The physical and chemical properties of a refractory product, as shown on data sheets, are characteristics which give an indication of the product's performance under specific operating conditions (i.e., slagging, load bearing, fluctuating high temperatures, etc.).

The significant physical properties include:

- Bulk Density
- Porosity
- Cold Crushing Strength
- Modulus of Rupture at Room Temperature and Elevated Temperatures
- Reversible Thermal Expansion
- Permanent Linear Change (After Reheating to Specific Temperatures)
- Load Subsidence or Creep
- Thermal Conductivity
- Abrasion Resistance
- Thermal Shock Resistance

BULK DENSITY

Bulk Density is the ratio of weight (or mass) to volume and it is expressed in pounds per cubic foot (lb/ft^3) or kilograms per cubic meter (g/cm^3).

POROSITY

Porosity can be characterized by the volume fraction of pores (or voids) present. In refractories, this property is reported as "% apparent porosity". Apparent porosity refers to the pores (or voids) connected to the surface, or open pores. The open pores that directly affect properties such as slag resistance and permeability.

Generally, refractories with a high amount of porosity have excellent insulating properties but low density, corrosion resistance, and strength. Lower porosity improves strength, load bearing capacity and corrosion resistance (via less slag penetration) but can lower the thermal shock resistance. In more porous brick, the pores present act as crack inhibitors. As a result, the amount of porosity is a compromise that you must weigh, depending on the specific service condition.

COLD CRUSHING STRENGTH

Cold Crushing Strength (CCS) is the product's ability to resist failure under a compressive load, at room temperature. A compressive load is applied to a refractory sample by a compressive testing machine until the sample fractures (or fails). The cold crushing strength is then calculated by dividing the compressive load applied by the sample area. Crushing can also be measured at elevated temperatures.

MODULUS OF RUPTURE

The modulus of rupture (MOR) indicates the product's bending or tensile strength. A refractory sample is supported in span. The testing machine applies a load at a specified rate to the center of the sample until the sample breaks. The modulus of rupture, expressed in pounds per square inch (psi) or mega-pascals (MPa), is calculated using the load at which the sample failed, the span between the supports, and cross-section of the sample. This property can be tested at either room temperature or high temperatures (called hot modulus of rupture).

REVERSIBLE THERMAL EXPANSION AND PERMANENT LINEAR CHANGE

Like most materials, refractories expand when heated and contract when cooled. This is called "reversible thermal expansion". Thermal expansion curves are available on most refractory products. These graphs depict the expansion rate at specific temperatures. The rate of expansion, as expressed by the coefficient of thermal expansion, is different for different types of materials. For example, magnesite (MgO) expands at a higher rate than alumina (Al_2O_3).

Refractory materials can undergo mineral formations or phase transformations when heated. These phase changes may result in either volume expansion or reduction. Upon cooling to room temperature, the material will possibly be larger or smaller than the original dimensions. This is evaluated by reheat tests, which are run at temperatures prescribed by ASTM (American Society for Testing and Materials) for each class of refractory. This is reported as permanent linear and volume change.

LOAD SUBSIDENCE OR CREEP

A refractory's load-bearing strength or creep resistance is determined by the product's subsidence under a compressive load at high temperature. Load resistance is the ability of a refractory to maintain dimensional stability under load at elevated temperatures. Accessory oxides like iron oxide (Fe_2O_3), Potash (K_2O), Soda (Na_2O) and others can flux the primary aggregate. The consequence of those naturally occurring impurities, in addition to those introduced by the process, is increased subsidence due to formation of glass phases within the bond matrix.

In a standard load test, the refractory sample length is measured and placed within a furnace. A loading device is placed on the sample and a specific load is applied (ASTM Test C-16 calls for 25 psi [0.20 N/mm^2] load but 50 psi and 100 psi [0.34 or 0.70 N/mm^2] loads can be applied.) With the load applied, the temperature is increased in accordance with a prescribed schedule. The maximum temperature is held for the specified time. The furnace is then cooled and the new sample length is measured, giving a subsidence vale expressed as a percent change from original sample size.

Thermal expansion and creep of refractories under load are related to load resistance with the additional factor of time, and are therefore more meaningful. Many mineralogical reactions are temperature and time dependent, and the creep test is run under load at a specific temperature over a period of many hours.

Thermal expansion under load is used to measure rates of subsidence or creep over long hold times. Samples are prepared and loaded as for the load test. Hold times at maximum temperatures can be 100 or 200 hours. Expansion and subsidence are continually measured during the test. As the furnace temperature increases, expansion occurs in the loaded sample (called "expansion-under-load"). Loading does not restrict a refractory material from its normal rate of expansion. The test specimen is held at the maximum temperature for an extended period of time. Any subsidence is measured, and is reported as present subsidence (at a constant temperature and load), and a creep curve is plotted. Subsidence is generally caused by the formation of viscous glassy phases with increasing temperature. The crystalline phases (such as mullite in high alumina products) present can reduce the amount of glassy phases and thus increase creep resistance.

Since impurities in raw materials can cause glassy phase formation, high purity materials should be used for refractories with high creep resistance and minimal subsidence under load. When evaluating service temperature limits, examine mineralogical purity (most technical data sheets report chemical analysis, not mineralogical analysis) in order to compare products of like compositions.

THERMAL CONDUCTIVITY

Thermal Conductivity is the amount of heat which flows from the hot face to the cold face of a refractory lining. Conductivity (K) is expressed as Btu/Hr. Ft.^{2}°F/In. or W/(m°K). The amount of heat flowing through a refractory wall is directly proportional to:

- Conductivity Value of the Refractory
- Temperature Drop from the Hot Face to the Cold Face
- Area of the Wall
- Time

The heat flow is inversely proportional to the thickness of the wall.

There are several different methods of measuring thermal conductivity, and each may produce different results. When comparing thermal conductivity of similar materials, it is important to know what test method was used.

"K" FACTORS FOR SELECTED REFRACTORIES"

Btu/Hr. Ft.^{2} °F/In.
To Convert to W/(m°K) Multiply by 0.1442

	TEMPERATURE (DEGREES F)					
BRAND	**200**	**700**	**1200**	**1800**	**2200**	**2600**
KS-4® GR	4.99	5.26	5.50	5.73	5.86	5.96
LO-ABRADE® GR	6.42	6.38	6.4	6.53	6.68	6.88
VERSAFLOW® THERMAX®	8.10	8.86	9.56	10.25	10.62	10.91
UFALA® XCR	15.91	13.21	12.28	12.28	12.78	13.64
RUBY® PLASTIC	24.3	19.3	17.9	17.1	16.7	16.1
ECLIPSE® 60P	32.40	39.80	38.72	36.10	34.94	34.63
GREENGUN ECLIPSE® 73P	34.87	35.17	37.10	41.88	45.88	51.23

Data for other products is available through your H-W sales representative

ABRASION RESISTANCE

In many types of service, refractories are subjected to impact from heavy pieces of material charged into the furnace, abrasion by moving metallic or non-metallic solids, or direct impingement by abrasive dusts in rapidly moving gases. For greatest resistance to these actions, refractories should be mechanically strong, and well bonded. As compared with other properties, the modulus of rupture, and cold crushing test offer the best indication of abrasion resistance.

There are several methods to measure abrasion resistance, but the ASTM C-704 is the most common. This test subjects a refractory sample to an impinging stream of silicon carbide grain. After testing, the sample's volume loss is measured and the abrasion resistance is expressed as volume (cc) loss. When comparing abrasion resistance, only data generated from the same test method should be compared.

THERMAL SHOCK RESISTANCE

In many service conditions, refractories can undergo rapid temperature changes. These temperature fluctuations develop unequal thermal stresses, within the refractory, by causing either rapid expansion or contraction of a section of material. Generally, the refractory with the lowest rate of thermal expansion (lowest coefficient of expansion) has the best thermal shock resistance. Inversely, the material with a high expansion has a low thermal shock resistance.

Thermal shock is a key property in your product selection process. The most undesirable consequence of thermal shock is obviously spalling. Spalling is the loss of fragments or "spalls" from the face of a refractory brick or structure through cracking and rupture, which exposes inner portions of the refractory.

The prism spalling test is used to evaluate the thermal shock resistance of refractory brick and monoliths. Test specimens are typically 2 x 2 x 3" (5 x 5 x 8 cm.) prisms. The test involves cycling samples from 2200°F (1204°C) for ten minutes, in water for two minutes, and in air for eight minutes, until the samples have broken into separate pieces or have undergone a total of 40 cycles.

The loss of strength test is a modified version of the prism spall test. It consists of testing two 3 x 1 x 1 inch (8 x 3 x 3 cm.) brick specimens from the same brick. One of the samples is cycled five times from 2200°F (1204°C) to room temperature. Modulus of rupture is then performed on a 2" (5 cm.) span on both the cycled and uncycled specimens. Percent loss of strength is then calculated by subtracting the MOR of the cycled sample from that of the uncycled sample. Loss of strength is repeated for an average of five specimens. The lower the percent loss of strength, the better the thermal shock resistance.

When comparing thermal shock resistance, only data generated from the same test method should be compared.