Materials Handbook

TWELFTH EDITION

An Encyclopedia for Managers, Technical Professionals, Purchasing and Production Managers, Technicians, Supervisors, and Foremen

GEORGE S. BRADY
(Deceased)

HENRY R. CLAUSER

Materials Handbo

An Encyclopedia for Managers, Technical Professionals, Purchasing and Production Managers, Technicians, Supervisors, and Foremen

GEORGE S. BRADY
(Deceased)

HENRY R. CLAUSER
Materials Consultant
Former Editor, Materials Engineering

TWELFTH EDITION

McGraw-Hill Book Company
New York St. Louis San Francisco Auckland Bogotá Hamburg
Johannesburg London Madrid Mexico Montreal New Delhi
Panama Paris São Paulo Singapore Sydney Tokyo Toronto

The Library of Congress cataloged the first printing
of this title as follows:

Brady, George Stuart, date
Materials handbook; an encyclopedia for purchasing agents, engineers, executives, and foremen. 1st– ed. New York, McGraw-Hill, 1929–
v. illus., maps. 18–24 cm.

1. Materials—Dictionaries. I. Title.
TA403.B75 29—1603 rev*
Library of Congress [r51u1]
ISBN 0-07-007071-7

1234567890 DOC/DOC 898765

ISBN 0-07-007071-7

The editors for this book were Harold B. Crawford and Vivian Koenig, the designer was Mark E. Safran, and the production supervisor was Teresa F. Leaden. It was set in ITC Baskerville by University Graphics, Inc.

Printed and bound by R. R. Donnelley & Sons Company.

Materials Handbook

OTHER McGRAW-HILL REFERENCE BOOKS OF INTEREST

Handbooks

Baumeister and Avallone: MARKS' STANDARD HANDBOOK FOR MECHANICAL ENGINEERS
Considine: PROCESS INSTRUMENTS AND CONTROLS HANDBOOK
Crocker and King: PIPING HANDBOOK
Dean: LANGE'S HANDBOOK OF CHEMISTRY
Fink and Beaty: STANDARD HANDBOOK FOR ELECTRICAL ENGINEERS
Fink and Christiansen: ELECTRONICS ENGINEERS' HANDBOOK
Hicks: STANDARD HANDBOOK OF ENGINEERING CALCULATIONS
Juran: QUALITY CONTROL HANDBOOK
Kaufman and Seidman: HANDBOOK FOR ELECTRONICS ENGINEERING TECHNICIANS
Lange: HANDBOOK OF METALS FORMING
McLellan and Shand: GLASS ENGINEERING HANDBOOK
Maynard: INDUSTRIAL ENGINEERING HANDBOOK
Merritt: STANDARD HANDBOOK FOR CIVIL ENGINEERS
National Association of Purchasing Managers: ALJIAN'S PURCHASING HANDBOOK
Perry and Green: PERRY'S CHEMICAL ENGINEERS' HANDBOOK
Rohsenow, Hartnett, and Ganic: HANDBOOK OF HEAT TRANSFER FUNDAMENTALS
Rohsenow, Hartnett, and Ganic: HANDBOOK OF HEAT TRANSFER APPLICATIONS
Rosaler and Rice: STANDARD HANDBOOK OF PLANT ENGINEERING
Rothbart: MECHANICAL DESIGN AND SYSTEMS HANDBOOK
Seidman, Mahrous, and Hicks: HANDBOOK OF ELECTRIC POWER CALCULATIONS
Teicholz: CAD/CAM HANDBOOK
Tuma: ENGINEERING MATHEMATICS HANDBOOK

Dictionaries

McGraw-Hill: DICTIONARY OF SCIENTIFIC AND TECHNICAL TERMS

Encyclopedias

McGraw-Hill: CONCISE ENCYCLOPEDIA OF SCIENCE AND TECHNOLOGY
McGraw-Hill: ENCYCLOPEDIA OF PHYSICS
McGraw-Hill: ENCYCLOPEDIA OF ENGINEERING
McGraw-Hill: ENCYCLOPEDIA OF ENERGY

Preface

The twelfth edition of the *Materials Handbook* is the cumulative development of an idea that originated with the late Colonel George S. Brady more than fifty years ago. Aware then of the steadily increasing number of materials being developed, Colonel Brady set out to prepare a one-volume encyclopedia that would intelligently describe the important characteristics of commercially available materials without involvement in details—an encyclopedia that would meet the job needs of managers and executives, purchasing and manufacturing managers, supervisors, engineers, students, and others. Attesting to both the validity of his idea and the success of its execution is the fact that over the years the *Materials Handbook* has come to be recognized as the leading reference work of its kind in the world.

The philosophy behind the *Materials Handbook,* as well as its purpose and scope, is best expressed in this excerpt from the foreword to the tenth edition:

> All materials, infinite in possible numbers, derive from only 92 natural elements. It is as basically simple as that, but the varying forms and usages are so intertwined in all the industries that a person can have no real comprehension of the characteristics and economics of any one of the materials which he procures for his own use unless he has an intelligent overall grasp of its varying forms and usages. The selection of data and of examples in the *Materials Handbook* has been made with a view toward giving the reader an intelligent overall insight. It is not

the purpose of the book to provide an exhaustive treatise on any materials, as it is assumed that the reader will consult producers of the materials for detailed specifications.

General information, with the most commonly accepted comparative figures, is given on materials in their group classifications in order to give a general picture; selected processed materials and patented and trade-named materials are then described to give a more specific understanding of commercial applications. The relative position and the length of description of proprietary materials are for purposes of illustration and bear no relation to the relative merits of the products of any one producer.

Since the first edition of the *Materials Handbook* was published, a virtual revolution in materials has been taking place, resulting in new types and grades of materials—plastics, metal alloys, rubbers, textiles, finishes, foodstuffs, chemicals, and animal products—that are being developed at an exponential rate. Each new edition of the *Materials Handbook* reflects this phenomenal proliferation in number and variety. Whereas the first edition covered only a few thousand materials, this latest edition describes some 14,000 different materials. Despite this manyfold increase in coverage, it is virtually impossible to include all commercially available materials in a one-volume work of this kind. Nevertheless, descriptions of the most important and most widely used of the thousands of materials introduced every year are added to each edition of this handbook.

After publication of the tenth edition, Colonel Brady retired and transferred to me the task of preparing this and subsequent editions of the *Materials Handbook*. In serving as co-author I have endeavored to hold to his standards of accuracy and readability. His help and counsel were invaluable to me in maintaining the original purpose and character of the handbook.

HENRY R. CLAUSER

Acknowledgments

The sources of information for *Materials Handbook* are too numerous to permit mention of all who furnished data and counsel, but acknowledgment is made of the ready and willing cooperation of producers, manufacturers, technical authorities, industrial-paper editors, and government bureaus in this country and abroad. A deep sense of appreciation is felt for the encouragement and advice given to the work by the many members of the National Association of Purchasing Management and the American Ordnance Association.

Contents

1

Materials, Their Properties and Uses

ABLATIVE AGENTS. Materials used for the outward dissipation of extremely high heats by mass removal. Their most common use is as an external heat shield to protect supersonic aerospace vehicles from an excessive buildup of heat caused by air friction at the surface. The ablative material must have a low thermal conductivity in order that the heat may remain concentrated in the thin surface layer. As the surface of the ablator melts or sublimes, it is wiped away by the frictional forces that simultaneously heat newly exposed surfaces. The heat is carried off with the material removed. The less material that is lost, the more efficient is the ablative material. The ablative material, in addition to low thermal conductivity, should have a high thermal capacity in the solid, liquid, and gaseous states; a high heat of fusion and evaporation; and a high heat of dissociation of its vapors. The ablative agent, or **ablator,** is usually a carbonaceous organic compound, such as a plastic. As the dissociation products are lost as liquid or vapor, the char is held in place by the refractory filler fibers, still giving a measure of heat resistance. The effective life of an ablative is short, calculated in seconds per millimeter of thickness for the distance traveled in the atmosphere.

Single ablative materials seldom have all of the desirable factors, and thus composites are used. Phenolic or epoxy resins are reinforced with asbestos fabric, carbonized cloth, or refractory fibers such as asbestos, fused silica, and glasses. The refractory fibers are incorporated not only for mechanical strength but have a function in the ablative process, and surface-active agents may be added to speed the rate of evaporation. **Ablative paint,** for protecting woodwork, may be organic silicones which convert to silica at temperatures above 2000°F (1093°C). **Pyromark,** of Tempil Corp., is a paint of this type.

Metals can resist temperatures higher than their melting point by **convection cooling,** or **thermal cooling,** which is heat protection by heat exchange with a coolant. Thus, tungsten can be arc-melted in a copper kettle which is cooled by circulating water. The container metal must have high thermal conductivity, and the heat must be quickly carried away and stored or dissipated. When convection cooling is difficult or not possible, cooling may be accomplished by a heat sink. **Heat-sink cooling** depends on the heat absorption capability of the structural material itself or backed up by another material of higher heat absorption. Copper, beryllium, graphite, and beryllium oxide have been used. A heat-sink material should have high thermal conductivity, high specific heat and melting point, and for aerodynamic applications, a low specific gravity.

ABRASIVES. Materials used for surfacing and finishing metals, stone, wood, glass, and other materials by abrasive action. The natural abrasives include the diamond, emery, corundum, sand, crushed garnet and quartz, tripoli, and pumice. **Artificial abrasives,** or **manufactured abrasives,** are generally superior in uniformity to natural abrasives, and are mostly silicon carbide, aluminum oxide, boron carbide, or boron nitride, marketed under trade names. Artificial diamonds are also now being produced. The massive natural abrasives, such as sandstone, are cut into grinding wheels from the natural block, but most abrasive material is used as grains or built into artificial shapes.

For industrial grinding, artificial abrasives are preferred to natural abrasives because of their greater uniformity. Grading is important because uniform grinding requires grains of the same size. The abrasive grains are used as a grinding powder, are made into wheels, blocks, or stones, or are bonded to paper or cloth. **Abrasive cloth** is made of cotton jean or drills to close tolerances of yarns and weaves, and the grains are attached with glue or resin. But the **Fabricut cloth** of the 3M Co. is an open-weave fabric with alumina or silicon-carbide grains of 100 to 400 mesh. The open weave permits easy cleaning of the cloth in an air blast. **Abrasive paper** has the grains, usually aluminum oxide or silicon carbide, glued to one side of 40- to 130-lb kraft paper. The usual grain sizes are No. 16 to No. 500.

Abrasive powder is usually graded in sizes from 8 to 240 mesh. Coarse grain is to 24 mesh; fine grain is 150 to 240. **Blasting abrasive** for blast cleaning of metal castings is usually coarse grain. **Arrowblast,** of the Norton Co., is aluminum oxide with grain sizes 16 to 80 mesh. **Grinding flour** consists of extremely fine grains separated by flotation, usually in grain sizes from 280 to 600 mesh, used for grinding glass and fine polishing. **Levigated abrasives** are fine powders for final burnishing of metals or for metallographic polishing, usually processed to make them chemically neutral. **Green rouge** is levigated chromic oxide, and **mild polish** may be levigated tin oxide; both are used for burnishing soft metals. **Polishing powder** may be aluminum oxide or metal oxide powders of ultrafine particle size down to 600 mesh. **Micria AD,** of the Monsanto Co., is alumina; **Micria ZR** is zirconia; and **Micria TIS** is titania. **Gamal,** of the Fisher Scientific Co., is a fine aluminum oxide powder, the smaller cubes being 1.5 μm, with smaller particles 0.5 μm. **Cerox,** of the Lindsay Div., is cerium oxide used to polish optical lenses and automobile windshields. It cuts fast and gives a smooth surface. **Grinding compounds** for valve grinding are usually aluminum oxide in oil.

Mild abrasives, used in silver polishes and window-cleaning compounds, such as chalk and talc, have a hardness of 1 to 2 Mohs. The milder abrasives for dental pastes and powders may be precipitated calcium carbonate, tricalcium phosphate, or combinations of sodium metaphosphate and tricalcium phosphate. Abrasives for metal polishes may also be pumice, diatomite, silica flour, tripoli, whiting, kaolin, tin oxide, or fuller's earth. This type of fine abrasive must be of very uniform grain in order to prevent scratching. **Cuttle bone, or cuttlefish bone,** is a calcareous powder made from the internal shell of a Mediterranean marine mollusk of the genus *Sepia,* and is used as a fine polishing material for jewelry and in tooth powders. **Ground glass** is regularly marketed as an abrasive for use in scouring compounds and in match-head compositions. **Lapping abrasives,** for finish grinding of hard materials, are diamond dust or boron carbide powder.

Aluminum oxide wheels are used for grinding materials of high tensile strength. **Silicon carbide** is harder but is not as strong as aluminum oxide. It is used for grinding metals that have dense grain structure and for stone. **Vitrified wheels** are made by molding under heat and pressure. They are used for general and precision grinding where the wheel does not exceed a speed of 6,500 surface ft/min (33 m/s). The rigidity gives high precision, and the porosity and strength of bond permit high stock removal. **Silicate wheels** have a silicate binder and are baked. The silicate bond releases the grains more easily than the vitrified, and is used for grinding edge tools to reduce burning of the tool. Synthetic resins are used for bonding where greater strength is required than is obtained with the silicate, but less openness than with the vitrified. Resinoid bonds are used up to 16,000 surface ft/min (81 m/s), and are used especially for thread grinding and cutoff wheels. Shellac binder is used for light work and for high finishing. Rubber is used for precision grinding and for centerless-feed machines.

Grading of abrasive wheels is by grit size number from No. 10 to No. 600, which is 600 mesh; by grade of wheel, or strength of the bond, which is by letter designation, increasing in hardness from A to Z; and by grain spacing or structure number. The ideal condition is with a bond strong enough to hold the grains to accomplish the desired result, and then release them before they become too dull. Essential qualities in the abrasive grain are: penetration hardness, body strength sufficient to resist fracture until the points dull and then break to present a new edge, and an attrition resistance suitable to the work. Some wheels are made with a porous honeycombed structure to give free cutting and cooler operation on some types of metal grinding. Some diamond wheels are made with aluminum powder mixed with a thermosetting resin, and the diamond abrasive mix is hot-pressed around this core wheel. Norton diamond wheels are of three types: metal bonded by powder metallurgy, resinoid bonded, and vitrified bonded.

ABRASIVE SAND. Any sand used for abrasive and grinding purposes, but the term does not include the sharp grains obtained by crushing quartz and used for sandpaper. The chief types of abrasive sand include **sandblast sand, glass-grinding sand,** and **stone-cutting sand.** Sand for stone sawing and for marble and glass grinding is usually ungraded, with no preparation other than screening, but it must have tough, uniform grains. **Chats** are sand tailings from the Missouri lead ores, used for sawing stone. **Banding sand** is used for the band grinding of tool handles, and for the grinding of plate glass, but is often replaced by artificial abrasives. Banding-sand grains are fine, 95% being retained on a 150-mesh screen. **Burnishing sand,** for metal polishing, is a fine-grained silica sand with rounded grains. It should pass a 65-mesh screen, and be retained on a 100-mesh screen.

ABS PLASTICS. The letters ABS identify the family of **acrylonitrile-butadiene-styrene.** Common trade names for these materials are **Cycolac, Kralastic,** and **Lustran.** They are opaque and distinguished by a good balance of properties, including high impact strength, rigidity, and hardness over a temperature range of −40 to 230°F (−40 to 110°C). Compared to other structural or engineering plastics, they are generally considered to fall at the lower end of the scale. Medium impact grades are hard, rigid, and tough, and are used for appearance parts that require high strength, good fatigue resistance, and surface hardness and gloss. High impact grades are formulated for similar products where additional impact strength is gained at some sacrifice in rigidity and hardness. Low-temperature impact grades have high impact strength down to −40°F (−40°C). Again, some sacrifice is made in strength, rigidity, and heat resistance. Heat-resistant, high-strength grades provide the best heat resistance—continuous use up to about 200°F (93°C), and a 264 lb/in^2 (2 MPa) heat distortion temperature of around 215°F (102°C). Impact strength is about comparable to that of medium impact grades, but strength, modulus of elasticity, and hardness are higher. At stresses above their tensile strength, ABS plastics usually yield plastically instead of rupturing, and impact failures are ductile. Because of relatively low creep, they have good long-term load-carrying ability. This low creep plus low water absorption and relatively high heat resistance provide ABS plastics with good dimensional stability. ABS plastics are readily processed by extrusion, injection molding, blow molding, calendering, and vacuum forming. Resins have been developed especially for cold forming or stamping from extruded sheet. Typical applications are helmets, refrigerator liners, luggage tote trays, housings, grills for hot air systems and pump impellers. Extruded shapes include tubing and pipe. ABS plated parts are now in wide use, replacing metal parts in the automotive and appliance field.

ACAROID RESIN. A gum resin from the base of the tufted trunk leaves of various species of *Xanthorrhoea* trees of Australia and Tasmania. It is also called **gum accroides** and **yacca gum. Yellow acaroid** from the *X. tateana* is relatively scarce, but a gum of the yellow class comes from the tree *X.*

preissii of Western Australia, and is in small hollow pieces of yellow to reddish color. It is known as **black boy resin,** the name coming from the appearance of the tree. **Red acaroid,** known also as **red gum** and **grass tree gum,** comes in small dusty pieces of reddish-brown color. This variety is from the *X. australis* and about 15 other species of the tree of southeastern Australia. The resins contain 80 to 85% resinotannol with **coumaric acid,** which is a hydroxycinnamic acid, and they also contain free cinnamic acid. They are thus closely related chemically to the balsams. Acaroid resin has the property unique among natural resins of capacity for thermosetting to a hard, insoluble, chemical-resistant film. By treatment with nitric acid it yields picric acid; by treatment with sulfuric acid it yields fast brown to black dyes. The resins are soluble in alcohols and in aniline, only slightly soluble in chlorinated compounds, and insoluble in coal-tar hydrocarbons. Acaroid has some of the physical characteristics of shellac, but is difficult to bleach. It is used for spirit varnishes and metal lacquers, in coatings, in paper sizing, in inks and sealing waxes, in binders, for blending with shellac, in production of picric acid, and in medicine.

ACETAL RESINS. Highly crystalline resins that have the repeating group $(OCH_2)_x$. The resins are **polyformaldehyde.** The natural acetal resin is translucent white and can be readily colored. There are two basic types: a homopolymer **(Delrin)** and a copolymer **(Ceclon)**. In general, the homopolymers are harder, more rigid, and have higher tensile flexural and fatigue strength, but lower elongation. The copolymers are more stable in long-term high-temperature service and have better resistance to hot water. Special types of acetals are glass filled, providing higher strengths and stiffness, and tetrafluoroethylene (TFE) filled, providing exceptional frictional and wear properties.

Acetals are among the strongest and stiffest of the thermoplastics. Their tensile strength ranges from 8,000 to about 13,000 lb/in^2 (55 to 89 MPa), the tensile modulus of elasticity is about 500,000 lb/in^2, (3,445 MPa), and fatigue strength at room temperature is about 5,000 lb/in^2 (34 MPa). Their excellent creep resistance and low moisture absorption (less than 0.4%) give them excellent dimensional stability. They are useful for continuous service up to about 220°F (104°C). Acetals' low friction and high abrasion resistance, though not as good as nylon's, rates them high among thermoplastics. Their impact resistance is good and remains almost constant over a wide temperature range. Acetals are attacked by some acids and bases, but have excellent resistance to all common solvents. They are processed mainly by molding or extruding. Some parts are also made by blow and rotational molding. Typical parts and products made of acetal include pump impellers, conveyor links, drive sprockets, automobile instrument clusters, spinning reel housings, gear valve components, bearings, and other machine parts. Delrin, of Du Pont, is used for mechanical and electrical parts. It has a specific gravity of 1.425, a tensile strength of 10,000 lb/in^2 (68 MPa) with elongation of 15%, dielectric strength of 500 volts per mil (19.6×10^6 volts per meter), and Rockwell hardness M94. It retains its mechanical strength close to the melting point of 347°F (175°C). Celcon, of the Celanese Corp., is a thermoplastic linear acetal resin produced from **trioxane,** which is a cyclic form of formaldehyde. The specific gravity is 1.410, flexural strength 12,000 lb/in^2 (82 MPa), Rockwell hardness M76, and dielectric strength 1,200 volts per mil (47×10^6 volts per meter). It comes in translucent white pellets for molding.

ACETIC ACID. Also known as **ethanoic acid.** A colorless, corrosive liquid of pungent odor and composition $CH_3 \cdot COOH$, having a wide variety of industrial uses as a reagent, solvent, and esterifier. A carboxylic acid, it is employed as a weak acid for etching and for soldering, in stain removers and bleaches, as a preservative, in photographic chemicals, for the manufacture of cellulose acetate, as a solvent for essential oils, resins, and gums, as a precipitant for latex, in tanning leather, and in making artificial flavors. Acetic acid is found in the juices of many fruits, and in combination in the stems or woody parts of plants. It is the active principle in **vinegar,** giving it the characteristic sour taste, acid flavor, and pungent odor. It is made commercially by the oxidation of ethyl alcohol, and also produced in the destructive distillation of wood. It is also made by the reaction of methanol and carbon monoxide. Its specific gravity is 1.049, its boiling point is 118°C, and it becomes a colorless solid below 16.6°C. The pure 99.9% solid is known as **glacial acetic acid.** Standard and laundry special grades contain 99.5% acid, with water the chief impurity. Standard strengths of water solution are 28, 56, 70, 80, 85, 90%.

Acetic anhydride, $CH_3COOCOCH_3$, a colorless liquid with boiling point 139.5°C, is a powerful acetylating agent, and is used in making cellulose acetate. It forms acetic acid when water is added. **Hydroxyacetic acid,** $HOCH_2COOH$, or **glycolic acid,** is produced by oxidizing glycol with dilute nitric acid and is intermediate in strength between acetic and formic acids. It is soluble in water, is nontoxic, and is used in foodstuffs, dyeing, tanning, electropolishing, and in resins. Its esters are solvents for resins. **Diglycolic acid,** $O(CH_2CO_2H)_2$, is a white solid melting at 148°C. It is stronger than tartaric or formic acids, and is used for making resins and plasticizers. **Thioacetic acid** has the formula of acetamide but with HS replacing the NH_2. It is a pungent liquid used for making esters for synthetic resins.

Chloroacetic acid, $CH_2ClCOOH$, is a white crystalline powder melting at 61.6°C and boiling at 189°C. It is used for producing carboxymethylcellulose, dyes, and drugs. **Sequestrene,** used as a clarifying agent