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Chapter 12: Materials

Adhesives

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Neoprene Rubbers (Polychloroprene, Chloroprene). These are some of the best general-purpose synthetic rubbers. They have excellent resistance to weather aging, moderate resistance to oils, and good resistance to refrigerants and mild acids. Shore hardness: 40 to 95. Temperature range: –40 to 115°C.

Chlorosulfonated Polyethylene Rubbers (CSM). These have poor mechanical properties but good resistance to acids and heat with complete resistance to ozone. They are used in chemical plants, tank linings, and high-voltage insulation. Shore hardness: 45 to 100. Temperature range: –100 to 93°C.

Ethylene Propylene Rubbers (EP, FPM). These specialized rubbers are especially resistant to weather aging heat, many solvents, steam, hot water, dilute acids and alkalis, and ketones, but not petrol or mineral oils. They are used for conveyor belts, limited automotive applications, silicone fluid systems, and electrical insulation. Shore hardness: 40 to 90. Temperature hardness: –50 to 177°C.

Fluorocarbon Rubbers. These comprise a wide range of rubbers with excellent resistance to chemical attack, heat, acids, fuels, oils, aromatic compounds, etc. They have a high service temperature. They are particularly suitable for vacuum applications. Shore hardness: 60 to 90. Temperature hardness: –23 to 260°C.

Isoprenes (Polyisoprene, IR). These are chemically the same as natural rubber but are more costly. The properties and applications are similar to those of natural rubber. Shore hardness: 40 to 80. Temperature hardness: –50 to 82°C.

Polyacrylic Rubbers (ACM, ABR). This is a group of rubbers with properties midway between nitrile and fluorocarbon rubbers with excellent resistance to mineral oils, hypoid oils, and greases and good resistance to hot air and aging. The mechanical strength is low. They are often used for spark plug seals and transmission seals. Shore hardness: 40 to 90. Temperature hardness: –30 to 177°C.

Polysulfide Rubbers. These have poor physical properties and heat resistance, but good resistance to oils, solvents, and weathering and are impermeable to gases and moisture. They are used for caulking and sealing compounds and as a casting material. Shore hardness: 40 to 85. Temperature hardness: –50 to 121°C.

Polyurethane Rubbers. These have exceptional strength and tear and abrasion resistance (the best of all rubbers), low-temperature flexibility, and good resistance to fuels, hydrocarbons, ozone, and weather. Resistance to solutions of acids and alkalis, hot water, steam, glycol, and ketones is poor. They are used for wear-resistant applications such as floor coverings. Shore hardness: 35 to 100. Temperature hardness: –53 to 115°C.

Silicone Rubbers (SI). These have exceptionally high service-temperature ranges, but the mechanical properties and chemical resistance are poor. They cannot be used in applications which expose them to fuels, light mineral oils, or high-pressure steam. They are used for high- and low-temperature seals, high-temperature rotary seals, cable insulation, hydraulic seals, and aircraft door and canopy seals. Shore hardness: 30 to 90. Temperature hardness: –116 to 315°C (380°C for intermittent use).

Fluorosilicone Rubbers. These are similar to silicone rubbers but have better oil resistance and a lower temperature range. Shore hardness: 40 to 80. Temperature hardness: –64 to 204°C.

12.3 Adhesives

Richard L. Lehman

Introduction

Adhesives are substances capable of holding materials together in a useful manner by surface attachment. The principal attribute of adhesives is their ability to form strong bonds with surfaces of a wide range of materials and to retain bond strength under expected use conditions. Although most adhesives do not have excellent bulk properties and it is therefore important to keep adhesive films thin, some materials such as epoxies have bulk properties which qualify them as engineering materials and thus can be used in multifunctional applications.

Advantages and Limitations of Use

The principal advantages of adhesives are their ability to bond similar to dissimilar materials of different thickness; to enable the fabrication of complex shapes not feasible by other fastening means; to smooth external joint surfaces; to permit economic and rapid assembly; to distribute stresses uniformly over joined interfaces, to provide weight reduction in critical structures via the elimination of fasteners; to dampen vibrations; to prevent or reduce galvanic corrosion; and to provide thermal and electrical insulation.

The limitations of adhesives depend on the specific adhesive and application and may include the necessity of surface preparation, long curing times, service-temperature limitations, loss of properties during service, toxicity of flammability during assembly or use, and the tendency of many adhesives to creep under sustained load.

Classes of Adhesives

Thermoplastic adhesives are a general class of adhesives based upon long-chained polymeric structure, and are capable of being softened by the application of heat with subsequent hardening upon cooling (hot-melt adhesives). The softening process if reversible for numerous cycles, which facilitates assembly and disassembly of structures. Thermosetting adhesives are a general class of adhesives based upon cross-linked polymeric structures which develop strong bonds that cannot be reversibly broken once they are formed. Thus, the thermoset adhesives are incapable of being softened once solidified.

Thermoplastic and thermosetting adhesives are cured, a process often referred to as setting, by polymerization or solidification, by heat, catalysis, chemical reaction, free-radical activity, radiation, evaporation of solvent, or another process as governed by the chemical nature of the particular adhesive.

Elastomers are a special class of thermoplastic adhesive possessing the common quality of substantial flexibility or elasticity. Refer to Section 12.2 on polymers.

Anaerobic adhesives are a special class of thermoplastic adhesive, the polyacrylates, that set only in the absence of air (oxygen). The two basic types are (1) machinery — possessing shear strength only and (2) structural — possessing both tensile and shear strength.

Pressure-sensitive adhesives are permanently and aggressively tacky solids which form immediate bonds when two parts are brought together under pressure. They are available as films and tapes as well as hot-melt systems.

Performance of Adhesives

To obtain optimum mechanical performance of an adhesive, it is critical to select the proper compound for the target application. Table 12.3.1 illustrates compatibility of adhesives and five broad classes of common materials. Generally, for good adhesive bonds the chemistry of the adhesive must match or be similar to the surface energy, polarity, and/or chemistry of the material being bonded. The elastic modulus of the adhesive should not be greater than the bonded material.

Adhesives are used in two classes of application, those requiring only shear strength and those requiring structural properties, often tensile and shear strength. Table 12.3.2 provides a quick reference for some typical applications. A much more detailed summary and classification of adhesives is given in Table 12.3.3.

Table 12.3.3 presents a sample of a number of adhesives (with practical information) that are available from various sources. The table is adapted from the rather extensive one found in J. Shields, *Adhesives Handbook*, CRC Press, Boca Raton, FL, 1970. For other extensive lists of trade sources, the reader is referred to Charles V. Cagle, Ed., *Handbook of Adhesive Bonding*, McGraw-Hill, New York, 1972, and Lerner et al., *Adhesives Red Book*, Palmerton Publishing Co., New York, 1968.

TABLE 12.3.1 Relative Performance of Adhesive Resins

	Adherence To:					Resistance			
Adhesive Resin	Paper	Wood	Metal	Ceramics	Rubbers	Water	Solvents	Alkali	Acids
Alkyd	6	7	5	6	7	7	2	2	5
Cellulose acetate	4	3	1	3	5	2	3	1	3
Cellulose acetate butyrate	3	1	4	5	2	3	1	3	3
Cellulose nitrate	5	1	5	5	3	2	2	4	4
Ethyl cellulose	3	1	3	5	2	3	3	3	3
Methyl cellulose	1	1	3	3	1	6	3	3	3
Carboxy methyl cellulose	1	2	3	2	1	6	1	4	4
Epoxy resin	10	8	8	8	8	7	8	8	8
Furane resin	7	2	8	7	8	9	7	8	8
Melamine resin	10	5	2	5	4	9	5	5	5
Phenolic resins	8	5	5	7	6	10	7	8	8
Polyeseter, unsaturated	8	4	5	7	7	6	2	5	7
Polyethylacrylate	4	3	5	6	8	4	6	7	7
Polymethylmethacrylate	4	4	3	6	6	5	6	7	7
Polystyrene	3	2	2	5	8	5	5	8	8
Polyvinylacetate	7	7	7	3	3	3	4	6	6
Polyvinyl alcohol	2	2	4	6	1	7	1	3	3
Polyvinyl acetyl	7	8	7	7	8	5	3	5	5
Polyvinyl chloride	7	6	7	6	8	6	10	9	9
Polyvinyl acetate chloride	8	6	7	5	8	5	8	8	5
Polyvinylidene copolymer	7	6	7	7	8	7	10	9	9
Silicone T.S.	6	7	7	8	10	7	6	6	6
Urethane T.S.	10	10	9	10	7	8	4	4	4
Acrylonitrile rubber	6	8	6	9	7	5	8	8	8
Polybutene rubber	3	6	2	8	8	3	10	9	9
Chlorinated rubber	5	7	4	7	6	3	10	9	9
Styrene rubber	7	6	5	8	7	3	8	9	9

Note: 1 = low performance; 10 = high performance.
Source: Adapted from Simonds, H.R. and Church, J.M., *A Concise Guide to Plastics*, 2nd ed., Reinhold, New York, 1963. With permission.

TABLE 12.3.2 High-Performance Engineering and Machine Part Adhesives

Thread locking	• Anaerobic acrylic
Hub mounting	• Anaerobic acrylic — compatible materials or flow migration unimportant
	• Modified acrylic — large gaps or migration must be avoided
	• Epoxy — maximum strength at high temperatures
Bearing mounting	• Anaerobic acrylic — compatible materials necessary and flow into bearing area to be prevented
	• Modified acrylic — for lowest cost
Structural joining	• Epoxies and modified epoxies — for maximum strength (highest cost)
	• Acrylics — anaerobic or modified cyanacrylates
Gasketing	• Silicones — primarily anaerobic

TABLE 12.3.3 Properties and Applications of Adhesive Materials

Basic Type	Curing Cycle, Time at Temperature	Service Temperature Range, C	Adherends	Main Uses	Remarks
			Animal		
Animal (hide)	Melted at 70–75°C; sets on cooling	<70	Paper, wood, textiles	Woodworking, carpet materials, paper, bookbinding	May be thinned with water
Animal (hide) + plasticizers	Applied as a melt at 60°C	<60	Paper, cellulosic materials	Bookbinding, stationery applications	Cures to permanent flexible film
Fish glue	1 hr at 20°C	<60	Wood, chipboard, paper	General-purpose for porous materials	Rapid setting; good flexibility, moderate resistance to water; high tack
Casein	Cold setting after 20 min standing period on mixing	<50	Timber with moisture content	Laminated timber arches and beams, plybox beams, and engineering timber work	Full bond strength developed after seasoning period of 48 hr
Casein + 60% latex	Cold setting after 20 min standing period on mixing	<60	Aluminum, wood, phenolic formaldehyde (rigid, leather, rubber)	Bonding of dissimilar materials to give flexible, water-resistant bond	Flexible
			Vegetable		
Dextrine	Air drying		Paper, cardboard, leather, wood, pottery	General-purpose glue for absorbent materials	Medium drying period of 2–3 hr
Dextrine–starch blend	Applied above 15°C air drying	<48	Cellulosic materials, cardboard, paper	Labeling, carton sealing, spiral-tube winding	Fast setting; may be diluted with water
Gum arabic	Cold setting	<50	Paper, cardboard	Stationery uses	Fast drying
			Mineral		
Silicate	8 hr at 20°C	10–430	Asbestos, magnesia	Lagging asbestos cloth on high-temperature insulation	Unsuitable where moisture; not recommended for glass or painted surfaces

TABLE 12.3.3 (continued) Properties and Applications of Adhesive Materials

Basic Type	Curing Cycle, Time at Temperature	Service Temperature Range, C	Adherends	Main Uses	Remarks
Silicate with china-clay filler	Dried at 80°C before exposure to heat	–180–1500	Asbestos, ceramics, brickwork, glass, silver, aluminum, steel (mild)–steel	General purpose cement for bonding refractory materials and metals; furnace repairs and gastight jointing of pipe work; heat-insulating materials	Resistant to oil, gasoline, and weak acids
Sodium silicate	Dried at 20–80°C before exposure to heat	0–850	Aluminum (foil), paper, wood–wood	Fabrication of corrugated fiber board; wood bonding, metal foil to paper lamination	Suitable for glass-to-stone bonding
Aluminum phosphate + silica filler	Dried $^1/_2$ hr at 20°C, then $^1/_2$ hr at 70°C + $^1/_2$ hr at 100°C + 1 hr at 200°C + 1 hr at 250°C; repeat for two overcoatings and finally cure at 1 hr at 350°C	<750	Steels (low-alloy), iron, brass, titanium, copper, aluminum	Strain-gauge attachment to heat-resistant metals; heater-element bonding	Particularly suited to heat-resistant steels where surface oxidation of metal at high temperatures is less detrimental to adhesion
Bitumen/latex emulsion	Dried in air to a tacky state	0–66	Cork, polystyrene (foam), polyvinyl chloride, concrete, asbestos	Lightweight thermal-insulation boards, and preformed sections to porous and nonporous surfaces; building applications	Not recommended for constructions operated below 0°C
			Elastomers		
Natural rubber	Air dried 20 min at 20°C and heat-cured 5 min at 140°C	<60	Rubber (styrene butadiene), rubber (latex), aluminum, cardboard, leather, cotton	Vulcanizing cement for rubber bonding to textiles and rubbers	May be thinned with toluene
Natural rubber in hydrocarbon solvent	Air dried 10 min at 20°C and heat-cured for 20 min at 150°C	<100	Hair (keratin), bristle, polyamide fiber	Brush-setting cement for natural- and synthetic-fiber materials	Resistant to solvents employed in oil, paint and varnish industries, can be nailed without splitting
Rubber latex	Air drying within 15 min	<60	Canvas, paper, fabrics, cellulosic materials	Bonding textiles, papers packaging materials; carpet bonding	Resistant to heat; should be protected from frosts, oils

TABLE 12.3.3 (continued) Properties and Applications of Adhesive Materials

Basic Type	Curing Cycle, Time at Temperature	Service Temperature Range, C	Adherends	Main Uses	Remarks
Chlorinated rubber in hydrocarbon solvents	Air dried 10 min at 20°C and contact bonded	–20–60	Polyvinyl chloride, acrylonitrile butadiene styrene, polystyrene, rubber, wood	General-purpose contact adhesive	Resistant to aging, water, oils, petroleum
Styrene–butadene rubber lattices	Air drying	–20–60	Polystyrene (foam), wood, hardboard, asbestos, brickwood	Bonding polystyrene foams to porous surface	—
Neoprene/nitrile rubbers in (?)	Dried 30 min in air and bonded under pressure; tacky	–20–60	Wood, linoleum, leather, paper, metals, nitrile rubbers, glass, fabrics	Cement for bonding synthetic rubbers to metals, woods, fabrics	May be thinned with ketones
Acrylonitrile rubber + phenolic resin	Primer air dried 60 min at 20°C, film cured 60 min at 175°C under pressure; pressure released on cooling at 50°C	–40–130	Aluminum (alloy)–aluminum to DTD 746	Metal bonding for structural applications at elevated temperatures	Subject to creep at 150°C for sustained loading
Polysulfide rubber in ketone solvent and catalyst	3 days at 25°C	–50–130, withstands higher temperatures for short periods	Metals	Sealant for fuel tanks and pressurized cabins in aircraft, where good weatherproof and waterproof properties are required	Resistant to gasoline, oil, hydraulic fluids, ester lubricants; moderate resistance to acids and alkalis
Silicone rubber	24 hr at 20°C (20% R.H.); full cure in 5 days	–65–260	Aluminum, titanium, steel (stainless), glass, cork, silicone rubber, cured rubber–aluminum, cured rubber–titanium, cured rubber–steel (stainless), aluminum–aluminum (2024 Alclad), cork–cork (phenolic bonded)	General-purpose bonding and scaling applications; adhesive/sealant for situations where material is expected to support considerable suspended weight; high-pressure exposure conditions	Resistant to weathering and moisture
Reclaim rubber	Contact bonded when tacky	<50	Fabric, leather, wood, glass, metals (primed)	General industrial adhesive for rubber, fabric, leather, porous materials	May be thinned with toluene
Polychloroprene	Air dried 10–20 min at 20°C	<60	Rubber, steel, wood, concrete	Bonding all types of rubber flooring to metals, woods, and masonry	Good heat resistance

TABLE 12.3.3 (continued) Properties and Applications of Adhesive Materials

Basic Type	Curing Cycle, Time at Temperature	Service Temperature Range, C	Adherends	Main Uses	Remarks
Modified polyurethane	3 hr at 18°C to 16 hr at –15°C	–80–110	Concrete, plaster, ceramics, glass, hardboards, wood, polyurethane (foam), phenol formaldehyde (foam), polystyrene (foam), copper, lead, steel, aluminum	Bonding to rigid and semirigid panels to irregular wall surfaces, wall cladding and floor laying; building industry applications	Foam remains flexible on aging even at elevated temperatures; will withstand a 12% movement
			Thermoplastic		
Nitrocellulose in ester solvent	Heat set 1 hr at 60°C after wet bonding	60	Paper, leather, textiles, silicon carbide, metals	Labeling, general bonding of inorganic materials including metals	Good resistance to mineral oils
Modified methyl cellulose	Dries in air	<50	Vinyl-coated paper, polystyrene foam	Heavy-duty adhesive; decorating paper and plastics	Contains fungicide to prevent biodeterioration
Ethylene vinyl acetate copolymer + resins	Film transfer at 70–80°C followed by bonding at 150–160°C	60, or 1 hr at 90	Cotton (duck)–cotton, resin rubber–leather, melamine laminate–plywood, steel (mild)–steel, acrylic (sheet) acrylic	Metals, laminated plastics, and textiles; fabrication of leather goods; lamination work	Good electrical insulation
Polyvinyl acetate	Rapid setting	<60	Paper, cardboard	Carton sealing in packaging industry	Resistant to water
Synthetic polymer blend	Applied as a melt at 177°C	<70	Paper, cardboard, polythene (coated materials)	Carton and paperbag sealing; packaging	—
Polychloroprene/resin blend in solvent	Air dried 10 min at 20°C and cured 4 days at 20°C to 7 hr at 75°C	<70	Chlorosulfonated polythene, polychloroprene fabrics, polyamide fabrics, leather, wood, textiles	Bonding synthetic rubbers and porous materials; primer for polyamide-coated fabrics such as nylon, terylene	—
Polychloroprene	Air dried 10–20 min at 20°C	—	Rubber, steel, wood, concrete	Bonding all types of rubber flooring to metals, woods, and masonry	Good heat resistance
Saturated polyester + isocyanate catalyst in ethyl acetate	Solvent evaporation and press cured at 40–80°C when tacky	—	Cellulose, cellulose acetate, polyolefins (treated film), polyvinyl chloride (rigid), paper, aluminum (foil), copper (foil)	Lamination of plastic films to themselves and metal foils for packaging industry, printed circuits	Resistant to heat, moisture, and many solvents

TABLE 12.3.3 (continued) Properties and Applications of Adhesive Materials

Basic Type	Curing Cycle, Time at Temperature	Service Temperature Range, C	Adherends	Main Uses	Remarks
Cyanoacrylate (anaerobic)	15 sec to 10 min at 20°C substrate dependent	Melts at 165	Steel–steel, steel–aluminum, aluminum–aluminum, butyl rubber–phenolic	Rapid assembly of metal, glass, plastics, rubber components	Anaerobic adhesive. Curing action is based on the rapid polymerization of the monomer under the influence of basic catalysts; absorbed outer layer on most surfaces suffices to initiate polymerization and brings about bonding
Polyacrylate resin (anaerobic)	3 min at 120°C to 45 min at 65°C or 7 days at 20°C	–55–95	Aluminum–aluminum	Assembly requirements requiring high resistance to impact or shock loading; metals, glass and thermosetting plastics	Anaerobic adhesive
			Thermosetting		
Urea formaldehyde	9 hr at 10°C to 1 hr at 21°C after mixing powder with water (22%)	<90	Wood, phenolic laminate	Wood gluing and bonding on plastic laminates to wood; plywood, chipboard manufacture; boat building and timber engineering	Excess glue may be removed with soapy water
Phenolic formaldehyde + catalyst PX-12	Cold acting	<100	Wood	Timber and similar porous materials for outdoor-exposure conditions; shop fascia panels	Good resistance to weathering and biodeterioration
Resorcinol formaldehyde + catalyst RXS-8	Cured at 16–80°C under pressure	<100	Wood, asbestos, aluminum, phenolic laminate, polystyrene (foam), polyvinyl chloride, polyamide (rigid)	Constructional laminates for marine craft; building and timber applications; aluminum–plywood bonding; laminated plastics	Recommended for severe outdoor-exposure conditions
Epoxy resin + catalyst	24–48 hr at 20°C to 20 min at 120°C	100	Steel, glass, polyester–glass fiber composite, aluminum–aluminum	General-purpose structural adhesive	—

TABLE 12.3.3 (continued) Properties and Applications of Adhesive Materials

Basic Type	Curing Cycle, Time at Temperature	Service Temperature Range, C	Adherends	Main Uses	Remarks
Epoxy resin + catalyst	8 hr at 24°C to 2 hr at 66°C to 45 min at 121°C	65	Steel, copper, zinc, silicon carbide, wood, masonry, polyester–glass fiber composite, aluminum–aluminum	Bonding of metals, glass, ceramics, and plastic composites	Cures to strong, durable bond
Epoxy + steel filler (80% w/w)	1–2 hr at 21°C	120	Iron, steel, aluminum, wood, concrete, ceramics, aluminum–aluminum	Industrial maintenance repairs; metallic tanks, pipes, valves, engine castings, castings	Good resistance to chemicals, oils, water
Epoxy + amine catalyst (ancamine LT)	2–7 days at 20°C for 33% w/w catalyst content	–5–60	Concrete stonework	Repair of concrete roads and stone surfaces	Excellent pigment-wetting properties; effective underwater and suited to applications under adverse wet or cold conditions
Epoxy resin (modified)	4–5 hr at 149°C to 20 min at 230°C to 7 min at 280°C	150	Aluminum, steel, ceramics	One-part structural adhesive for high-temperature applications	Good gap-filling properties for poorly fitting joints; resistant to weather, galvanic action
Epoxy	45 sec at 20°C	—	Gem stones, glass, steel, aluminum–aluminum	Rapid assembly of electronic components, instrument parts, printed circuits; stone setting in jewelry and as an alternative to soldering	—
Epoxy resin in solvent + catalyst	8 hr at 52°C to $^1/_2$ hr at 121°C	–270–371	Aluminum and magnesium alloys for elevated-temperature service	Strain gauges for cryogenic and elevated-temperature use; micromeasurement strain gauges	Cured material resists outgassing in high vacuum
Epoxy polyamide	8 hr at 20°C to 15 min at 100°C	100	Copper, lead, concrete, glass, wood, fiberglass, steel–steel aluminum–aluminum	Metals, ceramics, and plastics bonding; building and civil engineering applications	Resists water, acids, oils, greases

TABLE 12.3.3 (continued) Properties and Applications of Adhesive Materials

Basic Type	Curing Cycle, Time at Temperature	Service Temperature Range, C	Adherends	Main Uses	Remarks
Epoxy/polysulfide	24 hr at 20°C to 3 hr at 60°C to 20 min at 100°C	<120	Asbestos (rigid), ceramics, glass–fiber composites, carbon, polytetrafluoroethylene (treated), polyester (film), polystyrene (treated), rubber (treated), copper (treated), tungsten carbide, magnesium alloys, aluminum–aluminum, steel (stainless)–steel	Cold-setting adhesive especially suitable for bonding materials with differing expansion properties	Cures to flexible material; resistant to water, petroleum, alkalis, and mild acids
Phenol furfural + acid catalyst	2 days at 21°C	90–140	Alumina, carbon (graphite)	Formulation of chemically resistant cements; bedding and joining chemically resistant ceramic tiles	Extremely resistant to abrasion and heat
			Pressure-sensitive		
	Heated by air drying for several hours or 15–30 min at 210°F	—	Teflon–Teflon, Teflon–metal	—	Good resistance to acids and alkalis; excellent electrical properties
			Miscellaneous		
Ceramic-based	Dried for 1/2 hr at 77°C and cured 1/2 hr at 200°C + 1 hr at 250°C; postcured, 1 hr at 350°C	816	Metals	Strain gauges, temperature sensors for elevated-temperature work	—