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**Encyclopedic Dictionary of
Industrial Technology**
MATERIALS, PROCESSES AND
EQUIPMENT

DAVID F. TVER
ROGER W. BOLZ

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Preface

This volume has been prepared as a reference guide for all engineering, industrial and technical management personnel who are in any way involved in the manufacturing process, in product design, or in converting of raw materials to finished products. This *Encyclopedic Dictionary* covers a wide range of subjects from industrial materials, minerals, metals, plastics and synthetic fibers to machine tools, computers, lasers, robots and other production equipment as well as manufacturing processes.

Some of the materials reviewed are brass, steel, nickel, copper, bronze, cast iron, cements, clay, coal, coke, petroleum and petrochemicals, glass, limestone, rubber, paper, metal alloys, chemicals, synthetic fibers, textiles, plastics, resins, lubricants, and thermoplastics.

Various processes are reviewed such as metal casting, forming, machining, annealing, extrusion, heat treating, injection molding, papermaking and steel processing. In heat treating such areas as martempering, annealing, spheroidizing, tempering and austempering are included.

Different types of equipment related to the products are defined. In plastics such products are covered as nylons, polyesters, rayons, Teflon, Vinyon, Saran, acetates and acrylics.

Many of the manufacturing processes and equipment involved in the conversion of material to finished products are described along with products and their ultimate uses. Also, important associated manufacturing activities such as inspection, handling, and control are included to make the references as complete as is practicable.

This industrial materials, processes and equipment dictionary is an excellent hand guide in concise alphabetic form for easy reference but in sufficient depth to provide a clear understanding. In addition, there are tables showing the uses, strengths, characteristics and detailed composition of many materials.

It is believed that this book will be an invaluable quick reference source and should be a part of the library of every engineer, manufacturing supervisor, and management personnel involved in manufacturing as well as industrial processes.

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A

abrasive belt grinding. An old processing method originally used in woodworking, where power sanding is still widely used. Improvement in impervious plastic-bonded cloth belts makes precision abrasive belt grinding of surfaces practical using coolants. The so-called wet-belt process is a method of stock removal and surfacing performed on machines having a tensioned abrasive belt operating over precision pulleys at speeds between 2500 and 6000 sfp_m (760 and 1830 smp_m). Grinding takes place where the belt passes over a vertical support platen. The work is supported on a horizontal table or on a conveyor belt and contacts the abrasive belt with a motion against or normal to belt travel. Aluminum oxide or silicon carbide abrasive belts are used, generally with a water coolant, and finishes from around 40–50 μ in. (0.001–0.0013 mm) to as fine as 3 μ in. (8×10^{-5} mm) can be produced. Fixtures allow the grinding of cylindrical parts.

abrasive cut-off machine (see cut off machines)

abrasives. Except for diamonds, all abrasives used in large volume in industry are synthetic. Natural abrasives have some minor uses: garnet and flint are used for sandpaper; emery paper is used for polishing metals; rottenstone and pumice are used for wood finishing; and walnut shells are used for cleaning aircraft engine parts. Diamond, the only significant natural abrasive, is the hardest material known and is used for applications where the life of other abrasives is poor. Typical applications for diamond are in brick and concrete saws, wire drawing dies, drills for drilling hard rock, and cutters for machining hard metals. Next to diamond, the hardest abrasive in common use is silicon carbide, or "carborundum." In silicon carbide, sand, coke, and sawdust are mixed, and a high-temperature [4500°F (2480°C)] electric arc is passed through the mixture for a considerable period of time. Sawdust burns out to provide porosity for the escape of gases from the mass. At the conclusion of the process the center of the mixture is converted to silicon carbide, which is then crushed. Another abrasive is aluminum oxide, which is made from bauxite by fusion and, then, crushing. Aluminum oxide is not quite as hard as silicon carbide, but is tougher and more resistant to impact. It is preferable to silicon carbide for such applications as floor sanding machines. Aluminum oxide is the preferred material for grinding the harder metals, since it wears away faster than silicon carbide, thus exposing new edges for cutting. Silicon carbide is selected for cast iron and the softer types of nonferrous metals. In general, only these two abrasives are used in grinding wheels. The grit in the wheel is bonded either with a ceramic material such as sodium silicate or with an organic material such as a rubber or plastic cement.

2 • abrasives, sand

abrasives, sand (see sand)

accuracy. (1) Quality, state, or degree of conformance to a recognized standard. (2) Difference between the actual position response and the target position desired or commanded of an automatic control system.

acetal (plastics). Acetal is an engineering-type thermoplastic and is referred to as a linear polymer of formaldehyde. Acetals compete with nylons and polycarbonates in many structural applications such as hardware components, gears, bearings, business machine assemblies, and housings. Like nylon and polycarbonate, stiffness and dimensional stability are improved by incorporating glass fibers and lubricity is enhanced by adding fluorocarbons. Acetals do not embrittle with long-term exposure at elevated temperature. Tensile strength is substantially the same after 1 yr in air at 240°F (116°C). Acetals cannot be dissolved by organic solvents, which precludes solvent bonding. They withstand staining by most common household foods and resist discoloration by industrial oils or greases. Moisture absorption is extremely low, leading to usage in shower heads, sprinklers, and pump assemblies. Acetals have limited resistance to strong acids and oxidizing chemicals, and they resist weak alkalis.

acetal copolymer (plastics). Acetal copolymer is an engineering thermoplastic that has a balance of mechanical properties and processing characteristics. The mechanical properties of the copolymer enable the resin to be used in applications in which design parameters are critical. In addition, it has wide latitude in processing. The copolymer is produced by polymerization of trioxane and ethylene oxide. The resulting product is an engineering resin with long-term retention of mechanical properties at high temperatures and in numerous chemical environments. The polymer is available in natural translucent white and in a wide range of standard colors. The copolymer is designated as an engineering resin because of its predictable design, processing, and end-use characteristics. It exhibits toughness, stiffness, and excellent impact resistance. These properties are maintained in hostile environments such as hot water, organic solvents, inorganic flat solutions, lubricants, and hot air. Acetal copolymer is one of the most creep-resistant crystalline thermoplastics. Other key properties are fatigue endurance and dimensional stability. In both unreinforced or glass-reinforced versions, acetal copolymer can be processed using standard types of injection-molding equipment.

acetal homopolymer (plastics). The chemical structure and high crystallinity result in an unusual combination of physical properties that bridges the gap between metals and plastics. These properties include high melt point, high strength and rigidity, excellent frictional properties, and resistance to fatigue. Acetal homopolymer products retain many of these desirable engineering properties over a wide range of useful service temperatures and humidities, as well as solvent exposures. It is an easily processed engineering thermoplastic especially designed for injection molding and extrusion. The high crystallinity of acetal homopolymer makes it possible to mold it at unusually short cycles. One of the strongest and stiffest thermoplastics, acetal homopolymer has a tensile strength at room temperature of 10,000 psi (6.9×10^4 kPa), and a flexural modulus of 410,000 psi (2.8×10^6 kPa). It has the highest fatigue limit of any of the commercially unfilled thermoplastics. At room temperature the fatigue endurance limit is 5000 psi (3.4×10^4 kPa) at 105°F (41°C), it is 3000 psi (2.1×10^4 kPa). Moisture has very little effect on mechanical properties. It has excellent creep resistance. The notched Izod impact strength is essentially constant from -40 to 212°F (-40 to 100°C). The material is excellent for snap-fit assemblies and integral springs.

acetylene (C_2H_2) (metallurgy). Acetylene is a colorless, combustible gas, with a characteristic odor. It forms highly explosive mixtures with air and oxygen, so that laws and regulations forbid the generation or use of acetylene fuel at pressures above 15 psi (103 kPa). Acetylene is produced by the chemical reaction between water and

calcium carbide. When a piece of calcium carbide is dropped into water, bubbles will rise to the surface. With commercially pure oxygen and acetylene, the hottest known flame from gases can be produced, its estimated temperature being in the neighborhood of 6200°F (3425°C). Two volumes of acetylene together with five volumes of oxygen combine and react to produce four volumes of carbon dioxide and two volumes of water vapor. Therefore, for complete combustion of acetylene and oxygen, the ratio of oxygen to acetylene is $2\frac{1}{2}$ to 1. For oxyacetylene welding and heating, the most suitable mixture is generally obtained by using a 50-50 mixture of oxygen and acetylene through the torch. Such a mixture when burned at the tip of a properly designed torch, produces what is known as a neutral flame because its action is neutral in effect, being neither oxidizing nor carburizing in nature.

acid-Bessemer process. In steel making molten blast furnace iron (pig iron) of the correct composition is poured into a Bessemer converter, a pear-shaped container mounted on trunnions, and the converter is tilted to receive the molten metal. There is usually between 5 and 30 tons (4500 and 27,000 kg) of metal in the charge, depending on the custom and size of the plant. There is an acid refractory lining inside the converter so that the slag produced consists of more than 50% silica. After the converter is charged with molten pig iron, air is introduced from turboblowers, or blowing engines, from one of the two trunnions that support the vessel, into a blast box at the bottom of the converter. Air passes out of the box through many holes or tuyers that are $\frac{1}{2}$ – $\frac{7}{8}$ in. (13–22 mm) in diameter into the interior of the converter; blast pressure of the air ranges from 20 to 35 psi (138 to 241 kPa). Automatic controls are used to ensure a uniform rate of air volume.

Acrilan fiber. Acrilan acrylic fiber is a copolymer of acrylonitrile, the raw materials of which are obtained from petroleum by the cracking process. Acetylene is formed and is reacted with hydrocyanic acid to give acrylonitrile, a liquid. The acrylonitrile is copolymerized with about 12% of other constituents, including the basic material, the resulting polymer being a white powder similar in appearance to talc. The polymer is dissolved, usually as a 20% solution in dimethyl acetamide, and the solution is spun into a bath made up of dimethyl acetamide and water that precipitates the fibers, which are stretched 350% and are permanently crimped. The fiber is sold with 72,000 filaments or more depending on the filament denier and is cut to staple of various lengths. The density of Acrilan is 0.04 lb/in.³ (1.17 g/cm³) at 68°F (20°C). The dry tensile strength is 0.09 oz (2.5 g) per denier and extension break is 35%; corresponding figures for wet fiber are 0.07 oz (2.0 g) per denier and 44%. The fiber decomposes before it melts; under pressure it sticks to surfaces at about 473°F (245°C). Pure Acrilan is used mainly in sweaters, jersey knit outdoor fabric, and blankets. In blends with cotton, it is used in work clothes, where its chemical resistance is useful. In blends with rayon, Acrilan is used to give good resistance to creasing and for permanent pleating. With wool, Acrilan gives dimensional stability. Acrilan is easy to wash and quick to dry.

acrylic plastics. The term acrylic is descriptive of a large class of resins, the most important of which is polymethyl methacrylate. At least 30 acrylate and methacrylate monomers of varying importance can be synthesized. The acrylics are used by such diverse industries as building, automotive, lighting, sign, appliance, and aircraft. These thermoplastic resins are marketed primarily as molding pellets or in such cast stock shapes as sheet, rod, tube, and block. Fine powders, films, and light-conducting filaments are also available. The major constituent of acrylic plastics is methacrylate. Unmodified acrylics are transparent and extremely stable against discoloration. They have almost unlimited color possibilities, exhibit superior dimensional stability, and offer desirable structural and thermal properties. They also demonstrate resistance to weather, breakage, and chemicals, and are light in weight. Physical blends of acrylic resins with other polymers are also in use. Colorless acrylic stock has a white light transmittance of 92%

4 • adaptive control

and index of refraction of 1.49. Izod impact strength for cast acrylic is 0.4–0.5 ft-lb/in. of notch (0.22–0.27 J/cm); that of general-purpose molded acrylic range from 0.3 to 0.5 ft-lb/in. (0.16 to 0.27 J/cm). Tensile strengths for cast acrylics run from 800 to 11,000 psi (5500 to 7.6×10^4 kPa); for general-purpose molding material, from 7000 to 11,000 psi (4.8×10^4 to 7.6×10^4 kPa). Modulus of elasticity ranges from 350,000 to 470,000 psi (2.4×10^6 to 3.2×10^6 kPa). Unmodified acrylic compositions are not embrittled by temperatures of -40°F (-40°C). Impact resistance in most instances is a factor of thickness. Acrylics are not affected by alkalis, nonoxidizing acids, salt water and salt spray, photographic solutions, chemicals used in treating water, petroleum oils and grease, and household cleaning products; however, they are attacked by alcohols, strong solvents, and many aromatic hydrocarbons.

adaptive control. An adaptive-control system performs three basic functions: it measures on-line machine variables in a process in real time; it compares these measured outputs with established values; and it modifies machining activity by changing one or more variables to improve or optimize performance. The adaptive-control system performs these functions automatically.

additive assembly (see automatic assembly)

adhesives, acrylics. One of the chief advantages of modern acrylics is their tolerance of oily surfaces. The latest versions are said to be usable on many metals in their “as-received” condition. Acrylics get their tolerance through agents in the primer or adhesive that have the ability to penetrate or to react with the surface contaminants (oils) and make them harmless. Strength of the acrylics is comparable to that of some epoxies. Shear strengths of 6000 psi (4.2×10^4 kPa) have been reported. Although not formally called two-part adhesives, most first-generation acrylics are usually applied with a primer, so the effect is the same. Volume production requires automatic dispensing or coating equipment. Set time for acrylics can be 60 s and full cure can occur within 10 min. Although these adhesives cure at room temperature, cure time can be reduced by heating. Their gap-filling capability may range from 0.03 to 0.25 in. (0.76 to 6.35 mm). Some acrylics are sensitive to moisture. Operating temperatures may be as high as 350°F (177°C). The characteristic acrylic aroma can be objectional.

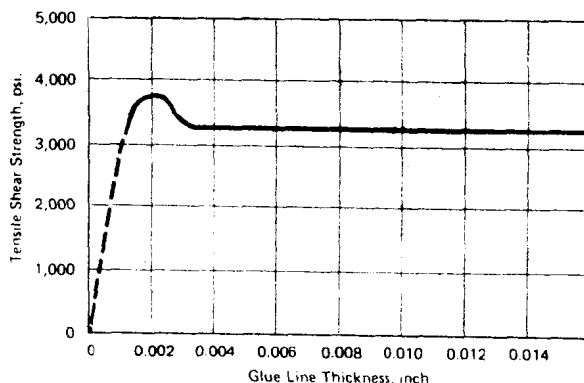
adhesives, anaerobics. This single-component adhesive cures in the presence of an active surface when oxygen is excluded. Anaerobics have become known chiefly for their use in threadlocking and machinery assembly. Typical applications are holding locking keys in place and securing bearings on shafts. They are also used to lock and seal pipe threads and, sometimes, to replace gaskets. The newer structural anaerobic adhesives are tough and impact resistant, and their shear strength is about 3000 psi (2.1×10^4 kPa). The operating temperature limit is in the 300 – 450°F (149 – 232°C) range. Because they are costly, anaerobics have been applied by the drop rather than the gallon and are usually limited to joining small parts. The use of heat or primers as surface-cure activators enables anaerobic adhesives to be used on nonmetallic parts with fast cures. Anaerobic threadlocking and sealing compounds can be controlled to develop required levels of removal strength. The most recent developments for anaerobic adhesives are combinations of urethanes and acrylics, which develop high-strength, flexible, and durable structural adhesives and gasketing compounds. Using surface activators, these single-component adhesives can cure in seconds and provide high tensile [4000 psi (2.8×10^4 kPa)], shear [3000 psi (2.1×10^4 kPa)], impact, and peel strengths on well-prepared metal surfaces. Since variations in surfaces can cause inconsistencies in strength and durability, parts should be carefully prepared for bonding. A unique new approach to anaerobic adhesive cure is the use of ultraviolet light for glass bonding or coating. The adhesive is sensitized only to light and will cure between transparent substrates in seconds when exposed to long-wavelength, ultraviolet, light.

Anaerobic structural adhesives also have limitations, including the fact that bond strengths may not be equal to those of other adhesives.

adhesives, cyanoacrylates. These adhesives are true single-component adhesives, with cure initiated by an alkaline surface. (Water vapor present on the surface of the part is often sufficient to initiate cure.) Because cyanoacrylates depend on joint spacing for cure, since they do not fill voids, they cure most quickly on smooth, close-fitting parts. The cyanoacrylate polymer forms strong, durable bonds to nearly every material in less than 10 s. As a result, such adhesives can be used for bonding plastics, metals, fabrics, paper, rubber, and, with some limitations, glass. The bonds provide good resistance to most environments. Limitations of cyanoacrylates are in both bond durability and application. Exposure to temperatures above 176°F (80°C), especially under conditions of high humidity, can cause bond failure. Cured bonds also offer limited resistance to impact and peel stresses. Finally, the hazard of the rapid cure, which can even bond skin, must be taken into consideration.

adhesives, epoxies. These are available as liquid pastes, films, tapes, microencapsulates, and powders. They can be cured either by mixing two or more components or by applying heat to a single-component adhesive. Cured epoxies adhere to many substrates; applications include structural bonding, potting, and coating. Through molecular modifications and additives, adhesives can be formulated for high tensile strength, good peel and impact strengths, heat resistance, or high durability. New formulations provide fast cures for two-component epoxies or low-temperature cures for single-component epoxies. Limitations still exist in application techniques for two-component adhesives, and heat-curing adhesives require refrigerated storage. Ultraviolet cures are available for some epoxy coatings, but these have limited use. Epoxy adhesives are generally used where large volumes of adhesive are required to develop strength and durability.

adhesives, polysulfone. Polysulfone is a tough, rigid, high-strength thermoplastic that maintains its properties over a temperature range from -150 to above 300°F (-101 to 149°C). It has found its widest commercial use in molding and extrusion applications for the electronic, electrical, appliance, automotive, aircraft, and general industrial markets. Even though polysulfone has been most extensively used in fabricated items, its ability to adhere to hot metals, its inherent high softening point, and its outstanding heat stability have aroused interest in the structural adhesive field. In addition to strong and ductile bonds, polysulfone adhesives combine the high strength, heat resistance,



Courtesy Union Carbide Corp.

Effect of glue line thickness on joint strength.

and creep resistance of a thermosetting-type adhesive with the processing characteristics and toughness of a high-molecular-weight thermoplastic. Metal joints, when bonded, combine good shear strength with high peel strength, excellent creep resistance, and a broad use-temperature range. This combination of properties is outstanding for a structural adhesive, especially for one that is thermoplastic. Both films and solutions of polysulfone can be used to bond metal with equal success. Since polysulfone is thermoplastic, it is possible to use it also as a hot melt directly from an extruder. Extruded or molded parts can be adhered directly to metal by means of heat. By using polysulfone-clad metal, structural bonds can be obtained at room temperature by the use of solvent or at elevated temperatures by hot melt in less than 1 min. For aluminum, the cladding can be done simply by heating the metal to 700°F (371°C) and laminating polysulfone film to it by passing the composite through a nip roll. When carbon steel is used, it should first be primed with a diluted solution of the resin and baked for 10 min at 500°F (260°C). Following this, the film can then be ironed on at 500–600°F (260–316°C). Since the polysulfone is now strongly adhered to the metal substrate, it is no longer necessary to use heat to bond the clad metal pieces together. A 2–5% solution of polysulfone in methylene chloride can be used to achieve a strong bond at room temperature. The parts can be assembled most successfully by dipping them into the solution, air drying for 15 sec, and then assembling them in a jig and placing them under pressure of about 500 psi (3450 kPa) for 5 min.

adhesives, urethanes. These adhesives are available as one- or two-part systems and, like epoxies, form strong, durable bonds to many different substrates. Urethane adhesives are generally cured at room temperature as two-component systems. Elongation of urethane adhesives is excellent, making them suitable for bonding nonrigid materials and components that are subjected to severe shock. Two-part urethanes require dry storage and mixing. Environmental resistance is not as good as that of other types of adhesives, with moisture resistance being a particular limitation. The upper temperature limitation is approximately 212°F (100°C). They have excellent low-temperature qualities. Newly developed heat-cured one-component urethane adhesives feature a longer open time and heat resistance to above 392°F (200°C). These high performance, 100% solid adhesives require no mixing and demonstrate good gap-filling ability. They are suitable for most substrates that can withstand the cure temperature and require only a solvent wipe for surface preparation with many substrates.

admiralty metal (see brasses)

aging. Precipitation from solid solution resulting in a change in properties of an alloy, usually occurring slowly at room temperature (natural aging) and more rapidly at elevated temperatures (artificial aging).

age hardening. An aging process that results in increased strength and hardness.

age softening. The loss of strength and hardness at room temperature that takes place in certain alloys due to spontaneous reduction of residual stresses in the strain-hardened structure.

AI (see artificial intelligence)

alclad plate. Composite plate comprised of an aluminum-alloy core having on both surfaces (if on one side only, it is called alclad one-side plate) a metallurgically bonded aluminum or aluminum-alloy coating that is anodic to the core, thus electrolytically protecting the core against corrosion.

alcohol, ethyl (ethanol; $\text{CH}_3\text{CH}_2\text{OH}$). Sometimes called grain alcohol because starch from grain, when hydrolized to sugars and fermented by enzymes, produces ethyl alcohol

and carbon dioxide. Starch from any source is a suitable starting material. Ethyl alcohol used in the laboratory for solvent purposes seldom is pure alcohol, but is usually a mixture of 95% alcohol and 5% water; 95% represents the maximum purity obtainable when alcohol is distilled because this is the constant-boiling-point composition. A constant-boiling-point mixture of liquids, called an azeotrope, cannot be separated by fractional distillation. In order to obtain absolute, or 100% ethyl alcohol, the water must be removed by methods other than fractionation, such as distilling a ternary mixture composed of alcohol, water, and benzene. These three liquids in a composition of 18.5%, 7.4% and 74.1%, respectively, also form an azeotrope with a constant-boiling-point temperature of 148.73°F (64.85°C). Therefore, if sufficient benzene is added to 95% alcohol and the mixture distilled, the water is removed in the distillate along with benzene and some alcohol, but pure alcohol is left in the still pot.

alcohols. Alcohols may be considered as hydroxyl-substituted hydrocarbons of the general formulas $R-OH$, and $Ar-OH$, respectively. The hydroxyl group ($-OH$) is the functional group that characterizes alcohols. Compounds that have hydroxyl groups joined to carbon atoms of alkyl groups are alcohols. The alcohols, like the alkyl halides, may be classified as primary, secondary, or tertiary according to the number of hydrocarbon groups attached to the carbon atom bearing the hydroxyl groups. However, the nomenclature of the alcohols is somewhat more extensive than that encountered in other families of substances. Common names usually are employed for the simpler members having one to four carbon atoms. Such names are formed simply by naming the alkyl group bonded to the hydroxyl function, followed by the word alcohol. Alcohols are named according to IUPAC rules by selecting and naming the longest carbon chain including the hydroxyl group. The terminal "e" of the parent hydrocarbon (alkane) is replaced by "ol". If more than one hydroxyl group appears in the chain, prefixes such as di, tri, etc., are used. Alkyl side chains and other groups are named and their position is indicated. The suffix "ol" is generic for compounds that contain hydroxyl groups. Although names such as cresol, glycerol, and cholesterol contain no clues to their structure, such names do indicate that each contains one or more hydroxyl groups.

aldehydes. Often referred to as carbonyl compounds. The carbonyl carbon of an aldehyde is always bonded to one hydrogen atom, the remaining bond being shared with an alkyl or an aryl group. Trivial names are commonly employed. The IUPAC system of nomenclature follows established rules. The longest carbon chain is named after the parent hydrocarbon with "al" added as a suffix to designate aldehyde. The carbonyl carbon atom of an aldehyde is always number one in the carbon chain and takes precedence over other functional groups that may be present. In many naturally occurring substances the "al" suffix is frequently employed in nonsystematic names to indicate the presence of aldehyde. The stem of the name frequently indicates the source of the substance. The aldehydes are practically insoluble in water. The lower-molecular-weight members of the aldehyde family have sharp, irritating odors, but the higher-molecular-weight members are fragrant.

alginate fibers. The Latin word for seaweed is *alga*, and it is from this that the word "alginate" is derived. One of the chief constituents of seaweed is alginic acid, and since this substance is a linear polymer, it is a valuable potential source of fibers. Alginic acid is a polyuronic acid, actually a polymer of *D*-mannuronic acid. Alginic acid is composed of very-long-chain molecules with reactive side chains (the carboxylic groups). Solutions of sodium alginate are readily soluble in water and, being very viscous, are highly suitable for spinning. In the manufacture of alginate fibers, seaweed, usually *Laminariae*, is collected, dried, and milled. The powdered seaweed is treated with a solution of sodium carbonate and caustic soda, which converts all the alginate in the seaweed to sodium alginate. The viscous, brownish solution of sodium alginate is suitably purified by

sedimentation and is bleached and sterilized by the addition of sodium hypochlorite. The alginic acid is extracted from this solution by a series of chemical reactions and then it is purified and dried. In spinning, an 8–9% solution of sodium is made, and is sterilized by the addition of a bactericide. It is filtered and spun on a viscose spinning machine into a coagulating bath that contains normal calcium chloride solution, 0.02 N hydrochloric acid solution, and a small quantity of a cationic surface-active agent. As the sodium alginate issues from the jet, it is precipitated in filament form as calcium alginate. The filaments are drawn together, washed, lubricated, and dried and wound. Calcium alginate yarns have a dry strength comparable with that of viscose rayon, but their wet strength is low, their extensibility is sufficiently high to meet most textile requirements.

alkyds (plastics). Alkyd compounds are dry, granular, or nodular types formulated from polyester-type resins. These unsaturated resins are produced through the reaction of an organic alcohol with an organic acid. Selection of suitable polyfunctional alcohols and acids permits manipulation of a large number of repeating units. Formulating can provide resins that demonstrate a wide range of characteristics involving flexibility, heat resistance, chemical resistance, and electrical properties. Unsaturated polyester resins are dissolved in and reacted with unsaturated monomers such as styrene, diallyl phthalate, diacetone, acrylamide, methyl methacrylate, or vinyl toluene. A catalyst, usually of the peroxide type, is added to speed the reaction of cross-linking the resin and monomers, which results in a cured thermoset. To prepare the final compound, pigments, lubricants, and fillers are added to the resin.

allotropic metals. The atoms of some chemical elements, both metallic and nonmetallic, will crystallize on different space lattices under different conditions of temperature or pressure. Such materials are said to be allotropic. The principal allotropic metals are chromium, cobalt, iron, manganese, nickel, tin, and tungsten. Of these, the most important is iron. All of the major changes that take place in steel, and the other iron alloys, are related either directly or indirectly to the allotropic changes occurring in iron. Without these changes, iron and its alloys could not have their properties modified so drastically by heat treatment.

alloys. An alloy may be defined as a material composed of two or more elements, at least one of which is a metal, and possessing metallic properties. The addition of a second element to the first so as to form an alloy usually results in greatly changed properties. It is to obtain these changed properties that alloys are produced and used. Alloys may be formed by any one of three mechanisms. The first and probably the simplest type is where the two components are insoluble in each other in the solid state. In this case the base metal and the alloying element maintain their individual identities and properties. The lattice structures of both are unchanged. The alloying element and the base metal exist in the alloy as an intimate mixture. The second mechanism occurs when the two elements are soluble in each other in the solid state. They thus form a solid solution with the alloying element being dissolved in the base metal. The third mechanism of alloying is where the elements combine to form intermetallic compounds. In this case atoms of the alloying element replace atoms of the lattice of the base element in definite proportions and in definite relationships as to position. As a result of this type of mechanism the lattices of these intermetallic compounds have less symmetry and fewer planes of greater atomic density. These compounds are, therefore, more resistant to deformation and tend to be hard and less ductile, and of high strength. Normally, a useful alloy can only be produced if the elements concerned are soluble in each other in the molten state, that is, they form a single homogeneous solution in the crucible. Some molten metals do not dissolve in each other but instead form two separate layers, as do oil and water when an attempt

is made to mix them. Thus, molten lead and molten zinc will not dissolve in each other completely [unless the temperature is in excess of 1468°F (798°C)]. Instead a layer of molten zinc (containing some dissolved lead) will float on top of a layer of molten lead (which will contain some dissolved zinc). Such a situation cannot be expected to give rise to the formation of a useful alloy. When cast, the lighter metal will tend to float to the surface before solidification is complete though there may be limited entanglement of the two component metals. Two such metals may be compounded successfully using the techniques of powder metallurgy. Generally, a prerequisite to the formation of a useful alloy is that all the components of the alloy shall be mingled intimately together in the liquid state. *Certain materials with an excessive amount of nonmetals are not considered alloys but rather "cermets."* The name is derived from the combination of ceramic materials and metals present.

alloy steels. These contain appreciable quantities of alloying elements in addition to carbon. They include (1) low-alloy, high-strength structural steels; (2) quenched and tempered low-carbon construction alloy steels; (3) AISI-SAE alloy steels; (4) alloy tool steels; (5) stainless steels; (6) heat-resisting steels; and (7) magnet steels.

alloy steels (AISI-SAE). Steels whose composition have been standardized by the American Iron and Steel Institute and the Society of Automotive Engineers. A numbering system using as many as five digits designates the composition of the alloy. The nominal carbon content is given in hundredths of a percent by the last two numbers when four digits are used and by the last three numbers when five digits are used. With the exception of the low-carbon, plain-carbon steels, the AISI-SAE steels are always used in the heat-treated condition. The AISI-SAE steels are used for applications such as carburized or through-hardened gears, steering mechanical parts, transmissions, shafting, and ordnance parts. The 52000 series are used mainly for ball and roller bearings.

alloy steels, austenitic. Steels that remain austenitic in structure (gamma iron) upon slow cooling from the temperature of solidification. These steels do not undergo any change in the condition of the iron and therefore exhibit no critical temperature upon cooling. These steels cannot be hardened by heat treatment, although they may be cold work hardened and annealed. If any precipitate occurs with these steels upon slow cooling from a high temperature, they may be reheated and quenched to redissolve the precipitate and keep it in solution. The austenitic steels exhibit great shock strength and low elastic strength, and are very ductile. They work harden very rapidly and develop great resistance to wear by abrasion. The chrome-nickel austenitic steels are very resistant to corrosion.

alloy steels, cementitic. Some alloying elements on being added to steel in increasing amounts fail to convert the steel into an austenitic type. A steel containing 18.0% of a special element and 0.6% of carbon, upon slow cooling from above its critical temperature, would have a structure of ferrite or martensite with numerous particles of cementite embedded in the ferritic or martensitic matrix. Such a steel has been referred to as a cementitic type of steel. The cementitic types of alloy steel are usually difficult to use, requiring special care in annealing to make it machinable. These steels are subject to such hardening heat treatments as to cause most of the cementite or carbides to be absorbed and retained in a martensitic structure. These steels are largely used in tools, particularly where hardness and resistance to wear are important.

alloy steels, cold work. Includes the water-, oil-, and air-hardening tool steels (W, O, A steels), all of which have a fairly high carbon content (0.60–2.25%) and varying degrees of hardenability as indicated by their names, and are controlled by the amount and kind of alloying elements they contain. The shock-resisting tool steels (S steels), considered as special cold-work tool steels, have a lower carbon content (0.50%) in order to improve their toughness. The high-carbon, high-chromium tool steels (D steels) have large amounts of chromium (12%) and other carbide formers. These alloy addi-

tions produce an air-hardening composition with excellent wear resistance, useful for blanking dies, thread-rolling dies, and brick molds. Since the strong carbide formers have such a great affinity for carbon, the carbon content is raised in these steels to ensure that there is enough uncombined carbon remaining in the austenite to yield a martensite matrix of adequate hardness upon hardening. The carbon tungsten tool steels (T steels) are similar to the oil- and water-hardening steels, but they have extra amounts of tungsten, resulting in improved wear resistance because of the tungsten carbide particles. The low-alloy special purpose tool steels (L steels) are similar to the W steels, but have higher amounts of strong carbide formers for improved wear resistance. The low-carbon mold steels (P steels) have the lowest carbon contents of all the tool steels and, after machining or pressing to shape, are carburized for improved wear resistance.

alloy steels, ferritic stainless. Contains chromium, no nickel, and tolerates only small amounts of austenite-stabilizing carbon. If the carbon content is increased, the chromium content must be increased in order to maintain balance and a ferritic structure. In this balanced condition these steels can be heated to the melting point without transforming to austenite. Thus, it is impossible to harden them by quenching and tempering.

alloy steels, high-speed. Contains either tungsten (T steels) or molybdenum usually with tungsten (M steels) as the principal carbide formers. Both T and M steels contain chromium and vanadium. The high carbon content is necessary to satisfy the carbide forming tendencies and to produce excellent wear resistance and hardness at red heat. At the same time the carbon content is not so high that toughness is lacking. Since molybdenum is a cheaper alloying element than tungsten and is about twice as effective as tungsten, the T steels have been almost entirely replaced by M steels. There is no significant difference between the performance of the two major classes of high-speed steels.

alloy steels, hot work. "H steels" contain fairly large amounts of strong carbide formers, and vanadium is found in these compositions. Their carbon content is below 0.65% carbon so that they exhibit moderately good toughness at high strength levels. They are used for forging dies, extrusion dies, and die-casting dies.

alloy steels, iron-chromium. Stainless steels containing from 14 to 18% chromium and a maximum of 0.12% carbon are magnetic and consist structurally of a solid solution of iron and chromium. They are a ferritic type of stainless steel used for general requirements where resistance to corrosion and heat is needed, but where service conditions are not too severe and slight discoloration of the surface during service can be tolerated. Steels of this type, which contain less than 0.10% carbon, with chromium from 14 to 20%, are not heat treatable except for an annealing treatment. They cannot be hardened by heat treatment because they do not transform into austenite when heated to an elevated temperature. These steels are susceptible to grain growth at elevated temperatures, and with a larger grain size they suffer a loss in toughness. The ferritic stainless steels may be cast and forged hot or cold, but they do not machine easily. They possess a high resistance to corrosion in an ordinary atmosphere providing they have been highly polished and are free from foreign particles. Their machinability can be improved by additions of molybdenum and sulfur, or phosphorus and selenium.

alloy steels, low-alloy, high-strength structural. Contains insufficient carbon and alloying elements to be hardened effectively by quenching to martensite. This is advantageous because it enables them to be welded without becoming brittle. At the same time, the alloying elements they contain alter the microstructure so that it resembles a higher-carbon steel cooled at moderately fast (air-blast quench) rates. In addition these steels contain slightly more phosphorus and silicon than do the carbon steels, thereby strengthening the ferrite network. These changes in microstructure raise the yield strength

Alloying Elements on Steel, Relative Effects

Element	Influence on the properties of steel	Uses in steel
Nickel	Stabilizes γ by raising A_4 and depressing A_1 . It is the universal grain refiner in alloy steels (and many nonferrous alloys). Strengthens ferrite by solid solution. Unfortunately a powerful graphitizer	In amounts up to 5% as a grain refiner in case-hardening steels. Along with chromium and molybdenum in low-alloy constructional steels. In larger amounts in stainless and heat-resisting steels
Manganese	Like nickel it stabilizes γ but unlike nickel it forms stable carbides	Low-manganese steels are not widely used though in recent years it has been used to replace small amounts of more expensive alloying elements, e.g. nickel. The high-manganese (Hadfield) steel contains 12.5% Mn and is austenitic but hardens on abrasion
Chromium	Stabilizes α by raising A_1 and depressing A_4 . Forms hard stable carbides. Strengthens ferrite by solid solution. In amounts above 13% imparts stainless properties. Unfortunately increases grain growth	In small amounts in constructional and tool steels. Also in ball bearings. In larger amounts in stainless and heat-resisting steels.
Molybdenum	Strong carbide-stabilizing influence. Raises the high-temperature creep strength of suitable alloys. Imparts some sluggishness to tempering influences	Reduces 'temper brittleness' in nickel-chromium steels. Increases red-hardness of tool steels. Now used to replace some tungsten in high-speed steels
Vanadium	Strong carbide-forming tendency. Stabilizes martensite and increases hardenability. Like nickel it restrains grain growth. Induces resistance to softening at high temperatures once the steel is hardened	Used in steels required to retain hardness at high temperatures, e.g. hot-forging dies, extrusion dies, die-casting. Also increasingly in high-speed steels
Tungsten	Has similar effects to chromium in stabilizing α . Also forms very hard carbides. Renders transformations very sluggish—hence, once hardened, a steel resists tempering influences	Used mainly in high-speed steels and other tool and die steels, particularly for use at high temperatures
Cobalt	Induces sluggishness to the transformation of martensite. Hence increases 'red hardness'	Super high-speed steels and 'maraging' steels. Permanent magnet steels and alloys
Silicon	A strong graphitizing influence — hence not used in high-carbon steels. Imparts casting fluidity. Improves oxidation resistance at high temperatures	Up to 0.3% in steels for sandcastings where it improves fluidity. In some heat-resisting steels (up to 1.0%)

Alloy Steels, Low-Alloy Constructional

Type of steel	Relevant spec'n: B.S. 970	Composition (%)	Condition	Mechanical properties				Heat-treatment	Uses
				Yield stress (N/mm ²)	Tensile stress (N/mm ²)	Elongation (%)	1/2rd (l)		
Low manganese	150M28	0.28 C 1.50 Mn	Normalized	355	587	20	—	Oil-quench from 860°C (water-quench for sections over 38 mm diameter). Temper as required	Automobile axles, crankshafts, connecting rods, etc., where a relatively cheap steel is required
Nickel-manganese	503M40	0.40 C 0.90 Mn 1.00 Ni	Quenched and tempered at 600°C	494	695	25	91	Oil-quench from 850°C; temper between 550° and 660°C and cool in oil or air	Crankshafts, axles, connecting rods; other parts in the automobile industry and in general engineering
Manganese-molybdenum	608M38	0.38 C 1.50 Mn 0.50 Mo	28.5 mm bar, o.q. and tempered at 600°C	1000	1130	19	70	Oil-quench from 830°-850°C; temper between 550° and 650°C and cool in oil or air	A substitute for the more highly alloyed nickel-chrome-molybdenum steels
Nickel-chromium	653M31	0.31 C 0.60 Mn 3.00 Ni 1.00 Cr	28.5 mm bar, o.q. and tempered at 600°C	819	927	23	104	Oil-quench from 820°-840°C temper between 550° and 650°C. Cool in oil to avoid 'temper brittleness'	Highly stressed parts in automobile and general engineering, e.g. differential shafts, stub axles, connecting rods, high-tensile studs, pinion shafts
Nickel-chromium-molybdenum	817M40	0.40 C 0.55 Mn 1.50 Ni 1.20 Cr 0.30 Mo	O.q. and tempered at 200°C O.q. and tempered at 600°C	— 988	2010 1080	14 22	27 69	Oil-quenched from 830°-850°C; 'light temper' 180°-200°C; 'full temper' 550°-650°C—cool in oil or air	Differential shafts, crankshafts and other highly-stressed parts where fatigue and shock resistance are important. In the 'light tempered' condition it is suitable for automobile gears. Can be surface hardened by nitriding
	835M30	0.30 C 0.55 Mn 4.25 Ni 1.25 Cr 0.30 Mo	Air-hardened and tempered at 200°C	1470	1700	14	35	Air-harden from 820°-840°C; temper at 150°-200°C and cool in air	An air-hardening steel for aero-engine connecting rods, valve mechanisms, gears, differential shafts and other highly-stressed parts. Suitable for surface hardening by cyanide or carburising
Manganese-nickel-chromium-molybdenum	945M38	0.38 C 1.40 Mn 0.75 Ni 0.50 Cr 0.20 Mo	28.5 mm bar, o.q. from 850°C and tempered at 600°C	958	1040	21	85	Oil-quench from 830°-850°C; temper at 550°-660°C and cool in air	Automobile and general engineering components requiring a tensile strength of 700 to 1000 N/mm ²

Carbon Steel, Properties and Uses

	Relevant specifications	Typical compositions (%)	Heat-treatment	Typical mechanical properties					Uses
				Y.P. (N/mm ²)	T.S. (N/mm ²)	Elong. (%)	Impact (J)	Hardness (Brinell)	
Mild steel	B.S. 970:040A10	0.10 C 0.40 Mn	No heat treatment—except process annealing (9.5.1) to remove the effects of cold-work	—	300	28	—	—	Lightly stressed parts produced by cold-forming processes, e.g. deep-drawing and pressing
Structural steels	B.S. 15	0.20 C	No heat treatment	240	450	25	—	—	General structural steel
	B.S. 968	0.20 C 1.50 Mn	No heat treatment	350	525	20	—	—	High tensile structural steel for bridges and general building construction—fusion welding quality
Casting steel	B.S. 1504 16:1B	0.30 C	No heat treatment other than 'annealing' (9.5.4) to refine grain	265	500	18	20	150	Castings for a wide range of engineering purposes where medium strength and good machinability are required
Constructional steels	B.S. 970:080M40	0.40 C 0.80 Mn	Harden by quenching from 830°–860°C. Temper at a suitable temperature between 550° and 660°C	500	700	20	55	200	Axles, crankshafts, spindles, etc., under medium stress
	B.S. 970:070M55	0.55 C 0.70 Mn	Harden by quenching from 810°–840°C. Temper at a suitable temperature between 550° and 660°C	550	750	14	—	250	Gears, cylinders and machine-tool parts requiring resistance to wear
Tool steels		0.70 C 0.35 Mn	Heat slowly to 790°–810°C and quench in water or brine. Temper at 150°–100°C	—	—	—	—	780	Hand chisels, cold sates, mason's tools, smith's tools, screwdriver blades, stamping dies, keys, cropping blades, miner's drills, paper knives
	B.S. 4659:BW1A	0.90 C 0.35 Mn	Heat slowly to 760°–780°C and quench in water or brine. Temper at 200°–100°C	—	—	—	—	800	Press tools; punches; dies; cold-heading, minting and embossing dies; shear blades; woodworking tools; lathe centers; draw plates
	B.S. 4659:BW1B	1.00 C 0.35 Mn	Heat slowly to 770°–790°C and quench in water or brine. Temper at 150°–150°C	—	—	—	—	800	Taps; screwing dies; twist drills; reamers; counter sinks; blanking tools; embossing, engraving, minting, drawing, needle and paper dies; shear blades; knives; press tools; center punches; woodworking cutters; straight edges; gouges; pneumatic chisels; wedges
	B.S. 4659:BW1C	1.20 C 0.35 Mn	Heat slowly to 760°–780°C and quench in water or brine. Temper at 180°–150°C	—	—	—	—	800	Engraving tools, tiles, surgical instruments, taps; screwing tools