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THE INDUSTRIAL MINERALS

Peter A. Ciullo
R.T. Vanderbilt Company, Inc.
Norwalk, CT

This guide to the industrial minerals is designed as a convenient reference for those who use these materials in the design, formulation or manufacture of finished goods. Each monograph includes the mineral's basic properties, the general types or grades of the mineral available, and the products in which it is commonly used. The industrial minerals today also include a number of synthetic materials; these are described in the appropriate sections when they are analogues or derivatives of a natural mineral.

The Industrial Minerals

ASBESTOS

Chrysotile $Mg_3Si_2O_5(OH)_4$
Refractive Index: 1.53-1.56
Specific Gravity: 2.5-2.6
Mohs Hardness: 2.5-4

Asbestos is a generic term applied to six minerals that occur in nature as strong, flexible, heat-resistant fibers. Nearly all (>98%) commercial asbestos is the mineral chrysotile. Chrysotile is differentiated from the other five asbestos minerals by its tubular serpentine rather than ribbon-like amphibole structure, its generally greater fiber flexibility and strength, its lower heat resistance, its greater surface area and positive surface charge, its lower refractive index, and its greater susceptibility to decomposition by strong acids. Of the ampibole asbestos minerals, only two – amosite, a magnesium iron silicate, and crocidolite, a sodium iron silicate – are produced in commercial quantities. The other three – anthophyllite asbestos, tremolite asbestos, and actinolite asbestos – are rare asbestiform varieties of the nonasbestiform prismatic minerals anthophyllite, tremolite, and actinolite. It is the rarity of these three asbestiform varieties that has precluded the assignment of distinct mineral names and unduly caused the prismatic analogues to become identified with asbestos. The nonasbestos forms of chrysotile, amosite, and crocidolite are sufficiently common to have earned separate mineral identities as antigorite, cummingtonite-grunnerite, and riebeckite, respectively. Asbestos ore is typically processsed in highly automated operations designed to minimize worker exposure to mineral dust. The ore is crushed, dried, screened, milled, and air separated to produce a variety of grades.

TYPES

The two major world producers, the former Soviet Union and Canada, designate several major grades of asbestos, with further subdivisions within each grade. Grades are based on fiber length, strength, color, and purity, plus intended application. The following grades are based on Canadian standards.

Spinning fiber – The cleanest and longest fibers, to >12mm, are reserved for producing woven asbestos textiles.

Asbestos cement fiber – This is the longest fiber grade that is <12mm.

Paper/shingle fiber – This is essentially <5 mm (-4 mesh) fiber, with shingle fiber being generally shorter than paper fiber.

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Shorts/floats – These are the shortest fibers, with most shorts or all floats <2mm (-10 mesh).

Crudes – This is crushed ore containing staple fibers >10mm. Crudes are sold to customers who process them into fibers for their own purposes.

USES

Approximately 3.5 million metric tons of asbestos are produced annually. Major producers are the former Soviet Union (60%) and Canada (17%). Production and use in the United States is very minor due to health and liability concerns, although California hosts a short fiber chrysotile deposit considered to be the largest single mineral ore body in the world. Major asbestos applications worldwide are asbestos cement, friction products, roofing, insulation, flooring, plastics, and gaskets.

Asbestos cement – In asbestos cement pipe asbestos provides good drainage and high green strength during manufacture, plus high pipe tensile strength, impact strength, heat resistance, and alkali resistance. In asbestos cement sheets it provides high flexural stregth as well.

Friction products – Paper and shingle fibers are used in molded clutch plates and disk brake pads, while short and float fibers are used in brake linings. Clutch plates are also made from open-weave asbestos cloth impregnated with resin. In all cases, asbestos is used for its durability, heat and moisture resistance, low thermal conductivity, and high strength.

Roofing – Short, float, and shingle fiber are used in asphalt shingles and roofing felts and in asphalt-based roof coatings to provide dimensional stability and flexibility, to enhance crack resistance and weatherability, and to control rheology (coatings).

Insulating products – Textiles for heat-resistant protective clothing are woven from spinning fiber, but most asbestos insulation products are in the form of paper, paperboard, millboard, and mat from paper-grade fiber. Asbestos provides flexibility, dimensional stability, tear resistance, heat resistance, chemical resistance, moisture resistance, low thermal conductivity, and high electrical resistivity. Products include pipe wrap, thermal insulation in appliances, and electrical and heat insulation in electronics.

Flooring – Short fiber is used in vinyl tile to provide flexibility, resilience, durability, fire resistance, and dimensional stability. Short fiber is also coated with rubber latex and formed into paper used as backing for vinyl sheet flooring.

Plastics – Abrasion-free asbestos is used to thicken and reinforce thermosets, providing heat, tear, and electrical resistance, low heat deformation, high strength, and stiffness. Short and float fibers are used as fillers; mat, felt, paper and cloth are impregnated with resin to form laminates.

Gaskets – Abrasion-free asbestos cement- and paper-grade fibers are used in rubber-based gaskets and packing to provide resilience, plus resistance to heat, tear, and chemical attack. Densified latex-asbestos paper is also used to make gaskets.

Other uses – Short and float fibers are used in textured paints, drywall joint cements, caulking compounds, automotive undercoatings, and asphalt paving mixes for high traffic areas.

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BARITE

Barite $BaSO_4$
Refractive Index: 1.64-1.65
Specific Gravity: 4.5
Mohs Hardness: 3-3.5

The commercial significance of barite is related almost entirely to its high specific gravity. Most processed barite (90%) is used as a weighting agent in well drillling fluids. Its physical and chemical properties assume more importance for its filler applications and for its use as a source of barium. Common mineral impurities in barite ores are quartz, carbonate minerals, sulfide minerals, and clay. Processing of barite depends upon ore purity and the nature of associated minerals. Drilling grades often require only crushing, grinding, screening, and milling. An intermediate washing step may be employed to achieve required minimal specific gravity and $BaSO_4$ content. Applications requiring high brightness and high chemical or mineralogical purity may necessitate flotation, bleaching with sulfuric acid, and wet grinding. Barite is also known as barytes and heavy spar. It is used as a source of bariuim in a number of barium compounds, including blanc fixe, a high-purity precipitated barium sulfate that is used in place of processed barite in certain demanding applications.

TYPES

Other than drilling fluid products, which account for most of production, barite is differentiated according to its chemical and filler uses.

Drilling grade – Barite for well drilling fluids is typically a 200 mesh product with specific gravity of at least 4.2 (i.e., >90% $BaSO_4$). Color is not critical, but water-soluble alkaline earth metals are controlled so as not to interfere with drilling fluid rheology.

Glass grade – Glass-grade barite is generally -30+140 mesh, with 96 to 98% $BaSO_4$, <2.5% SiO_2, and <0.15% Fe_2O_3. Iron and slica content may be further restricted for specific uses, and there may be limits on TiO_2 and Al_2O_3.

Chemical grade – Barite for barium chemicals is -16mm+0.84mm (20 mesh) and contains at least 95% $BaSO_4$, <1% $SrSO_4$, <1% combined iron oxides, and no more than a trace of fluorine.

Filler grade – Filler uses for barite generally require high brightness, high purity, and fine particle size, usually -325 mesh or finer. Purity is typically

>95% $BaSO_4$ and <0.1% Fe_2O_3, with no more than 0.5% moisture. The highest quality filler grades are made by flotation, followed by wet grinding, bleaching with sulfuric acid, washing, drying, and milling.

Blanc fixe – Blanc fixe is precipitated barium sulfate for uses where higher brightness and purity and finer particle sizes are required than are generally available with barite. The precursor to blanc fixe is common to most barium compounds made from barite. Crushed barite is first roasted with coke in a rotary kiln at about 1200^{o}C. This reduces the barium sulfate to barium sulfide in the form called black ash. The hot black ash is quenched in water and countercurrent leached to produce a barium sulfide solution. Blanc fixe is produced by treating this solution with sodium sulfate to precipitate ultrafine barium sulfate. This is then filtered, washed, milled, and dried.

Lithopone – Lithopone production starts with the same process used for blanc fixe, except that zinc sulfate is used in place of sodium sulfate. The intimate mixture of barium sulfate and zinc sulfide that precipitates is filtered, washed, dried, calcined, water quenched, wet ground, and dried. The result is a white mixture of barium sulfate, zinc sulfide, and zinc oxide. Lithopone was one of the first fine white pigments for industry but is now rarely used.

USES

Annual production of barite worldwide is approximately 5.4 million metric tons, dominated by China (33%), India (11%), and Morocco (8%). Ground barite for well drilling fluids accounts for 90% of all production. The balance is used in the manufacture of barium chemicals and glass and in filler applications.

Well drilling fluids – Drilling fluids are designed to cool the drill bit, lubricate the drill stem, seal the walls of the well hole, remove cuttings, and confine high oil and gas pressures by the hydrostatic head of the fluid column. A high specific gravity fluid is required to maintain sufficient hydrostatic pressure to control hydrocarbon release and prevent gushers and fires. Barite is uniquely suited as the weighting agent because it is heavy, chemically inert, and nonabrasive. The deeper the hole the more barite is used, because hydrocarbon pressure rises strongly with depth below about 2100 meters. In most drilling fluids barite is the major ingredient by weight percent.

Glass – In glassmaking barite saves fuel by reducing the heat-insulating froth on the melt surface. It also acts as an oxidizer and decolorizer, making the glass more workable. It reduces seeds and annealing time and improves glass toughness, brilliance, and clarity.

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Coatings – Paints and primers represent the largest use for filler-grade barite. High-brightness micronized barite is used as an extender to provide the weight that customers equate with quality and because of its low binder demand, which allows high loadings. Blanc fixe is used where a finer particle size is needed for denser packing of the paint film, as in premium metal primers, and to provide resistance to corrosion by acids and alkalis. Despite their high brightness barite and blanc fixe have poor hiding and tinting strength because they are close to the refractive index of binders. They function instead as extenders and spacers, keeping the pigment particles separated and uniformly disseminated to optimize light scattering.

Polymers – Finely ground barite is used in rubber, where its weight, inertness, isometric particle shape, and low binder demand are advantageous. It has little effect on cure, hardness, stiffness, or aging. It is used in acid-resistant compounds, in white sidewalls for tires, and in floor mats. Blanc fixe fine enough to be semireinforcing is used to provide the same compound softness and resilience as barite but better tensile strength and tear resistance. Barite is used in PVC and polyurethane foam backings for carpeting and sheet flooring because of its ability to form dense coatings due to its high specific gravity and its ability to be used at high loadings.

Other uses – Because barium sulfate is insoluble and opaque to X-rays, blanc fixe meeeting pharmacopeia specifications is used as an indicator in medical X-ray photography. Natural barite is used in concrete for the construction of facilities handling nuclear materials because it absorbs gamma radiation. Micronized white barite and blanc fixe are used as fillers and extenders, primarily to add weight, in bristolboard, playing cards, and heavy printing papers. Blanc fixe is used in the base coat of photographic papers to supply an inert substrate for the silver halide emulsion coat. Finely ground (-325 mesh) barite is used as an inert filler in brake linings and clutch plates.

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CALCIUM CARBONATE

Calcite	$CaCO_3$
Refractive Index: 1.66-1.74	
Specific Gravity: 2.71	
Mohs Hardness: 3	

Aragonite	$CaCO_3$
Refractive Index: 1.68-1.69	
Specific Gravity: 2.95	
Mohs Hardness: 3.5-4	

The mineral calcite is the major or sole constituent of most commercial calcium carbonate products. These include natural limestone, marble, and chalk, plus most precipitated calcium carbonate. Aragonite is a metastable polymorph of calcite that typically has an acicular crystal shape. Natural aragonite products are less common, but precipitated varieties are available. Many calcium carbonate deposits are the remains of the shells and skeletons of ancient sea life. The color, purity, density, and crystal morphology depend upon the influence of waves and water currents before burial, and upon temperature, pressure, and tectonic activity after burial. The most common mineral impurities are quartz and clay. The most common substitutes for calcium are other divalent cations, such as magnesium, strontium, and barium, although the amount of substitution is usually no more than a few percent. The exception is magnesium, which can substantially replace calcium to form the mineral dolomite, $CaMg(CO_3)_2$. Calcium carbonate rocks, a common constituent of the Earth's surface, range from high-calcium limestones containing >95% calcite to dolostones containing 90% or more dolomite.

Chalk is a fine-grained, white, friable, high-purity limestone. Marble is a dense, hard, low porosity stone composed substantially or solely of calcium carbonate. It is formed by the action of heat and pressure on buried limestone beds. Marble used for ground calcium carbonate products is chosen for color and purity. Marble for decorative and dimension stone (blocks, fascia slabs, tile) is selected for its characteristic shadings or veining, caused by minor mineral impurities, and for its ability to take a polish. Travertine is a banded, dense calcium carbonate also used as decorative and dimension stone. It is formed by rapid chemical precipitation around natural hot springs. A similar material is precipitated from cold water solutions as stalagmites and stalactites. This is known as onyx marble (true onyx is banded quartz), Mexican onyx, Algerian onyx, and oriental alabaster (true alabaster is dense gypsum).

Aragonite sand comprises extensive marine deposits off the south Florida coast. It is recovered by suction dredging and after drying and screening grades about 96% calcium carbonate. Most is used locally in cement manufacture.

TYPES

Filler uses for calcium carbonate generally require white color and a high degree of mineralogical purity, plus control of particle size and shape, surface area, and liquid absorptivity. Natural calcium carbonate fillers are generally called ground limestone or ground calcium carbonate but may also be sold as ground chalk, ground marble, or whiting. The synthetic alternatives are known as precipitated calcium carbonate, or PCC.

Ground calcium carbonate – Natural calcium carbonate ores high in chemical and mineralogical purity are wet or dry ground to a wide range of products. Dry-ground calcium carbonates, comprising nominal 200 to 325 mesh products, are among the least expensive white fillers available. They are simply ground from ore but may also be beneficiated by air separation. Wet-ground products are produced in finer particle size ranges and may be beneficiated by washing or flotation. They are informally classified by particle size as fine ground (FG; 3 to 12 micrometers median, 44 micrometers top), and ultrafine ground (UFG; 0.7 to 2 micrometers median, 10 micrometers top). There is some overlap between these classifications from one producer to another. As dry grinding technology advances, dry-ground products in fineness ranges previously associated with wet-ground grades are becoming more common. Wet processed FG and UFG products are of necessity more expensive than dry-ground products due to the cost of drying and in some cases remilling to break up agglomerates of ultrafine particles. Wet-ground fine and ultrafine products are also sold in 75% solids slurry form for high-volume paint and paper applications and in stearic acid- and stearate-treated forms for use in polymers.

Precipitated calcium carbonate – Precipitated calcium carbonate (PCC) is produced for applications requiring any combination of higher brightnesss, smaller particle size, greater surface area, lower abrasivity, and higher purity than is generally available from ground natural products. In the US PCC is most commonly made by the carbonation process. Limestone controlled for coloring oxides (e.g. of Mn and Fe) is calcined to calcium oxide and carbon dioxide. The calcium oxide (burnt lime) is then slaked with water to form calcium hydroxide (milk of lime). The carbon dioxide liberated on calcining is then reintroduced to precipitate calcium carbonate. Manipulation of process variables determines particle size and shape, surface area, and whether the product is isomorphous calcite or acicular aragonite. PCC products are also made by the lime-soda process, where milk of lime is reacted with sodium carbonate to form a calcium carbonate precipitate and a sodium hydroxide solution. This process is used by commercial alkali manufacturers to make a relatively coarse PCC as a byproduct of sodium hydroxide recovery. A third production route is to react milk of lime with ammonium chloride, forming ammonia gas and a calcium chloride solution. This solution is purified and reacted with sodium carbonate to form a calcium carbonate precipitate and a sodium chloride solution. This process is the simplest of the three, but to be economical it is usually carried out in a satellite facility adjacent to a Solvay-process soda ash plant. Although still common elsewhere, the Solvay process became obsolete in the US in 1986. PCC products are typically offered as fine (0.7 micrometer median) and ultrafine (0.07 micrometer median) grades, with and without stearate surface treatments.

USES

The major filler uses of calcium carbonate, both natural and PCC, are paper, paint, adhesives and sealants, and polymers. Filler uses account for only about 1% of the 700 to 800 million metric tons of calcium carbonate produced in the United States annually. Production is overwhelmingly dominated by commodity, low-value crushed stone, mainly for civil engineering uses and as aggregate for concrete and asphalt.

Paper – In alkaline papermaking, calcium carbonate is used as a paper filler and coating. Both uses require high brightness, high purity, small particle size, and lack of abrasion. Precipitated products generally retain a performance edge over the best ultrafine wet-ground grades. Commercial PCC products are at a disadvantage, however, in their high cost as dry products and in their difficulty in forming the high solids (usually 75%) slurries, due to their extremely small particle size, that large paper mills prefer. In Europe, where alkaline papermaking has been more common, an acceptable balance of performance and price has been met with high-quality ground chalk and marble. In the US PCC is preferentially used because the more recent and ongoing conversions to alkaline papermaking have beeen accompanied by the establishment of satellite PCC production facilities adjacent to paper mills. Byproducts of the pulping process are diverted to economically produce PCC, which is pumped to the paper mill in slurry form. About half these US satellite PCC plants produce enough slurry to also supply smaller mills where the construction of a full-scale PCC plant may not be justified. In Europe the establishment of satellite PCC plants is just now gaining popularity. Whether ground natural or precipitated, calcium carbonate is used as a paper filler and in coatings to provide opacity, high brightness, and improved printability due to its good ink receptivity.

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Coatings – Gound natural calcium carbonate is the most widely used white pigment in paints because it is available at relatively low cost and has high brightness for TiO_2 extension, high purity, low abrasivity, and resistance to weathering. The coarsest grades are used at loadings up to 50% in textured paints. Fine and ultrafine grades, including PCC, are used in a wide variety of other decorative and protective coatings. PCC products, with generaly higher brightness, provide better TiO_2 extension. PCC and ultrafine wet-ground grades contribute to rheology and stability and provide good dry hide and gloss retention. Slurries of 75% ultrafine natural calcium carbonate are sold for convenient use in the large-scale manufacture of water-based coatings. Stearate-treated natural and PCC products are used in nonaqueous coatings.

Adhesives and sealants – Calcium carbonate is the most widely used filler in adhesives and sealants. The coarsest grades of ground natural products are used at high loadings in drywall joint cements and in ready-mix adhesives for heavy wall tile. Somewhat finer and generally off-color natural products are used at high loadings in oil-based putties. Finely ground white grades are used as a general-purpose filler in most types of adhesives, sealants, and gap fillers for their balance of low binder demand and narrow particle size distribution. This allows economically high loadings without adversely affecting flow. High performance polymer-based adhesives and sealants use stearate-coated PCC and ultrafine natural products to control flow and slump on application and to provide low modulus with good tear and tensile properties in the cured state.

Polymers – Ground natural calcium carbonate is the most commonly used filler in plastics due to its low cost, low abrasion, low oil absorption, low moisture, high brightness, and easy dispersion with conventional mixing equipment. These attributes account for its widespread use in elastomers as well, where it can be used at very high loadings with little loss of compound softness, elongation, or resilience. PCC products, particularly stearate-coated grades, are used as functional fillers in rubber and plastics. In plastics they are used to improve mar and impact resistance, surface gloss, weatherability, shrinkage control, cold flow properties, low and high temperature properties, and dielectric properties, and to reduce plasticizer migration and crazing of molded parts. PCC is most widely used in rigid and flexible PVC and PVC plastisols. Fine and ultrafine natural products are also commonly used in PVC as well as in polypropylene and in polyester molding compounds. Lesser quantities are used in polyurethane foam, epoxies, and phenolic resins. In rubber stearate-coated ultrafine PCC is used for its low moisture absorption, good dispersion, and good elastomer-filler contact. This enables it to perform as a semireinforcing filler, imparting good tensile strength, tear resistance, resilience, abrasion resistance, and flex crack resistance. Dry-ground calcium carbonate is the most common filler in carpet backings. It is used to add weight and body and to extend the binder, usually latex, which secures the loop of tufted carpeting. It is also used as the filler in secondary backing and in separate underlay (the foam pad), both of which are usually urethane foam.

Other uses – Calcium carbonate meeting pharmacopeia requirements is used as a therapeutic source in anatacids and calcium supplements and as a tableting excipient. Fine particle size products are used as a fire extinguisher foam filler, as an abrasive in household cleaners, as a flux in welding rod coatings, as a diluent in agricultural pesticide dusts, and as a dusting agent to mitigate the explosion potential of coal dust generated during underground mining. Substantial quantites of crushed and ground limestone are also used in the manufacture of portland cement, lime, glass, and metallurgical fluxes, as well as in flue gas desulfurization processes and as a soil amendment.

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DIATOMITE

Diatomite SiO_2
Refractive Index: 1.40–1.43 / calcined 1.43–1.47
Specific Gravity: 2.0–2.1 / calcined 2.1–2.3
Mohs Hardness: 4.5–5 / calcined 5.5–6

Diatomite is comprised of the sedimentary remains of diatoms, a class of unicellular algae found in both fresh and sea water. It is their microscopic skeletons, composed primarily of amorphous opaline silica. These skeletons take a variety of forms – spheres, disks, wheels, needles, ladders – but all are characterized by a porous, lace-like structure. Individual skeletons, called frustules, can range from less than 1 micrometer to 1000 micrometers; more typically, they are in the 10 to 150 micrometer range. Diatomite products generally assay 86 to 94% silica, with typical impurities being clay, quartz, and feldspar. The chemistry and morphology of diatomite products provide the high porosity, high surface area, low bulk density, chemical inertness, and mild abrasivity that account for their commercial utility. Ores are processed by drying, gentle milling to preserve the skeleton structure, and air classification. Much of the diatomite sold is further procesed by calcining and size clasification to control surface area, porosity, and inertness for major filtration applications. Diatomite is also known as diatomaceous earth and (in Europe) kieselguhr. In the past it was also known as tripoli powder and tripolite.

TYPES

Diatomite products are generally differentiated by process and particle size.

Natural diatomite – This is diatomite ore which has been gently crushed and milled to retain the frustule shape and then screened and air classified to remove impurities and to segregate products into coarse fractions for filtration applications and fine fractions for filler uses.

Calcined diatomite – Also known as straight-calcined, this is diatomite which has been calcined at between 870° and 1100°C in a rotary kiln. This process burns off organic matter, converts some of the opaline silica to cristobalite, shrinks, hardens, and reduces the fine structure of individual particles, and forms agglomerates or clusters of particles through fusion. The overall effect is to decrease surface area but to increase bulk density and void volume due to the nature of agglomerate packing. Calcination generally turns the white to off-white natural diatomite pink from iron oxidation. The calcined diatomite is carefully milled, screened, and air classified to various size fractions, primarily for filtration uses.

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Flux-calcined diatomite – This is diatomite that has been calcined at about 1200°C with sodium carbonate or sodium chloride as a fluxing agent. The flux converts iron oxides to a colorless glassy phase, resulting in a white product, and produces greater agglomeration. Temperature, time, and flux content determine agglomerate size distribution, which is generally higher overall than for straight-calcined products. Flux-calcined diatomite is milled, screened, and air classified, with coarse fractions sold for filtration uses and fine fractions as white fillers. Flux-calcined products provide maximum void volume, which can exceed 90%, and consequent high absorptivity.

USES

Annual worldwide production of diatomite is approximately 1.6 million metric tons, dominated by the United States with about 37% of this total. Other major producers are France, the former Soviet republics, and Spain. Production in Romania and the former Soviet republics is almost exclusively of relatively low-value material for construction products. Uses elsewhere are dominated by filtration applications (80% in the US, 60% worldwide). The only other major use is as a filler.

Filtration – Diatomite is widely used as a filter aid for the separation of suspended solids from liquids. It is used as a precoat on the filter medium or dispersed in the liquid to be filtered; these two uses are often employed together. The precoat traps solids from the liquid and prevents them from blocking the filter medium. The dispersed aid adds to the precoat as filtration proceeds, so that the surface of the precoat does not build an occlusive layer of solids. The choice of diatomite grade for a particular filtration application depends upon the balance desired between filtrate clarity and flow rate. Natural diatomite provides the best clarity but the slowest rate. Flux-calcined products, with the highest level of agglomeration, provide less clarity but faster rates. Straight-calcined products provide intermediate results. Diatomite filtration is used in the clarification or processing of beer, wine, sugar liquors, swimming pool water, fruit juices, vegetable oils, water, pharmaceuticals, effluent wastes, and phosphoric acid.

Fillers – White, flux-calcined 325 mesh and finer diatomite is used as a functional filler, primarily in paint. The diatomite particles roughen the paint film to provide flatting and improved adhesion of subsequent coats. They also improve film toughness and durability, while their porosity helps control vapor permeability for reduction of blistering and peeling. Natural and flux-calcined products are used in certain specialty papers as a lightweight bulking agent, as a drainage aid, as an opacity builder, and as a fiber dispersion aid. In polyolefin films fine particle size flux-calcined products are used as antiblocking agents by projecting through the film surface and providing mechanical separation of film layers. Natural, straight-calcined, and flux-calcined diatomites are used as processing aids (absorbents) in high-oil, highly loaded rubber compounds and as both processing aids and semireinforcing fillers in mechanical goods.

Absorbents – Since calcined and flux-calcined diatomites can absorb 2 to 3 times their weight of liquids while remaining free flowing, they are used in pet litter and floor sweeping compounds, as pitch absorbers in paper manufacture, as pesticide carriers, as anticaking agents, and in the storage and transport of hazardous liquids such as phosphoric and sulfuric acids. Absorbent grades are controlled in particle size, dust free, and physically stable when wet.

Other uses – Diatomite is used as a nonscratching abrasive in polishes and cleansers, in concrete, mortars, grouts, plasters, and stucco for improved plastic and cured properties, in asphalt products to decrease cracking caused by rapid temperature changes, in catalyst carriers, in chromatographic supports, and as a silica source in the production of synthetic calcium and magnesium silicates.

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FELDSPAR

Orthoclase $KAlSi_3O_8$
Refractive Index: 1.52-1.54
Specific Gravity: 2.57
Mohs Hardness: 6

Microcline $KAlSi_3O_8$
Refractive Index: 1.52-1.54
Specific Gravity: 2.54-2.57
Mohs Hardness: 6

Albite $NaAlSi_3O_8$
Refractive Index: 1.53-1.54
Specific Gravity: 2.62
Mohs Hardness: 6

Anorthite $CaAl_2Si_2O_8$
Refractive Index: 1.58-1.59
Specific Gravity: 2.76
Mohs Hardness: 6

Feldspars are the most widespread mineral group, comprising approximately 60% of the Earth’s crust. Feldspar minerals are sodium, potassium, and calcium aluminosilicates. Their ores are commonly associated with quartz and mica and may also contain spodumene (a lithium aluminosilicate), kaolin, garnet, or iron minerals depending upon the type of deposit. Most commercial feldspars are produced by flotation and magnetic separation followed by milling. Air classification is used for the finest grades. Products typically contain quartz – low levels in high grade feldspars, high levels in feldspar/quartz mixtures sold for glassmaking. Feldspar ores and products generally contain mixtures of feldspar minerals rather than one mineralogically distinct feldspar type.

TYPES

Feldspars occur as solid solutions between their principal end member (Na, K, or Ca) compositions. Commercial products in most cases are employed for their chemistry (aluminum and alkali content) and are generally characterized accordingly. Certain products are more broadly described in geological terms.

Alkaline feldspar – This is feldspar with chemistry ranging between the potassium and sodium end members.

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Plagioclase feldspar – This is feldspar with chemistry ranging between the sodium and calcium end members.

Potash spar – Potash spar is principally orthoclase or microcline and contains at least 10% K_2O.

Soda spar – Soda spar is mostly albite and contains at least 7% Na_2O.

Calcium spar – This is principally anorthite.

Aplite – Aplite is a grainy granitic (containing quartz and alkali feldspar) rock containing a substantial proportion of plagioclase. It is also called lime-soda feldspar. Low-iron aplite is sold in the US for glassmaking.

Feldspathic sand – This is natural silica sand containing 10-35% feldspar, usually potash spar or soda spar. This sand is described, in decreasing feldspar content, as river sand, dune sand, and beach sand.

See also *NEPHELINE SYENITE.*

USES

Of the approximately 5 million metric tons of feldspar products produced annually, Italy is the leading supplier with about 29%, followed by the US with about 12%. Other major producers are Japan (aplite), France, Germany, Korea, and Thailand. The two major applications for feldspar worldwide are glass and ceramics, which rely more on feldspar chemistry than mineralogy. In the US, 54% is used in glass and 44% in ceramics.

Glass – Feldspar is used primarily in container glass, followed by flat glass and glass fiber. Glass-grade products are typically coarsely ground, 20-40 mesh, and contain 4-6% K_2O, 5-7% Na_2O, about 19% Al_2O_3, and less than 0.1% Fe_2O_3. Feldspar is used mainly as a source of alumina, which improves both the workability of the glass melt and the chemical and physical stability of the finished product. It also provides the alkaline oxides (Na_2O, K_2O) that provide fluxing in partial substitution for calcium oxide, which improves chemical resistance, and for more expensive soda ash. Feldspar is also a source of silica. Soda spars are favored over potash spars in most cases. Low-iron aplite is used as a lower cost alternative. In areas where inexpensive feldspathic sands are abundant, they may be used in preference to processed feldspar. Feldspar beneficiated free of all impurities except quartz is sold for glassmaking as well. Feldspar typically makes up about 5-6% by weight of a batch of container glass.

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Ceramics – Feldspars are used in sanitaryware, tiles, electrical porcelain, tableware, and glazes. Finely ground products, 120 mesh and finer, with a high K:Na ratio are generally preferred as fluxes in ceramic bodies to lower firing temperatures and allow faster firing schedules. Fine, 200 mesh, potash and soda spars are used in glazes as a source of alumina and water-insoluble alkali. Their function in glazes is similar to that in glass. Usage levels range from less than 10% in certain wall tiles to as much as 60% in some floor tiles. A glaze may contain 30-50% feldspar.

Other uses – Feldspar is used as a flux in welding electrodes, and beneficiated 325 mesh soda spar finds limited use as a filler in plastics, rubber, adhesives, and coatings. In filler applications it offers low vehicle demand, high dry brightness with low tint strength, and resistance to abrasion and chemical degradation. In coatings it also provides good film durability and high resistance to chalking and frosting.

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GYPSUM

Gypsum	$CaSO_4 \cdot 2H_2O$

Refractive Index: 1.52-1.53
Specific Gravity: 2.32
Mohs Hardness: 2

Gypsum is hydrated calcium sulfate formed by the evaporation of brines. Commercial deposits invariably contain some anhydrite ($CaSO_4$), the anhydrous form of calcium sulfate, and may also contain clay minerals, silica, limestone, dolomite, and soluble chloride and sulfate impurities. Gypsum is beneficiated solely by selective mining and screening. Products are typically white to off-white and range from 80 to 95% purity. The principal commercial use of gypsum is based upon the ability of calcium sulfate to readily take on and give up water of crystallization. The dihydrate ($CaSO_4 \cdot 2H_2O$), as mined, is converted to the hemihydrate form ($CaSO_4 \cdot {}^1/_2H_2O$) by partial calcination. When hemihydrate is then mixed with water, it hardens as it returns to the dihydrate form.

TYPES

Most of the gypsum products sold worldwide are produced as low cost ingredients for construction products. Although gypsum is commonly used as the collective term for all types of gypsum-derived products, the various forms differ in properties and use.

Gypsum – This is ground gypsum ore of at least 80% and more typically greater than 90% purity, with anhydrite as the principal impurity.

Stucco – This is the name used in the wallboard industry for the hemihydrate formed by partially calcining gypsum at 350°F. Also known as plaster of paris, this is the main product in North America because of its widespread use in wallboard and plasters.

Selenite – This is gypsum that forms in large, transparent crystals. Its commercial availability is limited.

Synthetic (byproduct) gypsum – Gypsum is produced as a byproduct of flue gas desufurization at coal-fired electric power plants, and is known as FGD gypsum. Chemical gypsum is generated as a byproduct during the production of phosphoric acid (phosphogypsum), hydrofluoric acid (fluorogypsum), and sulfate-process TiO_2 (titanogypsum). Until recently this gypsum was landfilled as waste. In most cases it is an unattractive alternative to natural sources because of impurities, crystal morphology, and/or price. It is disposed of as wet filter cake, but must incur the expense of drying to compete with natural gypsum. As environmental concerns result in restricted landfill access and increasing output of FGD gypsum, more widespread commercial use of byproduct gypsum may occur.

USES

Annual worldwide production of natural gypsum is approximately 100 million metric tons. The leading producer is the US (15%), followed by China, Iran, and Canada. Most of this production is used in the hemihydrate form, particularly in economically developed countries. In the US 75% is used in this form. Annual worldwide production of byproduct gypsum is estimated in the tens of millions of tons. FGD gypsum, at approximately 7 million tons per year, is the most likely candidate for expanded use in traditional gypsum applications. The main uses of gypsum products are in wallboard, portland cement, and soil conditioners.

Wallboard – The use of gypsum-based wallboard, once common only in the US and Canada, has spread to virtually all developed countries. The gypsum core provides a strong, fire-resistant, and inexpensive construction material. The -100 mesh stucco (hemihydrate) form is used. Japan is the largest user of synthetic gypsum products in wallboard, because it lacks natural gypsum resources. The other major source of synthetic (FGD-based) product for this market is Germany, which serves all of Europe. Most of current US wallboard production is based on natural sources.

Portland cement – Uncalcined gypsum crushed to $-1\frac{1}{2}$ $+\frac{3}{8}$ inch is used with portland cement to retard the setting time of concrete. This is the primary market in developing countries.

Soil conditioners – Gypsum rock ground to -100 mesh is used in treating alkaline, saline, and clayey soils, and as a source of sulfur. In the US its main application is in the cultivation of peanuts.

Other uses – The hemihydrate form is used in a wide variety of construction and industrial plasters. Minor amounts of purified gypsum are used in glassmaking and as a white filler (terra alba) in paint and paper. “Soluble anhydrite”, made by dehydrating gypsum into porous, highly absorbent granules, is used as a desiccant.

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HORMITE

Palygorskite (Attapulgite)	$(Mg, Al)_5Si_8O_{20}(OH)_2(OH_2)_4 \cdot 4H_2O$
Sepiolite	$Mg_8Si_{12}O_{30}(OH)_4(OH_2)_4 \cdot 8H_2O$

Refractive Index: 1.52
Specific Gravity: 2.0
Mohs Hardness: 2-2.5

The hormites are clay minerals with a chain instead of a sheet structure. The most common commercial varieties are acicular or needle-like palygorskite, also known as attapulgite in the US, and sepiolite. Like the sheet silicates (see *SMECTITE*), the central octahedral layer is situated between silica layers. The palygorskite unit cell has five octahedral sites and alternate pairs of silica tetrahedra inverted. The sepiolite unit cell has eight octahedral sites and alternate sets of four silica tetrahedra inverted. Because of the configuration of the silica layers, the central octahedral layer can grow only in one direction, giving a characteristic high surface area and acicular morphology. The inversion of silica tetrahedra also creates channels in the chain structure that are filled with water. This is both absorbed free water, also called zeolitic water, and the water of crystallization, which completes the coordination of the octehadral cations at the edges of the internal layer. If the water is removed, the resulting product has highly absorptive properties.

Commercial sepiolite typically has longer and more flexible needles than palygorskite. While the term attapulgite implies short (<2 micrometers) and low aspect ratio (<10:1) needles, long-needle palygorskite is produced, primarily in Ukraine. Sepiolite is the high-magnesia end member, with minor substitution by Al^{3+} and/or Fe^{3+} for octahedral Mg^{2+} and tetrahedral Si^{4+}. Palygorskite has higher substitution, principally aluminum for magnesium. Attapulgite has a Mg:Al ratio of approximately 1.5. The charge imbalance arising from these substitutions is compensated by exchangeable alkaline and alkaline earth cations. The most common impurities in commercial hormites are smectite, silica, and carbonate minerals.

In addition to their high absorptive capacity hormite clays offer useful thickening properties. When dispersed in water they do not swell, as smectites do. Instead, their needle-like colloidal particles deagglomerate in proportion to the amount of shear applied and form a random colloidal lattice. This loosely cohesive structure thickens the water and imparts thixotropy, pseudoplasticity, and yield value. Because of their mechanically-based dispersion and colloidal structure building, hormite clays are largely insensitive to the types and levels of acids, bases, and salts dissolved in the aqueous systems in which they are used. Since their dispersion is mechanically rather than ionically driven, as with smectites, they can be used in nonaqueous applications in much the same way as smectite-based organoclays. While smectite organoclays must be preformed before dispersion in an oil or solvent, hormites can be dispersed in hydrophilic form and then reacted *in situ* with the appropriate quaternary ammonium compound or amine.

The processing of hormite clays involves crushing, extruding, drying, milling, screening, and air classifying, as required, to produce a range of products from partially calcined, coarse absorbent granules to fine colloidal powders for thickening applications.

TYPES

In addition to the mineralogical distinction between palygorskite (attapulgite) and sepiolite, hormite clay products are generally classified by function and water content.

Gelling clay – Products for rheology control are typically dried to 12-16% free moisture and micronized. For use in well drilling fluids the American Petroleum Institute (API) sets specifications for moisture, viscosity, and yield (barrels of mud per ton of clay) that cover both smectite and hormite clays. The viscosity of the latter, however, is determined with a NaCl solution. Gelling grades may be extruded before drying to facilitate separation of the acicular particles. Drilling mud grades may have 1-2% MgO added to improve viscosity in salt water. Small tonages are water washed to remove impurities for pharmaceutical and cosmetic applications. Because the preparation of aqueous hormite dispersions is energy intensive, concentrated predispersed suspensions are sold as a convenience to major consuming industries.

RVM clay – These products for absorbent applications are dried at about 200°C to remove zeolitic water and thereby leave the internal channels of the clay open to penetration by gases and polar liquids. RVM (regular volatile matter) grades may be extruded during processing to improve absorption capacity and are produced in a wide range of sizes from coarse granules to fine powders.

LVM clay – These products (low volatile matter) are partially calcined at about 500°C to remove both zeolitic water and water of crystallization. This improves absorption capacity for oils, greases, and low-polarity organic compounds.

Fullers earth – This is a generic term that derives from an early use, the cleansing and decolorizing of woolens by fullers. It implies no specific mineralogy and in the US can encompass both hormite and smectite clays. In the United Kingdom fullers earth is smectite clay. The term is generally used to indicate high absorptive capacity and the ability to decolorize oils and fats.

USES

In the US attapulgite is available in gelling and absorbent grades from extensive reserves in Georgia and Florida, but American sepiolite is rare. The reverse is true in Europe, where extensive sepiolite deposits exist in Spain, and palygorskite is rare. Annual worldwide production of palygorskite is approximately 1.2 million metric tons, more than 80% of which comes from the United States. Annual production of sepiolite is approximately 1 million metric tons, dominated 90% by Spain. The uses for palygorskite are essentially the same as for sepiolite in countries where the latter is more readily available. Worldwide, the major application is pet waste absorbents. Other major uses are oil and grease absorbents, agricultural products, drilling fluids, coatings, and construction products.

Pet litter – Cat litter is the single largest application for hormite clays, typically RVM grades. The clay granules absorb both liquid waste and ammonia odor.

Floor absorbents – Both RVM and LVM products are sold as oil and grease absorbents for industrial and commercial workplaces (e.g. metalworking and automotive shops) and as absorbents in slaughterhouses, butcher shops, and animal barns.

Agricultural products – Gelling-grade clays are used to stabilize fertilizer suspensions, animal feed suspensions, and pesticide suspension concentrates. They are preferred to smectites in these applications because of their tolerance of and compatibility with high solute levels. Absorbent grades are used as pesticide carriers for dry applications and as binders and nutrient carriers in animal feeds.

Drilling fluids – Gelling grades meeting API specifications are produced for salt water drilling fluids since they are insensitive to electrolyte levels that will flocculate bentonite-based fluids. Because of their acicular shape, however, they are inferior to bentonite in controlling fluid loss through the bore hole walls.

Coatings and construction products – Gelling-grade clays are used as thickeners/stabilizers in paints, asphaltic coatings, adhesives, mastics, mortars, and cements. There is also limited use as a partial asbestos replacement in wallboard and certain cements, where long-needle products are preferred.

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Other uses – Hormite clays are also used as thickeners in grease, polyesters, and vinyl plastisols, odor absorbents, bleaching (decolorizing) agents for petroleum, mineral, and vegetable oils, filter aids, anticaking agents, pharmaceutical absorbents, acicular fillers in rubber (sepiolite), catalyst supports (sepiolite), and cosmetic/pharmaceutical thickeners and emulsion stabilizers.

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KAOLIN

Kaolinite	$Al_2Si_2O_5(OH)_4$

Refractive Index: 1.55-1.57 / calcined: 1.62
Specific Gravity: 2.58 / partially calcined: 2.50 / fully calcined: 2.63
Mohs Hardness: 2 / partially calcined: 4-6 / fully calcined: 6-8

Commercial grades of kaolin are composed primarily of the mineral kaolinite, a sheet silicate, and may contain greater or lesser quantities of related sheet silicates (mica, illite, chlorite, smectite) and quartz. An individual kaolinite particle has the shape of an hexagonal plate. In nature these plates occur in stacks or “books” that exhibit varying degrees of stacking regularity. Kaolin is hydrophilic (readily water dispersible); for nonaqueous applications matrix compatibility can be improved by surface treatment.

TYPES

Descriptive classifications of kaolin products are many and in certain cases specific to particular markets. The most common designations are as follows.

Primary (residual) kaolin – In reference to geologic origin, the clay occurs in the deposit where it formed.

Sedimentary (secondary) kaolin – In reference to geologic origin, the clay has been eroded and transported from its site of formation and deposited at a distant location. The world’s major kaolin belt, the 250 miles between Aiken, SC and Eufala, AL, consists of sedimentary kaolin.

Hard clay – In the rubber industry hard clay is very fine-grained, relatively poorly crystallized kaolin. It is used as a reinforcing filler in rubber, where it provides high modulus, high tensile strength, good abrasion resistance, and stiff (hard) uncured compounds.

Soft clay – In the rubber industry soft clay is coarser, better crystallized kaolin. It has low reinforcing effect in rubber, where it provides lower modulus, tensile strength, and abrasion resistance and softer uncured compounds than does hard clay.

China clay – This is a ceramics industry term synonymous with what is today called simply kaolin. China clay is substantially pure white or near-white kaolinite characterized by low plasticity, low green strength, and good fired whiteness.

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Ball clay – In the ceramics industry ball clay is a highly plastic, fine-grained sedimentary clay containing 70+% kaolinite. Ball clay is characterized by the presence of organic matter, high green strength, and light fired color.

Fire clay – In the ceramics industry fire clay is a refractory (heat resistant), high-kaolinite content clay often found in association with coal beds. Used in refractories or to raise the vitrification temperature of ceramics, the clay's fired color ranges from buff to gray.

Flint clay – A highly refractory hard rock, flint clay is composed principally of well-ordered kaolinite and is low in iron and fluxing compounds.

Airfloat clay – This is dry-ground kaolin that has been air separated to remove impurities and control the particle size distribution.

Water-washed clay – Water-washed kaolin has been slurried in water and centrifuged or hydrocycloned to remove impurities and produce specific particle size fractions. The refined slurry is either dewatered (to reduce soluble impurities) and dried, or concentrated to 70% solids and sold in slurry form. Water-washed clays are often treated to improve brightness. This includes chemical bleaching and/or high-intensity magnetic separation to remove iron and titanium impurities.

Delaminated clay – The coarse clay fraction from water washing is attrition milled to break down the kaolinite stacks into thin, wide individual plates. This improves brightness and opacity.

Calcined clay – The kaolin, usually water-washed soft clay, is calcined to either partially or totally remove surface hydroxyl groups. Calcining increases brightness, opacity, oil absorption, and hardness (i.e., abrasivity).

Surface-treated clay – This is processed kaolin that has been surface modified (e.g., with stearates or silanes) to improve compatibility with and performance in organic matrices.

USES

The United States is the leading supplier of kaolin clays, with about 40% of world production. Second largest is the United Kingdom with about 12%. US annual production capacity of 10 million metric tons is comprised of 40% water-washed, 15% airfloated, 13% calcined , and 10% delaminated clay. The major worldwide use for kaolin is in paper. In the US 40% of kaolin consumption is for coating and filling paper. Much lower but still substantial amounts are used in ceramics, refractories, paint, polymers (plastics, rubber, adhesives), and the production of fiberglass.

Paper coatings – High-brightness, low abrasion water-washed and delaminated kaolins are used in coatings for acid-sized paper to improve brilliance, gloss, smoothness, and ink receptivity.

Paper fillers – High-brightness, low-abrasion airfloated, water-washed and delaminated kaolins are used as pulp extenders in acid-sized paper, where they improve opacity, smoothness and ink receptivity. Partially calcined clay is used as a TiO_2 extender.

Ceramics – Whitewares use a combination of china clay (usually airfloat) and ball clay selected for consistent chemical composition so that firing and vitrifying characteristics of the body are controlled and color and translucency of the fired ware are satisfactory. The ratios used are chosen to optimize green strength, plasticity, and casting behavior.

Refractories – In North America certain foundry refractories contain flint clay to give a dense, strong product able to withstand much higher temperatures than ordinary clay-based refractories. In Europe calcined ball clay (chamotte) is used in place of flint clay. China clay is used in cordierite-based kiln furniture and insulating firebrick.

Coatings – The principal use of kaolin in coatings is as a TiO_2 extender. Partially calcined grades generally provide the best extension, durability, and dry hide. Water-washed and delaminated clays are used in water-based coatings to control gloss (coarser = flatter, finer = glossier), film integrity, durability, scrub resistance, covering power, suspension ability, flow, and leveling.

Plastics – The largest single use of kaolin in plastics is for calcined kaolin in PVC wire insulation to improve electrical resistivity. Calcined kaolin is also used in agricultural polyethylene films to improve infrared absorption characteristics and in engineering resins, in both silane-treated and untreated forms, for improved physical properties and heat deflection. Both airfloat and water-washed, fine-particle size kaolins are used in thermosets to provide a smooth surface finish, reduced cracking, warping and crazing, and to obscure fiber reinforcement patterns. Delaminated clays improve thermoplastic physical properties, including enhanced impact resistance when surface treated.

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Rubber – About 80% of the kaolin for rubber is airfloated hard clay. Water-washed and delaminated clays are used for further improved color, physical propeties, and abrasion resistance. Calcined and surface-treated clays are used for improved electrical properties and ease of extrusion.

Adhesives and sealants – Kaolin is used to control flow, penetration, and specific adhesion on application, and adhesive strength, tear strength, tensile strength, and elongation after cure. For aqueous systems the choice of airfloated vs. water-washed clay is dictated by cost, color, abrasion, and rheological properties pre-cure and reinforcing properties post-cure. Stearate-coated clays are used for improved compatibility in nonaqueous systems.

Fiberglass – Low-iron, low-alkali, low-moisture, low-cost, airfloated kaolin is used in the manufacture of continuous filament fiberglass.

Other Uses – Kaolin clays are used in the manufacture of aluminum chemicals, bricks, cements, cosmetics, pharmaceuticals, animal feeds, fertilizers, catalysts, wallboard, printing ink, linoleum, flexible tile, pesticides, and roofing granules.

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MICA

Muscovite $KAl_2(AlSi_3)O_{10}(OH,F)_2$
Refractive Index:1.58-1.62
Specific Gravity: 2.76-2.88
Mohs Hardness: 2-2.5

Phlogopite $KMg_3(AlSi_3)O_{10}(OH,F)_2$
Refractive Index: 1.56-1.64
Specific Gravity: 2.78-2.85
Mohs Hardness: 2.5-3

Micas are sheet silicates historically significant for their ability to be split into large, thin sheets that are uniquely useful for their electrical, thermal, and mechanical properties. They have high electrical and thermal insulating properties; they are resistant to chemical attack; they can be split into transparent or optically flat films; and they can be cut or stamped to shape. Most mica used today, however, is in ground form, although the mineral's platy nature and inertness are still primary attributes. The mica of commerce is principally muscovite. Muscovite products range in hue from colorless to pale green or ruby. Minor amounts of sericite, a fine-grained form of muscovite, are also sold. Phlogopite is the only other mica of commercial significance. It ranges in color from pale yellow to light brown. Phlogopite has superior thermal stability but is not as commonly available as muscovite.

TYPES

Mica products often are clasified in terms of to their traditional production in sheet form as opposed to the more recent filler forms.

Sheet mica – Sheet mica consists of “books” of mica laminae and is classified according to the thickness, purity, and maximum usable area that can be cut or stamped. These criteria dictate the subcategories, in order of decreasing thickness, of block, thins, film, and splittings. Film mica is split from block and thins. Splittings are very thin but have relatively small usable areas, so they are used mostly to fabricate built-up mica. The ASTM (American Society for Testing and Materials) designates 13 quality groups for sheet mica based on color and visible imperfections and 12 additional groups based on maximum usable rectangle. Although its overall volume is minor compared to ground mica, sheet mica is still widely used in the electrical and electronics industry for its combination of thermal and electrical insulating properties and high mechanical strength.

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Built-up mica – Also known as micanite, built-up mica is a fabricated sheet of desired thickness made by overlapping irregularly shaped splittings and then binding them together with an organic or inorganic binder, heat, and pressure. Some products are reinforced with a paper, fiberglass, or textile backing. Built-up mica is produced as an alternative to natural sheet mica for electrical insulation applications.

Mica paper – Mica paper is a fabricated alternative to natural sheet and built-up mica products. Scrap mica is delaminated through a combination of thermal, chemical, and mechanical treatments. The mica pulp is then processed on a papermaking machine into a continuous, homogeneous sheet of uniform thickness.

Scrap mica – The term “scrap” is a holdover from the days when sheet was the major mica product. It is basically mica that is insufficient in size or quality to qualify as sheet. Scrap is produced at mines and at sheet mica factories. Scrap mica can be a byproduct of sheet mica mining or of the recovery of other minerals or the sole product of a mine. Factory scrap is the trimmings from sheet mica. Scrap is the source for ground mica products, which today account for more than 95% of all mica sold worldwide.

Flake mica – Flake mica is essentially nonfactory-generated scrap mica. It is recovered by flotation from mica ores, from which quartz and feldspar are also generally separated and recovered, or as a floated byproduct during the beneficiation of feldspar, kaolin, or lithium-bearing ores.

Wet-ground mica – Flake mica concentrates from flotation are ground wet in mills designed to delaminate as well as to grind. Such mills provide products having a higher aspect ratio, sheen, and slip compared to dry-ground mica. Trimmings from good-quality sheet mica are also used as feed for wet-grinding plants.

Dry-ground mica – Flake mica flotation concentrates are at least partially dried and then ground in mills appropriate for the particle size desired. Coarse-milled products (>100 mesh) are processed with hammer mills and screens or air separators. Fine-ground products, -100 mesh to -325 mesh in particle size, are processed in fluid energy mills, usually with superheated air.

Micronized mica – This is dry-ground mica milled to -20 or -10 micrometers in fluid energy mills using superheated steam. Some is calcined for use in cosmetics.

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USES

The United States is the leading supplier of mica, with about 46% of the world’s production. The US produces only ground muscovite. The only significant production of phlogopite is in Canada and Finland, which together account for about 15% of total worldwide mica output. India produces 80% of the world’s sheet mica. In the US fully half the mica produced is used in wallboard joint cements. Other major end uses are coatings, plastics, and well drilling fluids.

Joint cements – Fine dry-ground (fluid energy-milled) muscovite is used in drywall joint compounds, where it contributes to consistency and workability, smooth surface finish, and resistance to shrinkage and cracking.

Coatings – Fine-ground, -325 mesh and micronized mica grades are used in paint as a pigment extender and for dry film reinforcement. The inert, platy mica improves suspension stability, controls film checking, chalking, shrinkage, and blistering, improves resistance to weathering, chemicals, and water penetration, and improves adhesion to most surfaces. Coarser grinds are used in textured paints, and wet-ground mica is used in high quality exterior house paints. High aspect ratio grades are preferred for porous surface sealers to seal pores, control penetration, and reduce sagging and film cracking. Automotive paints use high aspect ratio mica to achieve a metallic effect either as is, or after conversion to pearlescent pigments by surface coating with metal oxides.

Plastics – Finely ground, -325 mesh and micronized micas are used in plastics to improve electrical, thermal, and insulating properties. Mica is considered the most effective mineral for reducing warpage and increasing stiffness and heat deflection temperature in plastics. In general, mica reinforces crystalline better than amorphous polymers. Best results are obtained with nonpolar polymers when mica is pretreated with a coupling agent to improve wetting. Mica is used in both thermoplastics and thermosets. Its largest single use is in polyolefins, even though it requires stabilizers to prevent degradation of polypropylene. Both muscovite and phlogopite micas are used in plastics, with high aspect ratio grades preferred for their superior reinforcement properties.

Drilling fluids – Coarse, hammermilled (+10 mesh) mica is used in water-based oilwell drilling fluids to prevent fluid loss into porous rock formations. The coarse mica flakes bridge openings and seal porous sections of the drill hole against loss of circulation. Mica’s platy nature also aids in the suspension of drilling fluid solids and cuttings.

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Other uses – Ground mica is used as an asbestos substitute in certain thermal boards, brake linings, gaskets, and cement pipes, as a filler and nonstick surface coating for roll roofing and asphalt shingles, as a mold lubricant and release agent in the manufacture of tires and other molded rubber goods, as a flux coating on welding rods, and as a pearlescent pigment in wallpapers.

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NEPHELINE SYENITE

Nepheline $(Na,K)AlSiO_4$
Refractive Index: 1.53-1.55
Specific Gravity: 2.57
Mohs Hardness: 5.5-6

Microcline $KAlSi_3O_8$
Refractive Index: 1.52-1.54
Specific Gravity: 2.54-2.57
Mohs Hardness: 6

Albite $NaAlSi_3O_8$
Refractive Index: 1.53-1.54
Specific Gravity: 2.62
Mohs Hardness: 6

Nepheline syenite is a rock composed of soda and potash feldspars (see *FELDSPAR*) and nepheline. Nepheline has the theoretical chemical composition $NaAlSiO_4$, but potassium invariably substitutes for a portion of the sodium. The amount of potassium in natural nephelines ranges from 3 to 12% K_2O by weight. Nepheline is related to the structure of high-trydimite (a high-temperature form of silica), with Al^{3+} replacing Si^{4+} in half the tetrahedra. The charge imbalance is compensated by Na^+ and K^+. Unlike feldspars, the sodium is exchangeable for H^+, making nepheline less acid stable. Nepheline will gelatinize in HCl, while feldspar will not. Nepheline can form only in a geologic environment deficient in silica. Commercial nepheline syenite deposits and the products made therefrom are consequently free of crystalline silica impurities. These deposits are likewise exploited for their high mineral brightness and low level of dark mineral impurities. Commercial products are made by crushing, dry magnetic separation, and milling. Fine particle size grades are produced by air classification. In North America typical nepheline syenite is approximately 25% nepheline, 20% microcline feldspar, and 55% albite feldspar.

TYPES

Nepheline syenite is characterized primarily by chemistry and particle size.

Glass grade – Coarsely ground nepheline syenite, typically -40+200 mesh with <0.1% Fe_2O3, >23% Al_2O_3, and >14% total Na_2O+K_2O, is used in glassmaking. Refractory minerals must be absent. A higher iron grade containing 0.35% Fe_2O_3 maximum is used in amber glass and glass fiber.

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Ceramic grade – Grades for ceramics are finely ground (typically 200, 270, or 400 mesh), controlled for PCE (pyrometric cone equivalent), free of dark impurities, and white-firing without specking.

Filler grade – Filler grades are finely ground (325 mesh to 1250 mesh) and have a high brightness (>93) and low vehicle demand.

Aggregate grade – Off-color, gray and blue nepheline syenite is produced in Arkansas for use as a construction aggregate and as roofing granules.

See also *FELDSPAR*.

USES

Of the approximately 4 million metric tons of nepheline syenite produced annually, Russia is the largest source, accounting for more than 75%. Russian output is captive, however, and is devoted almost entirely to the making of portland cement and to the production of alumina and aluminum due to the relative local scarcity of bauxite. Russian products are generally too high in iron for use in major North American and European applications –glassmaking and ceramics. These markets are served instead by products from Canada and Norway. Of the approximately 900,000 metric tons annually produced outside of Russia, Canada supplies about 63% and Norway 37%. Glassmaking is the major use, consuming 70% of Canadian and 80% of Norwegian production. Both sources supply about 15% of their output for ceramics and the balance for filler applications.

Glass – Container glass is the single largest application for nepheline syenite, followed by flat glass and glass fiber. Nepheline syenite is used as a source of alumina, which improves both the workability of the glass melt and the chemical and physical stability of the finished product. It also contributes alkaline oxides (Na_2O, K_2O) that provide fluxing in partial substitution for more expensive soda ash. Nepheline syenite is a source of noncrystalline silica as well. It competes with feldspar and aplite by offering a higher alumina and alkali content per unit weight.

Ceramics – Nepheline syenite is used in sanitaryware, tiles, electrical porcelain, tableware, and glazes as an alternative to feldspar. It acts as a flux in ceramic bodies to lower firing temperatures and allow faster firing schedules. It is used in preference to feldspar when its chemistry and/or price warrants or when crystalline silica is an overriding issue.

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Coatings – Although nepheline syenite’s acid solubility makes it less resistant than feldspar to frosting, it does offer similarly low vehicle demand, high brightness with low tint strength, abrasion resistance, and good film durability. It is, in fact, more widely used than feldspar in coatings, due at least in part to its freedom from crystalline silica. Coatings consume about 10% of North American production.

Other uses – Nepheline syenite is also used as a filler in plastics, rubber, and adhesives because of its low vehicle demand, high dry brightness with low tint strength, nearly lamellar shape, and resistance to abrasion and chemical degradation. It is used as a sandblasting medium due to its absence of crystalline silica.

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PERLITE

Perlite	Volcanic Glass

Refractive Index: 1.48-1.49
Specific Gravity: 2.5-2.6
Mohs Hardness: 5.5-7.0

Perlite is a hydrated volcanic glass composed chiefly of amorphous silica with 12-18% aluminum oxide, lesser amounts of the oxides of potassium and sodium, and minor amounts of iron, magnesium, calcium, and titanium. It is because of the 2-5% water contained in perlite that this rock is commercially valuable. Perlite as mined is distinguished by its concentric fractures, a result of rapid cooling of the molten volcanic glass, which gives rise to an onion-skin appearance. Upon heating above 870°C the contained water, as both silanol and molecular water, expands the perlite grains, forming minute bubbles within the glass matrix. The result is low-density particles with cellular interiors. These particles are used for their acoustical and thermal insulating properties, their chemical inertness and physical resilience, their fire resistance, their water retention ability, and their low bulk density.

TYPES

Because most of the perlite used commercially is in its expanded form, products are differentiated according to whether they have been expanded.

Processed perlite – Since the objective of nearly all perlite production is the expanded form, the principal product of perlite mining is processed perlite. The ore is crushed and ground and then classified to remove as many nonexpandable impurities as possible. The size of expanded perlite particles is largely determined by the particle sizes of the processed perlite from which they were made. The last step in the production of processed perlite, therefore, is its segregation by screening or air classification into more than a half dozen size classifications. These range from -200 mesh to +12 mesh. Processed perlite is supplied primarily to regional plants that carry out the thermal expansion and local marketing.

Expanded perlite – Expanded perlite has a very low bulk density, so expansion of the processed material is caried out in regionally located plants in order to minimize the otherwise high cost of transportation to market per unit weight of product. The perlite is expanded by quick exposure in furnaces to temperatures of 870° to 1100°C. This allows simultaneous softening of the glass matrix and volatilization of the contained water. The perlite expands in volume up to 20 times and decreases in bulk density by up to 90%. The size and quality of the processed perlite feed and the design and operation of the furnace are controlled to maximize the production of desired particle size, density, and strength. Insufficient expansion will produce smaller, denser particles while overexpansion can cause the crude particles to shatter into fines. After expansion, the perlite is air classified to remove any unexpanded particles and fines. Depending upon the intended end use, the expanded product may be further size classified, surface treated, or milled.

Milled perlite (filter aid) – Some expanded perlite is milled to -100 mesh and sold as a filteraid, especially for use in rotary precoat filtration. Careful milling is required, because oversize particles will inhibit the formation of filtercake while excessive fines will slow the filtration rate.

USES

In a world market of approximately 1.8 million metric tons, the leading perlite producers are the former Soviet republics of Armenia and Ukraine (35%), the United States (25%), and Greece (12%). In the US the market for perlite is dominated by formed insulation products (58%), followed by filter aid, horticultural products, and filler applications.

Formed insulation products – Medium- to fine-grained expanded perlite is incorporated into pipe insulation, insulation boards, acoustical ceiling tiles, precast concrete floor and roofing tiles, and precast roof decks. The perlite contributes to reduced weight, acoustical and thermal insulation, and fire resistance.

Filter aid – Expanded and milled perlite is used as a filteraid in the processing of foods such as sugar, oils, beer, and fruit juices and in the filtration of chemical products and industrial effluents.

Horticultural products – The low density and high absorptive capacity of expanded perlite is useful in soil conditioning. Expanded products provide a permeable soil structure with good ventilation and water retention and are a source of aluminum, potassium, and sodium nutrients. In nursery potting soils they provide these same benefits and serve as a lightweight substrate that facilitates transplanting. Expanded perlite also is used as a rooting medium, as a growing substrate in hydroponics, as a fertilizer carrier, as an additive in animal feeds, where it is a carrier of liquid additives, a binder, an anticaking agent, and a digestive aid, and as an additive to manures to decrease their odor and improve their fertilizer value.

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Filler – Expanded perlite is used as a filler in textured paints and in auto underbody plastisol coatings to reduce weight and improve sound insulation. It is used in syntactic foams and in automotive polyester molding compounds and body fillers to reduce weight and improve sanding characteristics. Its spherical shape allows more perlite to be incorporated, compared to irregularly shaped fillers, because there is less effect on melt or plastisol viscosity.

Other uses – Expanded perlite is used as an aggregate in plasters, wallboard, lightweight concrete, and lightweight fire-resistant coatings for structural steel and concrete. It is used as cryogenic insulation in storage vessels for liquified gases, and with silicone treatment as loose-fill insulation in building cavities. Unexpanded perlite is used as an abrasive, a chemical source of silica, a foundry slag coagulant, and to cover molten metal prior to casting, such that the heat of the metal expands the mineral into an insulating layer.

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PYROPHYLLITE

Pyrophyllite $Al_2Si_4O_{10}(OH)_2$
Refractive Index: 1.59-1.60
Specific Gravity: 2.8
Mohs Hardness: 1.5

Pyrophyllite in pure or near-pure form is rare in nature and in commerce. It can be viewed as an aluminum analogue of talc, and a pure, platy specimen would share many of talc's physical characteristics. In addition to the platy morphology, pyrophyllite occurs in nature as massive aggregates of small crystals and as large needle-like crystals. In Japan and Korea, where pyrophyllite is abundant, beneficiated forms have been used in applications traditionally reserved elsewhere for kaolin and talc. The requirements for competing in a world economy, however, have more recently moved Pacific Rim countries toward wider use of imported kaolins and talcs. In other producing countries a relatively low value is assigned to pyrophyllite, so that many natural mineral mixtures (some even devoid of this mineral) are sold under its name, generally at low prices. In many cases the lack of purity has been used to advantage. The major current uses actually exploit the unique and desirable features of the mineral blends that constitute most commercial grades. The minerals most commonly associated with commercial pyrophyllite are the related sheet silicates (mica, kaolinite, chlorite, smectite, illite), plus diaspore, andalusite, and quartz.

TYPES

Since the pyrophyllite market is dominated by ceramics and refractories uses, the products available are best characterized in terms of mineralogy and resultant market suitability.

Refractory grade – For refractory uses the product must be low in alkalis (<1%), which necessitates a low mica content. Alkalis reduce the melting point of pyrophyllite. Content of fluxes (Fe_2O_3, FeO, TiO_2) should be <1%.

Ceramic grade – For ceramics the preferred product is high in alkalis, so a higher mica content is advantageous. The lower melting point caused by a high alkali content allows for faster firing. A low coloring oxides content is required for whiteware applications.

Agricultural grade – For use as a carrier for the active ingredients in pesticide dusts, pyrophyllite's neutral pH, inertness and nonhygroscopic nature are natural attributes. Beyond this, market acceptance is dictated by performance, which is affected by fineness and bulking values.

Filler grade – In the US quartz-induced abrasion restricts the use of pyrophyllite in polymers, although the fine platy nature of the pyrophyllite and mica components can be expected to contribute to physical properties in a manner similar to kaolin or talc. In paints a fine grind and good color are required for pigment extension, while a relatively coarse grind is needed for reinforcing high-build coatings. For wallboard joint cements grind, color, and water absorption are the key properties.

USES

Japan and Korea account for 80-85% of the world’s annual production of about 2 million metric tons. US pyrophyllite, 3% of the world's total, is all dry ground and more or less abrasive depending on the particle size distribution of its quartz content. As such, it is generally overlooked in filler applications in favor of kaolin or talc. In the US the ceramics and refractories industries consume about 75% of the pyrophyllite produced. Pesticides take 10% of production, and filler uses (paint, joint cements, mastics) take 3-5%.

Refractories – Low-alkali pyrophyllite is used in refractories for its permanent expansion on firing, excellent reheat stability, low hot load deformation, good hot creep resistance, low reversible thermal expansion, low thermal conductivity, and high resistance to corrosion by molten metals and basic slags. Refractory grades are used in metal pouring refractories, kiln car furniture, insulating firebrick, ramming and gunning mixes, foundry mold coatings, and refractory mortars. The largest use is in ladle bricks.

Ceramics – High-alkali products are used in whitewares for their contribution to increased firing strength in vitreous bodies, improved thermal shock resistance from their low coefficient of thermal expansion, the ability to produce bodies with little or no shrinkage and reduced warpage, and the ability to produce low moisture expansion bodies with excellent craze resistance. Ceramic grades are used in tile, sanitaryware, pottery, chinaware, electrical porcelain, and glazes. The largest use is in wall tile, where the mineral contributes to increased fired strength and faster firing.

Pesticides – Pyrophyllite is used as a carrier in insecticide dusts because it is nonhygroscopic, fluffy, neutral in pH, and compatible with both acid and alkaline active ingredients. In passing through the blowers of dusting machinery it picks up an electrostatic charge, which causes its attraction to the underside of leaves as well as the exposed upper plant surfaces.

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Coatings – Coatings use a finely ground, high-brightness pyrophyllite for low-cost pigment extension. The product’s platy nature, from its sheet silicate structure, promotes good dispersion by inhibitting pigment settling, helps film dry, and increases resistance to film cracking. Worldwide, paint is the largest filler market. In the US coatings are a minor market, generally utilizing relatively coarse grades for imparting mud-crack resistance to high-build coatings (textured paints, block fillers) and checking/cracking/frosting resistance to exterior latex paints.

Joint cements and mastics – Finely ground paint-grade pyrophyllite is used in wallboard joint cements and in mastics to control rheology and provide reinforcement. For joint cements in particular, water absorption is an important property because it affects the critical cement properties of consistency, spreading, shrinkage on drying, and resistance to cracking.

Other uses – In the US the mostly platy nature, low moisture content and inertness of pyrophyllite products qualify them as low-cost alternatives to kaolin and talc for other filler applications that can accommodate higher abrasivity.

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SILICA

Quartz SiO_2
Refractive Index: 1.54
Specific Gravity: 2.65
Mohs Hardness: 7

Synthetic (amorphous) Silica SiO_2
Refractive Index: 1.45
Specific Gravity: 2-2.3
Mohs Hardness: 5-6

Natural silica products are crystalline and are classified for most of their uses under the term “sand and gravel”. Finely ground natural silica with high mineralogical and chemical purity is nevertheless produced in substantial quantities. It is generally characterized as off-white to white and abrasive, with low suface area, low binder demand, and low cost. Amorphous forms of natural silica exist as diatomaceous earth (see *Diatomite*), volcanic glass (see *Perlite*), and noncommercial opaline minerals. Synthetic silicas are generally characterized as amorphous and white, with high purity, a high surface area, high liquid absorption, and ultrafine particle size. These include silica gel and precipitated silica, also known as hydrated silicas, and fumed silica, also known as pyrogenic or anhydrous silica. Hydrated silicas are made in aqueous media, which results in a relatively high density of surface silanol (-Si-OH) groups. They therefore absorb water readily and are typically sold with 5 to 6% free moisture. The pyrogenic process used to produce fumed silica leaves most surface silanols condensed to siloxane bridges (-Si-O-Si-), so that silanol surface density is only about 25% of that of hydrated silicas. There is consequently less tendency to absorb water, and the products typically contain less than 2% free moisture.

TYPES

The primary differentiation among silica products is their natural vs. synthetic origin, which translates to a division between crystalline and amorphous forms.

Ground silica – Ground silica, also known as ground quartz and silica flour, is produced by grinding high-purity quartz, quartzite, sandstone, or silica sand to finer than 200 mesh. Air separation is used as required to remove kaolin, mica, feldspar, or calcite impurities. Silica sand recovered as a byproduct during the flotation of other minerals is also used as a source. Ground silica for filler uses typically assays >99% SiO_2 and offers high brightness, low moisture, chemical inertness, relatively low surface area, and the low liquid absorption that allows high loading levels. Because of its hardness and the creation of sharp, angular particles upon grinding, most ground silica is too abrasive for use in certain plastics compounding machinery.

Novaculite – This form of ground silica is microcrystalline quartz that is milled to low-moisture, high-purity (>99% SiO_2), plate-like or disc-like particles. Brightness is generally lower than for other forms of ground silica, but particle shape, lower binder demand, lower abrasivity, and availability in a range of particle size distributions (to as small as 2 micrometers average) has earned novaculite a place in filler applications, particularly in paint.

Tripoli – This is a general term for a friable or powdery rock composed substantially of microcrystalline quartz. Commercial tripoli is ground mainly for use as an abrasive agent in buffing and polishing compounds, since particle edges tend to be less sharp than for most other forms of ground silica.

Flint – This is a relatively high silica ($\geq$85% SiO_2) rock composed of microcrystalline quartz, with calcite as the common major impurity. Flint is characteristically gray or black and consequently is not a source of ground silica for most applications. The exception is ceramics, particularly in Europe, where low-iron ground flint is used as a silica source in whitewares because it fires white. In Europe silex is a commercial term for flint.

Silica sand – Silica sand can be broadly defined as a natural quartz sand that is -4 mesh and +200 mesh. Silica sand has more rounded grains than are obtained by grinding high-silica rocks to an equivalent size range, although grain angularity varies from source to source. Products are commonly named for their intended use – e.g., glass sand, foundry sand, blasting sand, and hydraulic fracturing sand. Each term indicates compliance with requirements for minimum SiO_2, maximum chemical impurities, particle size distribution, and grain shape for that application. Most uses require at least 95% SiO_2 and have limits on the Al_2O_3 and Fe_2O_3 content.

Precipitated silica – Precipitated silica is made by the controlled neutralization of a sodium silicate solution under alkaline conditions using either sulfuric or carbonic acid (as CO_2 + HCl). This is carried out in a heated stirred reactor. The rate and order of addition of reactants, reactant concentration, and reaction temperature are varied to manipulate particle size and particle structure. Precipitation produces a low-solids slurry of amorphous silica particles within the byproduct salt solution. The discrete primary silica particles that initially form fuse into aggregates, which in turn form loose agglomerates. The precipitate is filtered, washed, and dried (usually spray dried) to a neutral pH product. The dry silica is milled to reduce average agglomerate size and is then frequently compacted to balance bulk density, freedom from dustiness, and dispersibility. The particle size conventionally reported is that of primary particles (10 to 30 nanometers), although it is the aggregates (30 to 150 nanometers) that are the actual functional particles. BET surface area is therefore frequently preferred for classifying the various grades. Products are also classified according to structure, which is a function of aggregate size, shape, and pore volume. For convenience, structure has been related to oil absorption, with five structure levels designated. These range from VLS (very low structure) at less than 75ml/100g to VHS (very high structure) at greater than 200ml/100g. In elastomer compounding, which uses approximately 75% of the precipitated silica produced, the silica is commonly treated with silane coupling agents *in situ* to promote better matrix compatibility and improved compound properties. Silica grades pretreated with silane are also available.

Silica gel – Silica gel is made by reacting a sodium silicate solution with sulfuric acid under acid conditions. Silica properties are manipulated by controlling the reaction rate, order of reactant addition, reactant concentration, reaction temperature, and mixing conditions. The silicate-acid reaction first forms a hydrosol, which is aged to a transparent rigid gel. This gel is broken into small lumps, washed to remove residual salts, and dried. When the gel's water is removed slowly, the colloidal silica structure contracts and a dry silica xerogel results. When the water is removed quickly, so that the colloidal silica structure is preserved, a dry silica aerogel with lower density and higher pore volume results. Aerogels are neutral in pH, while xerogels are usually processed to produce an acid pH (4 to 5) in water. The dried xerogel or aerogel is milled to a controlled particle size distribution, with the average particle size measurement reflecting aggregate rather than primary particles. Surface-treated grades are available for improved organic matrix compatibility. Major applications for silica gel depend on its small particle size for rheology control and its porosity for low particle density and high liquid absorption.

Fumed silica – Fumed silica is prepared by the hydrolysis of silicon tetrachloride in a flame of hydrogen and oxygen. Particle size and surface area are controlled by varying the ratio of the three reactants. The primary silica particles are round and 7 to 40 nanometers. These primary particles collide and fuse into branched or chain-like clusters. These aggregates, the functional particles, average about 1 micrometer, and in turn form agglomerates. In aqueous dispersions fumed silica provides a pH of appproximately 4. The very low bulk density of the agglomerates is increased by compaction with vacuum deaeration before packaging. Fumed silica is sold in a hydrophilic form as produced and in a hydrophobic form with silane surface treatment.

USES

To a large extent natural and synthetic silicas have little in common other than their gross chemistry. Applications reflect this. The United States produces about 25 milllion metric tons of silica annually under the general description “industrial sand and gravel”. Of this total about 40% is glass sand, 20% is foundry sand, 7% is abrasive sand, 6% is hydraulic fracturing sand, and 6% is gravel. Specialty silica, consisting of ground natural and synthetic silicas, accounts for 2 to 4% of total silica output. For silica sand the major use is as an inexpensive source of SiO_2. This encompassses the production of nearly all types of glass, plus ferrosilicon, silicon metal, silicon carbide, and metallurgical fluxes. Each of these applications has its own requirements for particle size distribution, minimum SiO_2, and maximum Fe and Al, as well as control over other chemical and mineralogical impurities. Other major silica sand uses have similar requirements, plus additional specifications on particle shape. Fracturing sand, for example, must penetrate and maintain openings through which oil or gas can flow to a well. It must consist of well-rounded grains to allow ease of placement and maximum permeability. Fractured angular grains with sharp edges are obviously prefered for most abrasive sand uses. The major uses of specialty silicas are in ceramics, coatings, rubber, plastics, adhesives, and sealants.

Ceramics – Low-iron ground silica, typically -200 mesh, and calcined silica are used in whiteware formulations to facilitate drying of the body, to control expansion characteristics and compatibility between the body and glaze to prevent crazing, and to provide whiteness and acid resistance. Ground silica is also used as a source of SiO_2 in glazes and enamels.

Coatings – Ground quartz and novaculite are used as extender pigments because of their low binder demand, which allows high loadings. The platy shape of novaculite imparts additional mar, wear, and weather resistance. Synthetic silicas are used in coatings to provide flatting, mar resistance, and abrasion resistance. In certain specialty coatings they are used as well for rheology control and as suspension aids.

Rubber – Finer (<0.025 micrometer) precipitated silica is the only fully reinforcing alternative to carbon black for general rubber compounding. Most of the precipitated silicas used in rubber are reinforcing grades rather than the coarser extending grades. Precipitated silica is used in compounds designed to be translucent or colored, and in general compounding to promote abrasion resistance, cut growth resistance, tear strength, elastomer-to-textile adhesion, and resistance to heat aging. It is often compounded with silane coupling agents to improve matrix compatibility. Because of its particular attributes, precipitated silica is used in radial ply passenger tires, off-road tires, and footwear. Fumed silica is the conventional reinforcing filler in silicone elastomers, although more recently it has been supplemented with precipitated silica and finely ground natural silica that extend its reinforcing properties at lower cost. Synthetic silicas have an index of refraction close to that of silicone rubber, so that transparent compounds can be formulated.

Plastics – Synthetic silicas, particularly fumed silica, are used as thixotropes in unsaturated polyester resins and gel coats and in epoxy resins. Fumed and precipitated silicas are used as thixotropes in PVC plastisols. Synthetic silicas are also used as antiblocking and antislip agents by temporarily absorbing plasticizers that can cause tack and by providing an imperceptible surface roughness. They are used as matting or flatting agents and as plate-out agents in highly plasticized compounds. Precipitated silica is used as a reinforcing filler in thermoset EVA and to provide controlled porosity in polyethylene battery separators. Finely ground natural silica is used in thermosets to provide dimensional stabiliy, improved thermal conductivity, and good electrical insulation properties at low cost.

Adhesives and sealants – Synthetic silicas are used in adhesives, caulks, and sealants to control flow and sag, improve bond strength, and provide reinforcement. Moisture-sensitive products, such as one-part RTV silicones, use fumed silica preferentially. Finely ground natural silica is used for its low moisture content, low cost, low binder demand, and its ability to improve tensile strength without affecting flexibility or durability.

Other uses – Synthetic silicas are used as thickeners in printing inks, as carriers for liquid and active ingredients, and as anticaking and moisture control agents. Fumed and precipitated silicas are used in high-temperature silicone greases. Silica gel is used as a thickening and polishing agent in dentifrices and as the abrasive agent in silicon wafer polishing compounds.

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SMECTITE

Montmorillonite	$(Al,Mg)_2Si_4O_{10}(OH)_2$
Hectorite	$(Mg,Li)_3Si_4O_{10}(OH,F)_2$
Saponite	$Mg_3(Si,Al)_4O_{10}(OH)_2$

Refractive Index: 1.50-1.64
Specific Gravity: 2.5
Mohs Hardness: 1-1.5

Smectites are water swellable clays that have a platy structure. Smectite is the mineralogical term for a group of clays, which includes montmorillonite, hectorite, and saponite. Most smectites are more commonly known under the geological term bentonite. By convention, bentonite is understood to be an ore or product with a substantial smectite content. The range of possible chemical variations in the basic smectite trilayer lattice starts with montmorillonite, the high-aluminum end member. Montmorillonite is composed of a central alumina octahedral layer sandwiched between tetrahedral silica layers. This is identical to the dioctahedral pyrophyllite structure except for small substitutions of Mg^{2+} for Al^{3+} in octahedral positions and Al^{3+} for Si^{4+} in tetrahedral positions. The resulting charge imbalance is compensated by exchangeable alkali and alkaline earth cations, which contribute to the ability of the clay to swell. When the exchangeable cations are predominately sodium, the individual platelets separate to produce a colloidal structure in water.

At the other end of the smectite series are the high-magnesium members, hectorite and saponite. These clays possess a talc structure, with a trioctahedral magnesia layer sandwiched between the silica layers. Swellability results from minor substitution of aluminum for silicon in saponite or lithium for magnesium in hectorite. As with montmorillonite, the type of exchangeable cation determines the degree of swelling. Hectorite also has partial substitution of lattice hydroxyls by fluorine.

Each macroscopic smectite particle is composed of thousands of submicroscopic platelets stacked in sandwich fashion with exchangeable cations and oriented water between each. The platelet faces carry a negative charge from lattice substitutions, while edges have a slight positive charge from broken bonds and cation adsorption. When smectite and water are mixed, water penetrates the area between the platelets forcing them farther apart. With calcium as the major exchange ion the platelets will swell in this fashion but have limited ability to completely delaminate. When sodium is the predominant exchange ion, the platelets separate farther apart and the exchange ions begin to diffuse away from the platelet faces. Further penetration of water betwen the platelets then proceeds in an osmotic manner until they are completely separated. The presence of dissolved substances in the water will prolong hydration time by inhibiting this osmotic swelling. Once the smectite platelets are separated, the weakly positive platelet edges are attracted to the negatively charged platelet faces. The resulting three dimensional structure, often referred to as a “house of cards”, imparts thixotropy, pseudoplasticity, and yield value.

Most smectities are processed by drying, crushing, and milling to a 200 mesh powder, with mineralogical purity determined by ore selection. Granular grades are produced for absorbent uses. A relatively small quantity of white or light colored smectite is beneficiated by hydroclassification to produce products of sufficient mineralogical, chemical, and microbiological purity for pharmaceutical, cosmetic, and the more demanding industrial uses. The impurities most commonly associated with commercial smectites are silica, feldspar, zeolites, and carbonate minerals.

TYPES

There are a number of descriptive terms for smectite products based on geographic source, exchangeable cations, production process, and end use application.

Sodium bentonite – Sodium bentonite is composed substantially of smectite, usually montmorillonite, with sodium as the major exchangeable cation. As such it is water swellable and will hydrate to form the characteristic colloidal structure.

Calcium bentonite – Calcium bentonite is composed substantially of smectite, usually montmorillonite, with calcium as the major exchangeable cation.

Ion-exchanged bentonite – This is calcium bentonite that has been dry blended or hydrotreated with sodium carbonate to increase the availability of exchangeable sodium ions sufficiently to enable the clay to behave like sodium bentonite. This is also called sodium-exchanged bentonite.

Acid-activated clay – This is calcium bentonite that has been treated with sulfuric or hydrochloric acid to exchange calcium with hydrogen ions, to dissolve carbonate impurities, to leach some tetrahedral aluminum and octahedral magnesium, aluminum, and iron, and to delaminate the edges of the stacks of clay platelets. The overall effect is to increase porosity and surface area and, thereby, the clay’s absorptive properties. This type of bentonite is used primarily to decolorize and deodorize petroleum and edible oils.

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Bleaching clay – Although certain natural smectite and hormite clays are used to decolorize oils, the term bleaching clay most commonly refers to acid-activated bentonite as described above.

Absorbent clay – This is usually calcium bentonite that has been partially calcined at 200° to 550°C to remove interlayer water and develop absorbency.

Wyoming bentonite – Also known as Western bentonite and swelling bentonite, this is generally a high mineralogical purity, tan to green sodium bentonite with good thickening properties. It is actually mined in Wyoming, South Dakota, and Montana. This term is sometimes used generically to denote a sodium bentonite with good thickening properties.

Southern bentonite – This is calcium bentonite mined in Texas, Mississippi, and Alabama. It is also known as nonswelling bentonite.

White bentonite – This is bentonite that is naturally light enough in color for use in color-sensitive applications such as pharmaceuticals, cosmetics, ceramics, laundry products, and the paper industry.

Hydroclassified smectite – This is white sodium montmorillonite, saponite, or hectorite that is dispersed in water to colloidal dimensions, beneficiated by centrifuges or hydroclones to remove mineral impurities, and dried. Some products are based on white calcium smectite that is exchanged with sodium carbonate prior to centrifugal beneficiation. Water processed smectites, individually and in blends, are produced for uses where high mineralogical and bacterial purity, control of whiteness and heavy metals, and greater performance efficiency justify their higher price.

Synthetic smectite – Smectite is synthesized in commercial quantities from component oxides at high temperature and pressure. The synthetics, most commonly hectorite, are sold for applications where a premium price is justified by their purity, consistency, and transparent or translucent colorless dispersions.

Organoclay – Organophilic smectite is most often produced by reacting water-purified clay in an aqueous dispersion with quaternary ammonium compounds, then filtering and drying. These products are designed to perform in oils and solvents in much the same way that their untreated counterparts perform in water.

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Pillared clay – Pillared clay is purified smectite, usually montmorillonite, treated in an aqueous dispersion with large metal hydroxide complexes (e.g., aluminum chlorohydrate), dried, partially calcined, and milled. The metal complexes form durable "pillars" between clay platelets, maintaining a fixed, well defined separation between them. Because of their size- and shape-selective absorption properties, pillared clays share certain molecular sieve applications with zeolites.

USES

Annual worldwide production of smectite clays is approximately 8.5 million metric tons. The leading producers are the United States with about 40%, followed by the former Soviet Union, Greece, and Japan. The largest worldwide application is well drilling fluids. In the US the major end uses are iron ore pelletizing, drilling fluids, and foundry sand bonding. Other significant applications are oil bleaching, absorbents, and water impedance.

Ore pelletizing – Finely ground taconite ore is bonded into pellets one inch or more in diameter using about 0.5% sodium bentonite. The pellets are then used as blast furnace feed. The bentonite provides both green and dry strength to facilitate forming, drying, and handling of the pellets.

Drilling fluids – Natural sodium bentonite and sodium-exchanged bentonite meeting American Petroleum Institute specifications for moisture, viscosity, water loss, wet screen residue, and yield (barrels of mud per ton of clay) are the most commonly used smectites for freshwater drilling fluids. Their primary functions are to lubricate the drill bit, seal the walls of the hole against fluid loss, and carry cuttings to the surface for removal. Hectorite is used in some instances for its higher efficiency and better heat stability in deep holes. Brine-based muds, or those used to drill through saltwater formations, use palygorskite. Mineral oil or synthetic oil-based drilling fluids, usually water-in-oil emulsions, use organoclays.

Foundry sand – Sodium bentonite, as well as some ion-exchanged and calcium bentonites, are used to provide bonding strength and plasticity to the molding sands used in metal casting. The choice of bentonite is based on a balance of green, dry, and hot strengths. Sodium bentonite generally provides superior dry and hot strength, whereas calcium bentonite provides better green strength.

Oil bleaching – Acid-activated and certain natural smectites are used to decolorize and in some cases to deodorize, dehydrate, neutralize, and filter mineral, vegetable, and animal oils. Products are qualified according to procedures prescribed by the American Oil Chemists Society. The method of preparation determines the suitability of a given clay for a specific oil.

Absorbents – Granular absorbent-grade (partially calcined) calcium bentonite is used as a floor absorbent, particularly for oily materials, and in pet litters. Uncalcined sodium bentonite is used as the agglomerant in scoopable cat litter.

Water impedance – Once swollen by contact with water, a layer of smectite will prevent further passage of water. Smectites, particularly sodium bentonite, are therefore widely used to prevent seepage loss from ponds, ditches, reservoirs, and waste disposal areas, to line and waterproof tunnels and the below-grade walls of residential and commercial buildings, and to seal cracks and fissures in rocks and concrete.

Other uses – Smectite clay is used to clarify water, wine, beer, and other consumable liquids because it will adsorb suspended impurities and facilitate their removal by filtration or flocculation. Hydroclassified sodium smectite is used to thicken and stabilize water-based coatings and cleaning products as well as cosmetic and pharmaceutical emulsions and suspensions. Organoclays are used similarly in solvent- or oil-based products and also to thicken oils into nonmelting greases. Finely ground high purity smectite is used as a binder for animal feed and to provide plasticity and green strength in ceramics.

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TALC

Talc $Mg_3Si_4O_{10}(OH)_2$
Refractive Index: 1.59-1.60
Specific Gravity: 2.75
Mohs Hardness: 1

Commercial talc is composed primarily of the mineral talc, a sheet silicate, but may contain related sheet silicates such as chlorite and serpentine, plus prismatic tremolite, anthophyllite, and carbonates such as magnesite, dolomite, and calcite. Talc particles are characteristically platy in morphology and are oleophilic/hydrophobic; they are wetted by oil instead of water. Talc's reinforcing and pigmenting properties, together with good color, make it desirable as a functional filler in both aqueous and nonaqueous applications. For nonaqueous uses its naturally good matrix compatibility can be further enhanced by surface treatment.

TYPES

Talcs are clasified by mineralogy, morphology, and geographic source. Talc products are processed using various combinations of dry grinding, air separation and flotation depending upon the quality of the crude ore and the properties required for intended applications.

Platy talc – This is distinctly lamellar, soft talc, typically of >90% purity naturally or through beneficiation, which is used in cosmetic, pharmaceutical, and reinforcing filler applications.

Steatite – This originally was a mineralogical name applied to pure talc. Today it refers to high-purity, dense, very fine-grained talc that can be machined. On firing, it has good electrical insulating properties and is used in the manufacture of electrical porcelain.

Soapstone – This is typically a less pure form of steatite that can be carved, sawed, drilled, or machined. Because of its chemical resistance, dense nature, and refractory qualities, it is fabricated into shaped products such as sinks and stoves.

Tremolitic talc – This is fine-grained "hard" talc that usually contains <50% talc but major quantities of hard, prismatic tremolite and fine, platy serpentine. It may also contain a minor amount of prismatic anthophyllite and traces of carbonates and quartz. It lacks the distinctly lamellar, soft, hydrophobic characteristics normally associated with talc and is consequently excluded from certain traditional talc applications. Its atypical properties, however, are used to advantage in ceramics and paint.

New York talc – This is generally considered synonymous with tremolitic talc as described above.

Vermont talc – Most crude Vermont talc is characterized by a significant content, 20-30%, of magnesite. The ore is beneficiated to produce products containing various amounts of residual magnesite and occasionally other carbonates, mainly for filler applications. High-purity cosmetic- and pharmaceutical-grade floated talc has been produced in Vermont as well.

Montana talc – Montana talc is known for its naturally high purity and brightness. The principal impurities are small amounts of chlorite, dolomite, and magnesite. The high natural purity makes it possible to produce products for a wide range of uses with little or no beneficiation.

Texas talc – Crude Texas talc is usually gray or black, due to organic materials, and contains quartz and dolomite impurities. It can be processed to filler grades having acceptable brightness, but its principal application is in ceramics. This talc fires to an acceptable color and is suitable for use in fast-fired bodies.

Canadian talc – Although the crude talc in Canada varies considerably in purity and color from one deposit to another, most of the material imported into the US is floated, high-brightness talc for filler and pitch adsorption applications. Some tremolitic talc is available in Canada.

Italian talc – Italian talc has the reputation as being the world's purest. Virtually all the Italian talc imported into the US is a particularly high-purity, soft, cosmetic and pharmaceutical grade.

Chinese talc – The main talc-producing region in China is the Haicheng district of Liaoning Province. Imports into the US are sometimes simply called Haicheng talc, although this includes talc of varying quality from a number of different mines. Chinese talc is known for its high purity and brightness, and filler uses account for most of its consumption in the United States.

USES

The United States, with 1.1 million metric tons of annual output, is the world's second largest producer of talc after China. Other major producing countries are France, Finland, and Australia. Imports into the US from these countries are generally of high-purity platy talc. The single largest use in the US is in ceramics (30-33%), followed by paint, paper, roofing, plastics, cosmetics, and pharmaceuticals.

Ceramics – Talc for ceramic applications is low in iron and carbonates, uniform in chemical composition and fired shrinkage, hard and fine grained, controlled in particle size distribution, and white or near-white firing. Talc's high fusion point and fluxing action enable lower firing temperatures and quicker firing schedules to be used in the production of wall tiles, sanitaryware, vitreous china and cordierite bodies (catalytic converter substrates and electrical insulators). Tremolitic talc is prefered for wall tile production, because bodies can be dry pressed without lamination and because its contribution to high uniform thermal expansion and low moisture expansion prevent crazing of glazed products.

Coatings – The principal use for talc in coatings is as a TiO_2 extender. It also contributes to suspension stability, flatting and sheen control, chemical resistance, leveling, film integrity, and weatherability. Architectural paints generally use -325 mesh talcs, whereas industrial paints use micronized grades. Because it is prismatic and lower in oil absorption, tremolitic talc provides easier dispersion, higher loading levels, less flatting, and better dry hide than does platy talc. It also provides better durability in exterior and traffic paints.

Paper – In the US high-purity, micronized platy talc is the preferred material for pitch adsorption. Its low abrasion and ability to preferentially wet oily materials in the presence of water are unique among mineral alternatives. Pitch adsorbers account for more than 70% of the talc sold to the US paper industry. The balance is high-purity, high-brightness platy talc for paper filling and coating. This talc is used for TiO_2 extension and for improved gloss, opacity, brightness, and ink holdout. A minor use is in the deinking of recycled paper. In Europe, where it can compete more effectively with kaolin, approximately 70% of the talc used by the paper industy is in filler applications, and pitch control accounts for less than 20%.

Roofing – Low-cost, off-color platy talc is used in roofing felts to add weight for lower cost per ft^2, to provide UV protection, to prevent oil penetration and migration, and to increase fire resistance.

Plastics – Platy talc is used for reinforcing and/or filling both thermosets and thermoplastics, although principally the latter. Talc is used in thermoplastics to control melt flow, reduce creep in molded parts, increase molding cycles, increase heat deflection temperature, and improve dimensional stability. The single largest use is in polypropylene to increase both stiffness and resistance to high temperature creep. The main requirements for plastics-grade talc are low iron, low moisture, and low abrasion. The color required depends on the finished plastic. Black polypropylene is less demanding than white or pigmented polypropylene used in furniture, appliances and automobiles.

Cosmetics and pharmaceuticals – Only high-brightness platy talc of exceptional purity is used in cosmetics and pharmaceuticals. The talc must have good lubricity or “slip” and acceptable fragrance retention and moisture absorption. It must also adhere to strict limits on acid-soluble substances, loss on ignition, microbial content, chloride, iron, and heavy metals. In cosmetics talc is used in makeup and dusting powders. In pharmaceuticals it is used in tablet manufacture as a filler and lubricant/glidant, and as a reinforcing agent in film coatings.

Other uses – Talc is used for flow control in animal feeds, as a dusting agent for rubber, as an anticaking agent for fertilizers, as a carrier for insecticides, as a wicking preventer in automotive undercoatings, as a filler in carpet and textile backings, as a filler in wallboard joint compounds and grouts, and as a functional filler in adhesives and sealants.

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VERMICULITE

Vermiculite $Mg_{0.3}(Mg,Fe)_3(Al,Si)_4O_{10}(OH)_4 \cdot 8H_2O$

Refractive Index: 1.55-1.58
Specific Gravity: 2.1-2.8
Mohs Hardness: 1.5-2.8

Vermiculite is a platy sheet silicate that is similar in appearance to the mica from which it was altered and similar in ion exchange properties to the trioctahedral smectites which it resembles in structure. Most commercial vermiculite was formed by the alteration of biotite or iron-bearing phlogopite micas. An individual vermiculite particle is composed of an octahedral magnesia layer sandwiched between two tetrahedral silica layers. There can be some substitution of iron and aluminum for magnesium in the octahedral layer. There is always some substitution of aluminum for silicon in the tetrahedral layer, creating a charge imbalance. Vermiculite layers are separated by two oriented water layers, between which magnesium cations reside to balance the charge on the mineral lattice. Because of the separation of platelets by the oriented water, the magnesium ion is not fixed but exchangeable for other cations. This ion exchange capacity is exploited in certain industrial applications. Unlike smectite, vermiculite will not readily incorporate additional layers of water between platelets and will not, therefore, completely delaminate in aqueous systems. Most commercial vermiculite is heat treated to volatilize its interlayer water and produce an expanded (exfoliated) product. Upon heating, the flat, macroscopic "books" of vermiculite flakes expand into elongated, concertina-like particles. Expanded vermiculite posseses absorptive, insulating, and ion exchange properties that serve as the basis for its industrial uses.

TYPES

Because more than 90% of vermiculite used is in the low-density, expanded form, commercial vermiculite is differentiated according to whether or not it has been exfoliated.

Vermiculite concentrate – Since the objective of nearly all vermiculite production is the expanded form, the principal product of vermiculite mining is a vermiculite concentrate. Vermiculite ores typically contain only about 35% vermiculite. The balance may consist of various proportions of mica, chlorite, and other sheet silicates. The ore is beneficiated to vermiculite flake concentrates of at least 90% purity by either dry or wet processes. The former include screening and air separation, while the latter may employ either froth flotation, hydroclassification, or heavy media separation as required. Vermiculite concentrates are supplied to regional plants which carry out the thermal exfoliation that results in the expanded products. Vermiculite concentrates are screened and sold under various grade designations based on relatively narrow particle size distributions (e.g., Grade No.1 is 4x8 mesh and Grade No. 2 is 8x16 mesh). Flakes that are less than 60 mesh are too fine for exfoliation and are discarded during beneficiation.

Expanded vermiculite – Expanded vermiculite has a very low bulk density, so exfoliation is carried out in regionally located plants in order to minimize the high cost of transportation to customers per unit weight of product. Vermiculite concentrates are expanded in furnaces by quick exposure (0.25–8 seconds) to 900°C or more. The heat rapidly turns the interlayer water to steam, which pushes the individual vermiculite laminae apart. The vermiculite increases in volume by 8-20 times and decreases in bulk density by 85-90%. The expanded particles are 90% entrapped air by volume and thereby posses excellent insulation properties. The expanded material is separated from nonexpanding impurities by air classification and is either bagged directly or ground to sizes suitable for various applications. If properly exfoliated, expanded vermiculite retains 90-95% of its ion exchange capacity.

Chemically exfoliated vermiculite – Vermiculite can be chemically delaminated by treating an aqueous dispersion alternately with a brine solution and an n-butylammonium solution. The mineral’s exchangeable magnesium is sequentially replaced by sodium and the alkylammonium cation. This increases the interlayer separation sufficiently to allow the osmotic entry of water. The mineral thus expands to form an aqueous gel. This gel is used to coat glass fibers and fiberglass fabrics, thereby doubling their effective working temperature.

USES

In a world market of approximately 600,000 metric tons, the United States is second to South Africa in vermiculite production, with 30% vs 40%, but leads in consumption by far with 50%. The US market for expanded vermiculite is divided one-third each between agricultural products and ready-mix plaster and cement premixes. The balance is used in insulation products of all types and as a lightweight concrete aggregate.

Agricultural products – In decreasing order of volume consumed, the major agricultural uses of vermiculite are as a fertilizer carrier, in horticultural products, and as a soil conditioner. Expanded vermiculite will absorb fertilizer and trace nutrient liquids, and the resulting free-flowing particles provide controlled, slow release of these liquids to the soil. The low density, high absorption, and ion exchange properties of expanded vermiculite find use in potting, nursery, and farm soils. Exfoliated vermiculite provides a permeable soil structure having good aeration and water retention. It also controls the release of nutrients to the plant, and in nurseries it ensures a lightweight soil that facilitates the transplanting of large nursery stock. Expanded vermiculite is also used as a growing substrate in hydroponics, as a carrier of liquid additives, binder, anticaking agent, and digestive aid in animal feeds, and as an additive to manures to decrease their odor and improve their fertilizer value.

Plaster and cement premixes – Expanded vermiculite is used in ready-mix plasters and cements to impart low density, high thermal insulation, and low thermal conductivity. These mixes are sprayed on as lightweight, fire-resistant coatings for structural steel and concrete. The laminar nature of the mineral also protects against cracking and spalling of these coatings when subjected to temperature extremes and mechanical shock. Vermiculite is also used in fire-protection boards at loading levels of up to 90%. These boards are used as cladding for structural steel and in residential and commercial buildings as more aesthetic alternatives to sprays.

Insulation – Vermiculite is used in thermal and acoustical insulation boards (e.g., ceiling tiles), lightweight insulating blocks, refractory blocks, and fire bricks. Coarse expanded vermiculite is used as loosefill insulation in interior building walls and, with a silicone coating to minimize moisture absorption, in exterior walls.

Lightweight aggregate – Coarse, up to 8mm, expanded vermiculite is used as an aggregate in ready-mix and preformed concrete to reduce weight and improve insulation properties. Of the alternatives (including pumice, pumicite, and perlite), vermiculite provides the lightest weight but physically weakest concrete.

Other uses–Expanded vermiculite is used as an absorbent for industrial spill containment and cleanup, in ground form as an alternative to asbestos for brake linings, in refractory mold releases, and as a water filtration medium in aquaculture. Unexpanded vermiculite is used to cover molten metal prior to casting, where the heat of the metal expands the mineral into an insulating layer.

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WOLLASTONITE

Wollastonite $CaSiO_3$
Refractive Index: 1.62-1.65
Specific Gravity: 2.92
Mohs Hardness: 4.5

Commercial grades of wollastonite are typically high in purity because most ores must be beneficiated by wet processsing, high-intensity magnetic separation, and/or heavy media separation to remove accessory minerals. The minerals most commonly found associated with wollastonite are calcite (calcium carbonate), diopside (calcium magnesium silicate), and garnet (calcium aluminum silicate). Wollastonite is hard, white, and alkaline (pH 9.8). It is exploited for its chemistry as a source of CaO and SiO_2, and its low ignition loss, low oil absorption, very low moisture absorption, and acicular morphology. For polymer applications matrix compatibility is improved by surface treatment.

TYPES

The natural morphology of wollastonite is acicular because its crystals grow longer than they are wide. This gives wollastonite particles a needle-like shape. The uses for commercial products are dictated by the length of individual needles in the ore and the extent to which this shape is preserved during grinding of the finished products. The acicular nature of wollastonite is measured in terms of aspect ratio – the ratio of particle length to width.

Wollastonite powder – This is milled wollastonite that has a low aspect ratio (3:1 - 5:1). It is produced from naturally low-aspect ratio ores and from high-aspect ratio ores that have been ground in a way that breaks the needles widthwise. Despite their relatively low aspect ratios, powder grades can provide better reinforcing properties than prismatic and even platy minerals in some applications.

Acicular wollastonite – This is produced from ore containing a suitably high percentage of long needles. The ore is milled and air separated in such a way that very fine, needle-like particles are preserved and recovered. Acicular grades typically have aspect ratios of 15:1 to 20:1.

Surface-treated wollastonite – Both powder and acicular forms of wollastonite are readily available with silane, organosilicone, and titanate treatments.

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USES

The United States is the world's leading supplier of wollastonite, with 34% of total annual production of approximately 365,000 metric tons. China is a close second at 33%. The single largest application is in ceramics, which consumes 40-45% of production. Significant uses also are found in plastics, asbestos substitution, metallurgical powders, and paint.

Ceramics – Wall tile is the principal ceramic application for wollastonite, which promotes low shrinkage, low warpage, good strength, and permeability for fast firing with minimal gas evolution. Grades with low ignition loss, high fired brightness, and low coloring oxides of Fe, Ti, and Mn are used. In glazes wollastonite is used as a source of calcium silicate in place of limestone and flint, thereby reducing volatiles and increasing gloss. Wollastonite is also used in small amounts in semivitreous and vitreous bodies to reduce shrinkage and increase strength.

Plastics – Wollastonite is used as a reinforcing filler in plastics because of its low oil and moisture absorption, high brightness and acicularity, and availability with a variety of surface treatments. Acicular wollastonite is a lower cost alternative to short-milled glass fibers for both thermoplastics and thermosets, most notably in BMC polyester and RRIM polyurethane for automotive applications. It is likewise used as an asbestos substitute in phenolic molding compounds and as a reinforcing filler in Nylon 6 and 66. Micronized (-10 micron) wollastonite is used in high-impact and platable nylon compounds. Acid treatment of the plastic surface dissolves the wollastonite and provides a uniform anchor pattern for strong, smooth plating.

Asbestos substitution – High-aspect ratio wollastonite is used in high-temperature insulation board, wallboard, shaped insulation, and roofing tile as a substitute for short-fiber asbestos. It offers thermal stability, reinforcement, good acoustical properties, and relatively light weight in these applications. It is used together with organic and metallic fibers in asbestos-free formulations for friction products such as clutches, brake linings, and brake pistons.

Metallurgical powders – Low ignition loss, low-phosphorous (<0.01%), low-sulfur (<0.01%) wollastonite powder is used as a low-temperature flux in welding and steel casting formulations. In composite flux powders it helps maintain the surface flow of molten steel as it is poured from ladle to tundish, thereby minimizing surface defects.

Coatings – Powder grades are used in coatings as an extender pigment and to provide resistance to flash and early rust. Low oil and water absorption allow high loading levels. The acicular nature, even at low aspect ratios, reinforces paint films, providing durability and superior scrub resistance. Finely ground and micronized grades are also used in epoxy powder coatings because they promote smooth flow, water resistance, improved wet adhesion, and good gloss.

Other uses – Wollastonite is used as an energy-conserving alternative to limestone and sand in the production of glass and glass fiber and as a white reinforcing filler in adhesives and sealants, where it can be used at high loadings.

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ZEOLITE

	Channel Size (Angstroms)
Chabazite	3.7 x 4.2
Clinoptilolite	3.9 x 5.4
Erionite	3.6 x 5.2
Faujusite	7.4
Mordenite	2.9 x 5.7
Phillipsite	4.2 x 4.4
	2.8 x 4.8
Type A	4.2
Type X	7.4
Type Y	7.4
ZSM-5	5.4 x 5.6
	5.1 x 5.5

Zeolites are framework silicates based on a three dimensional network of SiO_4 and AlO_4 tetrahedra linked by shared oxygens. Since two aluminum atoms cannot share the same oxygen atom (Lowenstein's Rule), a zeolite unit cell contains at least as many, and usually more, silicon atoms as aluminum atoms. The presence of structural aluminum imparts a negative charge to the zeolite lattice. This is balanced in nature by alkali and alkaline earth cations. Synthetic zeolites are usually formed as the sodium-exchanged species and are subsequently converted to a hydrogen-, alkali-, alkaline earth-, or rare earth-exchanged product as required. The mineral framework contains openings and internal voids or channels of fixed dimensions characteristic of individual varieties. These internal channels are occupied by water that can be reversibly removed, leaving a microporous structure with up to 50% void volume. In general, a higher framework Si:Al ratio results in decreased ion exchange capacity and increased acidity, thermal stability, and hydrophobicity.

TYPES

Zeolites are fundamentally differentiated as being either natural or synthetic. Further classification is based on those specific properties that dictate commercial suitability for the general applications of catalysis, molecular sieving, ion exchange, and adsorption.

Natural zeolites – More than three dozen natural zeolite varieties have been identified, but only clinoptilolite, chabazite, and mordenite are commercially exploited to any significant extent. Natural zeolites are typically crushed and screened or ground and air classified to the required particle size, and some are offered in pelletized form. They are available in both hydrated and activated (dehydrated) forms and may be enhanced in H^+ or Na^+ content by washing with acid or NaCl, respectively.

Synthetic zeolites – More than 100 zeolites have been synthesized, but the principal commercial synthetics are Types A, X, Y, and ZSM-5. Type A has a unique structure based on sodalite cages and has a 1:1 Si:Al ratio to maximize ion exchange capacity. It is sold in a sodium form for ion exchange applications or in a calcium form for adsorption applications, since the larger sodium ion restricts internal access. Types X and Y are isostructural with natural faujasite but are tailored in their Si:Al ratios and are exchanged with rare earth cations as required for major catalytic applications. ZSM-5 is based on a unique pentasil structure that allows very high Si:Al ratios. This minimizes ion exchange and hydrophilicity. Despite its low ion exchange capacity, the hydrogen form of ZSM-5 is treated to develop higher catalytic activity than is exhibited by other common synthetics. Its channels are too small for use in petroleum cracking, but they are well suited for catalysis of certain small cyclic hydrocarbons.

USES

Japan is the leading producer of natural zeolites, followed by the former Soviet Union. Of the estimated 1 million metric tons of natural zeolites produced annually worldwide, the United States accounts for only about 2%. The leading producers of synthetic zeolites are the United States, Germany, and Japan. Although the technical properties and performance of natural zeolites and their synthetic counterparts overlap appreciably, in practice their applications are largely different. The higher uniformity, purity, and price of synthetics reserves for them most uses that justify these attributes. The principal uses for natural zeolites are ammonia removal from organic wastes, removal of radioactive cesium^{137} and strontium^{90} from nuclear wastes, odor control, and soil treatment. Synthetic zeolites are used in catalytic cracking at petroleum refineries, for drying, purifying, and separating industrial gas streams, and as detergent builders.

Aquaculture – Zeolites, principally clinoptilolite, are used to remove ammonia from water at fish hatcheries and farms, in aquaria, and in live fish transport systems. This prevents the eutrophication of such systems and thereby enhances fish mortality and growth.

Agricultural products – Zeolites, principally clinoptilolite, are used as vehicles for the controlled release of ammonia in fertilizers and as carriers of insecticides, herbicides, and fungicides. They also are added to contaminated soils to scavenge radioactive Cs^{137} and Sr^{90}, plus Pb, Cd, and other toxic heavy metals. Zeolites are used as animal feed supplements to improve nutrient efficiency and growth rates for poultry and swine while reducing manure moisture and odor. Drier, less odoriferous manure can be used as a fertilizer that has slow release properties. Natural zeolites also are used as litter for horse stalls, pig pens, poultry houses, and household pets. Here they control ammonia odors and absorb liquid wastes.

Waste treatment – Clinoptilolite, chabazite, mordenite, and phillipsite remove radioactive Cs^{137} and Sr^{90} from nuclear waste streams and serve as encapsulants for these isotopes to facilitate solid waste disposal. Zeolites, particularly clinoptilolite, are used in treating sewage and industrial waste streams to remove ammonia and heavy metals. Extracted ammonia is subsequently vented, recovered for chemical use, or converted with sulfuric acid to ammonium sulfate fertilizer.

Gas adsorption – Zeolites with appropriate channel dimensions are used for the selective removal of cetain gases from gaseous mixtures. Mordenite and calcium Type A are preferred for adsorbing nitrogen from the air to generate relatively pure oxygen for medical and industrial uses. The latter include oxygenation of pulp and paper mill effluents, waste and sewage treatment streams, and metal smelters. Natural gas and methane generated by animal waste, sanitary landfills, and sewage systems are purified by treatment with synthetic zeolites, principally Type A, to remove H_2O, CO_2, SO_2, and H_2S. Clinoptilolite and mordenite can be used to remove SO_2 from the stack gases at fossil fuel-burning power plants.

Detergents – The sodium form of Type A is used in powdered detergents as a primary sequestrant for calcium. It also removes magnesium, plus the iron and manganese that can cause stains. Its high adsorptivity allows the incorporation of high levels of liquid surfactants, thus enabling the production of highly concentrated, free-flowing products.

Catalysts – The primary application for zeolites in catalysis is for specially stabilized Type Y in petroleum cracking, whereby crude oil is broken down into gasoline and fuel oils. The zeolite content of FCC (fluid cracking catalysts) ranges from 5% to 50% . The ultrastable Type Y zeolite also is used to improve the octane rating of gasoline. ZSM-5 zeolites are used primarily to produce gasoline from methanol by both catalysis and molecular sieving. Methanol is first converted to dimethyl ether, which is further converted by the zeolite to a mixture of hydrocarbons. Organic molecules too large to be suitable for gasoline are trapped within the zeolite structure until they are broken down enough to escape. The size- and shape-selectivity of ZSM-5 is likewise used in chemical synthesis for the conversion of toluene to benzene and *p*-xylene. The shape of any *m*- and *o*-xylene initially formed impedes their escape from the zeolite channels. Most remain “trapped” long enough for conversion to the *p* form.

Other uses – Zeolites find additional uses as desiccants, heat storage media, filters for air cleaning, and (in Japan) as paper fillers.

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