Dictionary of Ceramic Science and Engineering

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Preface

Ceramic science and engineering is one of the oldest, yet one of the newest, fastest growing, and most thoroughly exciting of man's endeavors. The products of the modern ceramic industry embrace every facet of modern living.

What are ceramics? The American Ceramic Society, the National Institute of Ceramic Engineers, the Ceramic Educational Council, The American Society for Testing and Materials, and other learned societies and associations define ceramics as inorganic, nonmetallic materials that are subjected to elevated temperatures during their processing and manufacture—temperatures of 540°C (1000°F) and above. Although the origin of ceramics is lost in antiquity, it is believed that the industry began during neolithic times with the production of pottery vessels for the storage of food and water, the vessels being formed by hand and baked in the sun. Later, the vessels probably were baked in bonfires or campfires to obtain a stronger and more durable product. By early biblical days, the art had attained a semblance of industry status; the city and tower of Babel were built of brick, and slime was used as the mortar (Genesis 11:3). Abraham sent Hagar into the wilderness with food and a "bottle" of water (Genesis 21:14). Today, through modern research and development, ceramic materials, products, and processes are so extensive, and so diverse, that they stagger the imagination. They encompass virtually every phase of modern life and living. Ceramic products are produced in every country of the world, and the list of these products is endless.

Many of the raw materials used in ceramics occur in nature and have been available since the days of the creation. These include the oxides, silicates, carbonates, nitrates, phosphates, chlorides, sulfates, chromates, fluorides, and other naturally occurring substances. Many of these are now upgraded by the use of beneficiation techniques, resulting in improved, more useful, and even more beautiful products of manufacture. During the past century, particularly since the outbreak of World War II in 1939, scientists, engineers, and production personnel have synthesized a host of new minerals and chemicals that have extended the influence of ceramics into previously undreamed of horizons. Some of these new products are the aluminides, beryllides, borides, carbides, nitrides, silicides, sulfides, and tellurides. These new materials have opened the door to the development of completely new industries and technologies. The development of ceramic dielectric components, nuclear fuel elements and other reactor components, lasers, magnetic ceramics and glasses, cermets, high-temperature lubricants, ceramic–glass and ceramic–metal composites, and similar materials such as the piezoelectric materials have permitted man to enter and to conquer scientific and technical worlds that previously were impossible to overcome, particularly the world of hostile environments.

At the risk of oversimplification, the ceramic industry at the turn of the century was divided into six generalized industrial classifications: whitewares, structural clay products, refractories, portland cement, glass, and porcelain enamels. Whitewares may be hypothesized to be the oldest of these categories on the basis of their production and use during neolithic times. Structural clay products may have followed with the advent of the adobe brick. Then came the refractories which were used to line the crucibles, furnaces, and tanks in which iron and steel, glass, portland cement, and porcelain enamels are made. These relative dates of origin are mentioned only as a matter of possible interest and not as a matter of fact. It has been stated, but unconfirmed, that the first manufacturing industry in what is now the United States was a glass factory established one year after the arrival of the Jamestown colonists in Virginia.

Whitewares

Whitewares are defined as products formed of raw materials which fire to a white color—materials such as clay, feldspar, potter's flint, whiting, and steatite. The term whitewares actually is a misnomer, however, as many products of this classification are produced in a myriad of colors. The more common whitewares are the earthenware, porcelain, and vitreous china products known as dinnerware or tableware used in the home and in commercial dining rooms, ceramic cooking ware such as casseroles and bowls, floor and wall tile, pottery, and a wide variety of artware such as figurines, vases, lamp bases, ash trays, and other decorative products. Whiteware products of industrial importance and use are the electrical porcelains such as spark plugs and insulators, laboratory ware such as porcelain crucibles, combustion boats, combustion tubes, grinding mill linings, grinding balls, and spheres for use in cracking and condensing towers. The list is quite long, and the examples given are presented to serve as illustrations of the industry and its products.

Structural Clay Products

The structural products of the ceramic industry are many and are so well known and commonplace that they are taken for granted. Prominent among such products are building brick, face brick, paving brick, drain tile, roofing tile, hollow building tile, quarry tile, wall coping, stoneware, conduits, and terra cotta. The uses and potential uses of these materials are indicated by the designations assigned to them. All of these products are made of clays native to the area in which they are manufactured, and are characterized by high strength, excellent load-bearing properties, and excellent durability and permanence in terms of weathering and underground corrosion.

It should be mentioned that many ceramic products other than structural clay products, per se, also are used in the construction industry. Concrete, mortar, plaster, and plasterboard are examples. Ceramic wall and floor tile are used where cleanliness and beauty are essential. Wall tile is used extensively in vehicular and pedestrian tunnels and subways. Because they are impervious to water and general wastes, and because they are easily cleaned, ceramic products are used in water-supply systems, waste disposal plants, and general sanitation systems.

Refractories

Refractories virtually laugh at fire. They are structural materials that are resistant to molten metals, glass, slags, and other corrosive substances at elevated temperatures. They are made of a wide variety of raw clays or minerals such as the refractory clays, kaolin, magnesite, chrome ore, olivine, diaspore, and bauxite. For more severe or for special service conditions, refractory products are made from synthetic compositions such as the carbides, borides, beryllides, and silicides, or from upgraded or purified minerals such as titania, zirconia, silica, chromium oxide, and alumina.

Refractory products are formulated and processed into shapes and forms as required to meet specific service requirements. In granular form, they are used as a cover for furnace bottoms, as mortars for the laying or setting of the various refractory shapes, and as castables for placement in furnaces and kilns by manual or mechanical means. The more widely used and better known of the refractory products are the fabricated products such as bricks, cubes, cones, rods, cylinders, pyramids, and many other geometrical forms and sizes used in heat resisting and structural applications.

The shaped refractory products are generally identified as neutral refractories (which are composed of alumina, silicon carbide, carbon, and other neutral ingredients), acid refractories (which are composed principally of silica and which react with lime, alkalies, and other basic materials at elevated temperatures), and basic refractories (which are composed of magnesite, dolomite, chrome ore, and forsterite which react with silica and other acidic materials at elevated temperatures).

Refractory materials are used to line furnaces and kilns. They also are used in the production of crucibles, saggers, and other containers. These products are employed in the production of iron and steel, a number of nonferrous metals, and in the melting of glass and porcelain enamel and glaze frits. They also are used in the production of portland cement and in the firing of pottery, spark plugs, glazes, porcelain enamels, and hundreds of other products as well as in the production of power and steam and in the refining of petroleum.

Special refractories are used in rocket motors, insulating tile, nose cones, and numerous other parts of space vehicles and missiles to resist the high temperatures and erosion conditions during the blast-off and the tremendous heat generated by friction with the atmosphere during re-entry. Refractories also provide resistance to solar and space radiations as well as insulation from heat and cold in order to keep the interior of space vehicles comfortable and safe for the astronauts and for their life-sustaining and other facilities. Even the launching pads for the space vehicles are of refractory compositions to insure thermal and physical stability during the blast-off.

A group of refractory products which might deserve a classification all its own is the group known as abrasives, one of the least publicized of the ceramic products. Although there are many natural abrasives such as the diamond, emery, and sand, the commercially produced synthetic materials are industrially the more important; these include alumina, silicon carbide, boron carbide, boron nitride, tungsten carbide, etc.

The abrasives are used in a wide variety of products from the abrasive cloths, papers, and stones which are used manually, to the abrasive disks and wheels for grinding and polishing machines. These are used in hundreds of applications from fingernail files, wood sanders, and tool sharpeners to the machines used for the grinding of shafts and bearings, the grinding and polishing of glass, and the grinding and polishing of other hard ceramics, many to dimensional tolerances that can be obtained in no other way. A significant development in recent years is the ceramic cutting tool which permits the faster, cooler, and more efficient machining of metals.

Not all abrasives are used in the form of a fabricated tool or wheel. Many are used in compressed-air streams or in liquid suspensions for high-speed cutting and polishing. Others are used as jewels and bearings in watches and a host of scientific instruments.

Cement and Concrete

Portland cement, concrete, mortar, plaster, and other pozzolanic products are ubiquitous. They are, perhaps, the most visible and well-known of all ceramic products. They are used extensively in the building of dams, canals, aqueducts, highways, bridges, airport runways, sidewalks, and other pavements. They are used in all types of building construction—foundations, walls, floors, and roofs of houses, schools, churches, office buildings, factories, hotels, hospitals, condominiums, apartments, and virtually every other type of permanent structure. In the artistic or aesthetic world they are used in the production of statuary, finials, copings, gargoyles, and bird baths. Concrete products are found in every country of the world.

Portland cement is a hydraulic cement made by calcining lime-bearing and other clay minerals to incipient fusion and then grinding the resultant clinker to a fine powder. Pozzolanic cements are made of slags and siliceous and aluminous products which react with slaked lime in the presence of water at room temperature. Concrete is a blended mixture of portland cement with aggregates such as sand and gravel with sufficient water to produce a workable mass that will set to rock-like hardness. Mortars are mixtures of portland or other pozzolanic cements with lime or gypsum plaster and water, usually of a trowelable consistency, used to bond brick, stone, concrete block, and other materials together in masonry construction. Plaster, an easily trowelable mixture of lime, sand, and water which will harden on drying, is used to coat walls, ceilings, and partitions. Plasterboard, a flat, sheet-like manufactured product of hardened gypsum plaster core encased in a paper, felt, or pulpboard envelope, is often used as a backing or substitute for plaster. All of these products are used as fireproofing or fire-resisting, waterproofing, and soundproofing materials of construction.

In addition to the conventional cements which are placed and shaped at the site of use, a number of other cements are of industrial importance. There are the reinforced concrete products which contain bars, rods, meshed wire, or metal or other fibers as the reinforcing medium. These are designed to carry tensile stresses such as are encountered in beams, columns, poles, chimneys, bridges, stairways, and other engineering structures. Under severe conditions, the reinforcing steel bars or rods may be placed under tension while the concrete is hardening to produce a product known as prestressed concrete, an even stronger product which enables the construction of longer bridge spans as well as shallow, light-weight, and more graceful concrete structures.

Precast concrete, which is formed in a factory and hauled to the site of construction, is used in the production of beams, culverts, columns, bridge sections, and pipe, the latter being employed for the movement of water and sewage. Panels of unusual and attractive appearance are made by the incorporation of aggregates of various colors and textures in the concrete slurry before pouring or casting.

Building blocks of a variety of shapes and sizes, some solid and some with hollow cores, are commonplace.

Lightweight concrete, a concrete made with lightweight aggregates such as perlite, vermiculite, or expanded products such as foamed clay, slate, shale, clinker, or slag, is used in the production of light-weight, unreinforced concrete of high insulating properties.

Packaged concrete mixtures are used in the repair of damaged or deteriorated concrete. In some instances in which the deteriorated areas are relatively large and deep, the voids are filled with aggregate and a portland cement grout is pumped over and around the aggregate. This procedure has proved useful in making underwater repairs. Aluminous cements made of lime and bauxite are rapid setting and frequently are used in making road repairs and for the insulation of furnaces. However, the aluminous cements usually will not set under water.

Terrazzo, a concrete containing colored aggregate, is widely used as a decorative and practical flooring in office buildings, hospitals, and other public buildings. After the concrete has set, it is ground smooth and highly polished on the job.

Glass

Glass, an ancient discovery, also is a modern miracle. It is all about us, serving us in many ways. Because of its tremendous versatility, glass also is a paradox.

Glass, for example, may be hard or soft, flexible or brittle, weak or strong—stronger even than steel. Some glasses are water soluble, and others are chemically inert—resistant even to boiling aqua regia. Some glasses are transparent, some are translucent, and others are completely opaque. They may be made to absorb, disperse, or reflect light, and they may be tinted or made in every color of the rainbow. The most obvious of the glass products are tableware, bottles, jars, mirrors, and the windows in our homes, automobiles, office buildings, factories, and hotels. These are known as soda-lime glasses and are made of sand, sodium carbonate, limestone or lime, and sodium sulfate, and comprise approximately ninety percent of the total glass production in the United States.

Borosilicate glasses are composed of blends of conventional glass-making materials plus a minimum of five percent of boric oxide. They are resistant to both heat and chemicals, properties which make them particularly useful in the production of domestic and commercial kitchenware, cookware, mixing bowls, laboratory beakers and flasks, and vessels in which chemicals are manufactured.

Lead-alkali glasses, which contain substantial amounts of lead oxide, are widely employed in artware, thermometer and barometer tubes, shielding windows for nuclear hot cells, and in applications where high electrical resistance is required.

Aluminum silicate glass, a glass in which aluminum oxide has been incorporated, is employed in instances where high thermal-shock resistance is required. Opal glasses, which are made translucent or opaque by the addition of fluorine compounds, are employed in the production of goblets, bowls, and artware, and are widely used in light fixtures and lamp bases.

Optical glass, a glass of high transparency and free of imperfections, is used in eyeglasses, microscopes, telescopes, and a wide variety of scientific and technical instruments. Light-sensitive glasses, which darken when exposed to bright light, also are used in the production of ophthalmic lens and sunglasses. Photosensitive glasses are employed in the production of permanent patterns in glass such as designs and photographs.

Fibrous glass products which have come into prominence are molded furniture, drapery materials, golf-club shafts, fishing rods, boat hulls, thermal and acoustic insulating materials, and an impressive number of consumer and industrial products. Fine filaments of special glasses have recently been developed to replace metals in telephone and other communication systems which have resulted in improved and more efficient services.

Cellular, or foamed, glass is being used widely as thermal and acoustic insulation in both domestic and industrial products.

Coated glass products, glass on which a coating or thin film of another material such as a metal has been applied, are employed as mirrors, resistors for electrical and electronic circuitry, space heaters, self-defogging windows, and heat-reflecting windows.

Glass ceramics, glass which has been converted from a glassy to a crystalline state, are used as missile nose cones, counter tops, cookware, and other products in which low thermal expansion and high resistance to thermal shock are required. Special compositions may be made magnetic and of high capacitance for use in dielectric components. The magnetic glasses are used as insulators and in some small direct current motors, computer memory cores, television yokes, telecommunication systems, and antennae.

Fused or vitreous silica, sometimes known as silica glass, is composed almost entirely of silica and is made in transparent and translucent forms. These are used in telescope mirrors, envelopes for mercury vapor lamps, and covers for solar cells. Glasses containing ninety percent silica and four percent other materials are employed as view ports in space craft and numerous industrial applications.

Mammoth mirrors for use in tapping the energy of the sun to heat furnaces to temperatures of 2760°C (5000°F) and above are in the process of development. Glass and ceramic-coated pistons may be used to improve the performance of automobile and other internal-combustion engines. Glass-coated materials have been shown to improve the resistance of agricultural, industrial, and other equipment to weathering, corrosion, and wear. Glass-fiber and ceramic-fiber timbers have been developed as lightweight construction materials for use in fire-proof, rot-proof, vermin-proof, storm-proof, and earthquake-proof structures. Ceramic–metal batteries also have been developed which eventually may be improved to the point where they will supply power for space equipment and under-the-ocean cities.

Ceramic–Metal Systems

Porcelain enameling, the application of relatively low-melting glasses and ceramic coatings to iron, steel, and other metals began before the birth of Christ; specimens may be seen in museums throughout the world. The early enamels first were applied to gold, then to silver and bronze, and finally to copper in the manufacture of small items such as jewelry and items of an artistic nature. In the nineteenth century, techniques for the enameling of cast iron were developed and a huge modern industry was born. Today, cast iron, sheet iron, steel, aluminum, copper, and other metals and alloys are coated with a wide variety of enamels and ceramic coatings in the production of hundreds of important household, industrial, and military products.

Available in all colors, porcelain enamels are used on kitchen ranges, refrigerators, laundry equipment, dishwashers, bath tubs, wash basins, kitchen sinks, hot-water heaters, and other household appliances. They are used in the manufacture of farm silos and other structures for the storage of animal and human foods. Since they are easily cleaned and sterilized, they are used in medical and hospital equipment. Enameled iron and aluminum both are used in commercial and residential construction, particularly as curtain walls and murals, because of their resistance to weathering and corrosion. They are used in the manufacture of automobile mufflers, signs, chalkboards, smokestacks, and to line milk tanks, beer tanks, and vessels used in the production of food and chemical products. Glass-coated copper wire increases the permissible operating temperatures of electric motors and similar equipment. Glass-to-metal seals are essential in the electrical and electronic industries, as are the refractory coatings in the aircraft, space, and nuclear industries. The development of new materials and techniques—vapor deposition, the fluidized bed, electrostatic deposition, chemical deposition, electrochemical deposition, plasma spraying, and the like—promises a bright future for the ceramic coatings industry.

Closely related to ceramic coatings for metals are the cermets which are heat-resistant and wear-resistant composite mixtures of ceramics and metals. These are formed into a wide variety of shapes and fired to high temperatures. Cermets currently are being used in brake-shoe linings, jet-engine components, nuclear fuel elements, electrical resistors, and other oxidation-resistant products.

Piezoelectrics

Piezoelectric ceramics are electromechanical transducers which convert mechanical vibrations to electric voltage, or which will convert electric voltage to mechanical force. Examples of such materials are barium titanate, lead zirconate titanate, potassium sodium niobate, and similar polycrystalline materials. They are made in a manner similar to that employed in the manufacture of ceramic insulators and are subjected to high direct-current voltage to develop permanent polarization.

The piezoelectric materials are used in crystal microphones, crystal loudspeakers, and cartridges for phonographic pickups. They are employed in television circuitry, mobile radio equipment, sonar transmitters and receivers, and ultrasonic cleaning equipment. They also are used in gauges to measure the blast pressures in firearms and explosives.

Electronics

Electronics is a branch of physics which deals with the emission, behavior, and effects of electrons, and the application of devices that utilize the flow of electrons as in a semiconductor, a transistor, a vacuum, or a gas contained in an appropriate tube. Although some understanding of the science was developed many generations ago, it has been only in recent years that electronic devices have exploded across the scientific, technical, and industrial world.

Among the more prominent or better known of the electronic ceramic materials are the semiconductors such as silicon, gallium arsenide, lead telluride, copper oxide, magnesium iodide, mercury indium telluride, zinc sulfide, and cadmium selenide; these are materials which exhibit electrical resistivities between those of a metal and those of an insulator. Ferroelectric materials are crystalline substances, such as barium titanate, potassium dihydrogen phosphate, and Rochelle salt, which exhibit spontaneous electric polarization, piezoelectricity, and electric hysteresis, and are used in dielectric amplifiers, acoustic transducers, and ceramic capacitors. The transducers are devices which are activated by power from one system and, in turn, supply power in another form to another system such as microphones, telephone receivers, loud speakers, automobile horns, door bells, barometers, phonographic pickups, and photoelectric cells. Thermisters are electrical resistors whose resistances vary sharply with changes in temperature. Varistors are two-electrode semiconductor devices whose resistance properties are dependent on applied voltage. Sensors are devices which will respond to a physical stimulus such as light, heat, pressure, or sound, and will transmit or convert the stimulus to a useful purpose such as the operation of a control mechanism, a television camera, or an information gathering system. Transistors are three-terminal semiconductor devices, typically containing two rectifying and one nonrectifying (ohmic) junctions, which are used as amplifiers, detectors, or switches.

Electronic devices are employed in a huge variety of domestic, business, commercial, industrial, military, space, medical, and scientific products. In communications, they are used in all facets of the telephone, radio, television, sound recording and reproduction systems, and similar products. High-speed computers, dictating machines, typewriters, duplicating equipment, and the like are commonplace in modern business, commercial, and industrial offices, nearly all containing electronic components. Domestic products employing these devices are the microwave ovens, refrigerators, laundry equipment, dishwashers, burglar alarms, light switches, air conditioners, and clocks. Industrial uses include controls for materials handling equipment, chemical processes, safety devices, and instruments which contribute to factory automation, including process and quality control. Electronic military equipment includes radar, navigational devices, sonar, supersnoopers, rocket instrumentation systems, gunfire control systems, guided missile systems, and many other such devices. The medical profession is heavily dependent on the electronic industry for such instruments and devices as X-ray machines, electrocardiographs, electroencephalographs, electromyographs, and other diagnostic devices, as well as X-ray diathermy, pacemakers, defibrillators, electroshockers, ultrasonic machines, hearing aids, and closed-circuit television.

Nuclear Energy

Nuclear energy is energy or power developed by one of two processes: (1) Nuclear fission, which is the splitting of an atomic nucleous into fragments, usually two fragments of comparable mass; and (2) nuclear fusion, which is the fusion or combining of two light nuclei to form a more massive nucleous (and possibly other reaction products) with a simultaneous release of energy. At the present time, the nuclear fusion process, which is in an advanced stage of development, offers a safe and inexhaustible source of tremendous power for the needs of mankind once it becomes available.

The ceramic materials used in the production of fuels for the fission process are the oxides and carbides of uranium, plutonium, and thorium. Graphite, beryllium, deuterium, and hydrogen are employed as moderators which slow down, control, or moderate the neutrons from the high velocities at which they were created during the fission process.

High-strength concrete, occasionally containing iron or lead particles of various sizes and shapes as a supplementary aggregate, is widely used in shielding structures around nuclear reactors and other sources of radiation to contain or reduce radiation to a safe level. Special high-lead-bearing glasses which maintain their optical transparencies when exposed to high levels of radiation are used as "hot cell" windows. Whitewares, refractories, structural clay products, electrical and electronic materials and instruments, porcelain enamel and ceramic coated metals, and other ceramic or ceramic-containing products are prominent in all nuclear installations.

Nuclear energy is most widely known as a source of electric power and for its use in military weaponry. From a humanitarian point of view, however, many peace-time uses have emerged as a result of research and development efforts by nuclear scientists and engineers. Nuclear energy has proved to be a safe and efficient source of power in propulsion systems for warships, submarines, and space vehicles. It is being used effectively in mineral explorations and mining. In public works projects, it is being used to create underground storage caverns for the storage of petroleum, for the disposal of wastes, and for the extraction of geothermal power.

Radiation research has provided the medical profession with a host of invaluable diagnostic and therapeutic tools. Radioactive tracers have been employed to detect irregularities in the blood and lymphatic systems, and to follow the progress and effects of medicines as they pass through the body. Radiation is being used for the sterilization of instruments and food. Radioactive autographs are used to detect brain and body tumors, and a radioactive breath analyzer is used to detect diabetes. Plutonium oxide is employed to power pacemakers and artificial hearts.

In the field of agriculture, radioactive treatments have resulted in plant mutations which have produced monosexual beets, fruits, and possibly other foodstuffs that do not require cross-fertilization for continued propagation. Radioactive tracers in fertilizers are being used to determine the availability and effect of trace elements in vegetables and fruits.

The industrial applications of radiation technology are many. Among these are instruments and techniques to determine the internal structures of materials, particularly materials in inaccessible locations, a particularly valuable procedure to locate areas of potential material failures. Instruments also are in use to assess the integrity of welds in pipelines, bridges, boilers, and jet engines. Gauges to measure the thickness of materials and coatings, and to assess the degree and effects of wear on materials in service are now available. The use of radiation in the curing of paints, as a catalyst in expediting chemical reactions, and in the cross polymerization of plastic materials is becoming increasingly important.

Aerospace

The exploration of outer space is a subject which has intrigued man for many centuries, beginning, perhaps, in the second century when Ptolemy of Alexandria proposed his concept of the movement of the sun and the planets about the earth. At about the same time, Samosata wrote of an imaginary flight to the moon. In later years, Copernicus, Sir Isaac Newton, and others presented their more accurate dissertations on the movement of bodies in space. Jules Verne, in 1865, wrote his interesting and amazingly accurate novel, *From the Earth to the Moon*.

The modern aerospace industry actually began in 1903 with the development of the first airplane by the Wright brothers in their Dayton, Ohio, bicycle shop. Today, the aerospace industry is the largest and the most complex industry in the United States. The industry generally is considered to be divided into three parts: Aircraft (55%), missiles (20%), and space vehicles (25%).

Ceramic raw materials, manufactured ceramic products, and products which contain ceramics are employed in virtually every segment of the aerospace industry. Concrete and refractory cements are used in the launching pads, and other refractories are used in rocket nozzles, heat shields, and other heat-resisting components. Special requirements for extreme environments not previously encountered are placing demands on ceramic research, development, and production personnel for new and improved products in virtually every segment of the industry—refractories, glass, coated metals, whitewares, structural clay products, electrical and electronic ceramics, nuclear ceramics, and so on, not to mention the fabrication and production techniques developed by the industry. These products are employed in the production of gauges, meters, and a host of instruments and devices used in airborne, space, and ground-based control systems. They are used in rocket motors and power-plant systems, auxiliary power-plant systems, land-based and airborne computers, life-support systems, guidance systems, tracking stations and communication systems, take-off and re-entry heat shields, and similar sophisticated instrumentation and equipment, to say nothing of simple hardware such as tubing, valves, knobs, actuators, and small electric motors. The list is without end.

Lasers

Lasers, which came into prominence in 1960, are devices which convert input power into very narrow, very intense beams of light in the ultraviolet, visible, and infrared regions of the spectrum by utilizing the natural oscillations of the atoms. They have contributed much, even revolutionized, scientific and technological fields such as interferometry, spectroscopy, metrology, holography, etc., and may well be the key to opening the door to nuclear fusion.

The original laser employed the ruby, a crystalline aluminum oxide ceramic containing a small amount of chromium, as the light-emitting medium. The yttrium aluminum garnet doped with neodymium is another. Glass doped with neodymium radiates in the infrared region.

Lasers are used in hundreds of scientific, engineering, commercial, industrial, military, and space applications. When focused on solid surfaces such as ceramics or metals, tremendous heat is generated which may be used to cut through the solid. The heat also may be used to weld parts together to form monolithic structures, to drill holes in ruby watch jewels, to drill holes and to cut grooves in electrical and electronic circuit boards, and to resize holes in worn wire-drawing dies.

In the field of medicine, the laser is used to repair torn or detached retinas, to remove blemishes and tatoos in skin surgery, and to excise and treat malignant tumors.

The laser-beam printer is finding wide application as a nonimpact printer for all types of documents. The laser camera is used extensively, particularly in making airborne photographs at night.

In the field of scientific instrumentation, laser anemometers are employed to measure wind velocities, laser ceilometers are used to measure the altitude of clouds, laser extensometers measure the flow of the tides, and laser-equipped transits improve the speed and accuracy of land surveys. The laser also is used in earthquake alarms, in guidance systems for missiles, bombs, projectiles, and aircraft control systems. They are vital components in computer memory cores and in communication systems such as radio, television, office equipment, and data control systems.

In Conclusion

It must be emphasized that the preceding discussions of ceramics, ceramic products, and their uses are brief. The illustrations that have been given are intended to illustrate the character and properties of some of the many and diverse products of the ceramic industry and their importance to mankind; to present a more comprehensive review is an impossible task. For example, no mention was made of many industrial ceramics such as paint and plastic pigments, paper fillers, roofing granules, molds for the casting of a variety of materials, high-temperature lubricants, valve bushings, toothpaste abrasives, pigments used to produce the white sidewalls of automobile tires, and many thousands of other uses. Tonnagewise, the ceramic industry is one of the largest, perhaps even *the* largest industry of the world.

Why, then, the need for a dictionary of ceramics? In this day of the interdisciplinary character of the various fields of science and engineering, the research and development personnel in technical areas other than ceramics are constantly seeking materials, products, and processes which the ceramic industry might supply to meet their needs. Similarly, ceramic scientists and engineers in one segment of this huge and diverse industry are constantly seeking information from the other segments which they might use. This is indicated, certainly, by the large attendance at the many conventions, meetings, symposiums, and conferences sponsored by ceramic societies, associations, colleges, and universities, as well as other technical organizations each year.

On an international scale, a ceramic dictionary will promote the standardization of terms and enhance the communication and understanding of the ceramic terms employed in the scientific and engineering communities throughout the world, particularly since the terms and definitions employed in one country frequently are quite different from those employed in another country for the same subject. These suggestions were first offered by Dr. Nicolae Ciontea, Director of the National Research Institute for Glass and Fine Ceramics of Romania, and have since been repeated by Ministers of Commerce and Industry, corporate executives, directors of national and corporate laboratories, and scientists and engineers in numerous countries of the world in which the author has served as a technical and science advisor.

Finally, a comprehensive dictionary should be a valuable asset in the libraries of colleges and universities, in the libraries of corporate and other laboratories, and even in the technical sections of public libraries to assist students and personnel pursuing scientific and technical careers.

It must be mentioned that this *Dictionary of Ceramic Science and Engineering* is a dictionary—a reference book listing the words, terms, materials, processes, products, and some of the more prominent business terms that are important to the ceramic and related industries. As a dictionary, it is not to be likened to an encyclopedia or to a textbook to be read from cover to cover, although such a reading certainly should be educational. As a dictionary, or reference book, it is intended to present only sufficient information on a particular subject to establish the interest of the reader as to the appropriateness of a more detailed search of the literature—technical journals, encyclopedias, textbooks, the informational literature of manufacturers and suppliers—for the information needed.

The entries for this dictionary were compiled from several hundred sources such as textbooks, glossaries, technical journals, trade journals, and other technical dictionaries. No word has been included which has not been gleaned from other sources.

The intent of the author has been to provide only definitions. No effort was made to include pronunciations, derivations, or syllabication of the entires.

It is the sincere hope of the author that this *Dictionary of Ceramic Science and Engineering* will be a valuable and useful contribution to the technical literature, and will promote a better understanding of ceramic terms, not only by those who are active in the ceramic industry, but by scientists, engineers, and production personnel in other technologies and industries as well.

Loran S. O'Bannon

Contents

A

abamurus. A buttress-like unit or a second wall, usually of concrete, concrete block, or other masonry, supporting or reinforcing a structure.

Abbe value. A number designating the deviation of light waves by an optical glass, expressed as the reciprocal dispersive power of the glass by the equation:

$$v = (n_D - 1)\ (n_F - n_c)$$

in which v is the Abbe value, n_D is the index of refraction of the sodium line at 589.3*n*, and n_F and n_c are the indices of the hydrogen lines at 486.1*n* and 656.3*n*, respectively. Also known as Abbe number, *nu* value, and constringence.

ablation. The process of wearing or wasting away of the surface of an object by erosion, melting, evaporation, or vaporization.

ablative material. A body or a coating of low-thermal conductivity, such as a ceramic or a glass-reinforced plastic, from which the surface layer is removed by a pyrolytic process, thereby resulting in the absorption or dissipation of heat from a substrate.

abopon. A viscous, liquid sodium borophosphate complex used in porcelain enamels and glazes as a suspension agent and binder.

Abrams' law. The strength of a concrete or mortar, with given concrete materials and conditions of tests, is governed by the quantity of mixing water employed so long as the mix is of workable plasticity; it may be calculated by the equation:

$$S = A/B^r$$

in which S is the strength, and A and B are constants, r being the water to cement ratio of the compacted cement.

abrasion. The wearing, grinding, or rubbing away of the surface of a solid by friction induced by moving solids, liquids, or gases.

abrasion hardness. The relative hardness of a solid substance in terms of its capacity to scratch, abrade, or indent another solid material or itself be scratched, abraded, or indented. See also Brinell test, Knoop hardness, Mohs hardness, Rockwell hardness, scleroscope.

abrasion resistance. A measure of the ability of a material to resist wear by friction. samples may be evaluated on the basis of loss in weight, loss of gloss, or by the degree or permanence of discoloration when a lead pencil, dye, or fine powder of contrasting color is drawn or rubbed across the abraded area.

abrasion tester. A laboratory device, usually provided with a scouring, cascading, or jet-propelled abrasive acting on the surface of a solid, employed in the evaluation of the abrasion-resistant properties of the surface. See Taber abrasion tester, Kessler abrasion tester.

abrasion-wear index. The ratio of the degree of wear on the surface of a solid material as a function of the conditions or the results of abrasion.

abrasive. Any substance which, by virtue of its hardness or other property, is used for grinding, cutting, or polishing, such as diamond, silicon carbide, alumina, sand, ceria, rouge, etc.

abrasive annealing. The heating and cooling of a solid material on a prescribed schedule as a treatment to remove stress, to induce softness, to refine its crystalline, molecular, or other structure, or to alter its physical properties.

abrasive belt. A band or endless loop of cloth, paper, leather, or sheet of other flexible substance to which an abrasive product has been bonded for use in grinding and polishing operations.

abrasive blasting. The cleaning, etching, or finishing of a surface by the impingement of a blast of air or steam in which an abrasive has been entrained.

abrasive cloth. A strong, usually pliable fabric or cloth to which an abrasive has been bonded, and which is used in manual or mechanical grinding and polishing operations.

abrasive cone. A solid, cone-shaped, bonded abrasive product mounted on a spindle for use in high-speed grinding and machining operations.

abrasive disk, bonded. A disk-shaped, bonded abrasive product mounted on a face plate for use on a grinding or milling machine; work is ground or polished on the side of the abrasive disk opposite the face plate.

abrasive disk, coated. A circular, usually flexible, paper, cloth, fiber, or other sheet material coated on one side with a mixture of abrasive and binder for use in mechanical grinding and polishing operations.

abrasive-jet cleaning. The process of removing dirt and soil from a solid surface by the impingement of an abrasive-bearing stream of liquid or gas on the surface of the solid.

abrasive, levigated. A very fine abrasive powder used as a burnishing medium.

abrasive machining. The technique of forming or shaping a solid item by grinding, drilling, or some similar mechanical process.

abrasive, mild. An abrasive, such as talc, having a hardness (Mohs) of 1–2.

abrasiveness. The ability of a material to wear down or rub away the surface of a solid material by friction.

abrasive paper. A strong paper sheet to which an abrasive has been bonded for use in grinding and polishing operations, such as sandpaper or emery paper.

abrasive sand. A sharp-grained sand, usually graded to a mesh size, used as an abrasive.

abrasive tumbling. A process to improve the surface finish or to deburr solid materials by tumbling in a rotating cylinder containing abrasive particles.

abrasive wheel. A grinding wheel or disk composed of an abrasive grit and an appropriate bonding material used for the grinding, polishing, shaping, or cutting of a solid surface.

absolute density. The weight of a unit volume of a substance under specified conditions of pressure and temperature, excluding its pore volume and interparticle voids.

absolute gravity. The specific gravity or density of a fluid under standard conditions of pressure and temperature.

absolute humidity. The weight of the water vapor contained in a unit volume of air.

absolute temperature. Temperature measured from absolute zero on an accepted scale of temperature measurement, such as the Celsius (Kelvin) or the Fahrenheit (Rankine) scale.

absolute zero. Temperature characterized by the complete absence of heat, or at which all particles whose motions constitute heat cease to move; believed to be equivalent to −273.16°C or −459.69°F.

absorbency. The ability of a material to penetrate into or to be penetrated by another material.

absorption. The process in which fluid molecules are taken up by, and distributed through, a solid or another liquid.

absorption, dye. A test in which the depth or degree of penetration of a dye solution into a nominally nonporous body, frequently under prescribed conditions of temperature and pressure, is taken as a measure of the porosity of the body.

absorption rate. The amount of water absorbed by a brick or other body during partial or complete immersion for a specified period, usually one minute; expressed in ounces or grams per unit of time for a sample of specified size.

absorption ratio. The ratio of the weight of water absorbed by a masonry unit during immersion in cold water to the weight absorbed during immersion in boiling water for an equivalent period of time. See absorption test (2).

absorption test. (1) A test in which a ceramic body is immersed in or is subjected to a spot of dye solution, and the depth of penetration is taken as a measure of the porosity of the body.

(2) A test in which a body is immersed in a selected or specified solution for a designated time and temperature, and the ratio of the weight of solution absorbed to the weight or the volume of the dry specimen is reported as the absorbency of the body.

absorption test, accelerated. An absorption test in which the end point is hastened by testing under conditions more severe than those anticipated in actual service.

absorption, x-ray. The absorption of energy from an x-ray beam by a medium through which the beam is passing.

abutment. The portion of a structure which receives the thrust or pressure of the arch in a furnace or kiln, and which generally consists of a skewback brick and steel support.

a-c. Symbol for alternating current.

acacia gum. A water-soluble gum derived from various acacia plants which is used as a binder in porcelain-enamel and glaze slips; also known as gum arabic, gum Senegal, and gum Kordofan.

accelerated-service life. The elapsed time required to reach the end point in a service test conducted under conditions more severe than those which will be encountered during the normal use of a product.

accelerated test. Any test of a property which is conducted under conditions more severe than will be encountered during the normal life of a product or material.

accelerator. A chemical admixture introduced into a batch of concrete, stucco, mortar, plaster, or similar material as a catalyst to hasten hydration or other reaction, thereby causing the batch to develop strength more rapidly than normally would be attained; examples are the alkali carbonates, potash alum, and powdered gypsum.

acceptability. The quality of a product in terms of its ability to meet minimum standards specified for its use.

acceptance level. The maximum and minimum limits of quality standards between which a product is considered to be acceptable for its intended use.

acceptance limits. The test levels used in the sorting of specimens that establish the rating group into which a material or product under test should be assigned.

acceptance number. The maximum number of defective pieces allowable in a sample of specified size.

acceptance standard. A specimen of a material or product selected to be used as a reference standard to indicate the acceptable measure of quantity, weight, extent, value, or quality of a material or product.

acceptance test. A test to determine the conformance of a product to a purchase order or contract, or to determine the degree of uniformity of the product, as a basis for its acceptance by the purchaser.

accessory. (1) A subordinate material such as a fastener, closure, coupling, gasket, or the like which is necessary for the installation or performance of a product.

(2) A product which in itself is not essential, but which adds to the convenience or effectiveness of another product.

accessory mineral. A mineral found in a subordinate quantity in another mineral, but which is not essential and which does not affect the character or the properties of the parent mineral.

accountability. (1) The section of nuclear materials management which is responsible for the measurement, control, record, and report systems of transfers and inventories to provide current and accurate information relative to the chemical and physical form, location, availability, and source of nuclear materials.

(2) The position of being responsible, answerable, liable, or accountable for an activity.

accuracy. (1) The degree of precision existing between an experimentally determined value and an accepted reference value.

(2) Freedom from error.

A. Cer. S. The official abbreviation for The American Ceramic Society.

achromatic glass. A glass which will transmit light without dispersing it into its constituent colors.

achromatic lens. A combination of two or more lenses of different focal powers which will transmit light free of undesired colors.

acicular. Needlelike in shape.

acid. In the ceramic context, an oxide of the general empirical formula RO_2, in which R represents an element such as silicon, titanium, zirconium, tin, etc., that will react chemically as an acid at elevated temperatures.

acid annealing. A process for preparing metal shapes for porcelain enameling in which the metal is coated with acid followed by annealing to remove oils, rust, and other soil from the surface by scaling, and to relieve stresses in the metal prior to application of the enamel coating.

acid bottom and lining. The exposed bottom and lining of a steel-making furnace composed of materials such as silica brick, sand, siliceous rock, or other refractories, which will react as an acid with the molten metal and slag at operating temperatures. See acid open-hearth furnace, acid refractories, acid slag, acid steel.

acid clay. A clay which will release hydrogen ions on contact with water.

acid embossing. The process in which the surface of glass is obscured by treatment with hydrofluoric acid or its compounds. See frosted.

acid-extractable material. Substances which may be dissolved and removed from a material by treatment with an acid, usually under specified conditions.

acid frosting. The etching of glass, particularly glass tableware, by treatment with hydrofluoric acid or its compounds.

acid gold. A decoration of gold applied to the surface of a glaze which previously was etched with hydrofluoric acid or other fluoride to improve adherence.

acidic oxide. Any oxide which will display acidic properties at elevated temperatures, such as SiO_2, TiO_2, ZrO_2, SnO_2, CeO_2, GeO_2, PrO_2, Sb_2O_3, As_2O_3, and P_2O_5.

acid open-hearth furnace. An open-hearth furnace lined with a highly siliceous refractory brick, the lining sometimes being coated with a fritted layer of silica sand.

acid polishing. The process of polishing glass surfaces by means of an acid treatment to minimize roughness.

acid refractories. Refractories containing substantial amounts of silica which may react with basic refractories, slags, or fluxes at high temperatures.

acid-refractory furnace. A furnace or cupola lined with an acid-type refractory, such as silica brick.

acid resistance. The degree to which porcelain enamels, glazes, glasses, and other ceramic surfaces are resistant to attack by acids.

acid-resisting brick. A fired, clay brick of low-water absorption and high resistance to attack by acids; usually used with acid-resisting mortars.

acid-resisting enamel. A porcelain enamel exhibiting high resistance to attack by acids, particularly household, fruit, and cooking acids.

acid scaling. The process of dipping or spraying raw metal with acid followed by annealing at a red heat as a means of removing oils, rust, and other soils prior to the application of a porcelain enamel to the metal.

acid slag. Slag in which the silica content is greater than the content of basic ingredients, such as lime and magnesia.

acid spar. A fluorspar containing 98% or more of calcium fluoride and 1% or less of silica.

acid steel. A grade of steel produced in furnaces lined with silicate refractories.

acid, white. A mixture of hydrofluoric acid and ammonium bifluoride employed in the etching of glass surfaces.

ACL kiln. A type of traveling-grate preheater employed to preheat a portland-cement batch before it is charged into the rotary cement kiln as a means of minimizing the length of the kiln required for the calcining operation.

acoustic insulation. Specially textured plaster, tile, or other product employed to diminish the intensity of sound; for example, a perforated tile.

acoustic plaster. A plaster having a chemically or mechanically textured or roughened surface which will absorb or prevent the transfer of sound.

acoustic tile. A thin, decorative tile of plaster, ceramic, fiber, or other material having sound-absorbing properties, which is used as a covering for walls, ceilings, and other surfaces.

acrylic polymer. A thermosetting resin used as a binder in laminated products; made by polymerization of acrylic acids, acrylates, etc.

actinic glass. A glass that transmits more of the visible components of light and less of the infrared and ultraviolet components.

activated alumina. A granular, highly porous form of aluminum oxide, Al_2O_3, exhibiting high-absorptive and catalytic properties. See alumina, activated.

activated carbon. A family of highly porous carbonaceous substances of high surface area per unit of volume manufactured in powdered, granular, or pelletized form by processes that develop high-absorptive properties. Also known as activated charcoal.

activated carbon, granular. Activated carbon in particle sizes predominately larger than 80 mesh. See activated carbon.

activated carbon, powdered. Activated carbon in particle sizes predominately smaller than 80 mesh. See activated carbon.

activated clay. A clay, such as bentonite, which is treated with acid to improve its bleaching and adsorptive properties.

activation. Any process, such as chemical treatment, heat, or radiation, which is employed to improve the reactivity or absorptive properties of a material.

activation analysis. A sensitive technique for the identification of trace elements based on the induced radiation characteristics of a specimen exposed to neutrons in a nuclear reactor.

activity. A general term describing the ability or capacity of a material to absorb or to react in a desired manner.

adapter. (1) A type of flange used to mount a grinding wheel on a shaft of smaller diameter than the center hole in the wheel.

(2) A device or attachment designed to connect or attach two dissimilar parts in an apparatus.

addition. A material added in relatively small quantities to a ceramic coating, body, or other composition to influence the manufacturing, working, or performance properties of the composition.

additive. A substance added in relatively small quantities to bring about a change in or to enhance the properties of another.

adherence. (1) In general ceramic usage, the bond or union developed at the interface between two substances by fusion or by chemical or physical reaction during fusion.

(2) The degree to which a porcelain enamel, glaze, or other ceramic coating adheres to its substrate.

(3) A measure of the stress necessary to cause one material to separate from another at their interface.

adherence failure. The separation of a porcelain enamel from its base metal, usually exposing bright metal in the fractured area; the traditional measure of the degree of failure is the ratio of bright metal to adherent enamel fragments remaining in an indented area which was deformed by a plunger in a specified manner to a specified size.