2,000-4,500 AT 70 F	3,500-7,000 AT 70 F	3,500-6,000 AT 70 F	4,000-25,000 AT 70 F
ABRASION RESISTANCE	VARIES	VARIES	VARIES	VARIES	GENERALLY GOOD	GENERALLY GOOD	GENERALLY GOOD	GENERALLY GOOD	GOOD
CORROSION RESISTANCE	VARIES	VARIES	VARIES	VARIES	GOOD	GOOD	GOOD	GOOD	GOOD
THERMAL SHOCK RESISTANCE	VARIES	VARIES	VARIES	VARIES	GOOD	GOOD	GOOD	GOOD	GOOD
MAXIMUM RECOMMENDED HOT FACE TEMPERATURE (F)	1,400-1,700	2,200-2,300	2,500-2,600	2,600-2,700	VARIES WITH CONDITIONS	VARIES WITH CONDITIONS	VARIES WITH CONDITIONS	VARIES WITH CONDITIONS	2,800-3,400

*AIRFLOW IN

Table II—Values for the physical properties of dense, non-insulating refractories are listed here. These values, which are a composite of data obtained from information published by various manufacturers of refractories, represent a range of values and should not be considered as specific for any one refractory. The data for a commercial refractory may differ from the values given here because of differences in raw materials, bonding materials, and manufacturing process. The values for specific heat, thermal expansion, and thermal conductivity may be used in a general way for engineering purposes.

The P.C.E. does not indicate a definite melting point or fusion point for a refractory, because the test is not a measurement of temperature alone. P.C.E., however, does furnish a means of comparing the refractoriness of materials.

Average Bulk Density

The density of refractories is a factor that affects their capacity to store heat. The average bulk density of a refractory may be expressed as weight per cu ft or as grams per cu cm. The bulk density of a refractory is almost invariably less than the true specific gravity of the material composing it because of the effect of porosity.

Porosity

Porosity has an effect on a refractory's thermal conductivity, permeability to gases, and resistance to penetration by slags, molten metal, glasses, and fluxes.

Permeability

Permeability to cold air is a relative measure of the number of open pores and their character. When a refractory has both high porosity and high permeability, a large number of connected pores is indicated. A high porosity and relatively low permeability indicates the structure consists largely of closed pores. Permeability, therefore, is an indication of the extent to which the refractory will be penetrated by gases, fluid slags, metals, and fluxes.

Mean Specific Heat

The mean specific heat of a refractory material is a number that expresses the ratio between the amount of heat required to raise one gram of the material one degree Centigrade, between 0 C and its mean temperature, and the amount required to raise one gram of water from 19.5 C to 20.5 C. The units for mean specific heat in the English system are Btu per lb per deg F. The numerical value for mean specific heat is the same in both the English and metric systems for any refractory material.

The heat content of a refractory brick or other shape at any temperature is the

OF DENSE REFRACTORIES

MULLITE	FUSION CAST ALUMINA	SILICON CARBIDE		ZIRCON	STABILIZED ZIRCONIA	SILICA REFRACTORIES		BASIC REFRACTORIES			
		CLAY BONDED	SiN BONDED			QUARTZITE	SEMI-SILICA	MAGNESITE (BURNED)	MAGNESITE -CHROME (BURNED)	CHROMITE (CHEMICALLY BONDED)	FORSTERITE
38-39 3,335-3,389	39-40 3,389-3,425	———	———	+42	4,600-4,700	31-33 3,061-3,169	27-31 2,984-3,061	38-41 3,335-3,578	VARIES	38-41 3,335-3,578	40 3,425
2.3-2.6	2.8-3.2	2.54	2.85	3.3	4.3-4.4	1.65-1.9	1.85-2.0	2.6-2.75	2.8-3.2	3.0-3.3	2.45-2.62
8.5-9.5	10-12	9.25	10.25	12	16	6-7	6-3/4 - 7-1/4	9-1/2 - 10	10-1/4 - 11-1/2	11-12	9 - 9-1/2
15-22	2.5-7.5	13-14	7 - 9	15-30	15-30	19-30	23-30	20-28	20-28	20-28	22-28
*3-40	*0.5-2.0	*2 - 6	*1 - 4	*10-78	*4-32	HIGH	MODERATE TO HIGH	LOW TO MODERATE	HIGH	VARIES WITH TEMPERATURE	*10-25
0.25 20-1,000 C	0.28-0.32 20-1,400 C	0.285 0-1,400 C	0.29 0-1,400 C	0.18 20-1,050 C	0.175 25-1,400 C	0.265 20-1,000 C	0.26 20-1,000 C	0.28 20-1,000 C	0.23 20-1,000 C	0.22 AT 1,000 C	0.27 20-1,000 C
4.5 TO 6.0 $\times 10^{-6}$ 25-1,400 C	8.4 $\times 10^{-6}$ 25-1,400 C	4.4 $\times 10^{-6}$ 25-1,400 C	4.4 $\times 10^{-6}$ 25-1,400 C	4.2 $\times 10^{-6}$ 20-1,550 C	8 $\times 10^{-6}$ 0-1,100 C	43 $\times 10^{-6}$ 20-300 C 3 $\times 10^{-6}$ 300-1,100 C	6.5 $\times 10^{-6}$ 20-1,200 C	14.5 $\times 10^{-6}$ 20-1,425 C	11 $\times 10^{-6}$ 20-1,500 C	8 $\times 10^{-6}$ 20-1,000 C	11 $\times 10^{-6}$ 20-1,500 C
14-16 500-2,000 F	24-31 AT 2,200 F	109 AT 2,200 F	113 AT 2,200 F	13.5 390-1,832 F	5 AT 2,000 F	13 390-1,832 F	8 400-2,000 F	14-18 AT 2,000 F	13.8 400-2,200 F	12.8 AT 2,400 F	10.3 AT 2,400 F
1,200-1,800 AT 70 F	700-1,500 AT 2,462 F	2,000 AT 2,500 F	5,000-7,000 AT 2,500 F	1,500-2,200 AT 70 F	1900 AT 70 F	600-1,200 AT 70 F	300-700 AT 70 F	1,200-4,000 AT 70 F	550-1,400 AT 70 F	800-1,500 AT 70 F	700-1,300 AT 70 F
0 - 2.0% AT 3,100 F	0 AT 2,730 F	0 AT 2,730 F	0 AT 2,730 F	2 - 5% 2,910 F	LESS THAN 1% AT 15 PSI AT 1,815 C PER 100 MIN	FAILS AT 2,900-3,070 F	0.5 - 2.0% AT 2,640 F	FAILS AT 2,900-3,200 F	FAILS AT 3,000 F	FAILS AT 2,300-2,700 F	FAILS AT 2,950-3,050 F
5,000-7,000 AT 70 F	———	10,000 - 15,000 AT 70 F	15,000-20,000 AT 70 F	5,000-12,000 AT 70 F	———	2,000-4,000 AT 70 F	1,400-3,000 AT 70 F	6,000-12,000 AT 70 F	1,800-6,000 AT 70 F	3,000-5,000 AT 70 F	1,500-4,000 AT 70 F
FAIR	FAIR TO GOOD	EXCELLENT	EXCELLENT	FAIR	FAIR	GOOD	GOOD	USUALLY POOR	———	———	FAIR
GOOD	GOOD	RESISTANT TO ACIDS	ACIDS: GOOD ALKALIES: POOR	RESISTANT TO ACID AND SILICEOUS SLAGS	RESISTANT TO ALKALIES AND MOST METALS	RESISTANT TO ACID SLAGS	RESISTANT TO ALKALI FUMES AND DUST	RESISTANT TO BASIC SLAGS	RESISTANT TO BASIC SLAGS	RESISTANT TO BASIC AND MODERATELY ACID SLAGS	RESISTANT TO ALKALIES AND BASIC SLAGS
VERY GOOD	POOR TO FAIR	FAIR TO GOOD	VERY GOOD	GOOD	FAIR	POOR BELOW 1,200 F. GOOD ABOVE 1,200 F	GOOD	FAIR	GOOD	FAIR	FAIR
3,000-3,200	3,300	2,500-3,000	2,900-3,000	3,000	4,250 F PROPERLY SUPPORTED	2,900-3,000	2,800-2,900	VARIES	VARIES	VARIES	VARIES

CU FT PER HR SQ FT PER IN. FOR ONE INCH H_2O PRESSURE DROP AS REPORTED BY REFRACTORIES DIVISION, CARBORUNDUM CORPORATION

product of its specific heat and its weight. This product is used when calculating the heat stored in a furnace structure.

Coefficient of Thermal Conductivity

The thermal conductivity of refractory materials is affected mainly by the chemical and mineral composition of the refractory, the structure of the material, its porosity, and its temperature. In general, the thermal conductivity of any one particular type of refractory is more dependent upon the porosity than any other factor. Thermal conductivity decreases with increasing porosity. The formula for heat flow through a refractory wall in service under steady-state conditions is:

$$Q = \frac{k\,(T_1 - T_2)At}{d}$$

where

Q = heat flow
k = coefficient of thermal conductivity for the refractory material
$T_1 - T_2$ = temperature drop from the hot face to the cold face
A = area of the wall
t = time
d = thickness of the wall.

In English units, k represents the quantity of heat in British thermal units which will flow through the refractory per hour, per sq ft of surface, per degree F temperature difference between the hotter and the colder faces, and for a one-in. thickness.

Modulus of Rupture

The modulus of rupture is a measure of the strength of a refractory. The modulus usually is determined at room temperature, although it may be determined at some higher temperature if desired. When determined at room temperature, the cold strength of the refractory is the quantity measured. The strength of a refractory at room temperature may have little or no relationship to the strength of the same refractory at higher temperatures in the normal operating range. Modulus of rupture determinations at room temperature may serve to indicate whether a refractory of a particular type has been properly processed and fired.

Load Test

Subsidence under load at high temperature is a standard laboratory test for determining the behavior of a refractory at or near its normal operating tempera-

PHYSICAL PROPERTIES OF INSULATING REFRACTORIES

PHYSICAL PROPERTIES	CLASSIFICATION									
	1,600 F	2,000 F	2,300 F	2,600 F	2,800 F	3,000 F	3,200 F	3,300 F ALUMINA BUBBLE BRICK	FUSED ZIRCONIA INSULATING	SILICA INSULATING
AVERAGE BULK DENSITY (G PER CU CM)	0.30–0.47	0.46–0.73	0.50–0.78	0.67–0.82	0.69–1.00	0.91–1.13	1.27	1.29–1.45	2.45	0.91–0.98
WEIGHT OF 9" x 4-1/2" x 2-1/2" BRICK (LB)	1.1–1.7	1.65–2.65	1.8–2.85	2.45–3.00	2.50–3.65	3.3–4.1	4.6	4.7–5.3	9.00	3.3–3.6
POROSITY (PER CENT)	———	65–80	65–75	63–73	50–70	50–65	50–64	50–67	———	———
PERMEABILITY TO COLD AIR FLOW ($IN.^3$ PER SEC PER $IN.^2$ PER IN. THICKNESS PER LB PRESSURE)	———	5.9–30.2	6.7–39.2	12.2–42.7	———	———	———	———	———	———
MEAN SPECIFIC HEAT	0.230 AT 1,000 F	0.245 AT 1,500 F	0.245 AT 1,500 F	0.260 AT 2,000 F	0.260 AT 2,000 F	0.260 AT 2,000 F	0.270 AT 2,400 F	0.320 70–2,550 F	0.175 70–2,550 F	0.270 2,000 F
MEAN COEFFICIENT OF EXPANSION (IN. PER IN. PER F)	2.5×10^{-6} AT 1,000 F	2.65×10^{-6} AT 1,500 F	2.65×10^{-6} AT 1,500 F	2.5×10^{-6} AT 2,000 F	3.1×10^{-6} AT 2,000 F	3.3×10^{-6} AT 2,000 F	———	5.0×10^{-6} AT 2,400 F	5.1×10^{-6} 85 – 2,730 F	SAME AS HIGH DENSITY SILICA
THERMAL CONDUCTIVITY (BTU PER HR PER SQ FT PER IN. THICKNESS PER F)	0.95–1.63 AT 1,000 F	1.28–2.10 AT 1,500 F	1.43–2.20 AT 1,500 F	2.82–3.20 AT 2,000 F	2.60–3.60 AT 2,000 F	3.6–4.1 AT 2,000 F	4.5–5.5 AT 2,400 F	5.0–7.0 AT 2,400 F	5.0 AT 2,800 F	5.5 AT 2,000 F
MODULUS OF RUPTURE (LB PER SQ IN.)	40–100	75–140	80–155	100–350	150–450	175–300	450–750	150–450	300	160–200
HOT LOAD STRENGTH — SUBSIDENCE IN 1-1/2 HR TEST UNDER 10 PSI LOAD (PER CENT)	———	0.0% AT 2,000 F	0.0–0.3% AT 2,000 F	0.3–0.5% AT 2,200 F	0.0–4.0% AT 2,400 F	0.0–4.0% AT 2,600 F	0.5–2.0% AT 2,600 F	0.0–0.7% AT 2,800 F	———	———
COLD CRUSHING STRENGTH (PSI)	50–110	90–160	100–210	150–450	350–900	400–750	1,000–1,600	350–1,300	———	150–200
ABRASION RESISTANCE	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR
CORROSION RESISTANCE	———	———	———	———	———	———	———	———	REDUCED ABOVE 2,900 F IN CONTACT WITH CARBON	RESISTANT TO ACID SLAGS AND IRON OXIDE
THERMAL SHOCK RESISTANCE	GENERALLY GOOD	GENERALLY GOOD	GENERALLY GOOD	GENERALLY GOOD	GENERALLY GOOD	GENERALLY GOOD	GENERALLY GOOD	GOOD	———	GOOD ABOVE 1,200 F
MAXIMUM RECOMMENDED HOT FACE TEMPERATURE (F)	EXPOSED 1,600 F BACKUP 2,000 F	2,000 F	2,300 F	2,600 F	2,800 F	3,000 F	3,200 F	2,800–3,300 F	4,000 F PROPERLY SUPPORTED	3,000 F

Table III—Insulating refractories, whose physical properties are listed here, are used to withstand temperature and act as insulation. These refractories are classified primarily by division in groups suitable for specified maximum recommended hot face temperatures. The groups are listed as 16, 20, 23, 26, 28, and 30. When multiplied by 100, the group number gives the recommended temperature. Insulating refractories are light weight and porous. The weight increases and porosity decreases as the group number increases. When used in furnace structures, insulating refractories give reduced heat storage due to their lighter weight and a reduced heat loss from the outer surfaces of the furnace due to low thermal conductivity. The values listed here are a composite of values obtained from several manufacturers of refractories and do not apply specifically to the products of any one manufacturer.

ture. When conducted according to the American Society for Testing and Materials method C16, the temperature is raised at a prescribed rate until a specified holding temperature is reached. The specified holding temperature differs according to the classification of the refractory undergoing test, ranging from 2,460 F for high duty fireclay to 3,000 F for 99 per cent alumina brick.

A vertical load of 25 psi is applied to a brick standing on its end. In most tests the maximum temperature is maintained for 1½ hours, with the furnace then being allowed to cool by radiation to 1,830 F or lower before the load is removed. The contraction or amount of subsidence is reported as a percentage of the original length.

Variations of the load test are made at times by some manufacturers to suit specialized products. In normal service, refractories are not generally required to bear loads of 25 psi. The load test, therefore, subjects the brick to conditions that are more severe than normal and thus accelerates plastic deformation.

Cold Crushing Strength

Cold crushing strength is a measure of the strength of a refractory under compression at room temperature. Here, as with modulus of rupture, the cold strength of a refractory cannot be relied upon to indicate its behavior at high temperature. The cold strength, however, is a valuable measure of resistance to impact and ability to withstand the abuse encountered in handling and shipping. It also may be of value in determining whether processing and firing procedures have been satisfactory.

Abrasion Resistance

While the ability of refractories to resist abrasion is important in some applications, it may be of no importance in others. Refractories that must resist abrasion are intentionally made to be hard, well bonded, and strong. Abrasion resistance is most often measured by impingement of a stream of abrasive particles against the face of a test brick, or by rubbing against an abrasive surface. The modulus of rupture test also is an indication of the relative resistance to abrasion.

Corrosion Resistance

Refractories may be subjected to a corrosive environment due to chemical reactions that occur when they are in contact with metals, slags, fluxes, dust, furnace gases, combustion products of fuels, and other refractories. As a general rule, fireclay, alumina, and silica refractories are considered to be resistant to acid fluxes and slags, while magnesia,

chrome, and forsterite are considered to be resistant to basic fluxes and slags. No definite rule can be given, however, because conditions vary greatly. The applications best suited to certain refractory types have been established through long experience and a process of trial and error. Manufacturers of refractories can generally recommend the type suitable for a particular purpose.

Thermal Shock Resistance

Thermal shock resulting from abrupt and rapid changes in temperature can cause rapid deterioration of a refractory due to the generation of cracks and the loss of pieces from the face of the refractory. The cracking and spalling are caused by mechanical stresses that result from non-uniform temperature changes that occur throughout the piece.

Resistance to thermal shock can be increased by a combination of physical properties that tend to reduce the magnitude of the stresses occurring during a temperature change. Properties that promote resistance to thermal shock, for example, are low thermal expansion, high thermal conductivity, a structure having some elasticity, and the absence of crystalline phase changes.

In many applications thermal shock resistance is of minor importance. For example, the operating temperature of a furnace or kiln may be slowly raised, then held there for years. In other applications such as kiln cars, which are continually going from room temperature to the operating temperature of the kiln and then back to room temperature, thermal shock resistance is of vital importance. The present trend towards shortening the time cycle in kilns and other industrial furnaces also has made thermal shock resistance of major importance for many applications.

Maximum Safe Temperature

Manufacturers of refractories usually specify a maximum safe operating temperature for their products. This is done, however, only when the manufacturer knows the exact environmental conditions to which his product will be subjected. Environment and operating variables exert so much influence upon the behavior of refractories that a maximum recommended temperature cannot always be given. Long experience has made it possible, however, to correlate industrial use of refractories with laboratory tests to discover the temperature range where failure is apt to occur.

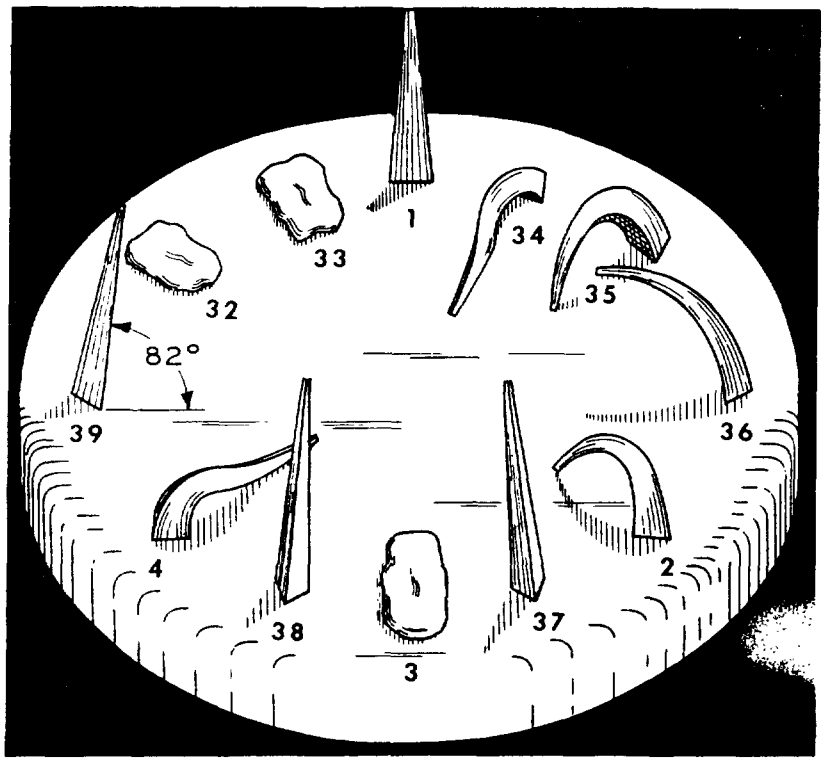


Fig. 1—Illustrated here are test cones and standard cones used in the Pyrometric Cone Equivalent evaluation method to determine the temperature softening behavior of fireclay and high-alumina refractories. Cones *1, 2, 3,* and *4* are test cones and cones *32* through 39 are standard cones.

Various Methods Used to Manufacture Refractories

Several methods are used to manufacture refractories. Some of the methods are well established practices, while others are of comparatively recent origin.

Pressing

Press forming of refractories is done by manual, power driven, or hydraulic presses. In most cases where pressing is used, the material is granular and contains relatively small amounts of moisture. Various binders are added to furnish a cold bond that aids in handling the shape after it is out of the press and in the drying and firing operations. Hydraulic presses are used to exert the high pressures necessary when extremely high density and strength properties are necessary.

Extrusion

Materials that are sufficiently plastic can be extruded as a column from a die through which the material is forced. As the column issues from the die it is cut into appropriate lengths for the subsequent reforming operations usually needed to obtain the desired shapes.

Slip Casting

In slip casting, the refractory ingredients are mixed with water to form a slurry which then is poured into a porous plaster mold. The mold absorbs water from the slurry, causing a layer of the refractory material to be formed on the inside surface of the mold cavity. Either solid or hollow shapes can be formed by the slip casting method.

Air Ramming

Air-operated rammers or vibrating hammers can be used to form refractory shapes in molds made of steel or wood. The process is used primarily for special shapes, or when conditions require only a limited number of pieces. The material usually is rammed in layers. The layers are bonded to one another by roughening the surface of the layer just rammed before the next layer of material is introduced into the mold. While good pieces can be made by this method if

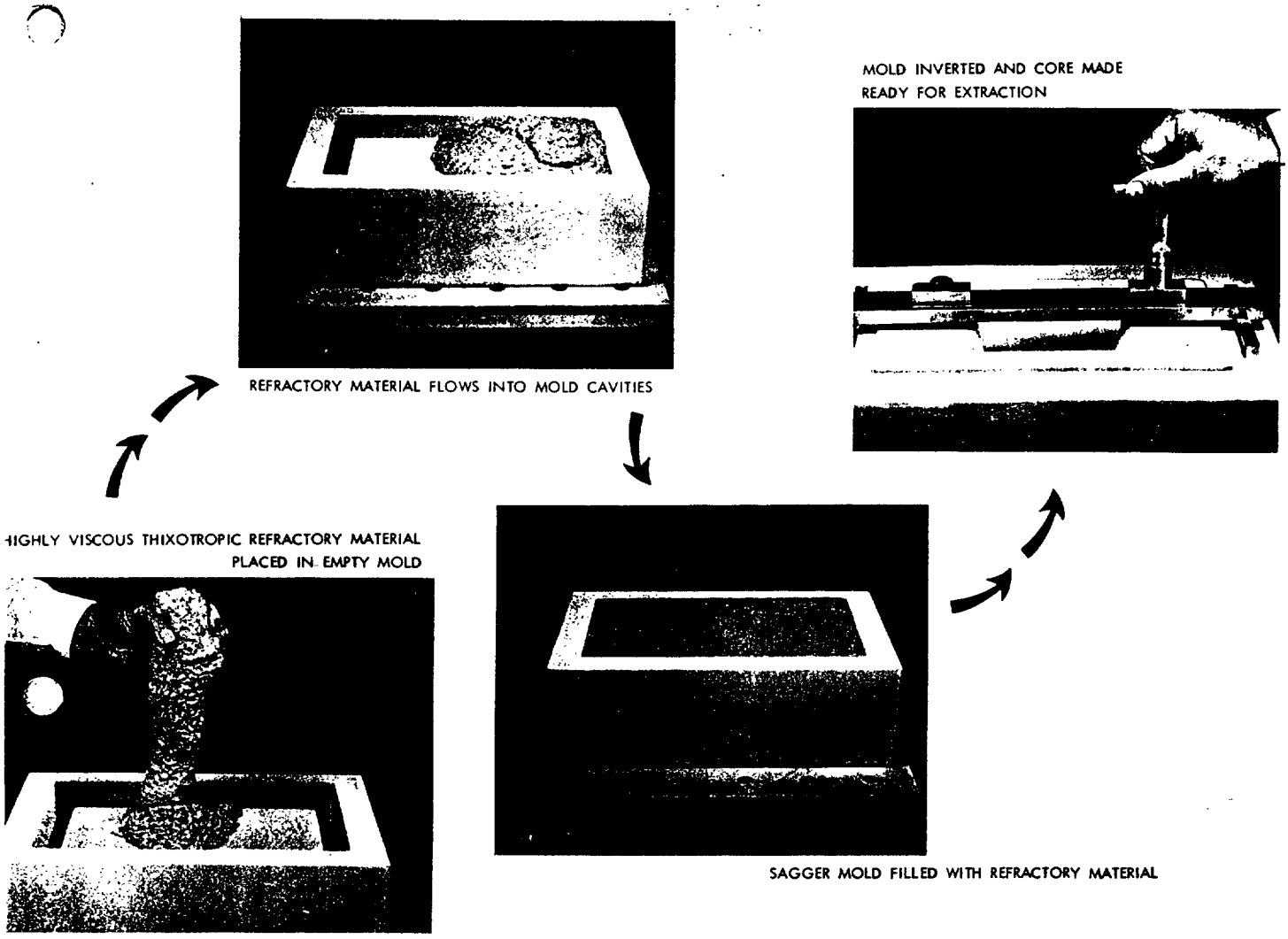


Fig. 2—The thixotropic casting process developed by AC Spark Plug Division is used to produce a variety of refractory products. Shown here are the principal steps involved in casting a sagger by the thixotropic method.

care is used, it is impossible to have uniform density throughout the piece; therefore, other methods are considered more desirable.

Hand Molding

Hand molding formerly was a common method used to make special refractory shapes. This method is used today only when the cost of dies and molds for machine operations is not justified.

Drying and Firing

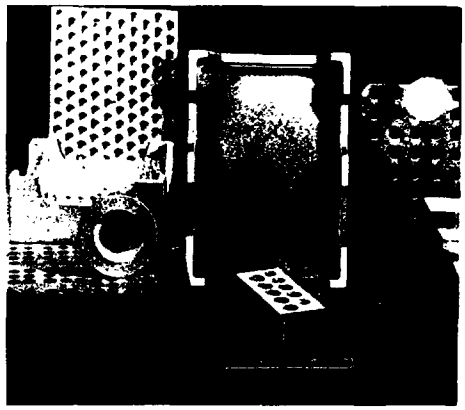
Refractories must be thoroughly dry before firing. Even a small amount of moisture is apt to cause bursting and cracks when the pieces are heated. The firing process is done either in periodic or tunnel kilns which produce a time-temperature cycle that has been found to be satisfactory for the particular content. In general, firing temperatures for refractories are sufficiently high to initiate chemical and physical changes that result in the development of the desired structure and composition, the elimination of volume changes, and the development of strength required for handling, shipping, and enduring structural loads in furnaces.

AC Develops Unique Process for Manufacturing Refractories

AC Spark Plug Division has had long experience in the manufacture of refractories, both for its own use and for others. AC was originally a ceramic plant, and the manufacture of saggers (ceramic boxes used to contain spark plug insulators during the firing process) and kiln refractories was continued after it became a Division of General Motors. The saggers were originally made of a plastic refractory composition containing a fairly high percentage of clay. The saggers were manufactured by forming them in steel dies on a steam-powered press.

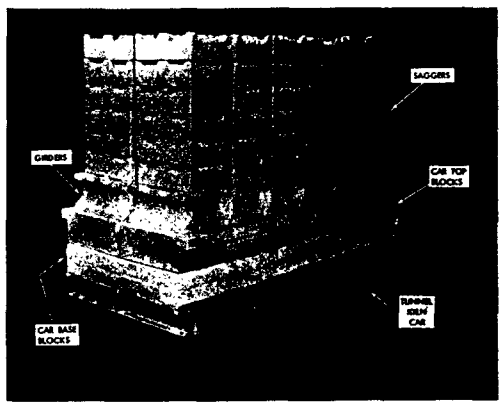
When AC became interested in manufacturing alumina spark plug insulators in the early 1930's, the high temperature refractories required for a kiln operating in the temperature range of 3,000 F to 3,200 F were not available in this country. It became necessary, therefore, for AC to produce its own high temperature refractories for the kiln and kiln cars.

CORE EXTRACTED FROM MOLD



TYPICAL REFRACTORIES MADE BY THIXOTROPIC CASTING PROCESS

OUTER RING REMOVED. MOLDED SAGGER THEN PLACED ON DRYING BOARD



LOADED TUNNEL KILN CAR WITH SAGGERS. THE GIRDERS, CAR TOP BLOCKS, AND CAR BASE BLOCKS ALSO ARE MADE BY THE THIXOTROPIC CASTING PROCESS.

At first, the refractories were hand molded. Bricks and other shapes also were made by hydraulic pressing methods. Hand molding then was replaced by air hammer ramming. Later on, AC developed a variation of slip casting known as the *thixotropic casting process*. Both the process and composition, patented by AC, now are used to produce refractory brick, shapes, and saggers used in kilns operating at temperatures up to 3,200 F and to make refractories for use in the power house and die cast areas. The thixotropic casting process also is used to make specialized refractories for unusual applications.

The thixotropic casting process makes use of electrolytes and surface active agents to obtain high density mixtures containing relatively little water. The mixtures, however, have sufficient fluidity to flow into and fill comparatively small spaces in a mold (Fig. 2), especially when the mold is vibrated. After the mold is filled, it is allowed to stand for a period of time until the refractory material has stiffened sufficiently to permit the piece to be removed from the mold. The removal of the piece from the mold must be done carefully because any appreciable vibration or movement of the material after the initial setting will make it fluid again due to its thixotropic quality.

Summary

Refractories represent a class of engineering materials that possess characteristics well suited to applications where resistance to heat, abrasion, corrosion, thermal shock, and attack by molten glass, metals, slags, and reducing or oxidizing atmospheres is required. To apply refractory materials properly, however, the engineer must be familiar with their varied physical properties and characteristics. Knowing the environmental conditions in which a refractory will be placed is a primary requirement in the proper selection of a refractory material. This will indicate the type or class of refractory material required. Examination of physical properties then will narrow the selection to the proper refractory material to use.

References

1. ..... Modern Refractory Practice (Pittsburgh, Pennsylvania: Harbison-Walker Refractories Company) 4th Edition, 1961.