

The KIP Company

21391 Hilliard Boulevard
Cleveland, Ohio 44116-0819
U.S.A.
Telephone: 440-331-8974
<http://www.kipco-online.com>

Ceramics Primer

Ceramics are "any class of inorganic, nonmetallic products which are subjected to a high temperature during manufacture or use".

Clay is "a natural mineral aggregate, consisting essentially of hydrous aluminum-silicates; it is plastic when sufficiently wetted, rigid when dried in mass, and vitrified when fired to a sufficiently high temperature".

Low-alumina Catalyst Bed Supports are made of naturally-occurring clays which have been mined, processed, formed and fired (heated) to a low surface area ceramic of the desired shape (usually balls or pellets).

Firing a Catalyst Bed Support produces a catalytically "inert" (relative to the catalyst) ceramic due to the low surface area (typically less than 1 square meter/gram) achieved. This contrasts with the group of catalysts made from oxides of aluminum and silicon (zeolites) fired to a high surface area (typically more than 200 square meters/gram); these have acidic properties that are used to catalyze the production of high-octane gasoline.

RAW MATERIALS

Several clays in commercial use consist largely of kaolinite, a hydrated aluminum silicate, in various grades. White kaolin clays are fine in particle size, soft, nonabrasive, and chemically inert over a wide pH range. Their largest use is in the paper industry, as a coating to make paper smoother, whiter, and more printable, and as a filler to enhance opacity and ink receptivity.

Ball clays are usually much darker because they contain more organic carbonaceous material. These fine-grained refractory bond clays have excellent plasticity and strength, and they fire to a light cream to white color. Ball clays are used extensively in white wares, sanitary ware, and wall tile, and as suspending agents in glazes and porcelain enamels.

Fireclays are soft, plastic clays used primarily in making refractory materials that will withstand temperatures of 1,500 degrees C or more. The most common fireclays, called "underclays", occur directly under coal seams.

Clays consisting of mixtures of illite (a hydrated potassium-iron-aluminum silicate), chlorite, kaolinite, and smectite, are used to manufacture structural clay products (brick and sewer pipe, etc) and lightweight aggregate (an additive for mortars, cements, and concretes with good structural properties and high crush strength). These clays vary widely in physical properties, depending on composition and the particle size of the mineral constituents. The cement industry also uses this clay, mostly for the charge to cement kilns.

CERAMICS MANUFACTURE

Three main steps are involved in making ceramic articles: forming, drying, and firing.

Forming

Powdered raw materials are mixed with water or other binding liquids, and are formed by hand, on a potter's wheel, in a mold, or in a press. The properties that are most important are plasticity, green (pre-firing) strength, dry strength, drying and firing shrinkage, vitrification range, and fired color.

Clay articles and refractory brick are usually pressed damp, with about 10 percent water, into dies or molds under moderate pressures.

Ceramics made of purified powders such as alumina and ferrites are pressed dry at higher pressure with an organic binder (for example, 1 percent polyvinyl alcohol). In isostatic pressing, the powder is held in a rubber mold, and external pressure is applied with a fluid such as glycerine.

Ceramics in bar, rod, or tube form can be extruded through a die.

In slip casting, a suspension of ceramic powder, usually in water, is poured into a mold made of plaster of Paris. Water is absorbed by the mold, and a hard lining on the mold wall is built up; excess liquid is poured out of the mold. Using slip casting, a number of complex shapes can be made economically, since the cost of the molds is low.

Drying

After forming, the ceramic ware must be carefully heated for a few hours to remove excess water or binder. The rate of drying must be carefully controlled so that warping and defects do not form as the sample shrinks.

Firing or Sintering

After drying, the article is fired at a high temperature (from 800 to 2,000 degrees C, or from 1,500 to 3,500 degrees F) to sinter or bind together the individual crystals of the ceramic powder into a solid, coherent mass. The higher the firing temperature, the more dense and less porous the material becomes. A wide range of properties in ceramics is possible with different firing temperatures and times.

The most common ceramic clays form complex mixtures of several different solid phases after firing. For example, traditional porcelains contain at least three starting materials--clay, feldspar, and silica sand. When a mixture of these materials is heated at high temperatures (above 1,200 degrees C or 2,200 degrees F), the feldspar (potassium- sodium aluminosilicate) melts and coats the clay and sand crystals. As firing proceeds, tightly bound water in the clay structure is removed, and fine, needlelike crystals of an aluminosilicate are formed from the clay. The grains of silica sand are partly dissolved in the viscous liquid feldspar. In the cooled structure there is a glassy phase from the liquid feldspar that binds together the sand grains and aluminosilicate crystals.

Fine, translucent porcelain requires high firing temperatures (up to 1,400 degrees C or 2,500 degrees F) so that more glass is formed.

Firing at an intermediate temperature (about 1,100 degrees C or 2,000 degrees F) produces stoneware, a heavy, opaque, nonporous ceramic.

At lower firing temperatures (less than 1,000 degrees C or 1,832 degrees F), more porous ware with a rough surface results; it is usually called earthenware.

NEW CERAMICS

"High technology" ceramics are new types of materials that surpass earlier ceramics in strength, hardness, light weight, or improved heat resistance. For example, ceramic powders can be made from particles of uniform size. When sintered, these powders produce ceramics that are far less vulnerable to fracture or thermal shock than ordinary ceramics.

In solid-state sintering, individual particles join together in an increasingly dense mass, as continuous pores are deformed, and finally only isolated pores remain. Smaller particles in the original powder lead to more rapid sintering. A more dense material is formed at longer times and at higher temperature, since fewer and smaller pores remain after these treatments.

In hot pressing, a sample is heated to firing temperature and pressed at the same time. Special dies, usually of graphite, are needed to produce materials that could be sintered only at much higher temperatures without simultaneous pressing.

Super-hard ceramics make excellent cutting tools and bearings.

Ferrites are iron oxides containing other elements such as nickel, manganese, and cobalt. These compounds are magnetic but do not conduct electricity as do magnetic metals. They are used in electronic devices such as filters and transformers, and in memory cores in computers. Other metallic ceramics are superconductors. At relatively high temperatures (77 kelvins), they conduct electrical current without the resistance produced by copper and other conductors.

Barium titanate has a high dielectric constant and is used in capacitors. It is also strongly piezoelectric (it develops electrical voltage when stressed in a particular crystallographic direction). It is used in microphones, phonograph pickups, strain gauges, and ultrasonic devices.

The apatites are a family of calcium phosphate minerals that have been widely used as phosphors in fluorescent lamps.

Hydroxylapatite is a bone mineral, and has been developed as a bone and tooth implant material.

In nuclear fuel manufacture, uranium ores are reacted and purified to form uranium dioxide, which is then sintered into pellets that serve as nuclear fuel. The pellets are packed into long tubes and are especially stable even with the severe radiation and thermal conditions they encounter.

Ceramics are ideal for the fluorescent ions needed in lasers. Garnet and ruby (alumina with chromium impurities) are the most used laser materials.

Amorphous ceramics are produced by firing ceramic material for a short time at low temperatures, to produce substances that lack the usual crystalline ceramic structure. Like plastics, these ceramics can be sprayed onto surfaces or injection-molded before they are fired. They are used to make complex shapes and thin ceramic films.

Ceramic fibers combined with epoxy glues produce a composite fabric that is lightweight but stronger than steel. It is currently used in making small airplane bodies.

Many ceramic materials are harder than metals and, while brittle in tension, demonstrate great compressive strength.

References:

Gary, James H, and Handwerk, Glenn E., Petroleum Refining: Technology and Economics, Marcel Dekker, Inc., NY, 1975.

Perkins, Walter W., ed., Ceramic Glossary 1984, The American Ceramic Society, Westerville, OH, 1984

Thomas, Charles W., Catalytic Processes and Proven Catalysts, Academic Press, NY, 1970

January 1995; revised April 2006, November 2008