

Guide for the Selection of (Reapproved 1997,2003) Polymer Adhesives with Concrete

Reported by ACI Committee 503

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*Members of Subcommittee who prepared the report.

This guide provides the engineer, contractor, and architect with a description of the various types of polymer adhesives (epoxy, polyester, acrylic, polyurethane, polysulfide, silicone, vinyl acetate, and styrene butadiene) most frequently used for adhesive bonding of fresh concrete to cured concrete, repair of cracks in concrete, bonding concrete to other materials, and adhesive grouting of bolts and other inserts into concrete.

The guide emphasizes the factors that should be considered where selecting a structural adhesive, including characteristics during installation and in service. The benefits and limitations of adhesive bonding are discussed for each application.

Keywords: acrylic resins; adhesives; bolts; bonding; epoxy resins; fire resistance; fresh concretes; grouting; latex; loads (forces); methacrylate; plastics; polymers; and resins; polyester; polysulfide; polyurethane; repairs; sealing; serviceability; silicone resins; styrene-butadiene resins; toxicity; vinyl acetate; water-borne adhesives.

CONTENTS

Chapter 1 -- General, pg. 503.5R-2

- 1.1-Organization of the Guide
- 1.2-Caution
- 1.3-Advantages/disadvantages of adhesive bonding
- 1.4-Glossary of terms

Chapter 2 -- Solvent-free adhesives, pg. 503.5R-4

- 2.1-Application characteristics
- 2.2-Properties during cure
- 2.3-Properties of cured adhesive
- 2.4-Distinguishing Characteristics

Chapter 3 -- Water-borne adhesives (latex and latex powder adhesives), pg. 503.5R-8

- 3.1-Application characteristics
- 3.2-Properties of cured adhesive
- 3.3-Distinguishing characteristics

Chapter 4 -- Adhesive selection criteria, pg. 503.5R-10

- 4.1-Type and magnitude of loads
- 4.2-Conditions during application

Chapter 5 -- Adhesive for bonding of hardened concrete to hardened concrete, pg. 503.5R-10

- 5.1-Important application characteristics
- 5.2-Important bond-strength considerations

Chapter 6 -- Adhesives for bonding of plastic concrete to hardened concrete, pg. 503.5R-11

- 6.1-Important application characteristics
- 6.2-Important bond-strength considerations

Chapter 7 -- Adhesives for repair of cracks in concrete, pg. 503.5R-11

- 7.1-Important application considerations
- 7.2-Important strength considerations

Chapter 8 -- Adhesives for bonding inserts into concrete, pg. 503.5R-12

- 8.1-Important application considerations
- 8.2-Important strength considerations

Chapter 9 -- Adhesives for bonding concrete and other materials, pg. 503.5R-13

- 9.1-Important application considerations

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Chapter 10 — Quick reference guide, pg. 503.5R-14

Chapter 11 — References, pg. 503.5R-15

11.1-Specified and/or recommended references

11.2-Cited references

11.3-Additional references

CHAPTER 1 — GENERAL

This guide is intended to aid the engineer, contractor, and architect in choosing a proper polymer adhesive for adhesive bonding applications encountered in joining concrete members in construction, repair, and rehabilitation of concrete structures.

1.1- Organization of the Guide

Sections 2 and 3 of the guide describe the properties of the two major classes of polymer adhesives in use (solvent-free adhesives and water-borne adhesives) and identifies the distinguishing features of the specific polymers (e.g., epoxy, acrylic, and polyvinyl acetate) within each class. Section 4 lists the basic criteria that should be used in all adhesive selections. Sections 5 through 9 provide additional guidance specific to the selection of adhesives for bonding fresh or hardened concrete to hardened concrete, repairing cracked concrete, bonding other materials to concrete, and bonding inserts into concrete. Section 10 is a quick reference guide to help narrow the search for a proper adhesive.

This guide includes more data and information on epoxy adhesives than on other types because epoxy adhesives are the most versatile and by far the most widely used with concrete. Information on other types is included where there is a choice.

1.2 - Caution

The Guide presents data on the various polymer and copolymer types (epoxy, polyester, acrylic, polyurethane, silicones, vinyl acetate, and styrene-butadiene) either as typical values, as a range of values, or as relative values. Because of the ease of tailoring polymer products by formulation, some very special products within a group may possess values for a particular characteristic that differ widely from the typical value or fall outside of the range. To include all extremes would lead to a less accurate perception of the true nature of these groups of products as they are commonly used. The cited characteristics of classes of polymer adhesives are only a guide to help narrow the field in a search for an appropriate adhesive.

When using an adhesive, the manufacturer's literature should always be reviewed. Manufacturer's recommendations should be followed because the adhesive may differ from other adhesives in its class.

Many adhesives contain hazardous ingredients. Material Safety Data Sheets (MSDS) and labels should always be consulted before using the adhesive.

1.3 — Advantages/disadvantages of adhesive bonding

The major advantage of adhesive bonding is that it

allows distribution of an applied load over much larger areas compared to other methods of fastening, thus reducing the unit stress on the elements that are bonded. It allows attachment without having to alter the shape or deface the elements to be attached. The adhesive bond line can also act as a moisture barrier. ^{1,2}

The major disadvantage of adhesive bonding is that the bonded elements cannot be disturbed after being joined, because the adhesive cures for hours or days depending on the cure rate of the adhesive used and the temperature of the elements being bonded. Thus, work progress may be slowed down if the other work tasks cannot be scheduled to accommodate the adhesive cure time.

1.4 — Glossary of terms

This glossary gives definitions of some terms which are used in adhesive bonding in the concrete industry. Other terms may be found in ASTM D 907.

Accelerator—A material that increases the rate of a chemical reaction.

Acrylic — One of a group of resins formed by polymerizing the esters or amides of acrylic acid.

Adhesives — The group of materials used to join or bond similar or dissimilar materials; for example, in concrete work, the epoxy resins.

Age hardening — The progressive change in the chemical and physical properties of an adhesive, leading to embrittlement.

Bond line — The interface between two surfaces bonded together with an adhesive.

Catalyst — A substance whose presence increases the rate of a chemical reaction. In some cases the catalyst is consumed and regenerated, in other cases the catalyst seems not to enter into the reaction, but functions by virtue of some other characteristic.

Cohesive — The type of molecular attraction that holds adhesives and other materials together.

Cohesive failure — A failure by separation within the adhesive itself, or within the substrate, rather than in the adhesive's bond to the substrate.

Copolymerization — Polymerization of two or more dissimilar monomers.

Crosslinking agent — A substance that increases the molecular weight of a polymer by chemically linking and bridging the polymer chains.

Cure— To change the properties of a chemical (usually a polymer) by increasing its molecular weight by polymerization or crosslinking, usually accomplished by the action of heat, catalyst, crosslinking agent, curing agent, or any combination, with or without pressure.

Curing agent — A substance that accelerates or participates in the curing of chemicals, sometimes referred to as a hardener.

Elastomeric— Pertaining to a substance which has rubberlike properties.

Emulsion — A two-phase liquid system in which small droplets of one liquid (the internal phase) are immiscible in, and dispersed uniformly throughout, a second continuous liquid phase (the external phase).



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Epoxy resins — A class of organic chemical bonding systems used in the preparation of special coatings or adhesives for concrete or as binders in epoxy resin mortars and concretes.

Exothermic -Pertaining to a chemical reaction which occurs with the evolution of heat.

Flexibilizer — A substance that is mixed with a more brittle material to make the latter more ductile.

Gel -A colloid in which the dispersed phase has combined with the continuous phase to produce a viscous jelly-like material.

Glass transition temperature — The temperature or range of temperature at which polymeric materials change from a rigid, glass-like state to an elastomeric-like state.

Heat deflection temperature (HDT) — The temperature at which a plastic material reaches an arbitrary deflection when subjected to an arbitrary load and test condition. It can be an indication of the glass transition temperature, although these two temperatures are not necessarily equal.

Initiator — A substance that causes a chemical reaction (such as polymerization or curing) to start. The term usually applies to free-radical polymerization-type reactions.

Latex — A dispersion of organic polymer particles in water.

Minimum-film-forming temperature (MFFT) — The lowest temperature at which the polymer particles of a latex have sufficient mobility and flexibility to coalesce into a continuous film.

Monomer -An organic liquid, of relatively low molecular weight, that creates a solid polymer by reacting with itself or other compounds of low molecular weight or both.

Plasticizer — A substance added to polymer or copolymer to reduce its minimum film forming temperature and/or its glass transition temperature.

Polyester — One of a large group of synthetic resins, mainly produced by reaction of unsaturated dibasic acids with dihydroxy alcohols; commonly prepared for application by mixing with a vinyl-group monomer and free-radical catalysts at ambient temperatures and used as binders for resin mortars and concretes, fiber laminates (mainly glass), adhesives, and the like.

Polymer — The product of polymerization; more commonly a rubber or resin consisting of large molecules formed by polymerization.

Polymerization - The reaction in which two or more molecules of the same substance (monomer) combine to form a compound containing the same elements, but of high molecular weight.

Polyol - A polyhydric alcohol, i.e., one containing two or more hydroxyl groups.

Polysulfide — Synthetic polymers obtained by the reaction of sodium polysulfide with organic dichlorides.

Polyurethane — Reaction product of an isocyanate with any one of a wide variety of other compounds

containing an active hydrogen group; used to formulate tough, abrasion-resistant coatings.

Polyvinyl acetate — Colorless, permanently thermoplastic resin; usually supplied as an emulsion or water-dispersible powder characterized by flexibility, stability towards light, transparency to ultraviolet rays, high dielectric strength, toughness, and hardness; the higher the degree of polymerization, the higher the softening temperature; may be used in paints for concrete.

Promoter — Substances, which added in small quantities, increase the activity of catalysts, as well as increase or promote polymerization activity.

Pseudoplastic — Often referred to as thixotropic, a substance whose viscosity decreases with increasing shear.

Rheology — The science dealing with the flow of materials.

Silicone — A resin, in which the main polymer chain consists of alternating silicon and oxygen atoms, with carbon containing side groups; silicones may be used in caulking or coating compounds, admixtures for concrete, or as adhesives.

Substrate — A material upon the surface of which an adhesive is spread for the purpose of bonding.

Surface-active agent — A substance that markedly affects the interfacial or surface tension of solutions even when present in very low concentrations.

Surface energy — The interfacial free energy per unit area of the boundary between the surface of a substrate and the air above it.

Surface tension — A measure of surface energy, arising from molecular forces at the surface of a liquid, which tend to contain the volume to a minimum surface area.

Surfactant — A contraction of the term "surface-active agent".

Thermoplastic — Becoming soft when heated and hard when cooled.

Thermosetting — Becoming rigid by chemical reaction and not remeltable.

Thixotrope agents — A substance incorporated into an adhesive to impart thixotropy.

Thixotropy — The property of a material that enables it to stiffen in a short period of time on standing, but to acquire a lower viscosity on mechanical agitation, the process being reversible; a material having this property is termed thixotropic or shear thinning (see **Rheology**).

Vinyl ester - One of a group of synthetic resins produced by the reaction of acrylic with epoxy resin or Bisphenol A, and commonly prepared for application by mixing with a vinyl group monomer and free-radical catalysts at ambient temperatures, and used as binders for resin mortars and concretes, and fiber laminates (mainly glass) adhesives.

Viscosity — The property of a material which resists change in shape or arrangement of its elements during flow, and the measure thereof. Specifically the ratio of the shear stress existing between laminae of moving fluid and the rate of shear between these laminae.

Working life -The period of time which an adhesive, after mixing with a curing agent or other ingredient, remains sufficiently workable to permit spreading and application.

CHAPTER 2 — SOLVENT-FREE ADHESIVES

Solvent-free adhesives cure by polymerization of monomeric resins. Section 2.1. describes the characteristics of polymeric adhesives prior to curing which are important in applying or installing the adhesive. Section 2.2 describes properties of these materials during and after curing which affect their suitability in achieving and maintaining an adhesive bond. Section 2.3 describes the features that distinguish each of the polymeric adhesives.

2.1- Application characteristics

2.1.1 Working life — Working life can vary from as little as 2 min to as long as 8 hr from one adhesive to another within each type of solvent free adhesive. In general, the longer the working life, the longer the curing time. Automatic metering and mixing equipment makes practical the use of adhesives with a very short working life.³

The temperatures of the adhesive components, the ambient temperature, and the substrates also influence working time. High temperatures shorten working time and low temperatures lengthen working time.⁴ The polymerization reaction is exothermic. Holding a mixed adhesive in a mass in a mixing container increases the temperature of the adhesive because the heat cannot dissipate efficiently. This significantly shortens the working life. Applying the adhesive to the substrate immediately after mixing lengthens the working life because most of the exothermic heat can be dissipated into the substrate without raising the temperature of the adhesive.

2.1.2 Curing -There are two mechanisms for curing adhesives. Epoxies and two-component polyurethanes cure by the chemical reaction of the base resin and a curing agent. Polyesters, one-component polyurethanes, methacrylates, polysulfides, and silicones cure by the addition of a catalyst or release of a catalyst included in the formulation.⁵

The curing reaction of a monomer/curing agent is very temperature-dependent.⁶ Lower temperatures extend the curing time and higher temperatures shorten the curing time. Although special adhesives are available that will cure at temperatures down to 0 F (-18 C), most adhesives will not effectively cure in a practical time at temperatures below 40 F (4 C).

Catalytic curing is less temperature-dependent than the monomer/curing agent reaction, and the cure rate can be increased by the addition of an accelerator.⁷

The adhesive must cure quickly enough to obtain strength levels that can resist stresses that develop from removal of support of the bonded composite, or from temperature changes in the bonded composite; and from exposure to moisture due to precipitation, tides, or other sources which could cause degradation.

2.1.3 Viscosity — Polymeric adhesives are available

with viscosities ranging from 15 centipoise (cps) to a paste-like consistency. The viscosity of the adhesive depends on the inherent viscosity of the base monomers and curing agents, fillers, and thixotroping agents. The viscosity of any adhesive can be lowered by raising its temperature. This can be achieved either by heating the adhesive itself or by heating the substrate.

2.1.4 Thixotropy — Very viscous adhesives are not necessarily thixotropic. When thixotropic properties of an adhesive are desired, an adhesive must be chosen that has been manufactured to include thixotroping agents. Generally, high temperatures will lower the thixotropic characteristic of the adhesive and lower temperatures will increase the thixotropy, but is not affected to the same extent as viscosity by temperature.⁸

Adhesives are available that will stand in a bond line as thick as 1/4 in. (6.4 mm) without external containment.

2.1.5 Toxicity and safety — Most components of solvent-free adhesives prior to curing have some degree of toxicity and some are flammable. Toxicity and hazard potentials vary widely from product to product. The manufacturer's literature and Material Safety Data Sheet (MSDS) for each product should be consulted, and all cautions should be observed. In general, adhesives require the use of protective clothing, good ventilation, good housekeeping, and personal cleanliness.

2.2 — Properties during cure

2.2.1 Gel — Cure of an adhesive is accompanied by an increase in viscosity and formation of a gel state before full cure. In the gel state, the adhesive does not possess the physical or chemical properties it will ultimately achieve. If the adhesive is stressed during curing, irreversible damage can be done to the bond with the substrate or the adhesive itself, resulting in lower strength.^{9,10}

2.2.2 Exothermic reaction — The chemical reaction of curing is exothermic and can accelerate cure rate, resulting in the adhesive reaching the gel state at an elevated temperature. If this happens, internal stresses are induced in the bond when the adhesive cools to normal temperature.

On a practical level, this condition occurs only in bond lines greater than 0.125 in. (3.2 mm) in thickness, because in narrow bond lines the heat dissipates into the substrates.

2.2.3 Shrinkage — All adhesives shrink when they cure. The addition of fillers to an adhesive system will reduce volumetric shrinkage but the inherent characteristics of a particular polymer system have by far the greatest influence on shrinkage.¹¹ Volumetric shrinkage from the uncured to the cured state varies from as low as 2 percent for filled epoxy systems to over 20 percent for some unfilled polyester systems.

Shrinkage works against good adhesion. It reduces the intimate contact between adhesive and substrate that is important for mechanical interlock and attraction of the adhesive molecules to the substrate surface; it also builds internal stress in the bond line.¹²

2.3 — Properties of cured adhesive

2.3.1 Bond strength — The strength of an adhesive bond depends on:

- Adhesion of the adhesive to the substrate materials.
- Cohesive strength of the adhesive.
- Cohesive strength of the substrate materials.

The bonded joint is only as strong as the weakest of these three strengths.^{13,14}

In all bonding/repair applications, the surface of the hardened concrete must be sound and clean. Grease and oil-type contaminants will interface with the formation of a sound bond.

The condition and strength of concrete at the surface is particularly important. If the larger aggregate is not exposed, the surface layer is considerably weaker than the concrete below the surface. The application of low-viscosity primers improves adhesion of solvent-free adhesives that are more viscous or that have relatively poor molecular attraction to concrete. The low-viscosity primer can provide more intimate contact with the substrate, resulting in better adhesion.

Adhesive strengths with concrete are usually measured in tension as a pulloff, in flexure in a bond line parallel with the direction of the applied load, or in shear. The slant-shear test described in ASTM C 882 is the most useful and commonly used test. See Table 1 for typical adhesive bond strengths.

The pipe cap pulloff test described in ACI 503R-80, Appendix A, is useful for field testing adhesive bonds.

2.3.2 Tensile strength and elongation — Because of the higher tensile strength of polymers relative to concrete, the tensile strength of an adhesive material itself is seldom a controlling factor.

Tensile strength of adhesives is most commonly measured by ASTM D 638. Tensile elongation as measured in ASTM D 638 is an indication of the relative stiffness of the adhesive.

The numerical value determined in the test method for percentage of elongation should not be taken as the elongation that will take place in an adhesive joint. The elongation in the test specimen is measured over a

length of 1 in. (25 mm) with an initial cross section of 1/2 x 1/8 in. (12.7 x 3.2 mm) or less. As the test specimen is loaded, the cross section can become smaller without any external constraints. In an actual adhesive joint loaded in tension, the “length” of the adhesive in the direction of the tensile load can vary from a few thousandths to a tenth of an inch. The “cross section” perpendicular to the tensile force can be literally thousands of square inches. Because the adhesive is bonded to the substrates it is not free to change its cross section by “necking down.” Thus, its ability to elongate is severely restricted and the elongation achieved in the adhesive joint is not the same as in the test specimen. In fact, at most it can only be a small fraction of the elongation measured in ASTM D 638.¹⁵

2.3.3 Shear strength — Shear strength is the most important property of adhesive materials commonly used to bond concrete. Shear strength is usually the only strength property for short-time loads that may be exceeded without the bonded concrete substrate failing first. If the shear forces in the bond line can be calculated, shear strength data can be used to determine if the adhesive has the strength required.

2.3.4 Flexural strength — As with tensile strength, adhesive materials have high flexural strength relative to concrete. Flexural strength of an adhesive is seldom a critical factor in adhesive bonding of concrete.

2.3.5 Modulus of elasticity — The stiffness of polymer adhesives varies from rubber-like with some silicones and polyurethanes to glass-like with some methacrylate and polyesters (see Table 1). However, the modulus of all polymer adhesives is affected by temperature, especially near or above the heat-deflection temperature (HDT). Below the HDT the change in modulus with temperature is modest (Fig. 1).

Although the modulus of elasticity of polymeric adhesives used with concrete ranges from about 2 percent to no more than 20 percent of the modulus of elasticity of concrete, this difference has an insignificant effect on transfer of load because of the very small volume of adhesive per unit area of bond line.

2.3.6 Heat-deflection temperature (HDT) — Each

Table 1 — Polymer materials — Typical physical properties*

		Acrylic	Epoxy	Polyester	Polyurethane	Silicone	Styrene-butadiene
Tensile strength ASTM 638	psi	5000-9000	4000-13,000	600-13,000	175-10,000	350-1000	100-9350
Tensile elongation ASTM D 638	percent	20-70	3-6	2-6	100-1000	20-700	20-1350
Compressive Strength ASTM D 695	psi	4000-14,000	15,000-25,000	13,000-30,000	20,000	NR	NR
Compressive modulus at 73 F — ASTM D 695	10 ³ psi	290-370	NR	300-400	10-100	NR	3.6-120
Heat deflection temperature — ASTM D 648	degF	165-209	115-550	140-400	NR	NR	<0-170
Coefficient of thermal expansion — ASTM D 696	10 ⁶ /in./in./deg C	48-80	45-65	55-100	100-200	300-800	67-140

*From Reference 26.
NR: Not reported.