

# ENGINEERED MATERIALS HANDBOOK®

## Desk Edition

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# Foreword

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This volume represents a culmination of efforts started more than a decade ago, when the American Society for Metals decided to change its name to ASM International and to broaden its technical scope to include nonmetallic engineering materials. Since that time, technical meetings, educational programs, and publications have covered metallic and nonmetallic materials, and it has become ASM's stated purpose to be recognized as the world's premier materials information society. As part of the expansion of its technical scope, the Society initiated a new series of handbooks on nonmetallic materials to complement the renowned *Metals Handbook* and to provide the same kind of definitive, peer-reviewed coverage that series has provided in the areas of metals and metalworking. To date, ASM International has published four volumes in the *Engineered Materials Handbook* series—*Composites* (1987), *Engineering Plastics* (1988), *Adhesives and Sealants* (1990), and *Ceramics and Glasses* (1991)—as well as the *Electronic Materials Handbook*, Volume 1, *Packaging* (1989). With the publication of these volumes, ASM International fulfilled its goal to assemble and disseminate authoritative handbook information on the most important nonmetallic engineering materials.

ASM International is proud that the extent and quality of its handbook coverage of non-metallic materials are such that the creation of this comprehensive *Engineered Materials Desk Edition* is now possible. This volume is intended to provide the same type of authoritative, one-stop coverage as that contained in the popular *Metals Handbook Desk Edition*. The information in this handbook is largely compiled from the four volumes of the *Engineered Materials Handbook*, with updates and additions made in key areas as suggested by reviewers. While the information in this new desk edition can certainly stand on its own, the book also serves as a companion volume to the *Metals Handbook Desk Edition*. Together, the two desk editions provide comprehensive yet concise information about the properties, selection, processing, and applications of the most widely used metals and nonmetallic engineering materials.

We offer our thanks to the many professionals who contributed their time and expertise to make this project possible. These include the hundreds of volume organizers, authors, and reviewers who have contributed to the *Engineered Materials Handbook* over the past decade, as well as those who participated by reviewing, updating, and editing information for this volume. We are grateful to the ASM Handbook Committee for their oversight of this effort, and especially to Michelle Gauthier, the Handbook Committee member who guided this project as Volume Chair. We also thank ASM's own editorial and production staff for their dedicated efforts in pursuit of publications excellence.

John V. Andrews  
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# Policy on Units of Measure

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By a resolution of its Board of Trustees, ASM International has adopted the practice of publishing data in both metric and customary U.S. units of measure. In preparing this Handbook, the editors have attempted to present data in metric units based primarily on *Système International d'Unités* (SI), with secondary mention of the corresponding values in customary U.S. units. The decision to use SI as the primary system of units was based on the aforementioned resolution of the Board of Trustees and the widespread use of metric units throughout the world.

For the most part, numerical engineering data in the text and in tables are presented in SI-based units with the customary U.S. equivalents in parentheses (text) or adjoining columns (tables). For example, pressure, stress, and strength are shown both in SI units, which are pascals (Pa) with a suitable prefix, and in customary U.S. units, which are pounds per square inch (psi). To save space, large values of psi have been converted to kips per square inch (ksi), where 1 ksi = 1000 psi. The metric tonne ( $\text{kg} \times 10^3$ ) has sometimes been shown in megagrams (Mg). Some strictly scientific data are presented in SI units only.

To clarify some illustrations, only one set of units is presented on artwork. References in the accompanying text to data in the illustrations are presented in both SI-based and customary U.S. units. On graphs and charts, grids corresponding to SI-based units appear along the left and bottom edges. Where appropriate, corresponding customary U.S. units appear along the top and right edges.

Data pertaining to a specification published by a specification-writing group, may be given in only the units used in that specification or in dual

units, depending on the nature of the data.

Data obtained according to standardized test methods for which the standard recommends a particular system of units are presented in the units of that system. Wherever feasible, equivalent units are also presented. Some statistical data may also be presented in only the original units used in the analysis.

Conversions and rounding have been done in accordance with ASTM Standard E 380, with attention given to the number of significant digits in the original data. For example, an annealing temperature of 1570 °F contains three significant digits. In this case, the equivalent temperature would be given as 855 °C; the exact conversion to 854.44 °C would not be appropriate. For an invariant physical phenomenon that occurs at a precise temperature (such as the melting of pure silver), it would be appropriate to report the temperature as 961.93 °C or 1763.5 °F. In some instances (especially in tables and data compilations), temperature values in °C and °F are alternatives rather than conversions.

The policy of units of measure in this Handbook contains several exceptions to strict conformance to ASTM E 380; in each instance, the exception has been made in an effort to improve the clarity of the Handbook. The most notable exception is the use of  $\text{g/cm}^3$  rather than  $\text{kg/m}^3$  as the unit of measure for density (mass per unit volume).

SI practice requires that only one virgule (diagonal) appear in units formed by combination of several basic units. Therefore, all of the units preceding the virgule are in the numerator and all units following the virgule are in the denominator of the expression; no parentheses are required to prevent ambiguity.

# Preface

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This *Engineered Materials Handbook Desk Edition* is intended to serve as a comprehensive single-volume reference work on the properties, selection, processing, and applications of the most widely used nonmetallic engineering materials. For the purposes of the *Engineered Materials Handbook* and this desk edition, engineered (or engineering) materials are roughly defined as nonmetallic materials capable of being used in primary structural/industrial applications. In following this general definition, limited attention has been given to basic construction materials such as wood and stone. Instead, the focus has been on two main groups of materials: (1) polymeric materials and (2) ceramics and glasses. These two groups can be further subdivided into monolithic and composite materials.

Section 1, "General Information and Data," contains information applicable both to polymers and to ceramics and glasses. It includes an extensive, illustrated glossary of terms and a collection of engineering tables and data, similar to those found in the *Metals Handbook Desk Edition*. In addition, it includes the "Guide to Materials Selection," which introduces and describes the major categories of engineering materials (including ferrous and nonferrous metals) and provides an overview of methodologies for selecting appropriate materials for particular applications. This Section contains valuable information for engineers seeking candidate material alternatives for specific applications.

Sections 2 through 7 focus on polymeric materials: plastics, elastomers, polymer-matrix composites, adhesives, and sealants. The information in these sections is largely adapted from the first three volumes of the *Engineered Materials Handbook*, with the emphasis on the properties, selection, processing, fabrication, and testing of these materials. New coverage has been added in selected areas, such as properties and characteristics of elastomers; and recycling, metallizing, and testing of plastics.

Ceramics and glasses are covered in Sections 8 through 12. The areas of focus in these sections are similar to those in the sections on polymeric materials. Significant updates and expansions have been made throughout the articles in these sections, especially in the areas of environmental considerations and ceramic-matrix composites.

It should be noted that metal-matrix composites are not addressed to any great extent in this volume, despite the fact that detailed information about MMCs is available in *Composites*, Volume 1 of the *Engineered Materials Handbook* series. They have been omitted because of this volume's focus on nonmetallic materials; it is intended that MMCs will be covered in a Second Edition of the *Metals Handbook Desk Edition*. However, coverage of carbon-carbon composites is provided in this volume, in Section 11.

This volume would not have been possible without the dedicated efforts of a great number of people. First and foremost, we must acknowledge the volume organizers and the hundreds of authors and reviewers who contributed to the original four-volume *Engineered Materials Handbook* series. (The authors of the original source articles are listed in the "Acknowledgments" at the end of each compilation article in this volume.) Thanks are also due to the many people who contributed new information for this volume and who edited and reviewed its contents. We especially want to recognize the efforts of Mara Woods, who prepared the original detailed outline for this volume; Linda Garverick, who edited many of the articles on polymeric materials; and Laurel Sheppard, who edited all of the articles on ceramics and glasses. We also must thank the members of the ASM Handbook Committee, who provided support and advice during the preparation of this project, and the ASM International editorial and production staff members, who have accomplished the enormous task of pulling all of the pieces and parts of information together into a single cohesive volume.

We hope that the *Engineered Materials Handbook Desk Edition* will serve as a valuable reference for anyone who works in areas affected by materials technology, including engineers, technicians, researchers, educators, and students. We have tried to organize the book so that a metallurgist, who may be overwhelmed by the many sources of information on nonmetallic materials, will be able to consult it for a comprehensive introduction to property, processing, and testing information; at the same time, we expect that it will serve the needs of novices and experts alike in a variety of fields, including polymers and ceramics, who need a good basic resource for general information on nonmetallic engineered materials.

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# Glossary of Terms

## A

**A.** The symbol for a repeating unit in a polymer chain.

**ABA copolymers.** Block copolymers with three sequences, but only two domains.

**Abbe value.** A number designating the dispersion of light waves by an optical glass, expressed as the reciprocal dispersive power of the glass by the equation  $v = (n_D - 1) / (n_F - n_C)$ , in which  $v$  is the Abbe value,  $n_D$  is the index of refraction of the glass for the sodium line at 589.3 nm, and  $n_F$  and  $n_C$  are the indices for the hydrogen lines at 486.1 and 656.3 nm, respectively. Also known as Abbe number, nu value, and constriction.

**adhesive.** A material that resists adhesion. A film or coating applied to surfaces to prevent sticking, heat sealing, and so on, such as a parting agent or mold release agent.

**ablation.** A self-regulating heat and mass transfer process in which incident thermal energy is expended by sacrificial loss of material.

**ablative plastic.** A material that absorbs heat (with a low material loss and char rate) through a decomposition process (pyrolysis) that takes place at or near the surface exposed to the heat. This mechanism essentially provides thermal protection (insulation) of the subsurface materials and components by sacrificing the surface layer. Ablation is an exothermic process.

**ABL bottle.** An internal pressure test vessel about 460 mm (18 in.) in diameter and 610 mm (24 in.) long used to determine the quality and properties of the filament-wound material in the vessel.

**abrasion resistance.** The ability of a material to resist surface wear.

**abrasive.** (1) A hard substance used for grinding, honing, lapping, superfinishing, polishing, pressure blasting, or barrel finishing. Abrasives in common use are alumina, silicon carbide, boron carbide, diamond, cubic boron nitride, garnet, and quartz. (2) Hard particles, such as rocks, sand, or fragments of certain hard metals, that wear away a surface when they move across it under pressure.

**ABS.** See *acrylonitrile-butadiene-styrene resins*.

**absolute humidity.** The weight of water vapor present in a unit volume of air, such as grams per cubic foot, or grams per cubic meter. The amount of water vapor is also reported in terms of weight per unit weight of dry air, such as grams per pound of dry air, but this value differs from values calculated on a volume basis and should not be referred to as absolute humidity. It is designated as humidity ratio, specific humidity, or moisture content.

**absolute viscosity.** See *viscosity*.

**absorption.** (1) The taking up of a liquid or gas by capillary, osmotic, or solvent action. (2) The capacity of a solid to receive and retain a substance, usually a liquid or gas, with the formation of an apparently homogeneous mixture. (3) Transformation of radiant energy to a

different form of energy by interaction with matter. (4) The process by which a liquid is drawn into and tends to fill permeable pores in a porous solid body; also, the increase in mass of a porous solid body resulting from the penetration of a liquid into its permeable pores. See also *adsorption*.

**AC.** See *acetal (AC) copolymers*, *acetal (AC) homopolymers*, and *acetal (AC) resins*.

**accelerated aging.** See *artificial weathering*.

**accelerated-life test.** A method designed to approximate, in a short time, the deteriorating effect obtained under normal long-term service conditions. See also *artificial aging*.

**accelerator.** A material that, when mixed with a catalyst or a resin, speeds up the chemical reaction between the catalyst and the resin (usually in the polymerizing of resins or vulcanization of rubbers). Also called *promoter*.

**acceptance test.** A test, or series of tests, conducted by the procuring agency, or an agent thereof, upon receipt, to determine whether an individual lot of materials conforms to the purchase order or contract or to determine the degree of uniformity of the material supplied by the vendor, or both. Compare with *preproduction test* and *qualification test*.

**accumulator.** An auxiliary cylinder and piston (plunger) mounted on injection molding or blowing machines and used to provide faster molding cycles. In blow molding, the accumulator cylinder is filled (during the time between parison deliveries, or "shots") with melted plastic coming from the main (primary) extruder. The plastic melt is stored, or "accumulated," in this auxiliary cylinder until the next shot or parison is required. At that time the piston in the accumulator cylinder forces the molten plastic into the dies that form the parison.

**acetal (AC) copolymers.** A family of highly crystalline thermoplastics prepared by copolymerizing trioxane with small amounts of a comonomer that randomly distributes carbon-carbon bonds in the polymer chain. These bonds, as well as hydroxyethyl terminal units, give the acetal copolymers a high degree of thermal stability and resistance to strong alkaline environments.

**acetal (AC) homopolymers.** Highly crystalline linear polymers formed by polymerizing formaldehyde and capping it with acetate end groups.

**acetal (AC) resins.** Thermoplastics (polyformaldehyde and polyoxymethylene resins) produced by the addition polymerization of aldehydes by means of the carbonyl function, yielding unbranched polyoxymethylene chains of great length. The acetal resins, among the strongest and stiffest of all thermoplastics, are also characterized by good fatigue life, resilience, low moisture sensitivity, high solvent and chemical resistance, and good electrical properties. They may be processed by conventional injection molding and extrusion techniques and fabricated by welding methods used for other plastics.

**acid-acceptor.** A compound that acts as a stabilizer by chemically combining with acid that may be initially present in minute quantities in a plastic, or that may be formed by the decomposition of the resin.

**acid refractory.** Siliceous ceramic materials of a high melting temperature, such as silica brick, used for metallurgical furnace linings. Compare with *basic refractories*.

**acoustic emission testing.** A nondestructive test method that monitors energy released when cracks nucleate and move or when phase changes occur; wave frequency and amplitude are monitored.

**acoustic impedance ( $Z_a$ ).** The ratio of the sound pressure in a medium to the rate of alternating flow of the medium through a specified surface due to the sound wave.

**acoustic microscopy.** A technique used to study features beneath the surface of light-opaque materials. Sound waves generated by a piezoelectric transducer are focused by a sapphire crystal through water onto a reflecting object. The reflected sound wave is used to build up a structural picture electronically.

**acrylate resins.** See *acrylic resins*.

**acrylic plastic.** A thermoplastic polymer made by the polymerization of esters of acrylic acid or its derivatives.

**acrylic resins.** Polymers of acrylic or methacrylic esters, sometimes modified with nonacrylic monomers such as the ABS group. The acrylates may be methyl, ethyl, butyl, or 2-ethylhexyl. Usual methacrylates are methyl, ethyl, butyl, laural, and stearyl. The resins may be in the form of molding powders or casting syrups and are noted for their exceptional clarity and optical properties. Acrylics are widely used in lighting fixtures because they are either slow burning or self-extinguishing and do not produce harmful smoke or gases in the presence of flame.

**acrylonitrile.** A monomer with the structure ( $\text{CH}_2\text{:CHCN}$ ). It is most useful in copolymers. Its copolymer with butadiene is nitrile rubber; acrylonitrile-butadiene copolymers with styrene (SAN) are tougher than polystyrene. Acrylonitrile is also used as a synthetic fiber and as a chemical intermediate.

**acrylonitrile-butadiene-styrene (ABS) resins.** A family of thermoplastics based on acrylonitrile, butadiene, and styrene, combined by a variety of methods involving polymerization, graft polymerization, physical mixing, and combinations thereof. The standard grades of ABS resins are rigid, hard, and tough, but not brittle, and possess good impact strength, heat resistance, low-temperature properties, chemical resistance, and electrical properties.

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

**activated alumina.** A highly porous, granular form of  $\text{Al}_2\text{O}_3$  made by thermal decomposition of gibbsite at 350 to 400 °C (660 to 750 °F), used as a catalyst, catalyst carrier, and absorbent. It is chemically inert to

most gases; will not swell, soften, or disintegrate in water; exhibits high resistance to thermal and mechanical shock abrasion; and will hold moisture without change in form or properties.

**activation.** The (usually) chemical process of making a surface more receptive to bonding with a coating or an encapsulating material.

**activation energy.** The energy required for initiating a chemical reaction. The activation energy may be calculated from the slope of the line obtained by plotting the natural log of the reaction rate versus the reciprocal of the absolute temperature.

**actuator.** A ceramic crystal with piezoelectric or electrostrictive properties, such as PZT, in which strains can be very accurately generated by using controlled electric fields. Such strains are used in devices to position semiconductor chips to tolerances of 0.1  $\mu\text{m}$  (4  $\mu\text{in.}$ ) for surface treatment.

**addition polymerization.** A chemical reaction in which simple molecules (monomers) are linked to each other to form long-chain molecules (polymers) by chain reaction.

**additive.** A substance added to another substance, usually to improve properties or processing characteristics; examples include plasticizers, initiators, light stabilizers, and flame retardants. See also *filler*.

**adhere.** To cause two surfaces to be held together by adhesion.

**adherence.** (1) In ceramics, the bond or union developed at the interface between two substances by fusion or by chemical or physical reaction during fusion. (2) The degree to which a porcelain enamel, glaze, or other ceramic coating adheres to its substrate. (3) A measure of the stress necessary to cause one material to separate from another at their interface.

**adherend.** A body held to another body by an adhesive. See also *substrate*.

**adherend preparation.** See *surface preparation*.

**adhesion.** The state in which two surfaces are held together by interfacial forces, which may consist of valence forces, interlocking action, or both. See also *mechanical adhesion* and *specific adhesion*.

**adhesion promoter.** A coating applied to a substrate, before it is coated with an adhesive, to improve the adhesion of the substrate. See also *primer*.

**adhesion promotion.** The chemical process of preparing a surface to provide for a uniform, well-bonded interface.

**adhesive.** A substance capable of holding materials together by surface attachment. Adhesive is a general term and includes, among others, cement, glue, mucilage, and paste. These terms are loosely used interchangeably. Various descriptive adjectives are applied to the term adhesive to indicate certain physical characteristics. See also *hot-melt adhesive*, *pressure-sensitive adhesive*, *structural adhesive*, *ultraviolet/electron beam cured adhesive*, and *water-based adhesive*.

**adhesive, anaerobic.** See *anaerobic adhesive*.

**adhesive bond.** Attractive forces, generally physical in character, between an adhesive and the base materials.

**adhesive bonding.** A materials joining process in which an adhesive, placed between the faying surfaces (adherends) solidifies to produce an adhesive bond.

**adhesive, cold-setting.** See *cold-setting adhesive*.

**adhesive, contact.** See *contact adhesive*.

**adhesive dispersion.** A two-phase system in which one phase is suspended in a liquid. Compare with *emulsion*.

**adhesive failure.** Rupture of an adhesive bond such that the separation appears to be at the adhesive-adherend interface. Sometimes termed failure in adhesion. Compare with *cohesive failure*.

**adhesive film.** A synthetic resin adhesive, with or without a film carrier fabric, usually of the thermoset-

ting type, in the form of a thin film of resin, used under heat and pressure as an interleaf in the production of bonded structures.

**adhesive, gap-filling.** See *gap-filling adhesive*.

**adhesive, heat-activated.** See *heat-activated adhesive*.

**adhesive, heat-sealing.** See *heat-sealing adhesive*.

**adhesive, hot-melt.** See *hot-melt adhesive*.

**adhesive, hot-setting.** See *hot-setting adhesive*.

**adhesive, intermediate-temperature-setting.** See *intermediate-temperature-setting adhesive*.

**adhesive joint.** Location at which two adherends are held together with a layer of adhesive. See also *bond*.

**adhesive, pressure-sensitive.** See *pressure-sensitive adhesive*.

**adhesive strength.** The strength of the bond between an adhesive and an adherend.

**adhesive, structural.** See *structural adhesive*.

**adhesive system.** An integrated engineering process that analyzes the total environment of a potential bonded assembly to select the most suitable adhesive, application method, and dispensing equipment.

**adiabatic.** Occurring with no addition or loss of heat from the system under consideration.

**adiabatic cooling.** A process in which the temperature of a system is reduced without any heat being exchanged between the system and its surroundings.

**admixture.** (1) The addition and homogeneous dispersion of discrete components, before cure of a polymer. (2) A material other than water, aggregates, hydraulic cement, and fiber reinforcement used as an ingredient of concrete or mortar and added to the batch immediately before or during its mixing. (3) Material added to (cement) mortars as a water-repellent or coloring agent or to retard or hasten setting.

**adsorbent.** Any solid or liquid, such as charcoal, activated alumina, silica, water, and mercury, having the ability to attract and concentrate significant quantities of another substance on its surface and to be penetrated by this substance.

**adsorption.** The adhesion of the molecules of gases, dissolved substances, or liquids in more or less concentrated form, to the surfaces of solids or liquids with which they are in contact. The concentration of a substance at a surface or interface of another substance. See also *absorption*.

**advanced ceramics.** Ceramic materials that exhibit superior mechanical properties, corrosion/oxidation resistance, or electrical, optical, and/or magnetic properties. This term includes many monolithic ceramics as well as particulate-, whisker-, and fiber-reinforced glass, glass-ceramics, and ceramic-matrix composites. Also known as engineering, fine, or technical ceramics. Contrast with *traditional ceramics*.

**advanced composites.** Composite materials that are reinforced with continuous fibers having a modulus higher than that of fiberglass fibers. The term includes metal-matrix and ceramic-matrix composites, as well as carbon-carbon composites.

**aerate.** To introduce air into a slurry by stirring or other means of agitation.

**aerated concrete.** Concrete containing a substantial amount of entrapped air that was introduced by foaming or some other process.

**aerogel.** The porous product obtained when alcogel is dried under supercritical conditions.

**AES.** See *Auger electron spectroscopy*.

**AFM.** See *atomic force microscope*.

**afterbake.** See *postcure*.

**A-glass.** High-alkali glass used to form single-filament glass fibers; a general-purpose reinforcing glass cheaper than E-glass, used mainly with plastic matrices; composition, wt%:  $\text{SiO}_2$  72.7;  $\text{Al}_2\text{O}_3$ , 1.5;  $\text{CaO}$ , 8.3;  $\text{MgO}$ , 3.5;  $\text{Na}_2\text{O}$  +  $\text{K}_2\text{O}$ , 14.0.

**agglomerate.** The clustering together of a few or many particles, whiskers, or fibers, or a combination thereof, into a larger solid mass.

**aggregate.** (1) A hard, coarse material usually of mineral origin used with an epoxy binder (or other resin) in plastic tools. Also used in flooring or as a surface medium. (2) A dense mass of particles held together by strong intermolecular or atomic cohesive forces. (3) Granular material, such as sand, gravel, crushed stone, or iron blast-furnace slag, used with a cementing medium to form hydraulic-cement concrete or mortar.

**aging.** (1) The effect on materials of exposure to an environment for a prolonged interval of time. (2) The process of exposing materials to an environment for a prolonged interval of time in order to predict in-service lifetime. (3) Generally, the degradation of properties or function with time. In capacitors, the loss of dielectric constant,  $K$ , by dielectric relaxation. Expressed as a percent change per decade of time.

**air-assist forming.** A method of thermoforming in which air flow or air pressure is employed to preform plastic sheet partially just before the final pull-down onto the mold using vacuum.

**air-bubble void.** Air entrapment within a molded item or between the plies of reinforcement or within a bond line or encapsulated area; localized, noninterconnected, and spherical in shape.

**air-fuel ratio.** The ratio of the air supply to the fuel supply during combustion, expressed in terms of volume or weight.

**air gap.** In extrusion coating, the distance from the die opening to the nip formed by the pressure roll and the chill roll.

**air ring.** A circular manifold used to distribute an even flow of the cooling medium, air, onto a hollow tubular form passing through the center of the ring. In blown tubing, the air cools the tubing uniformly, thereby providing a uniform film thickness.

**air setting.** The characteristic of some materials, such as refractory cements, core pastes, binders, and plastics, to take permanent set at normal air temperatures.

**air-slip forming.** A variation of vacuum snap-back thermoforming in which the male mold is enclosed in a box such that when the mold moves forward toward the hot plastic, air is trapped between the mold and the plastic sheet. As the mold advances, the plastic is kept away from it by this air cushion until the full travel of the mold is completed, at which point a vacuum is applied, destroying the cushion and forming the part against the plug.

**air vent.** A small outlet to prevent entrapment of gases in a molding or tooling fixture.

**alcogel.** The rigid product obtained in sol-gel processing when metal alkoxide-organic solvent solutions are hydrolyzed.

**alcohols.** Characterized by the hydroxyl ( $-\text{OH}$ ) group they contain, alcohols are valuable starting points for the manufacture of synthetic resins, synthetic rubbers, and plasticizers.

**aldehydes.** Volatile liquids with sharp, penetrating odors that are slightly less soluble in water than are corresponding alcohols.

**aliphatic hydrocarbons.** Saturated hydrocarbons having an open-chain structure, for example, gasoline and propane.

**alkali.** A general term applied to the oxides, hydroxides, and carbonates of sodium and potassium, the alkaline earth metals, and other alkaline metals; used primarily as fluxing agents in ceramic compositions.

**alkaline earth metal.** A metal in group IIA of the periodic system—namely, beryllium, magnesium, calcium, strontium, barium, and radium—so called because the oxides or “earths” of calcium, strontium, and

barium were found by the early chemists to be alkaline in reaction.

**alkaline glaze.** Glazes containing high percentages of alkaline materials, such as  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{Li}_2\text{O}$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{BaO}$ , and so forth.

**alkali resistance.** The relative degree to which porcelain enamels, glazes, and other ceramic surfaces will resist attack by aqueous alkaline solutions, the term most frequently referring to the resistance of these products to alkaline materials used in the home, for example, alkaline-resisting enamel.

**alkoxysilanes.** Materials such as the compound  $\text{CH}_3\text{CHCH}_2\text{Si}(\text{OCH}_3)_3$  that can be gelled by adding water and then heated to prepare  $\text{SiC}$  powders.

**alkyd.** Resin used in coatings. Reaction products of polyhydric alcohols and polybasic acids. Also used extensively as an adhesive for glass fibers.

**alkyd plastic.** Thermoset plastic based on resins composed principally of polymeric esters, in which the recurring ester groups are an integral part of the main polymer chain and in which ester groups occur in most cross links that may be present between chains.

**alkylation.** (1) A chemical process in which an alkyl radical is introduced into an organic compound by substitution or addition. (2) A refinery process for chemically combining isoparaffin with olefin hydrocarbons.

**allophanate.** Reactive product of an isocyanate and the hydrogen atoms in a urethane.

**alloprene.** Chlorinated rubber.

**allotropy.** (1) A near synonym for *polymorphism*. Allotropy is generally restricted to describing polymorphic behavior in elements, terminal phases, and alloys whose behavior closely parallels that of the predominant constituent element. (2) The existence of a substance, especially an element, in two or more physical states (for example, crystals).

**alloy.** A blend of polymers or copolymers with other polymers or elastomers under selected conditions; for example, styrene-acrylonitrile. Also called polymer blend.

**alluvial clay.** A brickmaking clay deposited in or near river beds by flowing water; more plastic, less refractory, and darker in color than residual clays.

**allyl plastic.** A thermoset plastic based on resins made by addition polymerization of monomers containing allyl groups; for example, diallyl phthalate (DAP).

**allyl resins.** A family of thermoset resins made by addition polymerization of compounds containing the group  $\text{CH}_2=\text{CH}-$ , such as esters of allyl alcohol and dibasic acids. They are available as monomers, partially polymerized prepolymers, or molding compounds. Members of the family are diallyl phthalate (DAP), diallyl isophthalate (DAIP), diallyl maleate (DAM), and diallyl chloroendate (DAC).

**alpha ( $\alpha$ ) alumina.** Occurs naturally as corundum and is obtained by heating alumina hydrates to temperatures in excess of  $900^\circ\text{C}$  ( $1650^\circ\text{F}$ ) but never to the melting point,  $2050^\circ\text{C}$  ( $3722^\circ\text{F}$ ); the hardest, most chemically stable form of alumina. See also *alumina*.

**alpha ( $\alpha$ ) cellulose.** A very pure cellulose prepared by special chemical treatment.

**alpha ( $\alpha$ ) loss peak.** In dynamic mechanical or dielectric measurement, the first peak in the damping curve below the melt, in order of decreasing temperature or increasing frequency.

**alpha ( $\alpha$ ) phase.** Rhombohedral quartz polymorph; stable below  $573^\circ\text{C}$  ( $1063^\circ\text{F}$ ).

**alternating copolymer.** A copolymer in which each repeating unit is joined to another repeating unit in the polymer chain ( $-\text{A}-\text{B}-\text{A}-\text{B}-$ ).

**alternating stress amplitude.** A test parameter of a dynamic fatigue test; one-half the algebraic difference between the maximum and minimum stress in one cycle.

**alumina.** A compound in the form of a white powder or colorless hexagonal crystals, the composition of which is  $\text{Al}_2\text{O}_3$ . Used in aluminum production, spark plugs, artificial gems, and manufacture of abrasives, refractories, electrical insulators, and structural ceramics. See also *corundum*.

**alumina brick.** Refractory brick containing 50% or more of  $\text{Al}_2\text{O}_3$ ; used in high-temperature applications, such as liners for kilns and furnaces, particularly in areas where the service conditions are severe.

**aluminum nitride (AlN).** A high-thermal-conductivity ceramic used as an electronic substrate. Also a key component in the production of *Sialons*.

**aluminum oxide ( $\text{Al}_2\text{O}_3$ ).** See *alumina*.

**amber glass.** A glass tinted to colors ranging from pale yellow to brown or reddish brown by the addition of iron oxide and sulfur compounds to the batch.

**ambient.** The environment that surrounds and contacts a system or component.

**amide.** One of a class of organic compounds containing the  $\text{COHN}_2$  radical.

**amine adduct.** Product of the reaction of an amine with a deficiency of a substance containing epoxy groups.

**amino.** Relating to or containing an  $-\text{NH}_2$  or  $-\text{NH}$  group.

**amino resins.** Resins made by the polycondensation of a compound containing amino groups, such as urea or melamine, with an aldehyde, such as formaldehyde, or an aldehyde-yielding material. Melamine-formaldehyde and urea-formaldehyde resins are the most important family members. The resins can be dispersed in water to form colorless syrups. With appropriate catalysts, they can be cured at elevated temperatures.

**amorphous.** Not having a crystal structure; noncrystalline.

**amorphous graphite.** A form of natural graphite formed by metamorphosis of coal seams exposed to high pressure and moderate temperatures. Not accurately described as amorphous but rather as cryptocrystalline; soft and black in appearance.

**amorphous plastic.** A plastic that has no crystalline component, no known order or pattern of molecule distribution, and no sharp melting point.

**amylaceous.** Pertaining to, or of the nature of, starch; starchy.

**anaerobic adhesive.** An adhesive that cures only in the absence of air after being confined between assembled parts.

**anatase.** The tetragonal form of  $\text{TiO}_2$ ; is used as an opacifier and pigment in porcelain enamels, glazes, and glass; the first polymorph to crystallize in enamels containing  $\text{TiO}_2$  but on annealing it changes to rutile. See also *titania* and *rutile*.

**anchorage.** Part of an insert that is molded inside the plastic and held fast by the shrinkage of the plastic.

**anchor pattern.** A pattern made by blast cleaning abrasives on an adherend surface in preparation for adhesive application prior to bonding. Pattern is examined in profile.

**andalusite.** A mineral of composition  $\text{Al}_2\text{O}_3\cdot\text{SiO}_2$  used as a component in refractories, spark plugs, insulators, and whiteware bodies. See also *kyanite* and *sillimanite*.

**anelastic deformation.** Any portion of the total deformation of a body that occurs as a function of time when load is applied and which disappears completely after a period of time when the load is removed.

**angle-ply laminate.** A laminate having fibers of adjacent plies, oriented at alternating angles.

**angle press.** A hydraulic molding press equipped with horizontal and vertical rams, specially designed for the production of complex plastic moldings having deep undercuts.

**angle wrap.** Tape fabric that is wrapped on a starter dam mandrel at an angle to the centerline.

**angstrom unit ( $\text{\AA}$ ).** A unit of linear measure equal to  $10^{-10}$  m, or 0.1 nm. Although not an accepted SI unit, it is occasionally used for small distances, such as interatomic distances, and some wavelengths.

**anhydrous.** Without water, both free water and water of crystallization.

**aniline.** An important organic base ( $\text{C}_6\text{H}_5\text{NH}_2$ ) made by reacting chlorobenzene with aqueous ammonia in the presence of a catalyst. It is used in the production of aniline formaldehyde resins and in the manufacture of certain rubber accelerators and antioxidants.

**aniline-formaldehyde resins.** Members of the aminoplastics family made by the condensation of formaldehyde and aniline in an acid solution. The resins are thermoplastic and are used to a limited extent in the production of molded and laminated insulating materials. Products made from these resins have high dielectric strength and good chemical resistance.

**aniline point.** As applied to a petroleum product, the lowest temperature at which the product is completely miscible with an equal volume of freshly distilled aniline. The aniline point is a guide to the oil composition.

**anionic exchange.** A type of ionic exchange in which the negative ions in a solution are exchanged with the negative ions in a solid, the superficial physical structure of the solid being unaffected. This process is preceded by anion adsorption.

**anisotropic.** Exhibiting different properties when tested along axes in different directions. In magnetics, capable of being magnetized more readily in one direction than in a transverse direction.

**anisotropic conductive adhesive.** An adhesive that can be made conductive in the vertical, or  $z$ , axis while remaining an insulator in the horizontal, or  $x$  and  $y$ , axes.

**anisotropic laminate.** One in which the properties are different in different directions along the laminate plane.

**anisotropy.** The characteristic of exhibiting different values of a property in different directions with respect to a fixed reference system in the material.

**anisotropy of laminates.** The difference of the properties along the directions parallel to the length or width of the lamination planes and perpendicular to the lamination.

**anneal.** To prevent or remove objectionable stresses in glassware by controlled cooling from a suitable temperature.

**annealing.** (1) A controlled cooling process for glass designed to reduce thermal residual stress to a commercially acceptable level, and, in some cases, modify structure. (2) Heating to a temperature at which the molecules have significant mobility, permitting them to reorient to a configuration having less residual stress. In semicrystalline polymers, heating to a temperature at which retarded crystallization or recrystallization can occur.

**annealing point.** That temperature at which internal stresses in a glass are substantially relieved in a matter of minutes.

**annealing range.** The range of glass temperature in which stress in glass can be relieved at a commercially practical rate. For purposes of comparing glasses, the annealing range is assumed to correspond with the temperature between the annealing point and the strain point.

**annealing temperature.** Any temperature within a temperature range at which internal stress in a glass can be substantially reduced or relieved, usually for commercially practical purposes, within a matter of minutes. In order to achieve this, the viscosity of the glass must be close to  $10^{12} \text{ N} \cdot \text{s/m}^2$ .

**anorthite.** A low-thermal-expansion aluminosilicate of composition  $\text{CaAl}_2\text{Si}_2\text{O}_8$ ; a calcium feldspar used in concretes, porcelain enamels, glazes, abrasives, abrasive bonds, artificial teeth, glass, insulating compounds, and conventional ceramic bodies. Also known as calcium feldspar.

**anorthoclase.** A feldspar of a composition between albite and orthoclase formed by rapid cooling to yield a perthite, therefore metastable, but persists indefinitely at normal temperatures; occurs only in lavas. Also known as soda orthoclase, soda microcline, anorthose.

**antiferroelectric.** A polar ceramic with equal numbers of dipoles aligned in opposite directions.

**antiferromagnetic material.** A material wherein interatomic forces hold the elementary atomic magnets (electron spins) of a solid in alignment, a state similar to that of a ferromagnetic material but with the difference that equals numbers of elementary magnets (spins) face in opposite directions and are antiparallel, causing the solid to be weakly magnetic, that is, paramagnetic, instead of ferromagnetic.

**antimony oxide ( $\text{Sb}_2\text{O}_3$ ).** Colloquially called antimony; used as an opacifier in porcelain enamels and as a minor adherence-promoting agent in white porcelain-enamel ground coats, as a constituent in Naples yellow pigments, as a decolorizer and fining agent in glass manufacture, and as a component in glass that is transparent to infrared radiation.

**antimony sulfide ( $\text{Sb}_2\text{S}_3$ ).** Used as an aid in the production of ruby and amber glasses, to promote opacity in opal glasses, and occasionally as a minor adherence promoting agent in porcelain enamels. Also known as stibnite, antimony orange, antimony black, antimony needles, antimonous sulfide.

**antioxidant.** Any additive for the purpose of reducing the rate of oxidation and subsequent deterioration of a material.

**antistatic agents.** Agents that, when added to a plastic molding material or applied to the surface of a molded object, make it less conductive, thus hindering the fixation of dust or the buildup of electrical charge.

**apatite.** A natural calcium phosphate of composition  $\text{Ca}_5(\text{F},\text{Cl},\text{OH})(\text{PO}_4)_3$  used as an opacifier in the manufacture of opal glass and as a substitute for bone ash in whiteware bodies; the major constituent of teeth and bones in mammals.

**apparent density.** (1) The weight per unit volume of a powder, in contrast to the weight per unit volume of the individual particles. (2) The weight per unit volume of a porous solid, where the unit volume is determined from external dimensions of the mass. Apparent density is always less than the true density of the material itself. See also *apparent specific gravity*.

**apparent porosity.** The relation of the open pore space to the bulk volume, expressed in percent.

**apparent specific gravity.** The ratio of the weight of a unit volume of a body to an equal volume of water at the same temperature determined by the formula  $G = W_f/V(W_s - W_p)$ , where  $G$  is the apparent specific gravity,  $W_f$  is the weight of the fired specimen in kilograms,  $V$  is the volume of the fired specimen in cubic meters, and  $W_s$  is the weight of the water-saturated specimen in kilograms. Also known as *apparent density*.

**applied stress intensity factor ( $K_I$ ).** See *stress-intensity factor*.

**aramid.** A manufactured organic fiber in which the fiber-forming substance is a long-chain synthetic aromatic polyamide in which at least 85% of the amide linkages are directly attached to two aromatic rings. Aramid fibers, most notably Kevlar fibers, were the first with a high enough tensile modulus and strength to be used as a reinforcement in advanced composites.

**arc plasma spraying.** Fine ceramic powder is injected into a plasma jet that heats and accelerates it onto a surface. Not all particles are melted because conven-

tional spray guns inject the powder orthogonally and some particles remain in the cooler outer layers of the plasma flame.

**arc resistance.** Ability to withstand exposure to an electric voltage. The total time in seconds that an intermittent arc may play across a plastic surface without rendering the surface conductive.

**Archimedes principle.** A body immersed in a liquid undergoes an apparent loss in weight equal to the weight of the fluid it has displaced.

**architectural glass.** Glass used in the building industry.

**architectural terra cotta.** Hard-fired, glazed or unglazed clay building units generally larger than brick or conventional facing tile; the units may be machine-extruded or hand-molded, and they may be plain or ornamental.

**areal weight.** The weight of a fiber reinforcement per unit area (width  $\times$  length) of tape or fabric.

**aromatic.** Unsaturated hydrocarbon with one or more benzene ring structures in the molecule.

**aromatic polyester.** A polyester derived from monomers in which all the hydroxyl and carboxyl groups are directly linked to aromatic nuclei.

**arsenic.** In the ceramic context, a term for arsenic oxide,  $\text{As}_2\text{O}_3$ .

**arsenic acid ( $\text{H}_3\text{AsO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ ).** Sometimes used as a source of arsenic in glass.

**arsenic oxide ( $\text{As}_2\text{O}_3$ ).** Used as a fining agent and decolorizer in glass and as an opacifier in glazes; sublimes at 193 °C (380 °F). Also known as arsenious oxide, arsenic trioxide, white arsenic.

**artificial aging.** The exposure of a plastic to conditions that accelerate the effects of time. Such conditions include heating, exposure to cold, flexing, application of electric field, exposure to chemicals, ultraviolet light radiation, and so forth. Typically, the conditions chosen for such testing reflect the conditions under which the plastic article will be used. Usually, the length of time the article is exposed to these test conditions is relatively short. Properties such as dimensional stability, mechanical fatigue, chemical resistance, stress cracking resistance, dielectric strength, and so forth, are evaluated in such testing. See also *aging*.

**artificial weathering.** The exposure of plastics to cyclic laboratory conditions, consisting of high and low temperatures, high and low relative humidities, and ultraviolet radiant energy, with or without direct water spray and moving air (wind), in an attempt to produce changes in the properties of the plastics similar to those observed after long-term continuous exposure outdoors. The laboratory exposure conditions are usually more intensified than those encountered in actual outdoor exposure in an attempt to achieve an accelerated effect. Also called *accelerated aging*.

**ash content.** Proportion of the solid residue remaining after a reinforcing substance has been incinerated (charred or intensely heated).

**aspect ratio.** The ratio of length to diameter of a reinforcing fiber.

**asperity.** Roughness of a surface.

**asphalt.** See *bitumen*.

**assembly adhesive.** An adhesive that can be used for bonding parts together, such as in the manufacture of a boat, an airplane, furniture, and the like. The term is commonly used in the wood industry to distinguish such adhesives (formerly called joint glues) from those used in making sheet materials such as plywood (sometimes called veneer glues).

**assembly time.** The time interval between the spreading of the adhesive on the adherend and the application of pressure or heat, or both, to the assembly. For assemblies involving multiple layers or parts, the assembly time begins with the spreading of the adhe-

sive on the first adherend. See also *closed assembly time* and *open assembly time*.

**A-stage.** An early stage in the reaction of certain thermosetting resins in which the material is fusible and still soluble in certain liquids. Synonym for *resole*. Compare with *B-stage* and *C-stage*.

**ASTM.** Acronym for the American Society for Testing and Materials.

**atactic stereoisomerism.** A chain of molecules in which the position of the side chains or side atoms is more or less random. See also *isotactic stereoisomerism* and *syndiotactic stereoisomerism*.

**atomic absorption spectrometry (AAS).** The measurement of light absorbed at the wavelength of resonance lines by the unexcited atoms of an element.

**atomic force microscope.** A scanning technique capable of imaging crystal surfaces as they grow with a resolution of about 0.3 nm.

**atomic number (Z).** The number of elementary positive charges (protons) contained within the nucleus of an atom. For an electrically neutral atom, the number of planetary electron is also given by the atomic number. Atoms with the same Z (isotopes) may contain different numbers of neutrons. Also known as nuclear charge. See also *isotope* and *proton*.

**attenuation.** (1) The fractional decrease of the intensity of an energy flux, including the reduction of intensity resulting from geometrical spreading, absorption, and scattering. (2) The diminution of vibrations or energy over time or distance. The process of making thin and slender shapes, as applied to the formation of fiber from molten glass. (3) The exponential decrease with distance in the amplitude of an electrical signal traveling along a very long, uniform transmission line, due to conductor and dielectric losses.

**attrition.** Removal of small fragments of surface material during sliding contact.

**attrition mill.** A machine in which materials are pulverized between toothed metal disks rotating in opposite directions.

**auger.** A machine that forces or extrudes moist clay and similar bodies through a die by means of a revolving screw contained in a closed cylinder or barrel.

**Auger electron spectroscopy (AES).** A technique for chemical analysis of surface layers that identifies the atoms present in a layer by measuring the characteristic energies of their Auger electrons.

**autoclave.** A closed vessel for conducting and completing either a chemical reaction under pressure and heat or other operation, such as cooling. Widely used for bonding and curing reinforced plastic laminates.

**autoclave molding.** A process in which, after lay-up, winding, or wrapping, an entire assembly is placed in a heated autoclave, usually at 340 to 1380 kPa (50 to 200 psi). Additional pressure permits higher density and improved removal of volatiles from the resin. Lay-up is usually vacuum bagged with a bleeder and release cloth.

**autogeneous grinding.** Grinding in a rotating cylindrical mill without the use of balls or rods; the grinding media is the incoming additions of the coarse material to be ground.

**automatic mold.** A mold for injection or compression molding of plastics that repeatedly goes through the entire cycle, including ejection, without human assistance.

**automatic press.** A hydraulic press for compression molding or an injection machine that operates continuously, being controlled mechanically (toggle) or hydraulically, or by a combination of these methods.

**average coefficient of linear expansion.** The average change in the unit length of a body per unit change in temperature over a prescribed temperature range.



**average molecular weight.** The molecular weight of the most typical chain in a given plastic; it is characteristic of neither the longest nor the shortest chain.

**average particle size.** A single value representing the entire particle size distribution.

**axial strain.** The linear strain in a plane parallel to the longitudinal axis of the specimen.

**axial winding.** In filament-wound reinforced plastics, a winding with the filament parallel to, or at a small angle to, the axis ( $0^\circ$  helix angle). See also *polar winding*.

**azo-** Prefix indicating the radical  $-N=N-$ .

## B

**B.** The symbol for a repeating unit in a copolymer chain.

**backing plate.** In plastic injection molding equipment, a heavy steel plate that is used as a support for the cavity blocks, guide pins, and bushings. In blow molding equipment, it is the steel plate on which the cavities (that is, the bottle molds) are mounted.

**back pressure.** Resistance of a plastic, because of its viscosity, to continued flow when the mold is closing.

**back-pressure relief port.** An opening in an extrusion die for plastics that allows for the escape of excess material.

**back taper.** Reverse draft used in a mold to prevent the molded plastic article from drawing freely. See also *undercut*.

**bagging.** Applying an impermeable layer of film over an uncured part and sealing the edges so that a vacuum can be drawn.

**baghouse.** A chamber containing bags for filtering solids out of gases.

**bag molding.** A method of molding or bonding plastics or composites involving the application of fluid pressure, usually by means of air, steam, water, or vacuum, to a flexible cover that, sometimes in conjunction with the rigid die, completely encloses the material to be bonded. Also called *blanket molding*. See also *vacuum bag molding*.

**bag side.** The side of a plastic or composite part that is cured against the vacuum bag.

**bag wall.** A refractory wall in a furnace or kiln designed and placed to deflect a flame to prevent it from striking ware being fired.

**bait.** A tool dipped into a bath of molten glass to start a drawing operation.

**Bakelite.** A proprietary name for a phenolic thermosetting resin used as a plastic mounting material for metallographic samples.

**balanced construction.** In woven reinforcements, equal parts of warp and fill fibers. Construction in which reactions to tension and compression loads result in extension or compression deformations only and in which flexural loads produce pure bending of equal magnitude in axial and lateral directions.

**balanced design.** In filament-wound reinforced plastics, a winding pattern so designed that the stresses in all filaments are equal.

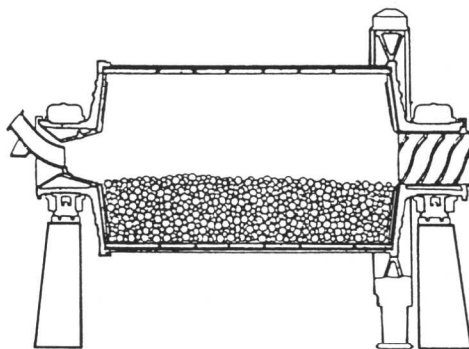
**balanced-in-plane contour.** In a filament-wound part, a head contour in which the filaments are oriented within a plane and the radii of curvature are adjusted to balance the stresses along the filaments with the pressure loading.

**balanced laminate.** A laminate in which all laminae at angles other than  $0^\circ$  and  $90^\circ$  occur only in  $\pm$  pairs (not necessarily adjacent) and are symmetrical around the centerline. See also *symmetrical laminate*.

**balanced twist.** An arrangement of twists in a combination of two or more reinforcing strands that does not kink or twist when the yarn produced is held in the form of an open loop.

**ball clay.** A secondary clay, commonly characterized by the presence of organic matter, high plasticity, high dry strength, long vitrification range, and a light color when fired. Used extensively in traditional ceramics, such as whiteware, wall tile, and china.

**ball mill.** A machine consisting of a rotating hollow cylinder partly filled with metal balls (usually hardened steel or white cast iron) or sometimes pebbles; used to pulverize crushed ores or other substances such as pigments or ceramics.



Ball mill

**banbury.** An apparatus for compounding polymeric materials. It is composed of a pair of contrarotating rotors that masticate the materials to form a homogeneous blend. This internal-type mixer produces excellent mixing.

**band density.** In filament winding of composites, the quantity of fiberglass reinforcements per inch of band width, expressed as strands (or filaments) per inch.

**band thickness.** In filament winding of composites, the thickness of the reinforcement as it is applied to the mandrel.

**band width.** In filament winding of composites, the width of the reinforcement as it is applied to the mandrel.

**Barcol hardness.** A hardness value obtained by measuring the resistance to penetration of a sharp steel point under a spring load. The instrument, called the Barcol impressor, gives a direct reading on a 0 to 100 scale. The hardness value is often used as a measure of the degree of cure of a plastic.

**bare glass.** Glass in the form of yarns, rovings, and fabrics from which the sizing or finish has been removed. Also, such glass before the application of sizing or finish.

**barite ( $\text{BaSO}_4$ ).** An orthorhombic mineral used in glasses as a flux to reduce seeds, increase toughness, improve brilliance, and reduce annealing time. Also known as barytes and blanc fixe.

**barium aluminate.** (1)  $\text{Ba}_3\text{Al}_2\text{O}_6$ ; used as a source of barium oxide in glass compositions to decrease the solubility and increase the brilliance of the glass; also used in cathode coatings for vacuum tubes. (2)  $\text{BaAl}_2\text{O}_4$ , barium aluminum spinel. (3)  $\text{BaAl}_{12}\text{O}_{19}$ .

**barium carbonate ( $\text{BaCO}_3$ ).** Used as a flux in porcelain enamels and glazes and to improve elasticity, brilliance, mechanical strength, and acid resistance and to prevent scumming; used as an ingredient in flint glass, pressed tableware, television tubes, and laboratory glassware to lower the melting point, improve workability, improve brilliance and hardness, and to improve dielectric constants and resistivity; used to obtain maximum flux density in hard-core permanent magnets; used in structural clay products to prevent scum and efflorescence; and employed in steatite, for-

sterite, zircon porcelain, and titanate electronic components to reduce dielectric loss.

**barium chloride ( $\text{BaCl}_2$ ).** Used as a set-up agent and scum preventative in porcelain enamels by precipitating soluble sulfates as insoluble barium sulfate.

**barium chromate ( $\text{BaCrO}_4$ ).** Used in the production of yellow and pale green overglaze colors. Sometimes known as chrome yellow.

**barium ferrite ( $\text{BaFe}_{12}\text{O}_{19}$ ).** Magnetic ceramic with a hexagonal magnetoplumbite structure; it has a high value of uniaxial anisotropy field and high coercive force that makes it stable in strong demagnetizing fields; a high resistivity  $10^6 \text{ ohm} \cdot \text{m}$ . Used as magnets in TV tubes. Many trade names: Ferroba, Magnadur, M-compounds.

**barium nitrate ( $\text{Ba(NO}_3)_2$ ).** Used to improve homogeneity and opacity in porcelain enamels and as an ingredient in optical glasses. Also known as nitrobarite.

**barium stannate ( $\text{BaSnO}_3 \cdot 3\text{H}_2\text{O}$ ).** Used as an additive to barium titanate bodies to decrease the Curie point for use as capacitors of high dielectric constant; also used in glass enamels to improve alkali resistance; loses  $\text{H}_2\text{O}$  at  $280^\circ\text{C}$  ( $535^\circ\text{F}$ ).

**barium tantalum oxynitride ( $\text{BaTaO}_2\text{N}$ ).** Deep-brown colored perovskite dielectric capable of being sintered in a reducing atmosphere, which allows the use of metals other than platinum as electrodes to be sintered in place during processing.

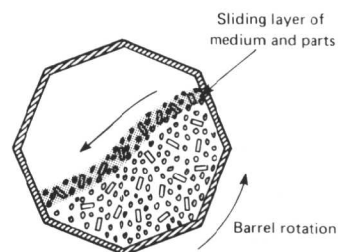
**barium titanate ( $\text{BaTiO}_3$ ).** The basic raw material used to make high dielectric constant ceramic capacitors. Used also in high thermal conductivity, thick-film ceramic pastes.

**barium tungstate ( $\text{BaWO}_4$ ).** Used as a white pigment and as a phosphor in ultraviolet radiation.

**barium zirconate ( $\text{BaZrO}_3$ ).** A perovskite used as an addition to barium titanate bodies to improve their dielectric properties.

**barometer.** A device for measuring the energy of an electromagnetic wave by absorbing the wave and registering an increase in temperature as measured by a change in its electrical resistance.

**barrel finishing.** Improving the surface finish of workpieces by processing them in rotating equipment along with abrasive particles that may be suspended in a liquid. The barrel is normally loaded about 60% full with a mixture of parts, media, compound, and water.



Barrel finishing

**barrier coat.** An exterior coating applied to a composite filament-wound structure to provide protection. In fuel tanks, a coating applied to the inside of the tank to prevent fuel from permeating the side wall.

**barrier film.** The layer of film used during cure to permit removal of air and volatiles from a reinforced plastic or a composite lay-up while minimizing resin loss.

**barrier plastics.** A general term applied to a group of lightweight, transparent, impact-resistant plastics, usually rigid copolymers of high acrylonitrile content. Barrier plastics are generally characterized by gas, aroma,