2

Sources of Fillers, Their Chemical Composition, Properties, and Morphology

The information included in this chapter is based on the data selected from the technical information included in the manufacturers literature and research papers. The main goal of this chapter is to provide information on:

- Physical and chemical characteristics of fillers
- Morphology of filler particles
- Sources of fillers
- Manufacturers
- Important commercial grades
- Major applications
- Relevant studies

Data for each filler are presented in the form of a standard table which contains, for a particular filler, only sections for which information was available. The physical characteristics of fillers and other data on characteristic parameters are taken from the manufacturers literature and open literature to show the range of properties rather than values for a particular grade. The information on the characteristics of every grade is extensive and comes from over 150 manufacturers. Large quantity of information gathered is presented as established data in tabular form. A future publication on CD-ROM will present full information on all grades available worldwide.

Commercial information is presented in an abbreviated form in the individual tables. In addition to this information, there is an appendix included at the end of this book which provides references to the manufacturers and distributors of these products worldwide. There is no distinction made in the tables between the manufacturers and distributors.

The text which follows the table for a particular group of fillers discusses manufacturing methods, morphology and explains and amplifies the tabular data.

2.1 PARTICULATE FILLERS

2.1.1 ALUMINUM FLAKES AND POWDER[1-6]

Names: aluminum flakes, aluminum pigments, leafing aluminum pigments		**CAS #**: 7429-90-5
Chemical formula: Al	**Functionality**: OH	
Chemical composition: Al - 95.3-99.97%; oxide content - 1-3%, lubricant content - 0.2-4%		
Trace elements: Si - 0.05-.025%, Fe - 0.1-0.4%, other - 0.03-0.05%		
PHYSICAL PROPERTIES		
Density, g/cm^3: 2.7	**Mohs hardness**: 2-2.9	**Melting point**, ^{o}C: 660
Specific heat, kJ/kg · K: 0.90		
Thermal conductivity, W/K · m: 204	**Thermal expansion coefficient**, 1/K**:** 25x10^{-6}	
CHEMICAL PROPERTIES		
Chemical resistance: excellent corrosion resistance, reacts with alkaline and acidic solutions yielding hydrogen gas		
OPTICAL & ELECTRICAL PROPERTIES		
Color: silvery white to chromelike (leafing) metalescent (nonleafing)		
Resistivity, Ω-cm: 2.8 x 10^{-6}		
MORPHOLOGY		
Particle shape: flat, spherical	**Crystal structure**: cubic	**Particle size**, μm: 10-23 (powder)
Aspect ratio: 20-100	**Particle thickness**, μm: 0.1-2	**Particle length,** μm: 0.5-200
Sieve analysis: 0.1-20% retained on 325 (44 μm) sieve		**Specific surface area**, m^2/g: 5-35

MANUFACTURER & BRAND NAMES:

Silberline Manufacturing Co., Inc., Tamaqua, PA, USA

manufactures several hundred grades of aluminum powders and flakes. The products are grouped by the particle character (powder, leafing, nonleafing), resistance to acids (non-resistant, resistant), application (general, waterborne, plastics, printing inks, specialty, other (inhibited aluminum pigments, water dispersible aluminum pigments, degradation resistant, sparkle and high series, lenticular series, glitter series, black iron flake, spherical pigments, extra sparkle spheres, metalescent pigments, dedusted flake, colored pigments, resin treated grades)). The following are trade names: Aqua Paste, Aquasil, Aquavex, EternaBrite, Extra Fine, Hydro Paste, Lansford, SilBerCotes, SilBerTones, Silcroma, Sil-O-Wet, Silvar, Silvet, Silvex, Sparkle Silver, Stamford, Super Fine, Tufflake

Transmet, Columbus, OH, USA

Aluminum, copper, brass, and zinc particulate materials manufactured in various shapes of square flake (K-102), rectangular flake (K-101), flat fiber (K-107), flake (K-109), needle (N-101), and tadpole (T-101, T-102, T-103). The symbols in parentheses are the grades numbers for aluminum. If other metal is requested the grade number is derived from the metal number which is the first digit (1 - aluminum, 2 - copper, 3 - zinc, 4 - brass). For example, square flake from brass is K-402. The materials are manufactured by two technologies Melt spin and Spinning cup which are discussed below.

MAJOR PRODUCT APPLICATIONS: coatings, inks, roofing, plastics, automotive, powder coatings, containers for sterilizing and storing medical instruments, molding tools, heat sinks for electronic devices, time-delay switch, egg poachers
MAJOR ADVANTAGES: heat reflectivity, low emissivity, temperature resistance, moisture and oxygen barrier properties, sealing properties, reinforcement

The technology of production of aluminum powders and flakes dates back to 1930 when a safe process of manufacture was developed by Hall of Columbia University. This method is still used today for most manufactured pigments. The principle of manufacture is based on wet ball milling aluminum in the presence of a lubricant and mineral spirits.

The grinding process depends on the grade to be manufactured and usually takes 5-40 hours. The grade is determined by the particle size and grading is accomplished by filtering the slurry to remove large flakes. Typical leafing grades have 55-65% leafing flakes. The ultraleafing grades have almost 100% leafing flakes. An important difference exists between leafing and nonleafing flakes. Leaving flakes are obtained by the addition of a fatty acid (e.g., stearic acid) lubricant during the milling process. The lubricant coats the surface of flakes which become hydrophobic. There is a large difference in behavior between leafing and nonleafing flakes in coatings. Nonleafing flakes are uniformly distributed through the thickness of coating. They are preferentially oriented parallel to surface but this orientation is not perfect. Leafing flakes are mostly situated close to the paint surface and far from the substrate. Their orientation is much closer to parallel than the orientation of nonleafing flakes. Nonleafing pigments are frequently used with other pigments to obtain colored metallic finish. Leafing flakes give paints a metallic luster and reflectivity. In plastics, a true leafing effect has not yet been accomplished.

Processing of materials containing aluminum flakes must take into account their fragile nature. If flakes are exposed to extensive shearing forces they will degrade. Slow mixing and gradual dilution of flakes normally produces good results.

The commercial products are in most cases in the form of a paste. Standard pastes contain 27-35% mineral spirits. For waterborne applications carrier contains mixture of mineral spirits, nitroethane, and polypropylene glycol. Ink grades contain isopropyl alcohol or ink oil. Plastic grades are dispersed in plasticizer (DOP, DIDP), mineral oil or resin.

Transmet Corporation manufactures flakes by a Rapid Solidification Technology. There are two variations of this method: Melt spin and Spinning cup methods. In the Melt spin method, molten metal of any composition (pure metal or alloy) is driven through an orifice and the shape formed in the orifice (continuous sheet) is rapidly cooled on a chilling block. This metal sheet is cut into segments in the form of flakes (square and rectangular), flat fibers, and ribbons of desired

dimensions. Typically, the sheet has thickness of 25 μm and the cut sides (length or width) have a length in the range of 0.5 to 2 mm. In the Spinning cup method, molten metal is driven through an orifice onto a rotating element (spinning cup) which works in manner similar to spray drying equipment. The particles are dispersed in space by tangential forces. In this process, spheres, needles and tadpoles are manufactured. The method can produce a broad range of compositions and shapes. It was determined, based on the rates of chemical reactions, that the shape of particles has a pronounced effect on the reaction rate. The shape of particles and their composition has an effect on their performance in conductive plastics and as reflecting media in coatings. The metal particles produced by this method have found applications in various products which are required to conduct heat and electricity, to shield EMI, and to reflect radiation in roofing materials, in addition to the traditional use of such materials in chemical and metallurgical processes. Figure 19.17 shows the cost of EMI shielding using aluminum flakes in comparison with other materials based on Transmet estimation.

2.1.2 ALUMINUM BORATE WHISKERS[7-8]

Name: aluminum borate whisker		
Chemical formula: $(Al_2O_3)_9(B_2O_3)_2$		
PHYSICAL PROPERTIES		
Density, g/cm^3: 2.93	**Thermal expansion coefficient**: 7.4x10^{-6}	
Tensile strength, GPa: 7.8	**Tensile modulus**, GPa: 400	**Compressive strength**, GPa: 3.9
MORPHOLOGY		
Particle shape: ribbon or cylinder	**Crystal structure**: single crystal	**Specific surface area**, m^2/g: 2.5
Particle length, μm: 10-30	**Particle diameter,** μm: 0.5-1	**Aspect ratio**: 20-30
MANUFACTURER & BRAND NAME: Shikoku Chemical Corp. - Alborex G		
MAJOR PRODUCT APPLICATIONS: experimental phase as reinforcing filler		

2.1.3 ALUMINUM OXIDE[9-12]

Names: anhydrous aluminum oxide, α-, or γ-, or θ-alumina		**CAS #**: 1344-28-1
Chemical formula: Al_2O_3	**Functionality**: PBD-coated[10]	
Chemical composition: Al_2O_3 - 99.6%		
Trace elements: SiO_2 - 0.02-0.1%, Fe_2O_3 - 0.03-0.2%, TiO_2 - 0.1%, Na_2O - 0.04-5%, HCl - < 0.5%		
PHYSICAL PROPERTIES		
Density, g/cm^3: 3.4-3.9	**Mohs hardness**: 9	**Melting point**, °C: 2015-2072
Thermal conductivity, W/K · m: 20.5-29.3	**Maximum temperature of use**, °C: 1600	
Compressive strength, MPa: 2000	**Surface properties**: hydrophilic	
CHEMICAL PROPERTIES		
Moisture content, %: 4-5	**Adsorbed moisture**, %: 17-27%	**pH of water suspension**: 8-10
OPTICAL & ELECTRICAL PROPERTIES		
Refractive index: 1.7		**Whiteness**: 80-90
Color: white through off white to brown		**Volume resistivity**, Ω-cm: >10^{14}
Dielectric constant: 9-9.5	**Dielectric strength**, V/cm: 2560	**Loss tangent**: 0.0002-0.004
MORPHOLOGY		
Particle shape: spherical or irregular		**Pore diameter,** Å: 58-240
Particle size, nm: 13-105	**Crystal structure**: rhombic	**Oil absorption**, g/100 g: 25-225
Sieve analysis: 0.05-5% on 45 μm sieve		**Spec. surface area**, m^2/g: 0.3-325

MANUFACTURERS & BRAND NAMES:

Alcan Chemicals, Gerrards Cross, UK
- Milled grades: RMA, MA, MAFR
- Calcinated alumina: C-70 series, RA (ceramics), Cera (polishing, electrical components), CA, CG, CK (glass, ceramic fibers, etc), Baco (polishing), MA-LS (refractories, ceramics), LS (electrical and engineering components)
- Activated alumina: AA (catalysts, desiccant, fluorine removal from water), Acidsorb (adsorption of HCl from chemical processes), Actibond (refractory binder)

Biotage, Inc.
- Unisphere

Degussa AG, Frankfurt/Main, Germany
- Al_2O_3 C

Electro Abrasives Corporation, Buffalo, NY, USA
- Electro-Ox brown aluminum oxide and precision aluminum oxide abrasive

Morgan Matroc, Stourport-on-Seven, UK
- Aluminum oxide

Nanophase Technologies Corporation, Burr Ridge, IL, USA
- NanoTec Aluminum Oxide

The PQ Corporation, Valley Forge, PA, USA
- Nyacol Colloidal Alumina, Nyacol AL20SD

MAJOR PRODUCT APPLICATIONS: composites, ceramics, refractories, abrasives, copy toner, electro-optic devices, polishing, electrical and engineering components, acid adsorption, catalyst, nanocomposites

Refractory grades have large particle sizes in the range of 5-25 μm and very low surface area at 0.3-1 m^2/g. Their specific gravity is high at 3.95 g/cm^3. Calcinated alumina is produced by the Bayer calcination process from aluminum trihydroxide in rotary kilns. During the process, water is removed and stable α-alumina structure is obtained. The particle size of calcinated grades is similar to refractory grades unless they are milled. Smaller particle size grades have a specific surface area of 3-10 m^2/g. Activated aluminas have particle sizes in the range of 6-80 μm but very large specific surface areas in the range of 220-325 m^2/g. They can readily absorb water to equilibrium at 18-22%.

The grades produced by Nanophase Technologies Corporation are obtained in a synthetic way by evaporation of the metal and its subsequent oxidation. This process produces regular spherical particles as shown in Figure 2.1.[13-14] These materials have properties which cannot be duplicated by conventional grades of alumina obtained from minerals or by chemical synthesis. The nanoparticles are known to enhance mechanical performance of plastic materials (tensile, hardness, wear, etc.). The hardness of compressed ceramics increases as the particle size decreases and it is possible to obtain materials which allow considerable light transmission. These materials are on the market now and they will find many high technology applications.

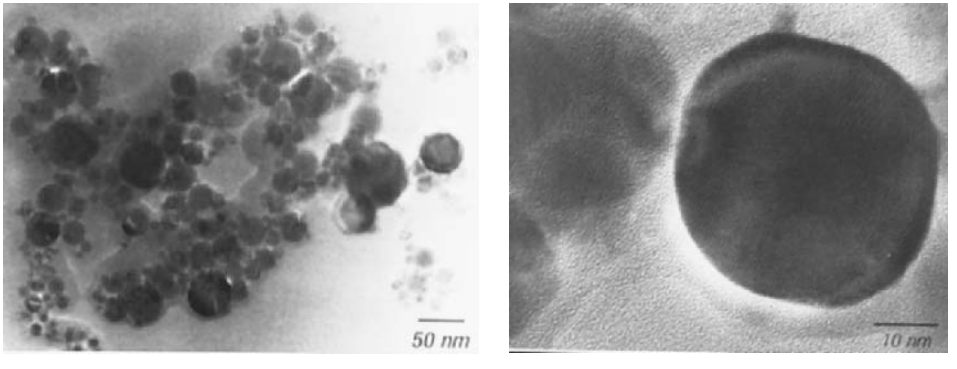


Figure 2.1. TEM of NanoTek aluminum oxide. *Courtesy of Nanophase Technologies Corporation, Burr Ridge, IL, USA.*

2.1.4 ALUMINUM TRIHYDROXIDE[15-39]

Names: aluminum trihydroxide, aluminum hydroxide, hydrated alumina		**CAS #**: 21645-51-2
Chemical formula: $Al(OH)_3$ or $Al_2O_3 \cdot 3H_2O$	**Functionality**: OH, methacryl, vinyl, stearic acid, viscosity reducer (Alcan grades S)	
Chemical composition: $Al(OH)_3$ - 94-97%, Fe_2O_3 - 0.01%, SiO_2 - 0.01-0.03%, Na_2O - 0.2-0.5%		
Trace elements: Pb < 0.0005%, As < 0.0002%		
PHYSICAL PROPERTIES		
Density, g/cm^3: 2.4	**Mohs hardness**: 2.5-3.5	**Melting point**, ^{o}C: 290 (decomp)
Loss on ignition, %: 34.5		
CHEMICAL PROPERTIES		
Chemical resistance: amphoteric material		
Moisture content, %: 0.1-0.7		
pH of water suspension: 8-10.5	**Loss on ignition**, %: 34.6%	**Specific conductivity**, µS/cm: 70
OPTICAL & ELECTRICAL PROPERTIES		
Refractive index: 1.57-1.59	**Reflectance**: 89-95	**Whiteness**: 93
Color: bright white (Hunter L = 90-98)		**Brightness**: 91-98
Electrical conductivity, µS/cm: 5		**Dielectric constant**: 7
MORPHOLOGY		
Particle shape: irregular	**Crystal structure**: gibbsite	
Particle size, µm: 0.7-55	**Oil absorption**, g/100 g: 12-41	**Hegman grind**: 5.5-6
Sieve analysis: 325 mesh residue - 0.001-0.15%		**Spec. surface area**, m^2/g: 0.1-12

MANUFACTURERS & BRAND NAMES:

Alcan Chemicals, Gerrards Cross, UK
: Alcan AF (toothpaste grade), DH 101 (feedstock grade), FRF (general purpose), FRF LV (particle size optimized to give higher loading), ULV (optimized morphology for high loading and reduced viscosity), CV (modified particle shape improvement of cure time and lower viscosity), Precipitated (rounder particles offer denser particle packing and lower viscosity), Superfine (small particle size 0.5-1.2 µm E grades have much lower ionic impurity for electrical insulation), and Ultrafine (low Na_2O content for application in cables), Flamtard S (zinc stannate), H (zinc hydroxystannate), HB1 (zinc hydroxystannate/zinc borate blend), Z10 & Z15 (zinc borate). Flamtard additives enhance performance of ATH. Cera Hydrate (abrasive)

Amspec Chemical Corporation, Gloucester City, NJ, USA
: Hydromax 100, 109

Charles B. Chrystal Co., Inc., New York, NY, USA
: Aluminum trihydroxide

Franklin Industrial Minerals, Nashville, TN, USA
: DH 35, 55, 80, 100, 200, 280, 500 (number = median particle size x 10)

Hitox Corporation, Corpus Christi, TX, USA
: Haltex 302, 310, 304

continues on the next page

MANUFACTURERS & BRAND NAMES:
Huber, J.M., Macon, GA, USA
PATH 6, 9, 9HB (optimized as partial replacement of TiO_2 in coating applications)
Martinswerk, Bergheim, Germany
Martinal ON-921, OL 104, OL111
Nabaltec GmbH, Schwandorf, Germany
Apyral 1, 2, 3, 4, 8, 15, 16, 24, 22, 40, 60, 90, 120 (number = specific surface x 10)

MAJOR PRODUCT APPLICATIONS: carpet backing, coatings, PU-foam, pultrusion, laminates, composites, conveyor belts, cables, flooring, chipboard, tub and shower stalls, coated fabrics, electrical products, polishing, exterior cladding, tiles, synthetic marble, adhesives, coatings and sealants, sheet molding compounds, toothpaste

MAJOR POLYMER APPLICATIONS: polyester, epoxy, acrylic, PVC, PP, PE, EVA, polyurethanes, phenolics

The production process for aluminum trihydroxide might be considered a spin off of aluminum metal production where in the first phase, the metallurgical grade of aluminum trihydroxide is produced.[38] At the same time, this grade contains numerous impurities and requires purification. Filler grade production is a separate from the production of the metallurgical grade and yields a pure aluminum trihydroxide. Two properties made aluminum trihydroxide very popular: its flame retarding abilities and its low absorption of UV.

The low absorption of UV makes it a suitable material for applications in UV curable materials. Its flame retarding activity is due to cooling, barrier layer formation, and dilution. The cooling capability of aluminum trihydroxide comes from its ability to release water at elevated temperatures with peak release at around 300^{o}C. The reaction by itself is endothermic and, in addition, water must be evaporated which consumes additional heat energy. Aluminum trihydroxide, after it has been decomposed, forms a barrier which slows the flow of oxygen and formation of gases. Large quantities (e.g., 150 phr) of filler must be used to obtain flame retarding properties (dilution factor). This provides flame retardancy but affects the mechanical and rheological properties of materials. Since the amounts of filler cannot be significantly reduced, additives such as compounds of zinc are used which allow for some reduction in $Al(OH)_3$ concentration. Mechanical properties are improved by the morphology and surface coating of the filler. Grades are available which can be used with many plastics without a fear of degrading their mechanical performance. The problem of rheology of materials during processing and use is addressed by the modification of the morphology of particles and with additives which help to reduce viscosity.

Figures 2.2 and 2.3 show how morphology might be tailored to improve viscosity. Figure 2.2 shows a precipitated grade which is composed of blocky round particles. The careful selection of an appropriate particle size distribution of these morphologically different species resulted in a low viscosity material. Figure 2.3 shows another grade which has platy particles which give a higher viscosity (as might be expected).

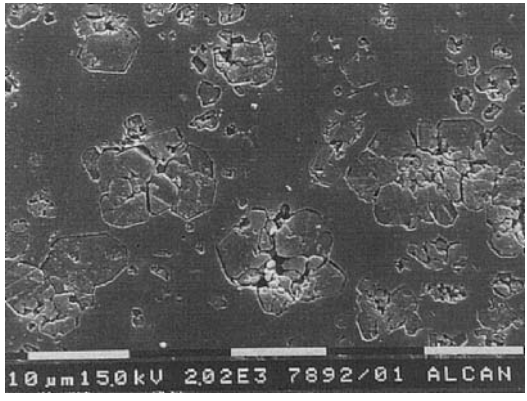


Figure 2.2. SEM of aluminum trihydroxide decreasing viscosity. *Courtesy of Alcan Chemical Europe, Gerrards Cross, UK.*

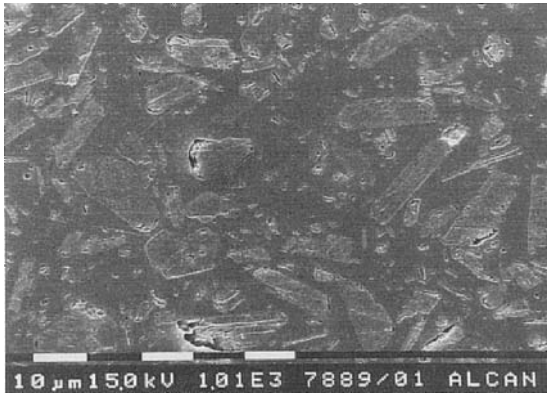


Figure 2.3. SEM of aluminum trihydroxide increasing viscosity. *Courtesy of Alcan Chemical Europe, Gerrards Cross, UK.*

2.1.5 ANTHRACITE[43]

Names: anthracite, semi-anthracite coal, bituminous coal		**CAS #**: 8029-10-5
Chemical formula: C	**Functionality**: OH	
Chemical composition: carbon - 77%, ash - 6-16%		
Trace elements: sulfur - 0.23-1.2%, silica oxide - 2.2-5.4%, alumina - 2%, ferric oxide - 0.4%		
PHYSICAL PROPERTIES		
Density, g/cm^3: 1.31-1.47	**Mohs hardness**: 2.2	
CHEMICAL PROPERTIES		
Moisture content, %: 0.5-4	**pH of water suspension**: 7-7.5	**Volatiles content**, %: 0.5-20
ELECTRICAL PROPERTIES		
Resistivity, MΩ-cm: 50		
MORPHOLOGY		
Sieve analysis: residue on 325 mesh - traces		**Particle shape**: irregular
MANUFACTURERS & BRAND NAMES: Anthracite Industries, Inc., Sunbury, PA, USA 4072-C, 505, 7002, 7004, Anthrin Filler, Carbon Filler Oxide Coal Fillers, Inc., Bluefield, VA, USA Austin Black - low specific gravity reinforcing and mineral filler Keystone Filler & Manufacturing Company, Muncy, PA, USA Mineral Black 121 OC, 123, 126, 325BA		
MAJOR PRODUCT APPLICATIONS: liner, battery cases		
MAJOR POLYMER APPLICATIONS: rubber, EPDM, PP, PE		

Anthracite abounds as a mineral and can be cost-effectively mined and ground. It was found[43] that materials containing it have improved strength, stiffness, environmental stress cracking, heat deflection temperature, antistatic properties, weathering resistance, and chemical resistance even if filled with substantial quantities of anthracite (up to 60 wt%). The disadvantages are color, flowability of melt, and increased moisture absorption. One major advantage creates growing interest. Most fillers used today are non-combustible and remain as ash when plastic materials are incinerated at the end of several recycling operations. Anthracite has, by comparison, a very low ash content and provides calorific value.

2.1.6 ANTIMONATE OF SODIUM

Name: sodium antimonate	
Chemical formula: $NaSbO_3$	**Functionality**: ONa
Chemical composition: Sb_2O_3 - 70-73%, Sb_2O_5 - 80%, $NaSbO_3$ - 95%	
Trace elements: As - 0.3-0.5%, Pb - 0.6-1%, Fe - 0.004-0.0055%, Cu - 0.004%	
PHYSICAL PROPERTIES	
Density, g/cm^3: 4.8	
CHEMICAL PROPERTIES	
Chemical resistance: it is soluble in, and reactive with, acids	
Moisture content, %: 0.5-3	**Acid soluble matter**, %: 100
OPTICAL PROPERTIES	
Refractive index: 1.75	**Color**: white to light tan
MORPHOLOGY	
Sieve analysis: 325 mesh residue - 12-45%	
MANUFACTURERS & BRAND NAMES: Laurel Industries, Cleveland, OH, USA Thermogard FR United States Antimony Corporation, Thompson Falls, MT, USA Montana Brand Sodium Antimonate Grade 1	
MAJOR PRODUCT APPLICATIONS: chemical intermediate in production of antimony pentoxide; flame retardant in plastics, paints, textiles	
MAJOR POLYMER APPLICATIONS: PBT, PET, PC, UHDPE, rubber	

Sodium antimonate must be used with halogen containing compounds for it to act as effective fire retardant. The source of chlorine may come from polymer (e.g., PVC, chlorinated rubber, etc.) or other chlorinated or brominated material. The benefits of using sodium antimonate over antimony oxide include its low tinting strength and the acid scavenging capability. For these reasons, it is used in semi-opaque or dark colored materials and in polymers such as polyesters and polycarbonates which are acid sensitive.

2.1.7 ANTIMONY PENTOXIDE

Name: antimony pentoxide		**CAS #**: 1314-60-9
Chemical formula: Sb_2O_5 or $HSb(OH)_6$ in hydrated form	**Functionality**: OH	
Chemical composition: Sb_2O_5 - 92-95%		
PHYSICAL PROPERTIES		
Density, g/cm^3: 3.8		**Melting point**, ^{o}C: 380
CHEMICAL PROPERTIES		
Chemical resistance: soluble in hot acid		
Moisture content, %: 0.2-1%	**pH of water suspension**: 2.5-9	
OPTICAL PROPERTIES		
Refractive index: 1.7	**Tinting strength**: low	**Color**: white to yellow
MORPHOLOGY		
Particle size, μm: 10-40, 0.025-0.075 (colloidal)		
MANUFACTURER & BRAND NAMES: The PQ Corporation, Valley Forge, PA, USA Nyacol Aqueous Dispersions: A1530, A1540N, A1550 (last two digits give oxide concentration) Nyacol Organic Dispersions: AB40, AP50, APE1540 (last two digits give oxide concentration) BurnEx Powders: Plus A1588LP, Plus A1590, ZTA BurnEx Nano-Dispersible Powders: A1582, ADP480, ADP494 (for dispersions in water, non-polar solvents, and polar solvents, respectively) BurnEx 2000: 10, 20 (dispersed in PP of nano-dispersible grade and organic bromine compound)		
MAJOR PRODUCT APPLICATIONS: textiles, coatings, nonwovens, adhesives, fibers (carpet, draperies, clothing), polyester laminates, wallcoverings, wire insulation, office furniture, automotive interiors, electrical housings, computers, printers, appliances, telecommunication, film, sheet		
MAJOR POLYMER APPLICATIONS: epoxy, polyester, PVC, ABS, HIPS, PP		

Antimony pentoxide is an alternative to antimony trioxide. It finds applications in semi-transparent materials and dark colors because of its low tinting strength. As with antimony trioxide, antimony pentoxide must be used together with halogen-containing compounds to function as a flame retardant (see discussion under antimony trioxide). The other advantages of antimony pentoxide include its refractive index which is closer to most materials, its very small particle size, its high specific surface area, and its substantially lower density. Because of its small particle size, its is frequently used in the textile industry since its addition has only a small effect on color or on mechanical properties. Production of fine-denier fibers requires a stable dispersion and a small particle size filler. The flame retardancy of laminates is also improved with antimony pentoxide because small particles are easier to incorporate in the interfiber spaces.

Antimony pentoxide, as an additive for plastic materials such as polyolefins and ABS, is produced in predispersed form containing halogen compounds and a polymeric binder which has a low melting index to aid incorporation.

Incorporation of aqueous dispersions of antimony pentoxide into latex requires a pH adjustment prior to adding it to latex to prevent latex coagulation. Dispersions of antimony pentoxide usually have a pH = 5 which is too low for use in most latex formulations. Adjustment of pH can be made with ammonia but prior to such a pH adjustment it is necessary to dilute the dispersion to a concentration below 40% Sb_2O_5.

The use of particulate Sb_2O_5 in plastics extrusion requires that some precautions be taken. The extruder temperature setting must be below the level which degrades halogen-containing additive (180-250^{o}C), The vented extruder should be used to remove free moisture. The antimony pentoxide must be kept sealed when not in use to prevent moisture pickup and dust generation should be prevented during handling. If antimony pentoxide is used in materials which do not contain halogen, the formulation should include sufficient halogen-containing additive to provide halogen/antimony mole ratio of 3/1.

2.1.8 ANTIMONY TRIOXIDE[39-42]

Name: antimony trioxide		**CAS #**: 1309-64-4
Chemical formula: Sb_2O_3	**Functionality**: none	
Chemical composition: Sb_2O_3 - 98-99.5%		
Trace elements: As - 0.02-0.2%, Pb - 0.04-0.3%, Fe - 0.004-0.01%, Se - 0.005%, SO_4 - 0.002-0.05%		
PHYSICAL PROPERTIES		
Density, g/cm^3: 5.2-5.67		**Melting point**, °C: 656
CHEMICAL PROPERTIES		
Chemical resistance: reactive with acids and bases		
Moisture content, %: 0.1	**Water solubility**, %: 0.001	
pH of water suspension: 2.0-6.5	**Acid soluble matter**, %: 100	
OPTICAL PROPERTIES		
Refractive index: 2.087		
Color: white		**Tinting strength**: high to low
MORPHOLOGY		
Crystal structure: cubic or orthorhombic		**Specific surface area**, m^2/g: 2-13
Sieve analysis: 325 mesh residue - 0.1-0.5%		**Particle size**, μm: 0.2-3
MANUFACTURERS & BRAND NAMES: AMSPEC Chemical Corporation, Gloucester City, NJ, USA KR (excellent whiteness and tinting strength), KR - Superfine (small particle size for fiber and film), LTS (low tint for darker colors), AMSTAR (utility grade for cost effective applications) Laurel Industries, Cleveland, OH, USA FireShield H (high tint strength), L (low tint strength), HMP (high purity, low trace metals), UltraFine (low particle size, 0.2-0.4 μm gives reduced loss of mechanical properties, and higher tinting strength than H) United States Antimony Corporation, Thompson Falls, MT, USA VF (very fine), MP (micro pure), HT (high tint), LT (low tint), Industrial Grade		
MAJOR PRODUCT APPLICATIONS: plastics, textiles, paper, paints, rubber, UV resistant pigments		
MAJOR POLYMER APPLICATIONS: PA, PVC, PP, PE, ABS, HIPS, polyester, polyurethanes, rubber, epoxy		

Antimony oxide is usually produced from stibnite (antimony sulfide) or by oxidizing antimony metal.

Many theories attempt to explain the mechanism of flame retardancy. The flame retarding action is thought to take place in the vapor phase above the burning surface. For antimony oxide to work, the halogen and antimony oxide must be found in a vapor phase which will occur at temperatures above 315°C. At these temperatures, antimony halides and oxyhalides are formed and act as flame extinguishing moieties by quenching radicals as they form.

The tinting strength depends on particle size. If particle sizes are below 300 nm they fall below visible range. Above this value, tint strength decreases as the particle size increases. The high tint strength grade usually has particle sizes in a range of 1.1-1.8 μm and the low tint strength grade has particle sizes in a range of 1.8-3 μm. The tint strength can also be affected by crystalline form. The orthorhombic form decreases tint strength.

Different formulations are needed for individual polymers (according to the manufacturer AMSPEC). These concentrations are recommended: PVC: Sb_2O_3 - 2-10 phr; PP: Sb_2O_3 - 2-4 phr, brominated organic 4-22 phr; ABS: 4:1 organo-Br/Sb_2O_3; HIPS: Sb_2O_3 - 4 phr, aromatic bromine - 12 phr, polyurethanes: 5-15 phr Sb_2O_3 and 5-15 phr halogenated compounds.

The manufacturers offer a wetted grade of antimony oxide to reduce dust. This is made by the addition of 3-4% plasticizer (DIDP, DOP, DINP, or ethylene glycol). Concentrates are produced by manufacturers and specialized companies. United States Antimony Corporation manufacturers concentrates with up to 90% active component. Laurel Industries produce both antimony oxide and organic flame retardants which are sold separately and in ready to use combinations which also include resin carriers. Paraffin is a convenient binder for extrusion and molding applications. Arethon International Plastics Ltd. has a full range of flame retardant masterbatches which are marketed under the brandname Areflam. The active content in these masterbatches is from 50 to 80%. They are prepared with more than 10 carrier resins and have the correct content of halogen-containing material and Sb_2O_3 or, in the case of halogen-free masterbatch, appropriate amount of $Al(OH)_3$.

Antimony oxide can be advantageously combined with huntite/hydromagnesite fillers to offer excellent flame retarding properties.[39,42] Also, zinc borate can be used to reduce the amount of antimony trioxide. Other performance enhancing additives include zinc stannate and ammonium octamolybdate.[40]

2.1.9 APATITE[44-45]

Names: apatite, calcium (fluoro, chloro, hydroxyl) phosphate		
Chemical formula: $Ca_5(PO_4)_3(OH,F,Cl)$	**Functionality**: OH, CL, F	
PHYSICAL PROPERTIES		
Density, g/cm^3: 3.1 - 3.2	**Mohs hardness**: 5	
OPTICAL PROPERTIES		
Color: white to yellow		**Brightness**: 58-63
MORPHOLOGY		
Particle size, μm: 43	**Crystal structure**: hexagonal	**Cleavage**: basal direction
MAJOR PRODUCT APPLICATIONS: paper, medical (replacement bones)		
MAJOR POLYMER APPLICATIONS: PMMA		

2.1.10 ASH, FLY[46-49]

Names: fly ash		**CAS #**: 60676-86-0
Chemical formula: variable composition	**Functionality**: variable	
Chemical composition: SiO_2 -30-60%, Al_2O_3 - 11-19%, Fe_2O_3 - 4-11%, MgO - 5-6%, CaO - 2-45%		
Trace elements: sodium, boron, potassium, strontium, barium, molybdenum, lithium, vanadium, chromium		
PHYSICAL PROPERTIES		
Density, g/cm^3: 2.1-2.2		
CHEMICAL PROPERTIES		
Moisture content, %: 2-20		
MORPHOLOGY		
Particle shape: irregular	**Particle size**, μm: 4	**Porosity**: high
Sieve analysis: residue on 325 mesh sieve - 5%		
MAJOR PRODUCT APPLICATIONS: concrete modification, composite, building materials, polyester mortar		
MAJOR POLYMER APPLICATIONS: PP, PE, PU, PET		

Fly ash may become more extensively used as a inexpensive filler. It is not used in large quantities at the present time. Research studies[46-49] show that materials can be improved when fly ash is used as a filler. The major hurdle is health and safety since fly ash contains crystalline silica and is, consequently, considered a hazardous material.

2.1.11 ATTAPULGITE

Names: attapulgite, hydrous magnesium aluminum silicate, Fuller's earth, palygorskite, clay		**CAS #**: 12174-11-7
Chemical formula: variable composition	**Functionality**: OH	
Chemical composition: SiO_2 - 50-68%, Al_2O_3 - 9-12%, MgO - 3-12%, Fe_2O_3 - 3-5%		
Trace elements: potassium, sodium, magnesium		
PHYSICAL PROPERTIES		
Density, g/cm^3: 2.3-2.4	**Mohs hardness**: 1-2	**Loss on ignition**, %: 5-23
CHEMICAL PROPERTIES		
Moisture content, %: 2-16	**Adsorbed moisture**, %: 1-6	**pH of water suspension**: 6.5-9.5
Volatiles content, %: 5-15		
OPTICAL PROPERTIES		
Color: buff, tan, cream		**Refractive index**: 1.57
MORPHOLOGY		
Particle shape: irregular, needle	**Crystal structure**: monoclinic	**Oil absorption**, g/100 g: 60-120
Particle size, μm: 0.1-20	**Specific surface area**, m^2/g: 120-400	
Sieve analysis: residue on 325 mesh sieve - 0.01-8		
MANUFACTURERS & BRAND NAMES: Milwhite, Inc., Houston TX, USA Attapulgite A, LMV, RVM, Basco Salt Mud, Econosorb, Fertogel, Gel B, Gel 420-P, Gel 540-P, Gel 601-P, High Yield Attapulgite, Milfines, Milsorb, Milsorb-CG, Supper Gel B Non-Metals, Inc., Affiliate of The China Non-Metallic Minerals, Tucson, AZ, USA Attapulgite clay for paint, adsorbent, drilling mud, and fertilizer		
MAJOR PRODUCT APPLICATIONS: pesticides, herbicides, fertilizers, absorbents, drilling mud, joint compounds, neutralizers, asphalt thickeners, adhesives, paints, coatings, sealants, environmental remediation materials, antidiarrheal medication, gels		

Attapulgite is naturally occurring crystalline hydrated magnesium aluminum silicate. It has a unique three-dimensional chain structure giving unusual colloidal and sorptive properties. Attapulgite is in the range of clay minerals classified as Fuller's earth. The natural mineral is ground, classified, and thermally activated. A high temperature drying produces LVM grade (LVM standing for low volatile matter) and having up to 1% of free moisture and up to 5% of total volatiles. Low temperature drying produces thickeners having up to 12% of free moisture and sorptive products of regular volatile matter, RVM, having 6% free moisture and up to 9% volatiles. Granular grades are manufactured by two basic methods: one includes drying or calcination, followed by grinding and screening to the size; in the other, a raw clay is pugged, extruded, dried or calcinated, followed by grinding and screening. Grades produced by the first method are designed as “A”, whereas

extruded grades are “AA”. Thus there are four different grades available: AA RVM, A RVM, AA LVM, and A LVM differing in water disintegrability. LVM grades resist disintegration in water whereas RVM grades do not.

There is a wide range of average particle sizes (0.1-20 μm) available. However, most commonly used products are in the range of 0.1-3 μm. Small particle size and high porosity result in a very high BET surface area (120-150 m^2/g) and an unusually high oil absorption in a range from 60 to 120%. Attapulgites are unusual in these respects. Also pH, which is in the range of 7.5-9.5, differs from that of kaolins.

Figure 2.4 shows the morphology of attapulgite which reveals the reasons for its high absorptivity.

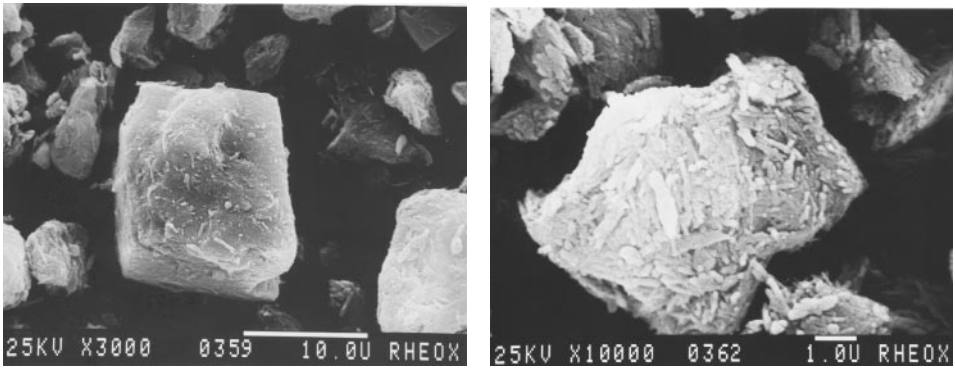


Figure 2.4. SEM micrograph of Attagel 50. *Courtesy of Rheox, Inc., Hightstown, NJ, USA.*

2.1.12 BARIUM METABORATE

Name: barium metaborate monohydrate		**CAS #**: 13701-59-2
Chemical formula: $BaB_2O_4 \cdot H_2O$	**Functionality**: OH	
PHYSICAL PROPERTIES		
Density, g/cm^3: 3.3	**Fusion point**, ^oC: 900-1050	
CHEMICAL PROPERTIES		
pH of water suspension: 9.8-10.3		
OPTICAL PROPERTIES		
Refractive index: 1.55-1.60		
Color: white		
MORPHOLOGY		
Oil absorption, g/100 g: 30		
MANUFACTURER & BRAND NAME: Buckman Laboratories, Memphis, TN, USA Busan 11-M1		
MAJOR PRODUCT APPLICATIONS: paints, coatings, sealants		
MAJOR POLYMER APPLICATIONS: alkyd resin, polyurethane, acrylic		

Barium metaborate is a truly multifunctional additive which inhibits corrosion, increases UV stability, inhibits mold growth, and has flame retarding properties when used in combination with halogenated materials. The commercial product of Buckman Laboratories is a modified product which contains 90% of active ingredient.

2.1.13 BARIUM SULFATE[50-57]

Names: barium sulfate, barite, blanc fixe		**CAS #**: 7727-43-7
Chemical formula: $BaSO_4$	**Functionality**: none if not surface grafted	
Chemical composition: $BaSO_4$ - 86-99%, $SrSO_4$ - 1-2%, CaO - 0-10.8%, Fe_2O_3 - 0.1-1.4%, SiO_2 - 0.9-2.1%		
Trace elements: iron, copper, manganese, and lead		
PHYSICAL PROPERTIES		
Density, g/cm^3: 4.0-4.9	**Mohs hardness**: 3-3.5	**Melting point**, ^{o}C: 1580
Linear coefficient of thermal expansion, 10^{-6} 1/K: 10		**Loss on ignition**, %: 0.2-2.6
CHEMICAL PROPERTIES		
Chemical resistance: resistant to acids and alkalis		
Moisture content, %: 0.1-0.3	**Acid soluble matter**, %: traces	**Volatiles content**, %: 0.1-0.5
Soluble content, %: 0.00025-0.4	**Water solubility**, ppm: 3	**pH of water suspension**: 6-9.5
OPTICAL & ELECTRICAL PROPERTIES		
Refractive index: 1.64		**Whiteness**: 94-96
Color: white		**Brightness**: 65-99
Tinting strength: medium		**Reflectance**: 90
Dielectric constant: 11.4	**Resistivity**, Ω: 19.075	**Conductivity**, μS/cm: 200-300
MORPHOLOGY		
Particle shape: depends on grade	**Crystal structure**: orthorhombic	**Oil absorption**, g/100 g: 8-28
Particle size, μm: 3-30 (barites and some synthetic grades), 0.7 (blanc fixe), <0.1 (special grades)		
Sieve analysis: residues on 325 mesh sieve - 0.01-12%, 0.001% (blanc fixe)		**Cleavage**: one direction
Specific surface area, m^2/g: 0.4-31		**Hegman fineness**: 2.5-7

MANUFACTURERS & BRAND NAMES:

Barium and Chemicals, Inc. Steubenville, OH, USA

Barium Sulfate, 98% Technical Precipitated Grade

CIMBAR, Cartersville, GA, USA

Bara 2002C, 325C, 200N, 325N, 200M, 325M (industrial grade ground barites)

Bariace B-30, B-34 (surface treated barium sulfate with SiO_2-Al_2O_3 to improve abrasiveness, dispersion, gloss, and hardness; particle size 0.3 μm)

Barifine, BF-1, BF-10, BF-20, BF21 (ultrafine barium sulfates in particle range of 0.03-0.06 μm, improve dispersion of pigments and prevent flocculation)

Barimite UF, XF, 22, 200, G-50 (flotation grade barites)

CIMBAR 325, XF, CF, UF, EX (high purity white barites)

Polywate (low $BaSO_4$ content materials, filled foam market)

continued on the next page

MANUFACTURERS & BRAND NAMES:

Hitox Corporation, Corpus Christi, TX, USA
- Bartex 10, 65, 80, OWX - barium sulfate for a broad range of applications, including TiO_2 replacement

J.M. Huber Corporation, Macon, GA, USA
- Huberbrite 1, 3, 7, 10, 12 (milled barite, the number refers to median particle size)

Milwhite, Inc., Houston, TX, USA
- Basco Wate (ground barite for drilling fluids)
- Blanca 2, 4, 8 (high quality ground barites; number refers to particle size)
- Marfil 2, 4, 8, 10, 20, 40 (natural ground barite for coatings and plastics, number refers to particle size)

Nippon Chemical Industry Co., Japan
- Barium sulfate AD

Polar Minerals, Mt. Vernon, IN, USA
- 1000 Series includes barites 1075, 1065, 1040 of different particle sizes for paints and coatings
- 2000 Series includes barites 2075, 2065, 2010 of different particle size for plastics, paints, and brake linings
- Blanc Fixe 1090P - precipitated barium sulfate

Sachtleben Chemie GmbH, Duisburg, Germany
- Albaryt and Albaryt Plus (wet processed and chemically bleached grades)
- Barytmehl F, N, G, 901 (natural ground white barites with different particle sizes, F - fine, N - medium, G - coarse)
- Blanc fixe N, F, micro (standard grades)
- Blanc fixe, HXH, HNF (finely precipitated barium sulfate of extremely high purity and brightness)
- Drilling mud grade BS
- EWO (wet processed and chemically bleached grade, slightly coarser than Albaryt)
- Fleur (wet processed and chemically bleached grade slightly coarser than Albaryt and EWO)
- Ground Barites C 101, CH 1177, C 7, C 14, TS (fine powders made by grinding with a lower brightness than Barytmehl but comparable particle sizes)
- K1, K2, K3, K4, M (high purity, synthetic grades having a high brightness (96-98) and high refractive index)
- Sachtoperse HP, HU-N, HU-D (smallest particle size grades from below 0.1 to 0.2 µm, used as nucleating agents and anti-flocculating additives)

ZEMEX Industrial Minerals, Atlanta, GA, USA
- Cherokee 289, 290, 291 (ground barites)

MAJOR PRODUCT APPLICATIONS: paints, inks, wood finishes, powder coatings, adhesive, mastics, seals, sealants, coatings, medical, paper, battery products, drilling fluids, brake linings, bowling balls, sound dampening, plastisols, urethane foams, acoustical compounds, insulating materials

MAJOR POLYMER APPLICATIONS: PET, PVC, melamine, polyurethanes, alkyd

Barites are the most common barium minerals, found in pure form but also together with many other minerals. The most frequent replacement for barium is that of strontium or radium. Barium sulfate, widely used in industry and in medical applications, originates from natural barites and synthetic materials. The quality of the filler depends on the purity of material used for production and the method of processing (a chemical purification is a complex process which determines the quality of synthetic or reprocessed material). The simplest method of processing includes grinding and dry classification. Finer products are obtained by concentration, wet grinding, bleaching, and classification. The product of highest quality is *blanc fixe* (permanent white). It is produced from the reaction between barium carbonate and sulfuric acid. Since the only other reaction products are water

and carbon dioxide, product purity depends on the quality of raw materials used. The particle size distribution depends on process parameters, including the concentration of reactants, the rate of addition, temperature, and efficiency of mixing. These parameters are easily regulated, so particle size distribution. In some applications, the filler must have a narrow range of particle size distribution. The average particle size diameter for natural products is usually in a range from 2 to 30 μm (maximum particle size: 15-75 μm). The price is related to the average particle diameter. *Blanc fixe* being the smallest is most expensive (the average diameter of particles ranges from 0.1 to 4 μm). Oil number depends on particle size, and for *blanc fixe* it is in a range from 12 to 28 g/100 g, whereas for natural products, it is lower, in a range from 7 to 12 g/100 g. Particles are non-porous and of irregular shape in the case of natural product, whereas *blanc fixe* is almost spherical.

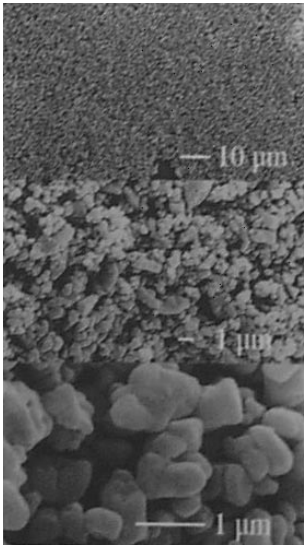


Figure 2.5. SEM micrograph of Blanc fixe micro at different magnifications (upper 1000x, middle 5000x, lower 25,000x). *Courtesy of Sachtleben Chemie, Duisburg, Germany.*

Further information on morphology is discussed below based on electron microscopy data. Figure 2.5. shows morphology of blanc fixe. The particle size of blanc fixe (0.7 μm) is comparable with the particle size of titanium dioxide (0.3 μm). Comparison of blanc fixe with another synthetic grade of barium sulfate, barium sulfate K2, produced by Sachtleben Chemie shows a difference in particle size but the morphological structure is quite similar (Figure 2.6). Figure 2.7 shows a still finer grade developed by Sachtleben Chemie which has particle size similar to titanium dioxide (0.35 μm). This is a quite extraordinary filler which has core made out synthetic barium sulfate (an insulator) coated with a semi-conducting layer of antimony doped with SnO_2 (Sacon P401). This material has high brightness, electric conductivity, and light transparency in thin coatings. The material is used to eliminate static charges from plastics and painted surfaces. At approximately 19% PVC material has a percolation threshold and surface resistivity drop rapidly by 8 orders of magnitude. Sachtoperse is still smaller in particle size, from 0.2 μm to below 0.1 μm, depending on grade. This is used as nucleating additive to polymers, such as PET. It decreases cycle time and reduces processing temperature, increases crystallization rate, and prevents flocculation of pigments. Figure 2.8 explains the mechanism by which Sachtoperse prevents pigment flocculation. Pigment particles (lighter particles) adhere to Sachtoperse (smaller darker particles) which act as a spacer. This process results in brighter colors and improved gloss.

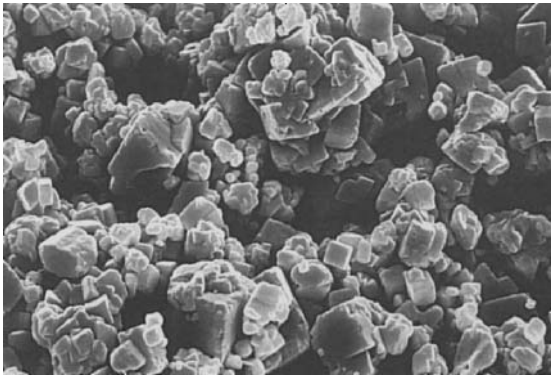


Figure 2.6. SEM micrograph of K2 grade at 2000x magnification. *Courtesy of Sachtleben Chemie, Duisburg, Germany.*

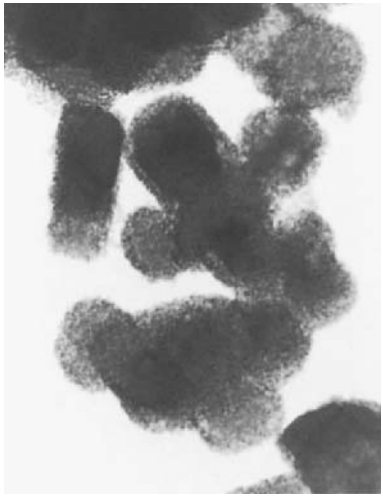


Figure 2.7. TEM micrograph of Sacon P 401 at magnification of 350,000. *Courtesy of Sachtleben Chemie, Duisburg, Germany.*

Figure 2.8. Anti-flocculating action of Sachtoperse HU. *Courtesy of Sachtleben Chemie, Duisburg, Germany.*

When images of synthetic grades are compared with image of ground barites (Figure 2.9), the morphological differences become apparent. These differences are not simply in particle size and distribution but also in the shape of particles.

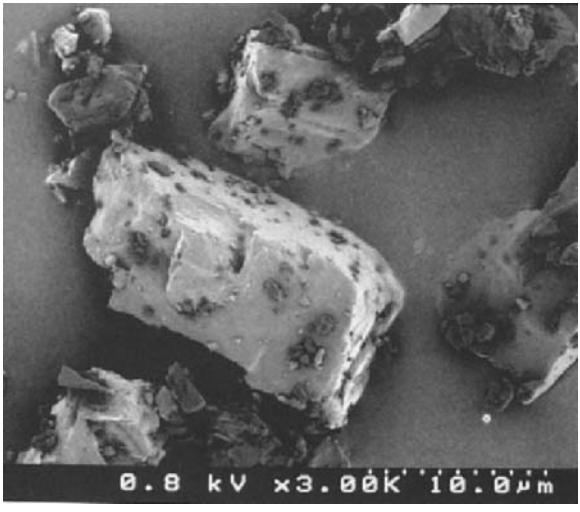


Figure 2.9. SEM micrograph of milled barite, Huberbrite. *Courtesy of J. M. Huber Corporation, Macon, GA, USA.*

Chemical composition is another factor which determines quality, particularly in chemical and medical applications but also in paints and coatings where it affects brightness. Barium is highly toxic but only in the form of water soluble salt; therefore in every application the water soluble barium must be controlled. Other usual admixtures contain iron, copper, manganese, and lead, and depending on application, their concentration is also restricted. Natural products contain 94-99% $BaSO_4$, whereas *blanc fixe* contains from 97.5 to over 99%.

For some applications, a refractive index is important. A match between the particle size of some barium grades and the refractive index of matrix material allows the formulation of products with desirable optical properties. A series of synthetic barium sulfates is produced by Sachtleben Chemie which have particle sizes between 4 and 10 μm. If the particle size of these barium sulfates is well coordinated with the refractive index of the matrix polymer, semi-opacity combined with translucency results. This permits the formulation of a light disperser in lampshades or in illuminated advertising displays. The correct particle size can be calculated from the equation: $d = (100n - 141)/2$, where n is the refractive index of the resin and d the particle size of barium sulfate.

Barium sulfate has found many applications mainly because of its unique chemical resistance and inertness (for example, it is not affected by acid rain). The other reason for its frequent application is high absorptivity of light and, significantly, X-rays (for use in X-ray detectable materials).

2.1.14 BARIUM & STRONTIUM SULFATES

Name: barium strontium sulfate natural blend		
Chemical formula: $BaSO_4$ & $SrSO_4$		**Functionality**: none
Chemical composition: $SrSO_4/BaSO_4$ - 87-95%, $CaCO_3$ - 2.6-5%, CaO - 1.9-2.5%, Fe_2O_3 - 0.1-1.7%, $CaSO_4$ - 0.7-3%, SiO_2 - 0.1-1%		
PHYSICAL PROPERTIES		
Density, g/cm^3: 3.8-3.9		
CHEMICAL PROPERTIES		
Chemical resistance: similar to $BaSO_4$		
Moisture content, %: <0.3	**pH of water suspension**: 7-7.5	
OPTICAL PROPERTIES		
Color: white		**Reflectance**, %: 86-88
MORPHOLOGY		
Particle size, μm: 11-20	**Crystal structure**: rhombic	**Oil absorption,** g/100 g: 9.5-11.5
Sieve analysis: retained on 325 mesh sieve - 0.1-2%		**Hegman fineness**: 3.5
MANUFACTURER & BRAND NAME: Milwhite, Inc., Houston, TX, USA Microwate 10, 20, 40 (natural ground product)		
MAJOR PRODUCT APPLICATIONS: plastics, paints, cellular foams		

2.1.15 BARIUM TITANATE[58]

Names: barium titanate	
Chemical formula: $BaTiO_3$	**Functionality**: none
Chemical composition: $BaTiO_3$ - 98.9-99.5%	
Trace elements: Sr, Ca, Nb, Fe, Si, Al, Mg, Na	
PHYSICAL PROPERTIES	
Fusion point, °C: 1250	**Loss on ignition**, %: 0.8
CHEMICAL PROPERTIES	
Moisture content, %: 0.2	
OPTICAL & ELECTRICAL PROPERTIES	
Refractive index: 2.4	**Dielectric constant**: 3.8
MORPHOLOGY	
Particle size, μm: 0.07-2.7	**Specific surface area**, m^2/g: 2.4-8.5
MANUFACTURERS & BRAND NAMES: Cabot Performance Materials, Boyertown, PA, USA Hydrothermal Barium Titanate (barium titanate of small particle size obtained by a hydrothermal method) TAM Ceramics, Niagara Falls, NY, USA Ticon HPB, HPB-B, TME, F (high purity grades) Ticon C, P, T (solid state grades) Ticon 5016 (solid state, high purity grade) Ticon COF-40, COF-50, COF-70, CN (solid state niobium-doped grades)	
MAJOR PRODUCT APPLICATIONS: thermistors, capacitors, optics, ferroelectric ceramics, filler for ferroelectric polymers, pyro and piezoelectric composites	
MAJOR POLYMER APPLICATIONS: poly(vinylidene fluoride)	

2.1.16 BENTONITE[59-66]

Names: bentonite, clay, montmorillonite, Na-montmorillonite, Ca-montmorillonite, hydrated sodium calcium aluminum magnesium silicate hydroxide		**CAS #**: 1302-78-9
Chemical formula: $(Na, Ca)(Al, Mg)_6(Si_4O_{10})_3(OH)_6 \cdot nH_2O$		**Functionality**: OH, ONa, OCa
Chemical composition: SiO_2 - 56-72%, Al_2O_3 - 13-21%, Fe_2O_3 - 0.9-5%, MgO - 1.7-2.4%, CaO - 0.7-2.2%, Na_2O - 0.3-2.7%, K_2O - 0.2-0.3%		
Trace elements: AS, Ba, Cd, Pb, Se, Hg		
PHYSICAL PROPERTIES		
Density, g/cm^3: 1.6 - 3	**Mohs hardness**: 1-2	**Loss on ignition**, %: 8.4-11.9
CHEMICAL PROPERTIES		
Moisture content, %: 2-14	**pH of water suspension**: 7-10.6	**Water solubility**, %: 3
OPTICAL PROPERTIES		
Color: light cream, buff to tan, light gray, white to off-white		
MORPHOLOGY		
Particle size, μm: 0.18-1	**Oil absorption**, g/100 g: 36-52	
Sieve analysis: residue on 325 mesh sieve - 2%		
Specific surface area, m^2/g: 0.8-1.8		**Hegman fineness**: 2-7
MANUFACTURERS & BRAND NAMES: Charles B. Co., Inc., New York, NY, USA Wyoming Granular Bentonite, Bentonite 200, 325 (sodium bentonite) Bentonite 34, (silicate of aluminum which swells eight times the volume) Cream Bentonite (light color bentonite) Bentonite Semi-dried Crude (sodium bentonite) CIMBAR Performance Minerals, Cartersville, GA USA Organotrol 2200, 3300, 3440, 3550, 3660, SA (general purpose thickener and suspension additive) Suspengel 16, 30, 200, 325 (high purity bentonite thixotropes) Suspengel Ultra, Elite, Micro (high purity bentonite accepted for use in food) Milwhite, Inc., Houston, TX, USA Basco Gel (blended bentonite for viscosity modification) Bentonite B (calcium montmorillonite for ceramics and molding) Milbond 3 (water treatment and sealant grade) Rev-Dust (calcium montmorillonite) Non-Metals, Inc., Affiliate of The China Non-Metallic Minerals, Tucson, AZ, USA HB-Ca, JJ-Ca, JJ-Na, JL-Na, ZL-Na, LL-Ca - Ca and Na bentonites in powder form		
MAJOR PRODUCT APPLICATIONS: paints, coatings, paper, adhesives, sealants, inks, cosmetics, plastics compounding, , pharmaceuticals, foods, drilling muds, waterproofing		
MAJOR POLYMER APPLICATIONS: alkyd, polyurethane, butyl resin, PP, PS		

Bentonite is a clay derived from the weathering of volcanic ash and composed of the mineral montmorillonite. There are two varieties: sodium bentonite which has high swelling capacity in water and calcium bentonite with negligible swelling capacity. Figures 2.10 and 2.11 show the morphology of ground ore and the

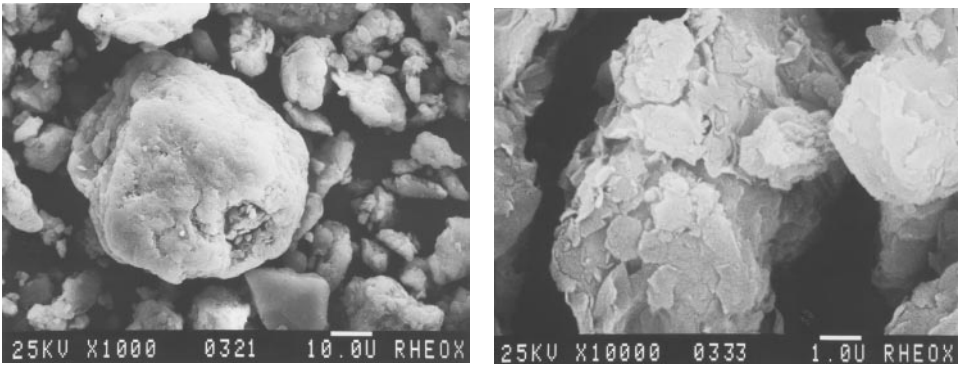


Figure 2.10. Bentonite ground ore. *Courtesy of Rheox, Inc., Highstown, NJ, USA.*

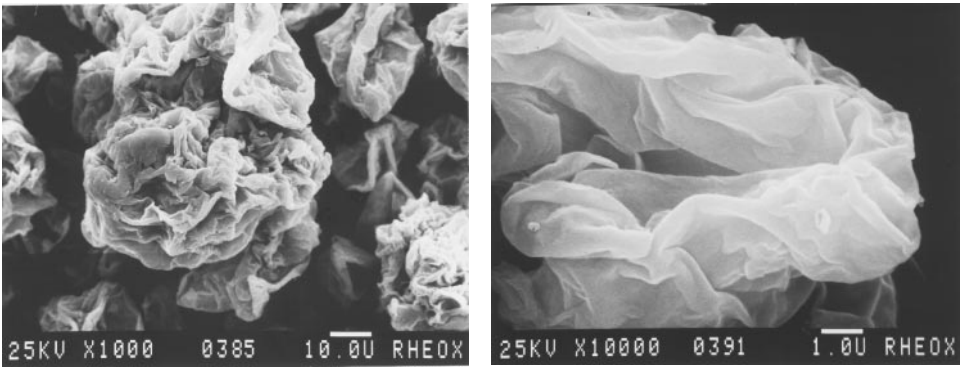


Figure 2.11. Bentonite purified and spray dried. *Courtesy of Rheox, Inc., Hightstown, NJ, USA.*

purified material. The high surface area and a structure which allows water to penetrate mineral layers are responsible for the swelling capabilities of bentonite clays.

In addition to the traditional use in paints as viscosity regulator, bentonite is currently used in the development of new materials with nanocomposite structures.

2.1.17 BERYLLIUM OXIDE

Names: beryllium oxide		**CAS #**: 1304-56-9
Chemical formula: BeO	**Functionality**: none	
Chemical composition: beryllium oxide - 99.5%		
Trace elements: Al, Ca, Mg, Si		
PHYSICAL PROPERTIES		
Density, g/cm^3: 2.85		**Melting point**, ^{o}C: 2570
Thermal conductivity, W/m·K: 250		**Specific heat**, kJ/kg · K: 1.03
Thermal expansion coefficient, 10^{-6} 1/K: 9	**Maximum temperature of use**, ^{o}C: 1800	
Tensile modulus, MPa: 138	**Poisson ratio:** 0.26	**Compress. strength**, MPa: 1550
OPTICAL & ELECTRICAL PROPERTIES		
Color: white	**Resistivity**, Ω-cm: 10^{17}	
Dielectric constant: 6.8	**Dielectric strength**, V/cm: 100	**Loss tangent**: 0.0004
MORPHOLOGY		
Particle size, μm: 20	**Crystal structure**: hexagonal	
MANUFACTURERS & BRAND NAMES: Accuratus Ceramic Corporation, Washington, NJ, USA San Jose Delta Associates, Inc., Santa Clara, CA, USA		
MAJOR PRODUCT APPLICATIONS: combination of extremely high thermal conductivity and excellent dielectric properties		

2.1.18 BORON NITRIDE

Names: boron nitride		**CAS #**: 10043-11-5
Chemical formula: BN	**Functionality**: none	
Chemical composition: BN - 95-99.5%		
Trace elements: Cu, Al, Mg, Fe, K, Si		
PHYSICAL PROPERTIES		
Density, g/cm^3: 2.25	**Knoop hardness**, kg/mm^2: 11	**Specific heat**, kJ/kg · K: 794
Coefficient of expansion, 10^{-6} 1/K: <1		
Thermal conductivity, W/K · m: 250-300	**Maximum temperature of use**, ^{o}C: 985	
OPTICAL & ELECTRICAL PROPERTIES		
Dielectric constant: 3.9	**Volume resistivity**, Ω-cm: 10^{15}	**Loss tangent**: <0.0002
MORPHOLOGY		
Particle size, μm: 3-200	**Crystal structure**: hexagonal	**Spec. surface area**, m^2/g: 0.5-25
MANUFACTURERS & BRAND NAMES: Accuratus Ceramic Corporation, Washington, NJ, USA Advanced Ceramics Corporation, Lakewood, OH, USA PolarTherm 100 Series (five grades of hexagonal powders of different particle sizes) PolarTherm 300 Series (low density agglomerates) PolarTherm 600 Series (four grades of high density agglomerates) Carborundum Corporation, Amherst, NY, USA CarboTherm (seven grades of different particle sizes for refractory applications) Combat (thirteen grades of different particle sizes for liquid coatings and aerosol sprays) San Jose Delta Associates, Inc., Santa Clara, CA, USA - hot pressed boron nitride shapes		
MAJOR PRODUCT APPLICATIONS: rubber pads, liquid encapsulants, underfills, printed circuit boards, adhesives, greases, liquid coatings, aerosol sprays		
MAJOR POLYMER APPLICATIONS: silicone, epoxy		

Boron nitride filler address the “burning need” of modern electronic industry which is to protect electronic equipment from ever increasing generation of heat by high performance electronic devices. The combination of high electric resistivity with high thermal conductivity gives required performance to electronic adhesives and components.

Figure 2.12 shows SEM micrograph of boron nitride with 8-14 μm particle size.

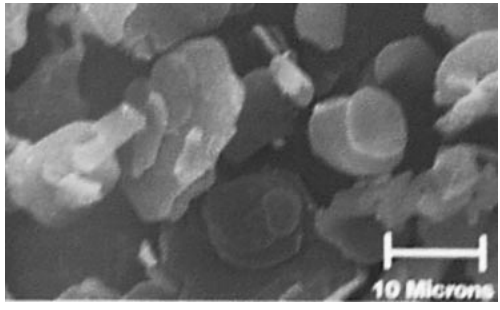


Figure 2.12. PolarTherm PT 120 boron nitride. *Courtesy of Advanced Ceramics Corporation, Lakewood, OH, USA.*

2.1.19 CALCIUM CARBONATE[67-138]

Names: calcium carbonate, limestone, chalk		**CAS #**: 1317-65-3
Chemical formula: $CaCO_3$	**Functionality**: only from admixtures or surface treatment	
Chemical composition: $CaCO_3$ - 85-99%, SrO - 0.5%, $MgCO_3$ - 0.4-13%, BaO, MnO, SiO_2, Fe_2O_3, Al_2O_3		
Trace elements: As, Ba, Hg, Pb		
PHYSICAL PROPERTIES		
Density, g/cm^3: 2.7-2.9	**Mohs hardness**: 3-4	**Melting point**, ^{o}C: 1339
Decomposition temp., ^{o}C: 1150	**Loss on ignition**, %: 43.5	**Surface tension**, mJ/m^2: 207
Thermal conductivity, W/K · m: 2.4-3	**Linear coefficient of expansion**, 1/K: 4.3-10 x 10^{-6}	
Young modulus, MPa: 35,000	**Poisson coefficient**: 0.27	
CHEMICAL PROPERTIES		
Chemical resistance: reacts with acids		
Moisture content, %: 0.01-0.5	**Water solubility**, %: 0.99 x 10^{-8}	**pH of water suspension**: 9-9.5
OPTICAL & ELECTRICAL PROPERTIES		
Refractive index: 1.48, 1.65, 1.7	**Birefringence indices**: 1.48 & 1.65 (calcite)	**Whiteness**: 80-98
Color: white to gray	**Reflectance**, %: 86-94	**Brightness**: 82-94
Dielectric constant: 6.1	**Volume resistivity**, Ω-cm: 10^{10}	
MORPHOLOGY		
Particle shape: irregular	**Crystal structure**: see text	**Hegman fineness**: 2-6.5
Particle size, μm: 0.2-30, 0.02-0.4 (precipitated)		**Oil absorption**, g/100 g: 13-21
Sieve analysis: residue on 325 mesh sieve - 0.005-14%		**Specific surface area**, m^2/g: 5-24

MANUFACTURERS & BRAND NAMES:

Charles B. Co., Inc., New York, USA
- Calofort U, U70 - small particle size, high specific surface area, precipitated calcium carbonate
- Granulated Oyster Shell - low heavy metals designed for pharmaceutical applications
- Food Grade Calcium Carbonate, FCC Grade - food grades
- Ultrafine Calcium Carbonate - general purpose ground limestone
- Hiflex - surface treated calcium carbonate for easy compounding in water pipes, cables, etc.
- Precipitated USP Grade - 3 grades for pharmaceutical, cosmetic, and food industries
- 402 - surface modified calcium carbonate for PVC plastisols and other plastics

ECC International, Cornwall, UK
- Carbital 110S, 110, 120 - high whiteness grades for PP derived from Italian marble (S stearate coating)
- Polcarb 60 & 90 - PVC extrusion, plastisol and PP sheeting
- Queensfil 25, 240, 300 - footwear, latex, PE masterbatch, PA moldings, all PVC applications
- Polcarb S, SB, 40S, 60S (stearate coated) - cable, extrusion, PE masterbatch and film, all PVC applications, PP molding and sheeting

continued on the next page

MANUFACTURERS & BRAND NAMES:

J.M. Huber Corporation, Macon, GA, USA
Hubercarb G series (2, 3, 8, 260, 325) milled high brightness grades for paints and coatings
Hubercarb M (6, 4, 3) and S (6, 4) series milled high brightness grades for paints and coatings
Hubercarb Q (325, 6, 4, 3, 2, 1) and W (3, 3N, 4) series milled grades for paints

Milwhite, Inc., Houston, TX, USA
Calfrost MG-NCS dry ground grade for paints, rubber, putties, caulks, adhesives

OMYA/Plüss-Staufer AG, Oftringen, Switzerland
130 companies worldwide producing the large number of grades for different industries under the following brand names:
paper industry: Hydrocarb (slurry), Snowcal (slurry), Omyacarb, Setacarb, Omyafil, Covercarb
paint & coating: Omyacarb, Durcal, Inducarb, Britomya, Snowcal, Calmote, Granitos, Violette Etikette, Micromya, Omya BSH, Omya BLP, Omyalite, Omya BL, Millicarb, Hydrocarb, Setacarb, Calibrite, Calcigloss, Calcimatt, Calcicoat (slurry), Wical WS
plastics: Omyacarb, Millicarb, Omyalite, Omya BRL, Omyalene, Omya EXH 1, Britomya, Snowcal, Omyafoam
rubber and other industries
The available grades in one location are given based on the production in Avenza - Carrara/Italy which manufactures grades of high purity for paints and plastics in one of the oldest and world famous location. The grades manufactured in other locations worldwide have similar quality.
The following grades are produced in Carrara:
Omyacarb 1-AV, 1T-AV, 2-AV, 2T-AV, 5-AV, 10-AV, 15-AV, 30-AV. The number signifies (and it is close to) the mean particle size; the letter T stands for the coated grade

Piqua Materials, Inc., Piqua, OH, USA
Piqua Minerals Filler 30, 60, 70, 200, 300, 600, 1800 - dry ground limestone of particle size increasing with grade number

Polar Minerals, Mt. Vernon, IN, USA
Fine Calcium Carbonates 8102, 8103, 8105, 8107 exceptionally pure calcium carbonates of different particle sizes. Also grades are manufactured with the same number symbol followed by letter C which stands for stearate coated grade
Ultrafine Calcium Carbonates 8.14, 8101 particle size 0.2-1.4 μm produced with (C) and without stearate coating
Polishing Marl - a filler designed to replace diatomaceous earth and calcinated kaolin in automotive and household polishing formulations which improves H&S due to the lack of crystalline silica

Solvay Alkali GmbH, Rheinberg, Germany
Rheinberg Plant - Socal P2, P3, N2R, U1R
Giraud, France - Socal 90A, 92E, BO, 31, 311, 312, 322
Angera, Italy - Socal 90AV, 91CV, 92EV, P2V, 312V, 322V
Ebensee, Austria - Socal P2E, N2, NP, E_2, U_1, U_1S_1, U_1S_2, U_3
the application of grades listed under precipitated grades; pharmaceutical/food grades: P2, U1R, E2, P2V

Suzorite Mica Products, Inc, Boucherville, Canada
Calcium carbonate 80/325 - dry ground limestone

MAJOR PRODUCT APPLICATIONS: *milled grades*: plastics, paper, paints and coatings, and numerous other applications difficult to list due to the widespread use
precipitated grades: emulsion paints, matt paints, paints containing solvent, printing inks, cigarette paper, fine paper, coated paper, special paper, rigid PVC, rubber, PP, PE, polyester, PVC plastisol, PSF, PU, silicone, polyacrylate, filling materials, pharmaceutical preparations, foodstuffs, beverages, toothpaste, wine deacidification, salt after-treatment, welding electrodes, peroxides

MAJOR POLYMER APPLICATIONS: PVC, PE, PP, PS, PA, PSF, PU, silicone, acrylic, rubber, polyester, and many more

Calcium carbonate is the most widely used filler. In the past its use was associated with a substantial cost reduction but today it is the material engineered for the

different requirements of modern products. This discussion begins with an introduction to the origins of calcium carbonate which has been given a thorough evaluation in a paper by Bosshard of Omya/Plüss-Staufer AG.[138]

Calcium at 4.8% is the fifth most common elemental constituent of the earth's crust after oxygen, silicon, aluminum, and iron. It is so popular in practical applications because it is found in rocks and minerals which have very high concentration of calcium carbonate. Calcium carbonate is the most common deposit formed in sedimentary rocks. The process of formation of calcium deposits begins with weathering of land surface due to the changes in heat, frost, rain, and the effect of sun. Calcium carbonate is not readily soluble in water but calcium bicarbonate is. The concentration of carbon dioxide in water is thus important for calcium carbonate transportation from the land to the sea since rain water is the carrier. It is estimated that 500,000,000 tons of minerals are carried by rivers to the seas every year out of which about 10-15% of sedimentary rocks containing calcium carbonate are formed.

The soluble form of calcium can be precipitated in the marine environment to form rock by some physical conditions such as warming of the water (carbon dioxide is less soluble in warm water than in cold water and thus calcium carbonate is precipitated), by the use of carbon dioxide by marine plants, or by alterations in the pH of water by ammonia-producing bacteria which also lowers the solubility of calcium carbonate. However, the majority of calcium carbonate deposits are formed from skeletal fragments of organisms living in the marine environment. Some of these organisms inhabit reefs but the majority float free in water. Figure 2.13 shows various shapes of shells formed by Coccolithophorides which can be spherical coccospheres some, such as dicoaster, are star shaped.[138]

These shells not only have spectacular shapes, but they are small and in abundance. They measure 2-25 μm in diameter and there is up to 35,000,000 cells of coccoliths in a liter of sea water. When they die they sink to the sea bed. It is estimated that 68% calcareous mud covers the bottom of Atlantic. By comparison, only 36% of the Pacific is covered with calcareous mud – the difference is believed to be caused by the differences in solubility of carbon dioxide, and thus of calcium carbonate in the two oceans. When shells or a physically formed precipitate reaches the sea bed, a series of other processes occurs preceding formation of rock. The material loosely deposited on the sea bed contains 80-90% water which is gradually expelled by the overlaying sedimentary matter and the process of lithification takes place. The transformation to rock occurs when the residual porosity attains about 30% which requires a pressure of about 300-500 meters of sediment equivalent to about 80 atmospheres. During this slow process, cementation occurs which is based on redissolving of unstable carbonates such as aragonite or vaterite present in sediments and depositing them in pore spaces as calcite or dolomite. The rocks formed in such a manner are then lifted from the sea bottom in geological upheavals and exposed to weathering to continue the cycle.

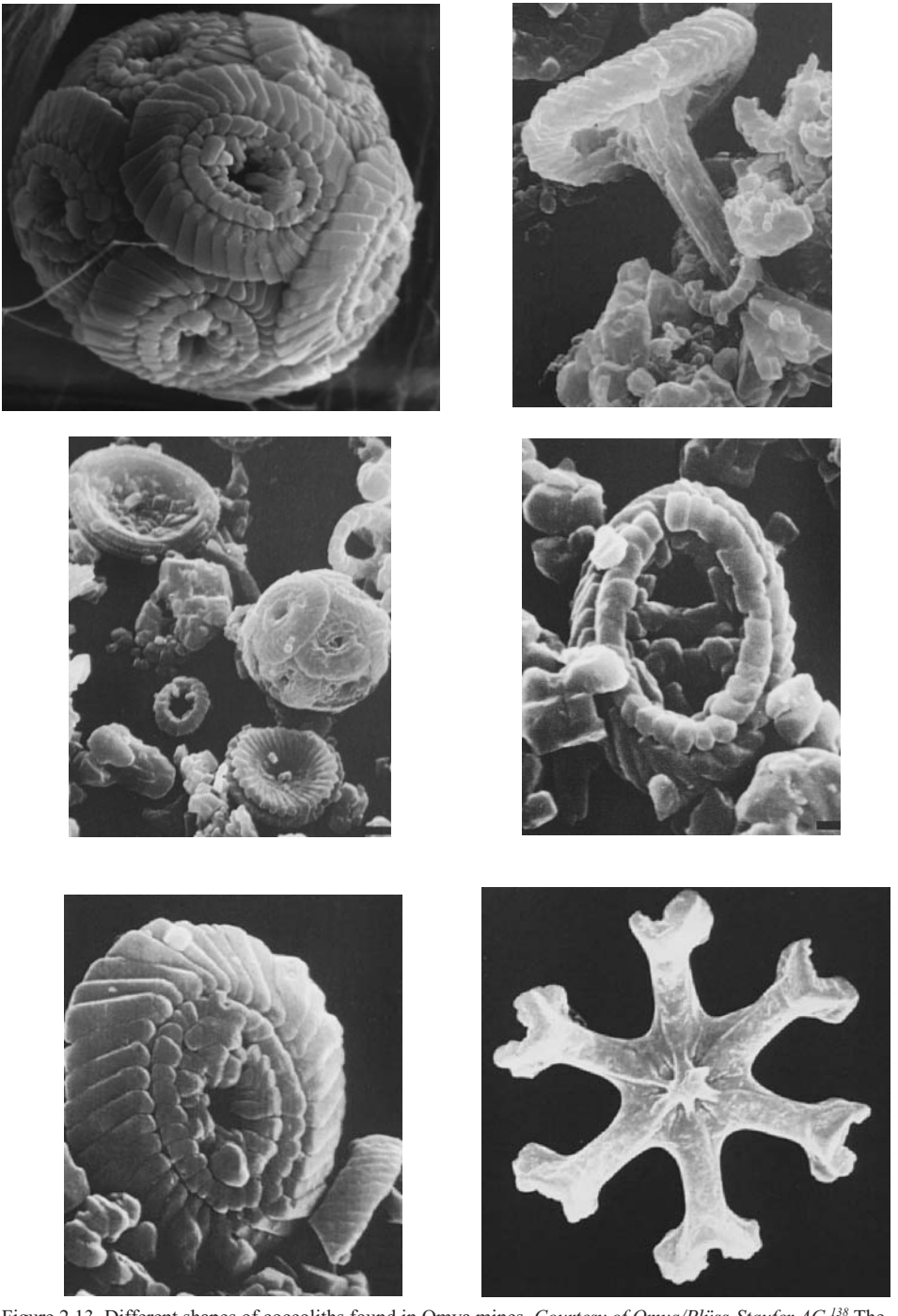
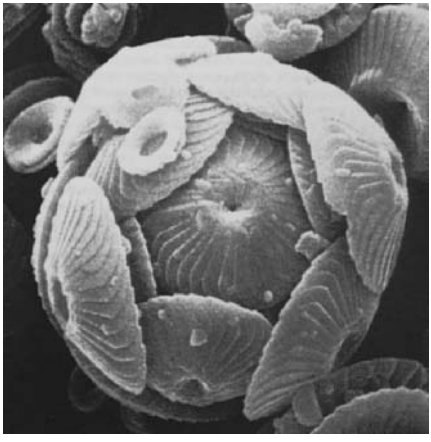


Figure 2.13. Different shapes of coccoliths found in Omya mines. *Courtesy of Omya/Plüss-Staufer AG.*[138] The first micrograph (upper left corner) - *Courtesy of ECC International Ltd., St. Austell, UK*.



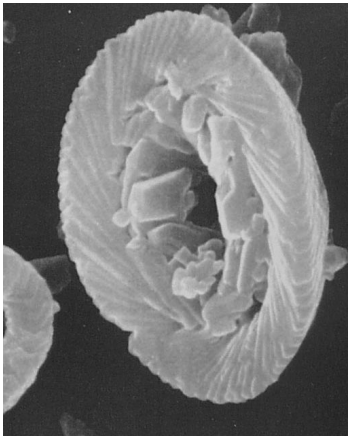


Figure 2.13 (continuation). Different shapes of coccoliths found in Omya mines. *Courtesy of Omya/Plüss-Staufer AG.*[138]

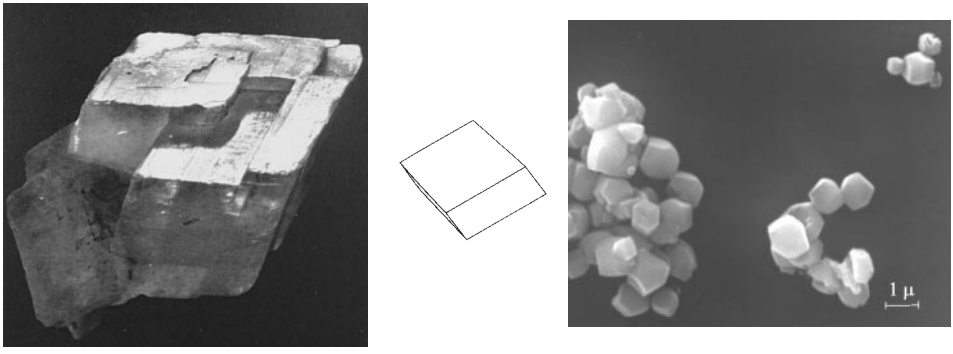
Most of the concerns about global warming has been for land based plants. It can be seen from the proceeding paragraphs that the oceanic conversion of calcium carbonate by microorganisms and of carbon dioxide by plankton are perhaps more important in the regulation of our environment. Incidents such as an underwater volcanic explosion may affect this balance since they alter the temperature of water and the concentration of carbon dioxide in water and, consequently, its internal use and release to the atmosphere.

As was mentioned before, several crystalline forms can be produced. These forms are used to build minerals and rocks. These are defined below. There are three crystalline forms which are mostly used in production of calcium carbonate filler:

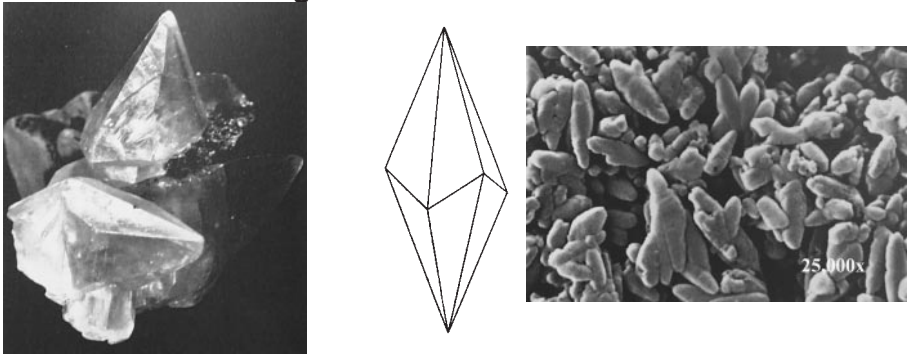
calcite	a mineral also called calcspar which has trigonal rhombohedral or trigonal scalenohedral form
aragonite	orthorhombic crystals

Figure 2.14 explains differences between these three forms and compares them with morphology of fillers having these crystalline forms as well as with schematic diagrams of the crystals.

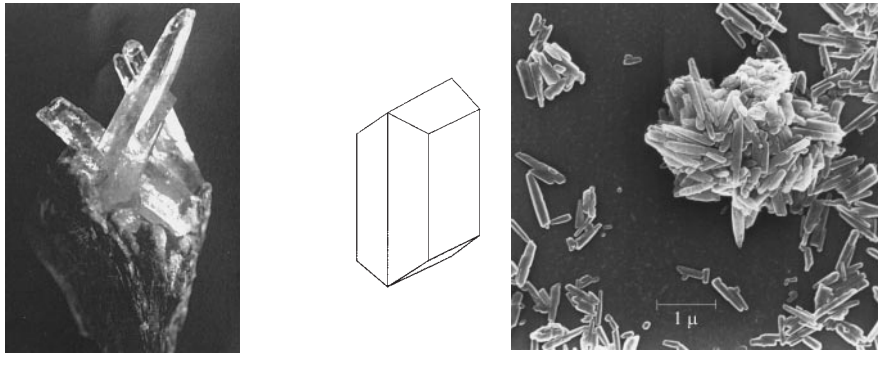
During the biological process of formation, each organism produces a specific crystalline form. For example, the mother-of-pearl or pearl itself are aragonite. Here the prismatic layer is formed of calcite. Aragonite is a less stable form and it can be converted by heating to calcite. Both minerals can be easily distinguished by their physical properties such as density (aragonite 2.9 and calcite 2.7), refractive index (aragonite 1.7, calcite with two refractive indices of 1.49 and 1.66 which



Trigonal-rhombohedral calcite



Trigonal-scalenohedral calcite



Orthorhombic aragonite

Figure 2.14. Different crystalline forms of calcium carbonate. *Courtesy of Omya/Plüss-Staufer AG* (micrographs of crystals)[138], *Solvay, GmbH, Rheinberg, Germany* (crystal structure and micrographs of Socal trigonal-scalenohedral calcite),[132] and *ECC International Ltd., St. Austell, UK* (rhombohedral calcite and aragonite).

causes a double refraction effect), and hardness (aragonite 3.5-4 and calcite 3). There are several other minerals and rocks associated with calcium carbonate:

chalk	a sedimentary rock of soft texture formed from nanofossils
dolomite	mineral composed of calcium magnesium carbonate
limestone	consolidated sedimentary rock
marble	a metamorphic rock originally composed of either calcite, aragonite, or dolomite which was recrystallized to a dense rock under the influence of high pressure and temperature. Its color depends on admixtures (e.g. iron oxide gives yellow to brownish coloration, Carrara marble is white because of high purity)
travertine	deposits from spring water in a form of calcite or aragonite which form in caves dripstones (stalactites and stalagmites)
vaterite	a hexagonal modification of calcium carbonate which is very unstable and it is readily converted to calcite

The above review of rock and mineral formation indicates that all calcium carbonates are not the same. Their type and properties depend on their history of formation. In addition to the above processes of formation, the presence of admixtures also determines the process used to extract or refine the filler and its utility. Other minerals such as silicates and clays are formed simultaneously and within calcium carbonate and altogether they form a broad range of mixtures which must be processed. This aspect of the production is underlined in recognition that it is very important for a final product process to use a particular grade of material dependent on the technology of production and the place of origin.

Three major technological processes are used in the production of calcium carbonate filler. These are milling, precipitation, and coating. More than 90% calcium carbonate is processed by milling. Two methods are used: dry and wet. The milling technology was developed for reproducibility and to obtain the required particle size distribution. In addition to general grades, ultrafine grades are also produced by the milling process. If the wet milling process is used, the material is frequently delivered to the customer in the form of a slurry which makes subsequent processes more economical and environmentally friendly. The paper industry uses about 80% of its calcium carbonate in the form of slurry. Also, paints use large quantities of slurried calcium carbonate. Figure 2.15 shows SEM micrograph of milled calcium carbonate. In this process, the crystalline structure of the rock has an important influence on the morphology of the filler.

Figure 2.16 shows a schematic diagram of the production of precipitated calcium carbonate. Such grades are also termed synthetic calcium carbonate since several chemical operations are performed. The first operation is calcination which is performed in a kiln at 900^{o}C. At this stage, calcium carbonate is decomposed to

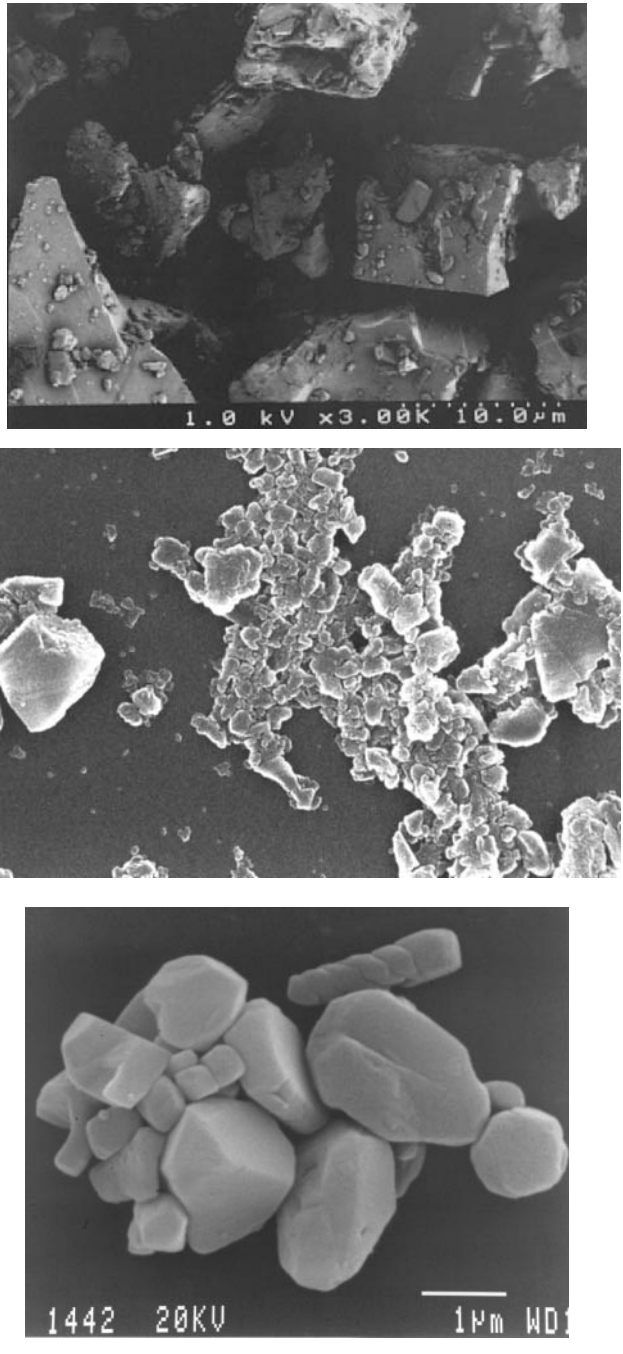


Figure 2.15. SEM of different calcium carbonates. upper - milled calcium carbonate, middle - ultrafine ground calcium carbonate, bottom - chalk. *Courtesy of J.M. Huber Corporation, Macon, GA, USA (upper), and ECC International Ltd., St. Austell, UK (middle and bottom).*

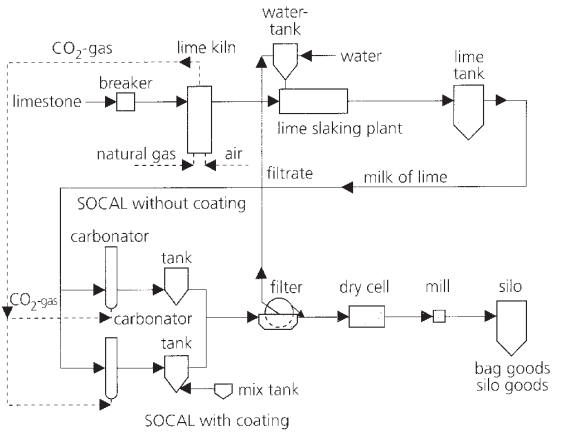


Figure 2.16. Schematic diagram showing the production of precipitated calcium carbonate. *Courtesy of Solvay GmbH, Rheinberg, Germany.*

calcium oxide and carbon dioxide which is used in further step. In the next step, calcium oxide is mixed with water in a process called slaking. This converts calcium oxide to lime and permits a material purification operation to be performed which results in a product of improved purity. In the (sometimes) final operation, the milk of lime is saturated by carbon dioxide which precipitates calcium carbonate. Depending on process parameters such as temperature, degree of purification, and concentration of reagents, different grades are produced which can be distinguished by particle size distribution, or crystalline form, or may be graded for food or pharmaceutical use (Figure 2.14). One additional operation is surface coating during which a 1-3 wt% coating is deposited on the surface of calcium carbonate particles. In most cases, salts of fatty acids are used for coating but titanates and zirconates are also used although less frequently. Grafting various polymers onto the surface is the subject of current research. Rhombohedral calcite is the most likely to be coated. Because of coating its particles do not agglomerate and become hydrophobic. Aragonite or calcite scalenohedral form is likely to be used if calcium carbonate must play the role of a secondary pigment. Here, higher light scattering and brightness are obtained by forming some aggregation. Scanning electron micrographs show that the surface coating, by itself, does not introduce any particular morphological features.

There are also special morphological grades of calcium carbonate which can be used to change the rheological characteristics of materials. One example of such a product is shown in Figure 2.17. The combination of particulates and elongated particles creates special rheological effects. In addition, the elongated particles are

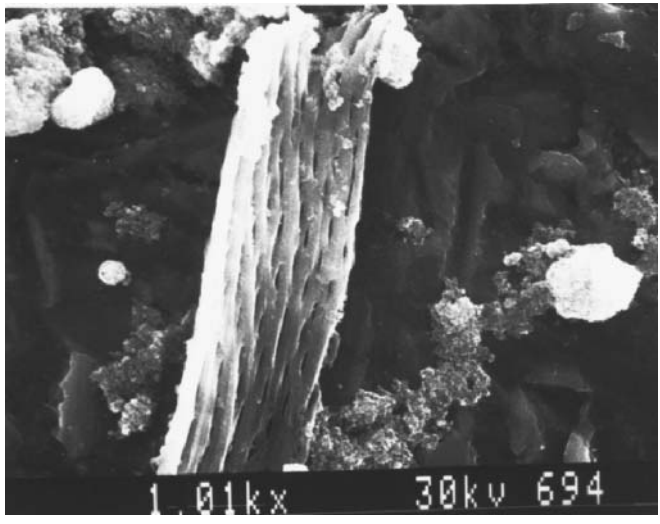


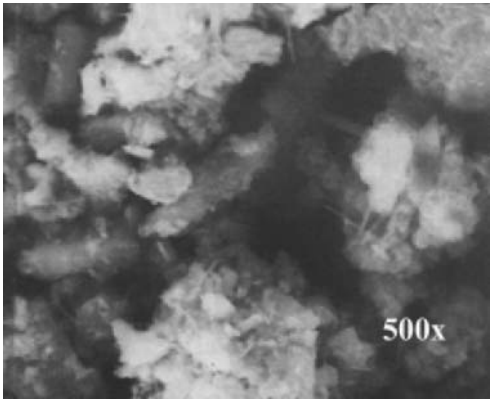
Figure 2.17. SEM micrograph of Viscolite U.

covered by a system of microcracks which contribute to non-Newtonian rheological characteristics which this filler imparts.

2.1.20 CALCIUM HYDROXIDE

Names: calcium hydroxide, carbide lime, lime hydrate, hydrated lime, slaked lime		**CAS #**: 1305-62-0
Chemical formula: $Ca(OH)_2$	**Functionality**: OH	
Chemical composition: $Ca(OH)_2$ - 80-90%, $CaCO_3$ - 10-20%		
PHYSICAL PROPERTIES		
Density, g/cm^3: 2.2-2.35		**Melting point**, ^oC: 272
CHEMICAL PROPERTIES		
Chemical resistance: not resistant to strong acid, phosphorus, maleic anhydride		
Moisture content, %: 1.5	**pH of water suspension**: 11.4-12.6	
OPTICAL PROPERTIES		
Refractive index: 1.57	**Color**: gray	
MORPHOLOGY		
Particle shape: round	**Crystal structure**: hexagonal	**Particle size**, μm: 5
Specific surface area, m^2/g: 1-6		
MANUFACTURER & BRAND NAME: ReBase Products, Inc., Barrie, Canada White Knight 100 - acetylene production co-product derived from carbide lime		
MAJOR PRODUCT APPLICATIONS: similar to calcium carbonate		
MAJOR POLYMER APPLICATIONS: PVC and PE already use the product		

Calcium hydroxide is a product new to the market. There have been, in past, positive scientific reports of its usefulness. The benefits of calcium hydroxide over calcium carbonate are its functionality, particle shape (more spherical and thus less abrasive to the equipment) (Figure 2.18), its lower density (decreases the density of product and lowers the price), a refractive index closer to many polymers, and its lower cost (approximately half of the price of calcium carbonate). The manufacturing equipment includes an excitement chamber, metered conveying, pneumatic transportation, flash drying, classification, and silo storage. The manufacturer delivers product to customers by its own silo-trucks.



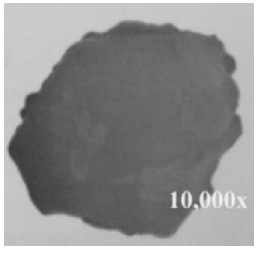


Figure 2.18. SEM micrograph of White Knight 100 calcium hydroxide particle. *Courtesy of ReBase, Barrie, Canada.*

2.1.21. CALCIUM SULFATE

Names: calcium sulfate, gypsum, anhydride	**CAS #**: 7778-18-9 or 10101-41-4 (dihydrate)	
Chemical formula: $CaSO_4$, $CASO_4 \cdot 2H_2O$	**Functionality**: none	
Chemical composition: $CaSO_4$ - 98.7-99%, SiO_2 - 0.31% (dihydrate contains $CaSO_4 \cdot 2H_2O$ - 82.3% and $CaCO_3 \cdot MgCO_3$ - 12.2%)		
Trace elements: Fe, heavy metals - ppm quantities		
PHYSICAL PROPERTIES		
Density, g/cm^3: 2.3-3	**Mohs hardness**: 2	**Melting point**, ^oC: 1450
Decomposition temp., ^oC: 128-63	**Maximum temperature of use**, ^oC: 128	
CHEMICAL PROPERTIES		
Chemical resistance: reacts with strong mineral acids		
Moisture content, %: 0.1	**pH of water suspension**: 6.8-10.8	
OPTICAL PROPERTIES		
Refractive index: 1.52-1.61	**Color**: white to light gray	
MORPHOLOGY		
Crystal structure: monoclinic	**Cleavage**: one direction	
MANUFACTURERS & BRAND NAMES: Charles B. Chrystal Co., Inc., New York, USA Terra Alba USP Granulated & English - pure forms for pharmaceutical industry NF Grade - calcinated terra alba for food and pharmaceutical industries LP #2 - dihydrate for filling and fire retarding applications 204 - anhydrous grade for TiO_2 replacement and drying agent		
MAJOR PRODUCT APPLICATIONS: pharmaceutical, food, plastics, paints		
MAJOR POLYMER APPLICATIONS: polyester, PU, PVC		

Gypsum shows very little variation in chemical composition, and it is the most common of the sulfate minerals. Its origin is related to a high concentration in sea water (4%) from which it is deposited by sedimentation or evaporation. The last mode of formation may also result in anhydrite formation because both forms are metastable and exist in equilibrium conditions.

The hydrous form of calcium sulfate, *Terra Alba*, contains about 20% water of crystallization. It is processed by fine grinding and air-separation to a selected, white, high purity gypsum. The anhydrous gypsum form is obtained by the same process, the addition of a calcination step in which water is almost entirely removed (only about 0.3% remains). Particles are mostly smaller than 10 μm. Oil absorption is rather high, in the range of 23 to 26 g/100 g. The choice between the hydrous and the anhydrous forms depends on the processing temperature and the moisture sensitivity of the formulation.

Color is another important consideration. Anhydrous forms are brighter than the hydrous ones because of their crystalline form, particle size, and purification during the calcination process. Particle size distribution depends mostly on the grinding process. *Terra Alba*, made by fine grinding and air-separation, has an average particle size of 12 μm, whereas anhydrous calcium sulfate has an average particle size of 7 μm. A fine grinding yields a product with an average particle size equal to 1.4 μm.