

USE OF EPOXY COMPOUNDS WITH CONCRETE

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Epoxy compounds have found a wide variety of uses in the concrete industry as coatings, grouts, binders, sealants, bonding agents, patching materials, and general adhesives.

Properties, uses, preparations, mixtures, application, and handling requirements of epoxy resin systems when applied to and used with concrete and mortar are presented. The adhesiveness of epoxy and its chemical, thermal, and physical properties are given. The modification of the foregoing properties to accommodate given situations is reviewed.

Problems encountered in surface preparation are reviewed and procedures and techniques given to insure successful bonding of the epoxy to the other materials. Temperature conditioning of the base material and epoxy compound are outlined. The cleaning and maintaining of equipment is reviewed. Procedures to be followed in the application of epoxy compounds in the several use situations are given. The important factors which insure that the epoxy compound will harden (cure) and therefore perform its function are discussed together with alterations of the hardening rate. The allergenic and toxic nature of epoxies and the chemicals used with them in the industry create a hazard and precautions are detailed throughout the report.

ACI Committee Reports, Guides, Standard Practices, and Commentaries are intended for guidance in designing, planning, executing, or inspecting construction and in preparing specifications. References to these documents shall not be made in the Project Documents. If items found in these documents are desired to be a part of the Project Documents, they should be phrased in mandatory language and incorporated into the Project Documents.

Keywords: abrasion resistant coatings; abrasive blasting; acid treatment (concrete); adhesion; adhesives; aggregates; bonding; bridge decks; **chemical analysis**; chemical attack; cleaning coatings; compressive strength; concrete construction; concrete finishes (hardened concrete); concrete pavements; concretes; cracking (fracturing); electrical properties; **epoxy resins**; flexural strength; floor toppings; fresh concretes; grout; grouting; history; joints (junctions); metals; mix proportioning; mixing; mortars (material); patching; **plastics**; **polymers and resins**; popouts; repair; resurfacing; shrinkage; skid resistance; stairways; **temperature**; tensile strength; underwater construction; waterproof coating; wood.

CONTENTS

Chapter 1 -- Introduction, pg. 503R-2

- 1.1 -- Background
- 1.2 -- General
- 1.3 -- Scope

Chapter 2 -- History of epoxies, pg. 503R-4

- 2.1 -- Origin of epoxies
- 2.2 -- Early attempts at using epoxies
- 2.3 -- Development of epoxy applications with concrete
- 2.4 -- Present status of epoxies

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Chapter 3 -- Chemical and physical characteristics of epoxy resins, pg. 503R-5

- 3.1 -- General
- 3.2 -- Adhesion properties
- 3.3 -- Susceptibility to chemical attack
- 3.4 -- Electrical properties
- 3.5 -- Abrasion resistance
- 3.6 -- Resilience
- 3.7 -- Creep
- 3.8 -- Thermal expansion
- 3.9 -- Exothermic reaction during cure
- 3.10 -- Curing and aging stresses
- 3.11 -- Thermosetting properties

Chapter 4 -- Uses of epoxy resins, pg. 503R-8

- 4.1 -- General
- 4.2 -- Protective coating
- 4.3 -- Decorative coating
- 4.4 -- Skid-resistant coating
- 4.5 -- Grout
- 4.6 -- Adhesive
- 4.7 -- Binder for epoxy mortar or concrete
- 4.8 -- Underwater application
- 4.9 -- Epoxy-modified concrete

Chapter 5 -- Preparing surfaces for epoxy compound application, pg. 503R-10

- 5.1 -- General
- 5.2 -- Concrete surface evaluation
- 5.3 -- Removal of concrete for repairs
- 5.4 -- Surface preparation
- 5.5 -- Temperature conditioning

Chapter 6 -- Preparing epoxy compound and epoxy mixtures for use, pg. 503R-13

- 6.1 -- General
- 6.2 -- Temperature conditioning of material
- 6.3 -- Mixing and proportioning
- 6.4 -- Mixing
- 6.5 -- Cleaning of equipment
- 6.6 -- Caution of solvents and strippers

Chapter 7 -- Applying epoxy compounds, pg. 503R-16

- 7.1 -- General considerations
- 7.2 -- Specific applications
- 7.3 -- Underwater applications

Chapter 8 -- Hardening, pg. 503R-23

- 8.1 -- Rate of hardening
- 8.2 -- Adjusting the hardening rate
- 8.3 -- Opening the job to service

Chapter 9 -- Handling precautions, pg. 503R-24

- 9.1 -- General hazards
- 9.2 -- Safe handling
- 9.3 -- What to do in case of direct contact
- 9.4 -- Use of solvents
- 9.5 -- Education of personnel

Appendix A -- Test methods, pg. 503R-25

- A.1 -- Field test for surface soundness and adhesion
- A.2 -- Simplified field test for surface soundness

Appendix B -- Terminology, pg. 503R-28**CHAPTER 1 -- INTRODUCTION****1.1 -- Background**

1.1.1 -- There are many characteristics of epoxies and their uses which make them a desirable adhesive for use with concrete. Some of these advantages are:

1.1.1.1 Adhesion -- Epoxy resins have excellent adhesive qualities and will bond to nearly all construction materials. A few of the nonpolar thermoplastics such as polyethylene, present adhesion problems and are exceptions.

1.1.1.2 Versatility -- The wide range of available physical and chemical properties of epoxy resin systems makes their consideration requisite in any situation involving repair, overlay, coating, or adverse environment, of concrete. The variety of curing agents, extenders, diluents, fillers and other modifiers available to the formulator permit the attainment of special characteristics for any particular application.

1.1.1.3 Chemical resistance -- Epoxies are resistant to the attack of acids, oils, alkalies, and solvents.

1.1.1.4 Low shrinkage -- Compared to other thermosetting resins, epoxies have low autogenous shrinkage. Formulations are available in which effective linear shrinkage is as low as 0.001 percent.

1.1.1.5 Rapid hardening -- At normal ambient temperatures it is possible for a mixed resin and hardener system to go from a liquid to a solid state in a matter of several minutes, or the time can be extended several hours by changing the system.

1.1.1.6 Moisture resistance -- A thin coating of an appropriate epoxy system can provide a high degree of impermeability even when continuously inundated in water. Some, though not all, epoxy materials absorb significant amounts of water in a moist environment. Select and use epoxy products (adhesives, coatings, mortars) that have low water absorption. Water absorption will not be a problem if the material has less than 1 percent absorption as measured by ASTM D 570 and specified by ASTM C 881.

1.1.2 -- The benefits of using epoxy resins are noteworthy but caution must also be exercised. The following discussion briefly summarizes some of the precautions necessary:

1.1.2.1 Strain compatibility

1.1.2.1.1 Epoxy bonds very rapidly to a concrete surface and within a short time may be considered as monolithic. The autogenous shrinkage strains which take place in some epoxy formulations during curing can cause severe strains at the bond line and when combined with thermal strains contribute significantly to delamination,

generally by failure in the top ¼ in. (6 mm) of concrete interface.

1.1.2.1.2 There is a wide difference in the coefficients of thermal expansion between concrete and the cured epoxy. Even normal temperature variations can be the cause of delamination. Filling the epoxy system with fillers such as silica reduces the difference in thermal expansion in proportion to the amount used. The use of a flexible epoxy compound will allow the system to adjust for the difference in thermal coefficient of expansion.

1.1.2.2 Thermosetting plastic -- The components which make up the epoxy system must be mixed thoroughly and close control of temperature must be exercised before and during mixing and curing. Selection of the epoxy formulation that will cure at a given substrate temperature is crucial to the cure. All epoxies will not cure on cold substrates. Proper selection is the best solution. ASTM C 881 specifies three temperature cure classes. Once cured the epoxy will not melt. However, many systems lose some of their elasticity at higher temperatures and become cheesy since their mechanical properties change significantly beyond their heat deflection temperature (HDT). The HDT is different for each formulation but for those systems used in construction, it generally ranges from 60 to 160 F (15 to 71 C).

1.1.2.3 Slabs on grade -- Slabs on grade can present unique bonding problems if there is moisture present in or under the slab during application and cure of an epoxy (or any other impervious polymer) material on the slab. Rising moisture in the slab caused by capillary action can exert forces on the epoxy material that will prevent an adequate bond from being achieved. Even if moisture is not present during application and cure these same forces can subsequently cause loss of a bond that was weak because of other factors such as inadequate surface preparation.

1.1.2.4 Safety -- Epoxy compounds are allergenic and safe handling practices must be exercised in each instance. Solvents used on the job to clean epoxied equipment often require more caution than the epoxy. Previous experience dictates that the user be thoroughly familiar with the information contained in [Chapter 9](#), Handling Precautions.

1.1.3 -- The foregoing cautions can be satisfied by using the appropriate epoxy system, selected on the basis of a carefully prepared listing and evaluation of all job and application restrictions (those which bear on handling are noted in [Chapter 9](#)) and requirements involved. Epoxies have very selective properties and it is unwise to rely on a general specification or general performance criteria.

1.2 -- General

1.2.1 Recommended references -- The documents of the various standards producing organizations referred to in this document are listed below with their serial designation.

American Concrete Institute

- 224.1R Causes, Evaluation, and Repair of Cracks in Concrete Structures
- 503.1 Standard Specification for Bonding Hardened Concrete, Steel, Wood, Brick, and Other Materials to Hardened Concrete with a Multi-Component Epoxy Adhesive
- 503.2 Standard Specification for Bonding Plastic Concrete to Hardened Concrete with a Multi-Component Epoxy Adhesive
- 503.3 Standard Specification for Producing a Skid-Resistant Surface on Concrete by the Use of a Multi-Component Epoxy System
- 503.4 Standard Specification for Repairing Concrete with Epoxy Mortars
- 504R Guide to Joint Sealants for Concrete Structures
- 515.1R A Guide to the Use of Waterproofing, Damp-proofing, Protective, and Decorative Barrier Systems for Concrete

ASTM

- C881 Specification for Epoxy-Resin-Base Bonding Systems for Concrete
- C884 Test Method for Thermal Compatibility Between Concrete and an Epoxy-Resin Overlay
- D 570 Test Method for Water Absorption of Plastics
- D 648 Test Method for Deflection Temperature of Plastics Under Flexible Load (1820 kPa/264 psi)

ANSI

- Z 129.1 Precautionary Labeling of Hazardous Industrial Chemicals
- K 68.1 Guide for Classifying and Labeling Epoxy Products According to their Hazardous Potentialities

Code of Federal Regulations

- 16 CFR 1500 Hazardous Substances and Articles; Administration and Enforcement Regulations
- 29 CFR 1910 Occupational Safety and Health Standards
- 49 CFR Transportation

The preceding publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 19150
Detroit, MI 48219-0150

ASTM
1916 Race Street
Philadelphia, PA 19103

American National Standards, Inc.
1430 Broadway
New York, NY 10018

U.S. Office of the Federal Register
National Archives and Records Administration
Washington, D. C. 20408

1.2.2 -- This report is based on those known and most accepted field practices for the use of epoxy resins with concrete. It provides the user with an adequate guide for successful application and performance of epoxy resins to the extent of its coverage. However, the epoxy supplier should always be consulted concerning each new variable introduced by the user.

1.3 -- Scope

1.3.1 -- The rapid growth of the use of epoxy compounds in the concrete industry and the proliferation of available epoxy systems emphasizes the need of this committee report. The wide range of epoxies which can be used as adhesives on, in, or with concrete limits the detail which can be given herein. The result is an often brief coverage of any particular topic with constant referral of the user to the formulator for details of application and performance. Nevertheless, those problems which are generally encountered in the use of epoxies with concrete are noted and their solutions presented.

1.3.2 -- Emphasis is given to the preparation of surfaces to receive epoxy adhesive, details of compound preparation, use and application, with notes concerning rate of hardening of compound, and cautions to be exercised when using any epoxy. Ranges of physical properties are noted as well as possible uses of the material.

CHAPTER 2 -- HISTORY OF EPOXIES

2.1 -- Origin of epoxies

2.1.1 General -- The word "epoxy" is of Greek derivation. The Greek word "epi," which means "on the outside of," was combined with the word "oxygen" which describes the presence of the oxygen atom in the molecular structure. In short, the word is a Greek description of the chemical symbol for the family of epoxies (see Fig. 2.1).

2.1.2 Discovery of epoxy applications -- The first practical application of epoxy resin took place in Germany and Switzerland in the 1930s with concurrent experiments being conducted in the United States, although the basic chemistry had been known for several decades. The first known patent on epoxy was issued to Dr. Pierre Castan in Switzerland in 1936. Three years later, Dr. S.O. Greenlee of the United States explored and developed several basic epoxy systems, many of which we use today as adhesives and coatings.

2.2 -- Early attempts at using epoxies

2.2.1 General -- Limited production of epoxy resins started in the late 1940s and commercially produced epoxy resin adhesives became available in the early 1950s. Initial laboratory tests using epoxies on concrete also began in the late 1940s and were directed toward

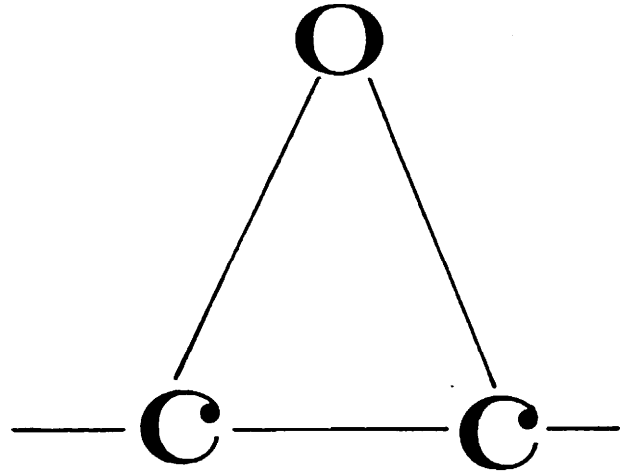


Fig. 2.1 -- Chemical symbol for the family of epoxies

their use as coatings on floors and highways. Developments were limited to the laboratory until about 1953, as engineers and scientists attempted to identify the basic physical properties and probe potential uses of epoxy systems.

2.2.2 Early field tests for bonding

2.2.2.1 First interest in the use of epoxy as an adhesive in the construction industry was in 1948 when it was used as a bond for two pieces of hardened concrete. Epoxy proved to be a satisfactory structural adhesive with the capability of being stronger than the concrete it bonded together.

2.2.2.2 In 1954 the California Highway Department became interested in epoxies as a bonding agent for raised traffic line markers on concrete highways. The successful utilization of an epoxy as a bonding agent encouraged the extension of research into the field of structural repair of concrete, and the eventual application of an epoxy-polysulfide polymer, as a bonding material for joining new concrete to old.

2.2.3 Early field tests for surfacing materials -- In 1953 the Shell Chemical Corp. initiated field tests to evaluate epoxy systems as surfacing materials on highways, following successful laboratory tests by the company. Favorable results encouraged the pursuit of this as a solution to an age-old problem of restoration of deteriorated concrete surfaces.

2.3 -- Development of epoxy applications with concrete

2.3.1 General -- Epoxy formulations developed until there were available systems with a combination of properties which made them uniquely suited for use as an adhesive with concrete. They had high bond strength, characteristics similar to other structural materials when cured and long-term resistance to aggressive environments, with easy application characteristics and low shrinkage during cure. These properties led to many different applications, some of which are discussed below.

2.3.2 Epoxy for bonding -- The ability of epoxy to

bond two pieces of concrete generated interest in the possibility of bonding fresh concrete to existing concrete. Experiments with the latter situation met with limited success until the development of epoxy resin-polysulfide systems. Since that time efforts with these and other recently developed adhesive systems have extended their desirable properties and their general acceptance by the concrete industry until they are now widely used.

2.3.3 Epoxy for grouting

2.3.3.1 Epoxy injection systems -- Epoxy injection as a means of performing structural grouting and repair was first used in the late 1950s. The approach was to premix the epoxy and then pump the mixed epoxy system. The injection of epoxy into structural cracks permitted for the first time a positive technique for the restoration of the structural integrity of cracked concrete. In 1960 a system was developed utilizing pressure injection with a mixing head at the nozzle of the injection gun which expanded the applications of epoxy as a grouting adhesive in structural concrete.

2.3.3.2 Epoxy bolt grout -- The use of epoxy as a grout to bond bolts or dowels to hardened concrete was first attempted in the late 1950s. This application came about from the need to grout bolts in existing concrete slabs for mounting heavy machinery. Concurrently, epoxy grout was used to bond dowels into the ends of existing concrete slabs as a shear transfer mechanism for extension of existing slabs.

The use of an epoxy grout which could attain high early strength and which would not shrink significantly during curing solved an old problem for manufacturing plants, that of rapid installation of new equipment with minimum delay until full operation.

Epoxy grout has also been successfully used for installation of handrails, architectural metals, precast concrete panels, structural members (both concrete and steel), concrete railroad ties, and for numerous other applications.

2.3.4 Epoxy coating materials

2.3.4.1 Epoxy seal coat

2.3.4.1.1 Epoxy seal coating was first applied as test patches in industrial plants along the eastern coast in 1953 and on highways in 1954. Although there were varying degrees of success and failure with these applications, the initial results were encouraging to many observers. Large scale experimental applications were attempted in 1956 on the Wilbur Cross Parkway, the Triborough Bridge and the George Washington Bridge. The apparent success of these latter applications led to more elaborate testing all across the United States by 1958. Tests at that time were conducted primarily with coal tar epoxies applied as seal coats and then given a skid-resistant surface by broadcasting fine sand or emery aggregate across the surface. This procedure, while successful in many respects, was not as utopian as had been hoped. Then in 1962 a thin topping of asphaltic concrete on top of a coal tar epoxy seal coat was tried as an alternative solution on a bridge in New York City which moved quite successful.

The method has since been extended using other epoxy systems.

2.3.4.1.2 Seal coats using epoxies of low viscosity have also been successfully applied on highway, industrial and commercial surfaces.

2.3.4.2 Epoxy polymer concrete as a wearing course -- Epoxy polymer concrete was first used as a wearing course in the repair of popouts and spalled areas on the surfaces of various concrete bridge decks in California in 1957, on the San Francisco-Oakland Bay Bridge, and in industrial plants and warehouses. The epoxy polymer concrete consisted primarily of the epoxy resin system and clean, dry well-graded sand. By 1963, several bridges in various parts of the United States had been successfully resurfaced with epoxy polymer concrete.

2.2.4.3 Epoxy resin specifications -- The U.S. Army Corps of Engineers published the first Federal specification for an epoxy resin system in 1959 and ASTM specification C 881 was first published in 1978. The use of the epoxy systems has since expanded in many directions, because of requirements for solution of coating, patching and resurfacing problems.

2.4 -- Present status of epoxies

2.4.1 Epoxies are presently used with concrete in the form of coatings, repair materials, grouts, bonding agents, paints, adhesives, epoxy mortars and polymer concrete, seal coats, penetrating sealers, wearing surfaces, and as admixtures to portland cement concrete to make epoxy polymer modified concrete. Thus, the appeal for epoxies has been enhanced, both from an economy and performance standpoint.

CHAPTER 3 -- CHEMICAL AND PHYSICAL CHARACTERISTICS OF EPOXY RESINS

3.1 -- General

Epoxy compounds are generally formulated in two or more parts. Part A is most often the portion containing the epoxy resin and Part B is its hardener system. Almost without exception, epoxy systems must be formulated to make them suitable for specific end uses.

3.2 -- Adhesion properties

3.2.1 General -- Epoxies bond well ([Fig. 3.1](#)) to almost every material providing that an appropriate surface preparation has been given (see [Chapter 5](#)). Because the quality and surface condition of concrete is rarely completely known, tests for adhesion are advised (see [Appendix A](#)). There are many reasons why epoxies make good adhesives including, but not limited to, the following:

- They can be in liquid form and yet contain no volatile solvent
- They adhere to most materials used in construction
- No by-products are generated during curing
- Curing shrinkage is low

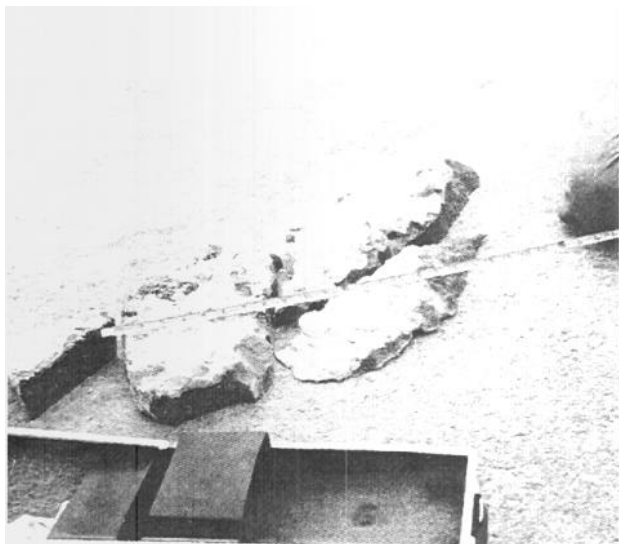


Fig. 3.1 -- Epoxy adhesive when properly applied can form a bond with greater strength than the concrete to which it is applied, as shown here (courtesy L. Mitchell, Consulting Engineer)

- e) Long time dimensional stability is good
- f) They have high tensile and compressive strengths
- g) Appropriate formulations are resistant to the action of weathering, moisture, acids, alkalis and most other environmental factors

3.2.2 Mechanical property comparisons of epoxies and concrete

3.2.2.1 Physical properties -- In Table 3.1 epoxy strengths and tensile elongation are the values at time of rupture. However, even highly elongating epoxy binders may have negligible stretch when heavily filled.

Table 3.1 -- Comparative mechanical properties of epoxy system and concrete

	Flexural strength psi (MPa)	Tensile strength psi (MPa)	Compressive strength psi (MPa)	Tensile elongation percent
Structural concrete (typical)	500-1000 (3.4-6.9)	300-700 (2.1-4.8)	3000-10,000 (20.7-68.9)	001
Epoxy compounds (typical)	1500-5000 (10.3-34.1)	500-7000 (3.4-48.9)	500-12,000 (3.4-82.7)	0.2 to 150

3.2.2.2 Temperature effects -- Epoxy resins react upon combination to form a thermosetting plastic which thereafter does not melt. The properties of a cured epoxy system generally change very little with temperatures well below the Heat Deflection Temperature (HDT) as measured by ASTM D 648. Beginning in the region about 18 F (10 C) below the HDT rigidity, creep resistance and chemical resistance are adversely affected as temperature is increased. Above 572 F (300 C) most resins will char and generally volatilize. The resulting fumes may be

toxic.

3.3 -- Susceptibility to chemical attack

3.3.1 -- Epoxies are considered as generally resistant to chemical attack. A general comparison with concrete is given in Table 3.2.

Table 3.2 -- Chemical properties of epoxy and concrete

	Epoxy	Concrete
Wet-dry cycling	Excellent	Excellent
Chloride deicing salts	Excellent	Fair
Muriatic acid (15 percent HCl)	Excellent	Poor
Foods acids (dilute)	Good	Poor
sugar solutions	Excellent	Fair
Gasoline	Excellent	Excellent
Oil	Excellent	Excellent
Detergent cleaning solutions	Excellent	Excellent
Alkalies	Excellent	Good
Sulfates	Excellent	Fair

Epoxy systems used to protect concrete from the effects of food spillage must be compounded for specific end uses. For example, a system resistant to acetic acid may not be resistant to all concentrations of acetic acid. This is because many organic acids have vapor pressures lower than water and, therefore, as spillage evaporates, the acid solution becomes more concentrated. Another note of caution relative to potential failures is that chemical resistance tests are often run at 77 F (25 C) whereas spillage may be much hotter. Food acid absorption by epoxy resins is a function of temperature. Acid absorption at 150 F (66.5 C) may be up to 100 times the absorption at 77 F (25 C). Furthermore, vegetable acid spillage usually contains plant sugars which form a series of organic acids when bio-oxidized. These acids, usually present in small amounts, also may become more concentrated as evaporation of spillage progresses. Therefore, proper selection of the epoxy formulation is important to the success of the substrate protection. Follow the recommendations of the epoxy manufacturer. A typical installation is shown in Fig. 3.2.

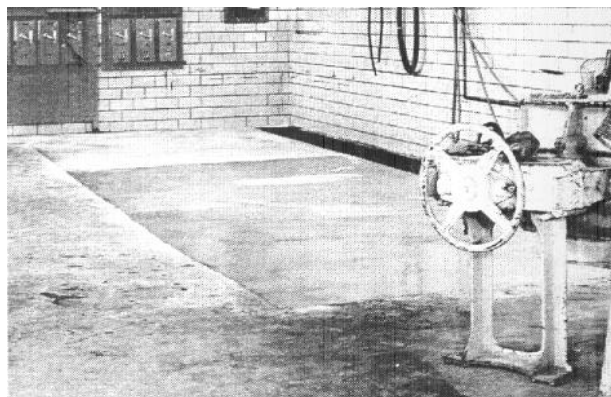


Fig. 3.2 -- Epoxy mortar floor topping in a food processing plant (courtesy Protex Industries)

3.3.2 -- Epoxies are widely used for industrial applications where chemical spillages are the normal environmental condition. Consult with the epoxy manufacturer to determine which formula should be considered.

3.4 -- Electrical properties

3.4.1 -- Epoxies are excellent electrical insulators.

3.4.2 -- Special techniques must be employed to enable an epoxy formulation to be a conductor or partial conductor of electricity. There are places where this is necessary, such as operating room floor surfacings in hospitals, clean rooms and manufacturing areas where static discharge cannot be tolerated. The reader is referred to the instructions from manufacturers specializing in such applications.

3.5 -- Abrasion resistance

3.5.1 -- Epoxies can be formulated to withstand severe abrasion, but conditions of use have to be understood before the best selection of materials can be made. For example, will the surface be dry or wet? Hot or cold? Will abrasion be from rubber wheels, steel wheels, water-borne rocks, etc.? For specific end uses, the epoxy compound manufacturer should be consulted and given a full description of service environmental conditions.

3.6 -- Resilience

3.6.1 -- Epoxies can undergo deformation, and yet recover and return to their original shape providing that their elastic limit has not been exceeded.

3.7 -- Creep

The amount of creep which will occur depends not only on the load but also on how close the service temperature is to the Heat Deflection Temperature (HDT), the amount of inorganic filler in the system, and the degree of confinement of the epoxy system as it is loaded.

3.8 -- Thermal expansion

3.8.1 -- A major difference between epoxy compounds and concrete lies in their coefficients of thermal expansion (see Fig. 3.6).

3.8.2 -- Steel and concrete usually have similar thermal expansions. Combined as reinforced concrete, the difference in their coefficients of thermal expansion does not usually become a problem either in design or use. On the other hand the considerable difference in coefficient of thermal expansion between epoxies and portland cement concrete does require careful consideration.

3.8.3 -- Consider the factors indicated in Fig. 3.3 where (a) is a slab of concrete surfaced with an epoxy (b). Due to the difference in coefficients of thermal expansion as the temperature rises (b) will attempt to grow larger than (a) and, if the concrete were as elastic as the epoxy, the result would be as shown in Fig. 3.4, obviously exaggerated. Conversely, if the temperature drops, (b) will shrink more than (a) and will produce the deformation

503R-7

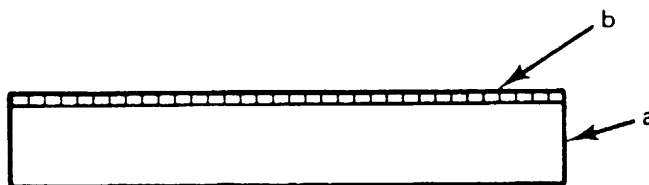


Fig. 3.3 -- A layer of epoxy (b) adhered to a thickness of concrete (a)

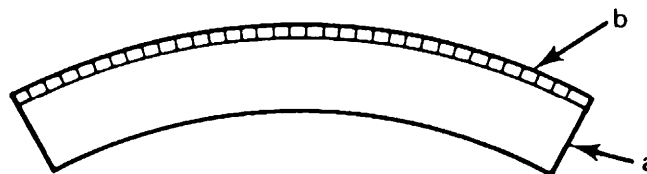


Fig. 3.4 -- The effect of temperature increase in an epoxy-concrete system

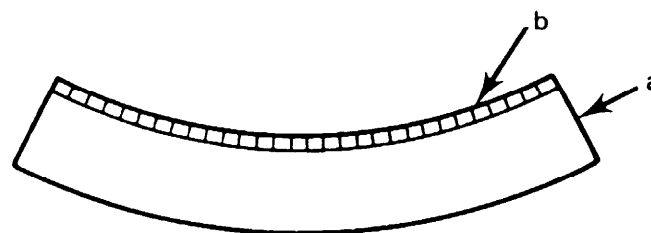


Fig. 3.5 -- Effect of temperature decrease in an epoxy-concrete system

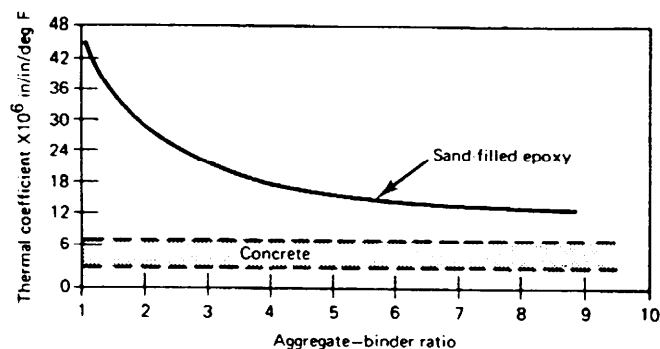


Fig. 3.6 -- The effect of changes in the sand aggregate-binder ratio on the thermal coefficient of an epoxy system

shown in Fig. 3.5.

3.8.4 -- The higher elastic modulus of concrete tends to restrain the movement of the epoxy, thereby causing severe stresses at the interface upon temperature changes. Epoxies yield under stress, and, if properly formulated, they will accommodate relatively larger dimensional changes resulting from thermal effects. Also, the coefficient of thermal expansion of the epoxy can be reduced by the addition of fillers, see Fig. 3.6, with an increase in modulus of elasticity typically resulting.

3.8.5 Thermal coefficient of epoxy-aggregate systems -- The thermal coefficient of an epoxy system will be reduced as the aggregate content of the system is increased as indicated in Fig. 3.6.



Fig. 4.1 -- Application of a thin epoxy mortar floor coating in an area subject to abrasion and chemical attack (courtesy Sika Chemical Corp.)

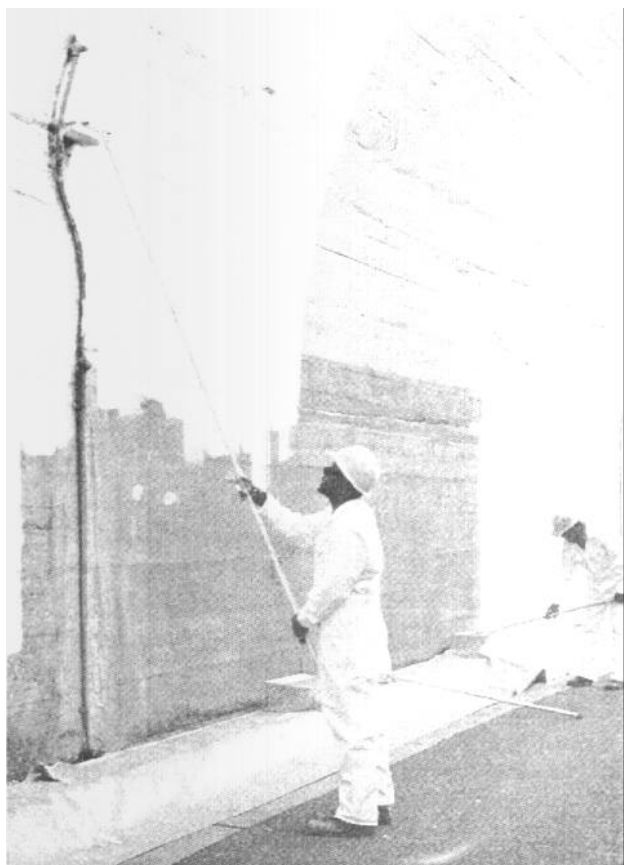


Fig. 4.2 -- An epoxy sealer and light reflector on the walls of a highway tunnel (courtesy Adhesives Engineering)

3.9 -- Exothermic reaction during cure

Epoxies develop heat during their cure. The temperature rise will depend on mass as well as formulation. To keep this temperature rise to a minimum, it is advisable to maintain a high surface area to volume during mixing



Fig. 4.3 -- Epoxy grouting of keyways in rapid transit bridge (courtesy Adhesives Engineering)

and application, to add the maximum quantity of aggregate consistent with the intended application, or both.

3.10 -- Curing and aging stresses

Curing and aging stresses are developed in epoxies. These stresses can be minimized by correct formulation.

3.11 -- Thermosetting properties

Epoxy resins are thermosetting plastics, i.e., in the process of hardening, they undergo chemical change and cannot be reliquified by heating.

CHAPTER 4 -- USES OF EPOXY RESINS

4.1 -- General

Epoxy resins, meeting ASTM C 881 have good adherence to concrete under all conditions whether wet or dry, and have been found useful for a wide variety of applications with concrete (Fig. 4.1-4.5). For the best performance under each condition of use, the properties of the epoxy resin system should be tailored to meet the specific needs of each type of application. Thus, it is unlikely that a system consisting only of an epoxy resin and pure hardening agent will find wide utility. It is for this reason that the epoxy resin systems sold commercially are generally the products of formulators who specialize in modifying the system with flexibilizers, extenders, diluents, and fillers to meet specific end-use requirements. It logically follows that it is important to adhere to the formulator's recommendations for use.



Fig. 4.4 -- Repair of a concrete bridge railing upright (courtesy Protex Industries)

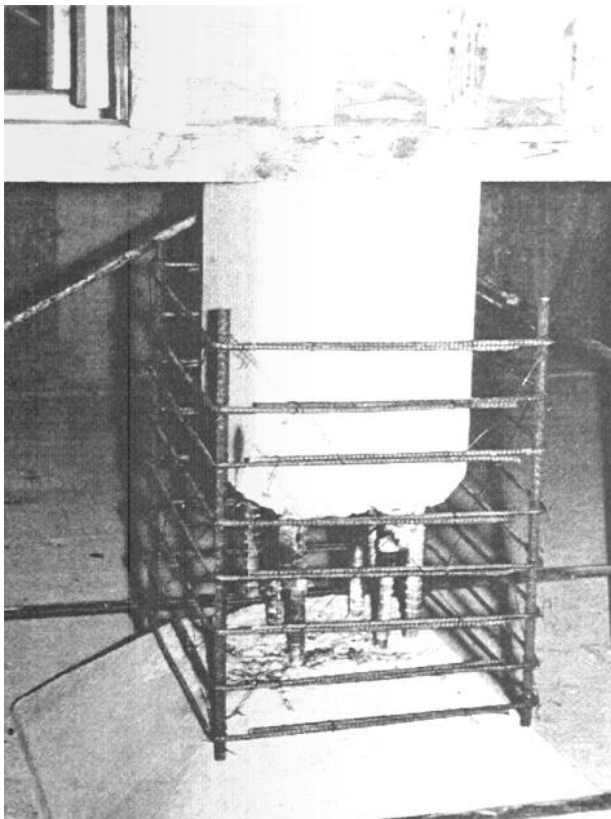
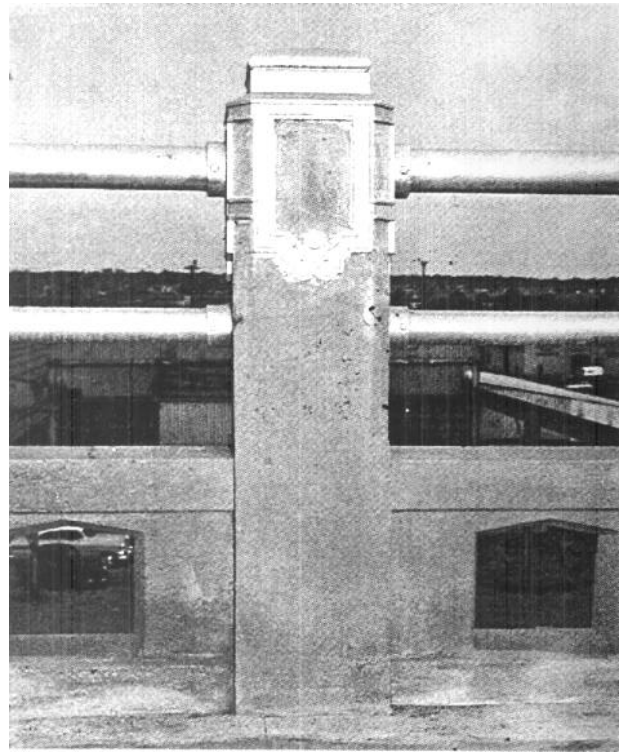


Fig. 4.5 -- Repair of a column-base connection. All exposed surfaces will be epoxy coated prior to casting new concrete (courtesy Protex Industries)

4.2 -- Protective coating

4.2.1 -- Because of their impermeability to water and their resistance to attack by most acids, alkalis, and many solvents, epoxy resin systems have been widely used as protective coatings for concrete. Such coatings may vary from sealers with thin films of 2 or 3 mil (0.05 or 0.08 mm) thickness to high-build coatings amounting to overlays. When used as a coating it is essential that the system be compounded so as to avoid or relieve excessive shrinkage and thermal stresses between the coating and concrete surface in order to prevent delamination of the coating through loss of bond or failure of the concrete.

4.2.2 -- Some of the most severe environments for the protective-coating type of applications are those of the highway bridge deck, industrial floor and parking deck surface for the purpose of preventing penetration of acid rain, chemicals, water and deicing solutions into the concrete. The coating may be used either as the wearing surface itself or may be covered by some type of asphaltic concrete overlay. In either case the coating should have mineral particles imbedded in the surface to provide adequate skid resistance for traffic when it is used as the wearing surface (see [Section 4.4](#)), and to provide bond when used beneath a bituminous overlay.

4.2.3 -- Many industrial environments involve exposure of concrete to acid, alkali, or solvents. Floors and walls located in such areas, as well as storage vats, can be made chemically resistant by the use of the epoxy resins.

4.3 -- Decorative coating

Epoxy resins serve exceptionally well as tile-like coatings; however, they surface chalk in outdoor exposure. In the case of wall surfaces, epoxy coatings present a hard, glossy surface and can withstand the abrasive and

corrosive action of cleaning materials. Epoxy coatings are especially suitable for floors, car washing areas, and such outdoor locations as patios and porches, because of their good resistance to wear and moisture. In this connection, they make an appropriate coating for swimming pools, serving the additional function of sealing the concrete surface to the passage of water.

4.4 -- Skid-resistant coating

Concrete surfaces can be made highly skid resistant by the application of an epoxy coating into which mineral particles are embedded. Typical applications are treads of stairways, walkways in certain critical areas, and highway pavement surfaces near toll booths. As mentioned in [Section 4.2.2](#), bridge decks are often given such a skid-resistant coating although the primary purpose for the treatment is often protection of the bridge deck itself.

4.5 -- Grout

Epoxy resins find wide application as grouting materials. The filling of cracks, either to seal them from the entrance of moisture or to restore the integrity of a structural member is one of the more frequent applications. Cracks of ¼ in. (6 mm) or less are most effectively filled with a pourable or pumpable epoxy compound, whereas an epoxy resin mortar should be used for wider cracks. Epoxy resins are useful as grouts for setting machine base plates and for grouting metal dowels, bolts, and posts into position in concrete.

4.6 -- Adhesive

4.6.1 -- Epoxy resin is a good adhesive for most materials used in construction, such as concrete, masonry units, wood, glass, and metals. However, many plastics, such as polyethylene, cannot be effectively bonded. Typical applications where epoxy resin has been used for cementing various materials to harden concrete are the joining of masonry units, precast concrete bridge deck girders, wood and metal signs, plastic traffic marker buttons, and the setting of dowels in preformed or drilled holes in concrete.

4.6.2 -- Epoxy resin is useful as the bonding medium between fresh and hardened concrete for such purposes as bonding a concrete overlay to an existing slab. For this purpose, it is essential that a formulation be used which will cure and bond properly under the moist conditions present in fresh concrete. Epoxy compounds can also be used as shear connectors for composite construction such as a metal beam and cast-in-place concrete slab.

4.7 -- Binder for epoxy mortar or concrete

Epoxy can be used as the sole binding material to form a resin mortar or polymer concrete. Such mixtures have been widely used for patching or repairing surface defects of many types of concrete structures, particularly highway bridges and pavements. Epoxy mortars and concretes are also especially adapted to repair of hydraulic structures where continued submersion lessens the prob-

lems of thermal expansion.

4.8 -- Underwater application

Epoxy resin formulations are now available which can be used to coat, overlay, patch or grout concrete and other construction materials in the splash zone or underwater in either brackish, fresh or salt water environments.

4.9 -- Epoxy-modified concrete

Most recently, epoxy resins when emulsified have found use as an additive to portland cement concrete and mortars to form "epoxy-modified concrete." These epoxy resin systems when added to concrete can increase adhesion of the concrete to concrete or to steel, increase strength, and reduce permeability. This use of epoxy resin is relatively new, but is growing.

CHAPTER 5 -- PREPARING SURFACES FOR EPOXY COMPOUND APPLICATION

5.1 - General

5.1.1 -- The preparation of surfaces to receive epoxy compound applications must be given careful attention as the bonding capability of a properly selected epoxy for a given application is primarily dependent on proper surface preparation. Concrete surfaces to which epoxies are to be applied must be newly exposed, clean concrete free of loose and unsound materials. All surfaces must be meticulously cleaned and be as dry as possible, and be at proper surface temperature at the time of epoxy application. When a substrate is still moist after the cleaning process, a moisture-insensitive epoxy formula should be used.

5.1.2 -- The method or combination of methods employed for satisfactory surface preparation will depend on the type, extent and location of the application. If preparation work involves the removal of concrete, such removal should be accomplished by well controlled mechanical means (see [Section 5.3.2](#)). Those surfaces or areas which do not require concrete removal in depth must be satisfactorily cleaned to remove all substances detrimental to bond of epoxy compounds. All equipment for supplying compressed air must be equipped with efficient oil and water traps to prevent surface contamination from the compressed air supply.

5.1.3 -- Prior to the application of epoxy resin compounds, it is generally considered necessary to field test the condition of the prepared concrete surface to receive the epoxy resin as well as the adhesion of the epoxy resin compound. Methods of field surface evaluation, determination of moisture percolation through the concrete, and of surface preparation are discussed hereinafter.

5.2 -- Concrete surface evaluation

5.2.1 General

5.2.1.1 Efforts to obtain good adhesion to a weak surface are futile since failure of the surface is likely to

occur. Conversely, poor bonding can occur with perfectly sound surfaces if they are not properly prepared. Surfaces should be prepared according to ACI specifications ACI 503.1, 503.2, 503.3 and 503.4:

- a) The surface must be strong, dense and sound.
- b) The surface should be dry and clean, i.e., free from surface contaminants such as dust, laitance, oil, grease, and curing compounds.
- c) The surface must be at the proper temperature to permit proper wetting by the epoxy application and to provide for prompt curing of the epoxy resin compound.
- d) Moisture and water vapor may sometimes permeate through the concrete to the surface being treated, and must be recognized as a potential problem.

Evaluate moisture content or outgassing of the concrete by determining if moisture will collect at bond lines between old concrete and epoxy adhesive before epoxy has cured. This may be accomplished by taping a 4 x 4 ft (1 x 1 m) polyethylene sheet to concrete surface. If moisture collects on underside of polyethylene sheet before epoxy would cure, then allow concrete to dry sufficiently to prevent the possibility of a moisture barrier between old concrete and new epoxy.

5.2.1.2 To insure that the above conditions will be met, tensile test methods have been the principal means for field testing horizontal concrete surfaces. The same methods can be adapted for use on inclined or vertical surfaces. The tests serve either of two purposes:

- a) To provide a convenient means for determining the bonding strength (adhesion) of the epoxy compound to a surface which has been prepared for bonding, or;
- b) To detect a weakened concrete surface.

5.2.1.3 The test methods described in [Appendix A](#) are suggested as being suitable field tests.

5.2.2 Evaluation of surface preparation

5.2.2.1 Extensive use of the field test method described in [Appendix A, Section A.1](#), has shown that where proper bonding has been obtained on properly prepared portland cement concrete surfaces, failure usually occurs in the concrete. Such failures indicate that the bond strength of the epoxy compound is greater than the tensile strength of portland cement concrete and satisfactory bonding of the epoxy compound has been demonstrated. At the same time, the magnitude of stress measured at failure of the concrete indicates whether the surface may be weak and requires further investigation. An evaluation of the quality of the concrete will be required to properly evaluate failures lower than 175 psi (1.2 MPa), recognizing that in some instances lower stress levels might be expected and acceptable.

5.2.2.2 The simplified field test method described in [Appendix A, Section A.2](#), was originally developed to evaluate the sufficiency of surface preparation for an epoxy application and to detect relative differences in

potential surface strength over the area to be repaired. This test method is also considered adequate to detect deficiencies in a prepared concrete surface. Although experience with the simplified method has not been as extensive as with the field test method ([Section A.1](#)) it is the simpler, less costly and less time consuming test of the two and, therefore, has the advantage of enabling more complete coverage of a surface area in a given length of time. Average values from the test method of [Section A.2](#) can be used to assess the adequacy of the surface and the magnitude of stress measured at failure of the concrete indicates whether the concrete is sufficiently sound for the application. Failure of the portland cement concrete at stress levels below 175 psi (1.2 MPa) generally indicates that the surface is suspiciously weak and further investigation of the surface may be necessary before full scale application of the epoxy compound.

5.3 -- Removal of concrete for repairs

5.3.1 -- The removal of the unsound or damaged concrete may be a part of rehabilitation work on structures involving epoxy applications (see [Fig. 5.1](#)). Such removal should be accomplished by well controlled mechanical means.

5.3.2 -- a first step in most concrete removal operations, it is generally recommended that the periphery of the required removal area be saw cut to a depth consistent with the type of repair. Saw cutting delineates the repair area and serves to essentially (if not totally) eliminate edge spalling and weaknesses that might be introduced by outlining the repair area with other types of equipment. It also serves to produce a shoulder against which repair material can be placed and smoothly finished, thus producing a neat appearing repair. The saw



Fig. 5.1 -- Removal operation of all unsound concrete in bridge deck down to top steel. Repair was made by bonding the fresh high early strength concrete patch to the old concrete using an epoxy adhesive at the interface (courtesy Adhesives Engineering)

cut line should be located several inches outside of the visual limit of the defect to insure that all defective concrete is removed and that the ultimate repair is bonded to sound concrete. The depth of saw cut should be at least $\frac{1}{2}$ in. (13 mm) for epoxy-bonded portland cement concrete and mortar repairs; $\frac{1}{4}$ to $\frac{1}{2}$ in. (6 to 13 mm) saw cuts are adequate for repairs employing epoxy mortars providing that removal of concrete within the repair area may be accomplished without spalling or otherwise damaging the concrete at the saw cut.

5.3.3 -- In preparing cutouts for popouts or small spalls wholly within a structural component (i.e., not involving joints, edges, or comers), very thin edges (sometimes referred to as feather-edging) may be permitted, but these should be at least $\frac{1}{4}$ in. (6 mm) deep thereby providing a shoulder of sufficient depth to permit a smooth finish. High frequency chipping hammers have been successfully used to make cutouts for this latter type of repair.

5.3.4 -- The concrete within the area delineated by the saw cut must be removed to a depth sufficient to expose sound concrete over the entire repair area. If doubt exists concerning the completeness of unsound concrete removal, it is best to remove the concrete to what may be a somewhat excessive depth to assure an eventually sound repair. Concrete removal should be accomplished mechanically with medium to lightweight air hammers equipped with appropriate cutting tools; or, for relatively large, horizontal areas, other equipment such as a mechanical scarifying machine may be appropriately and economically used.

5.3.5 -- Upon completion of the concrete removal operation, all newly exposed surfaces should be cleaned by an abrasive blasting method. When water is used as the abrasive blasting method the wet concrete should be allowed to dry (see **5.2.1.1**). When forced drying is necessary, the surface may be dried with radiant heaters, or hot air blowers.

5.4 -- Surface preparation

5.4.1 General -- Proper preparation of any surface to receive an epoxy application is of primary importance no matter how carefully other phases of the application procedure have been performed. Bond failure can be expected if surface preparation is inadequate. Proper preparation of a given surface is an art and a science and must be given careful attention.

5.4.2 Concrete surfaces

5.4.2.1 Recommended procedures -- Those surfaces or parts of surfaces which do not require removal of concrete in depth must nevertheless be precleaned to remove all substances detrimental to bond of epoxy compounds, such as laitance, curing membranes, dust, dirt, grease, oils, fatty acids and other debris resulting from surface preparation operations. The cleaning method or combination of methods will typically include abrasive blasting techniques such as sandblasting, steel shot blasting, high pressure water blasting or flame blasting. Whatever preparations are used, the result should be a

surface abraded to an extent that small aggregate particles are exposed but the surface should not be polished or be unnecessarily rough and it must be free of all surface contaminants. Care must be exercised to assure that any water used in cleaning is itself clean and also that no contaminants are present in any compressed air.

5.4.3 Previously coated surfaces -- Surfaces which have been previously treated with curing membranes, oils, silicones, paints, coatings (including epoxies) and other treatments may be encountered. Also, occasionally a bond or tack coat of an epoxy compound may harden before application of the top coat can take place. It is necessary to completely remove such materials and the best assurance of complete removal is by abrading methods. When there is doubt concerning selection of a cleaning method, it is considered good practice to make a small trial installation using one or more cleaning methods, applying the epoxy compound to be used in the work, and checking adhesion by one of the tensile test methods described in **Appendix A**.

5.4.4 Metal surfaces

5.4.4.1 General -- Metal surfaces must be cleaned and at the time of epoxy application be free of dust, dirt, oil, grease, rust, mill scale, weld splatter, and any other contaminant. Abrasive cleaning methods must be carefully considered. Adequate cleaning and surface profile are important factors in the abrasive cleaning selection. The method selected must be capable of cleaning the entire surface area, especially when vertical or overhead surfaces are to be cleaned. Precleaning is necessary if oil and grease deposits are on the surface. Mineral spirits, naphtha (100 F (38 C) minimum flash point) toluol (toluene) and xylol are satisfactory solvents for this purpose. Good ventilation and adequate safety precautions are necessary when solvents are used. After precleaning and mechanical cleaning, any dust or debris created by the mechanical cleaning must be removed prior to epoxy application. A cleaned metal surface is very susceptible to corrosion, particularly in a humid atmosphere, so the work should be planned to permit the epoxy application as soon as possible after cleaning to prevent flash rusting which may occur within minutes.

5.4.4.2 Test for adequacy of metal surface preparation -- The sufficiency of preparation of a metal surface can be partially determined by use of the water-break-free test. The test is a check of the surface tension of the metal surface. Individual droplets of distilled water are applied to the surface with an eyedropper. Depending on the cleanliness of the surface the water will tend to remain in a hemispherical shape, or will immediately spread. If the surface is not clean, the water will not spread but will behave somewhat like a drop of water on wax paper or on a polyvinyl chloride sheet. If the surface is clean and the surface tension is low the water will spread into a thin film, wetting a relatively larger area. There are, of course, all degrees of wetting between the two extremes and anything less than apparent low surface tension should be suspect.

5.4.4.3 Steel -- Epoxy resins adhere well to steel. Steel surfaces should be abrasive blasted for good results and should be scrubbed thoroughly after abrading, washed well, and dried. Solvent precleaning is necessary if oil or grease is present. Adequate adhesion can often be attained using only solvent cleaning where there is bright metal with no mill scale. Surface adequacy should be checked by the water-break-free test.

5.4.4.4 Galvanized metals -- The surface treatment for galvanized metals is the same as that given for steel except that the surface need not be abrasive blasted unless there are signs of subsurface corrosion. The surface should be scrubbed thoroughly with a solvent (see [Section 5.4.4.1](#)), washed well with clean water, and dried. A good water-break-free condition should be obtained. An improved bond can be obtained by etching with muriatic (hydrochloric) acid (20 parts by weight concentrated acid to 80 parts by weight water) for 3 or 4 min. After the etching treatment, the surface must be washed with clean water and dried.

5.4.4.5 Aluminum -- Adequate preparation of aluminum surfaces is difficult to achieve and care must be exercised to see that cleaning has truly been complete. The following procedures are designed for field use where abrasive blasting is not practical and for large surfaces that cannot be immersed in acid storage cylinders. The aluminum surface must be scrubbed with a nonchlorinated cleaner until a good water-break-free test is obtained and then etched with proprietary chromate treatment following manufacturer's directions and safety requirements. These treatments are generally plant operations.

5.4.4.6 Copper and copper alloys -- Copper and copper alloys are very difficult to bond, especially if high adhesive strength is desired, primarily because of rapid oxidation of the copper surfaces. Abrasive blasting is the preferred method of surface preparation, followed by thorough scrubbing with distilled water and drying. The following procedures are recommended as alternatives for field use.

5.4.4.6.1 Clean the surface with methyl ethyl ketone, then wash with acetone. Immerse the metal in or wash the surface with either: (a) 15 parts by weight ferric chloride, 30 parts by weight concentrated nitric acid, and 200 parts by weight clean water; or (b) 20 parts by weight ferric chloride, 50 parts by weight concentrated hydrochloric acid, and 30 parts by weight clean water. The surfaces should be washed or immersed in either of the above two solutions for 2 or 3 min, then rinsed thoroughly with clean water and dried. The cleaned prepared surface should be bonded or primed as soon as possible. The above concentrated acids should be handled with caution. They emit acrid fumes and can cause skin burns.

5.4.4.6.2 Copper is also readily cleaned with household ammonia (aqueous ammonia) which is more readily handled safely than are the foregoing acid compounds. The surface must be washed as before.

5.4.4.7 Hazards -- Many of the solvents and chemicals used for preparing metal surfaces are toxic, volatile, flammable or all three. Precautions associated with the particular materials used should be studied and carefully followed.

5.4.5 Wood surfaces -- Epoxy resin systems bond very well to wood surfaces. The surface of the wood should be free of sanding or filling dust. Such dust may be cleaned from the wood by wiping with an alcohol soaked rag or by an air jet.

In some woods and in some humid locations this degree of dryness may produce cracking of the wood and therefore be impractical. In such cases, tests should be made to determine the lowest acceptable moisture content to which the wood can be temporarily subjected and the epoxy formulator apprised of the existence of moisture in the application to obtain the best adhesive for the job. Before application, the wood surface should be filed with a rough file or rasp. Fine filing or sanding is not desirable since it will tend to fill the wood pores and inhibit thorough wetting by the epoxy. All filing residue must be removed before the application of bonding agents.

5.5 -- Temperature conditioning

5.5.1 -- The ease and effectiveness of epoxy application is greatly influenced by the temperature of surfaces on which the epoxy compound is applied. Epoxy compounds commonly in use today react most favorably when substrate temperatures are in the range of 0 to 140 F (-18 to 60 C). The conditions under which epoxy compounds are to be employed should be anticipated and provisions made for proper temperature conditioning of the epoxy.

5.5.2 -- When concrete and atmospheric temperatures exceed 90 F (32 C), difficulties may be experienced in application of the epoxy compound owing to acceleration of the reaction and hardening rates. If ambient temperatures are anticipated, work should be scheduled when the temperature is lower, such as in the early morning hours. At temperatures below 40 F (4 C), difficulties may occur due to deceleration of the reaction rates. The presence of frost or ice crystals may also be detrimental. If it is necessary to apply epoxy compounds at temperatures exceeding 90 F (32 C), the work should be supervised by a person experienced in applying epoxy at high temperatures. Epoxy systems formulated for elevated temperature are available.

CHAPTER 6 -- PREPARING EPOXY COMPOUND AND EPOXY MIXTURES FOR USE

6.1 -- General

Epoxy resins and their hardeners or curing agents are co-reactants in a chemical reaction. The proportioning of the resin and hardener is extremely important. The two must be combined in very specific ratios and they must be mixed very thoroughly to produce homogeneity within

the mixed compound and insure complete reaction. Temperature of the components of the epoxy compound can greatly affect the mixing procedure and temperature conditioning may be required. An itemization of other handling precautions is given in [Chapter 9](#).

6.2 -- Temperature conditioning of material

In field work where low ambient temperatures exist it is helpful to raise the temperature of the components since both the epoxy resin and hardener exhibit a very marked lowering of viscosity as their temperatures rise. The lower viscosity makes mixing much easier and faster. A lower viscosity also reduces the tendency to whip air into the compound during mixing. Components that are above normal temperatures exhibit a shortened working life (pot life) of the mixed compound. In this case, precooling of the components before mixing may be desirable.

6.2.1 Epoxy compound components

6.2.1.1 Heating -- Several methods are available for heating the adhesive material to a temperature where effective mixing can take place. A simple method is to store the components indoors in a heated room or warehouse overnight prior to using and to remove them from the heated room shortly before use. When such storage space is not available, or a more rapid heating is required, ovens can be used or even simple heated field enclosures can be built. Still another method is to immerse the components in their containers in a hot water bath (see Fig. 6.1).

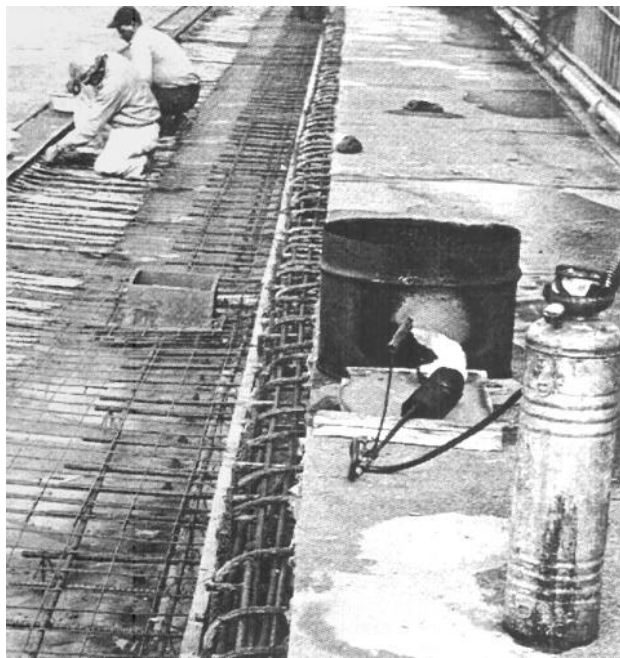


Fig. 6.1 -- Heating a water bath in which cans of epoxy resin and hardener can be temperature conditioned to facilitate use and proper hardening. In background workmen are brushing on an epoxy grout for bonding new plastic concrete to an old concrete section

When elevated temperature sources are used, care must be taken not to heat the components of the compound even locally to temperatures which might cause degradation of the material. The degradation temperature depends upon the specific compound. Epoxy component materials in general use in the construction industry will not be harmed by temperatures as high as 150 F (65 C). Care must be taken, however, not to shorten the working life too much by heating the material, since the temperature of the mixed compound significantly affects the working life or pot life of the materials.

6.2.1.2 Cooling -- When cooling is required to provide adequate working life, the following methods can be used: store in the shade, store in a refrigerator or refrigerated room, immerse containers in a bath of cold water.

In no case should the material be cooled to the extent that adequate mixing becomes difficult below about 60 F (15 C).

6.2.2 Aggregate

6.2.2.1 Heating -- Aggregates for epoxy mortars or concretes are often warmed before being added to the epoxy compound to make mixing easier, to help cure the epoxy mortar or concrete more quickly, or to drive off aggregate surface moisture. Aggregates, like the epoxy compound components, may be warmed by storing in a heated building, or by burners or radiation.

Care must be taken not to heat aggregates excessively because such heating can limit the working life of the epoxy mortar and change the characteristics of the cured epoxy compound. The manufacturer's instructions for the specific epoxy compound should be followed; however, in general, aggregate temperatures over 120 F (49 C) should be avoided.

6.2.2.2 Cooling -- Aggregate which has been stored in the sun or has been dried may be considerably above normal ambient temperature and can substantially shorten the working life of epoxy mortar or epoxy concrete. Spreading the aggregate into thin layers and storing in the shade will accelerate cooling.

The aggregate should not be cooled to the extent that when combined with the epoxy mixing becomes difficult or that condensation of moisture from the air takes place.

6.3 -- Mixing and proportioning

6.3.1 Components of epoxy -- The required accuracy of proportioning varies with each epoxy compound. Some compounds can tolerate a wider variation but such variations should only be allowed if test data are available that demonstrate the complete effect of the variation on both mechanical and chemical resistance properties of the cured compound.

6.3.1.1 Methods of proportioning -- The most accurate method of proportioning is the use of preproportioned units supplied by the manufacturer so that the entire contents of both component containers are mixed together. If such packaging is not available, the compo-

nents may be mixed together in the ratios specified by the manufacturer. These ratios may be expressed either by weight or volume.

6.3.1.2 Automatic metering -- Automatic metering equipment is available which is designed specifically for metering paste or liquid adhesive components. These metering devices are either "shot" type where successive specific quantities of each component are dispensed or the continuous type where the metering device regulates the flow rate of the epoxy components in the proper ratio.

6.3.2 Epoxy mortar and epoxy concrete -- Epoxy mortars are proportioned by adding the mixed epoxy compound to a specified amount of aggregate. This again can be done either by the use of premeasured packages or by weight or by volume.

6.4 -- Mixing

6.4.1 General -- Mixing of epoxy systems must produce a uniform and homogeneous mix.

6.4.2 Components of epoxy -- The components of the epoxy compound are first mixed in a manner which provides stirring or agitation which will effectively put them into a solution together.

6.4.2.1 Batch mixing -- The normal methods of providing the required agitation in small containers (one quart) (one liter) involve the use of spatulas, palette knives, or similar devices. For larger volumes, a mechanically driven tumbling type mixer is desirable (see Fig. 6.2). A paint mixing paddle driven by a low speed electric drill (see Fig. 6.3) may be used with the caution that paddle type mixers introduce air which can reduce adhesion and strength if cured with air still entrapped. Mixing should continue until the compound is homogeneous. This may take from 2 to 10 min, depending upon the viscosity, density and flow characteristics of the epoxy. Paste-like materials may also be mixed on flat surfaces with a trowel by repeated straight strokes which tend to drag one component through the other. Many compounds have their components distinctly pigmented so that mixing produces a third color. This is very helpful in determining when a complete mix has been achieved.

6.4.2.2 Continuous mixing -- Commercial equipment is available which will pump the epoxy compound components through a mixing head which forces the components to blend together (see Fig. 6.4). Mixing heads are frequently used with two component airless spray equipment for epoxy coatings and membranes.

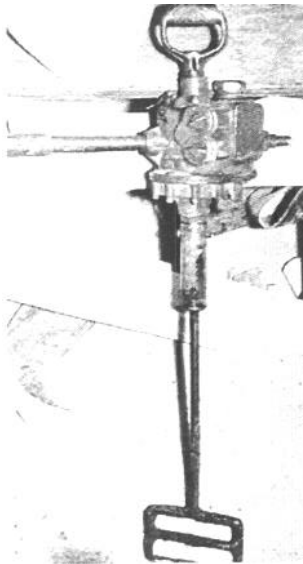
6.4.3 Epoxy mortar -- The mixing of epoxy mortar requires that the epoxy binder thoroughly wet each and every one of the aggregate particles.

6.4.3.1 Hand mixing -- Although it is difficult to do, epoxy mortars can be hand mixed in small quantities using a spatula or trowel.

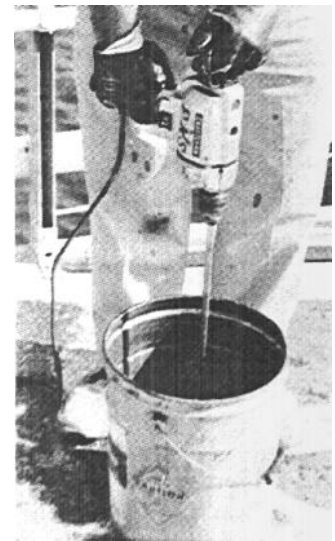
6.4.3.2 Mechanical mixing -- The most preferred method of mixing is by mechanical means. Larger quantities can be mixed in portland cement drum type mortar mixers or a mixing unit that blends the epoxy compo-



Fig. 6.2 -- Rotating bucket mixing of epoxy compounds (courtesy Protex Industries)



(a)



(b)

Fig. 6.3 -- Mixing of epoxy system components can be performed using a blade on a drill. Shown here are (a) pneumatic and (b) electric drills (courtesy L. Mitchell, Consulting Engineer, and Sika Chemical Corp.)

nents and aggregate together into a homogenous mass.

6.4.4 Epoxy (polymer) concrete

6.4.4.1 Order of addition -- Epoxy polymer concretes are mixed in a similar manner to epoxy mortars with one exception. In relatively stiff mixes the finer aggregate should be added to the mixed epoxy binder before the larger aggregate. This order of addition will help prevent the tendency of the mix to "ball" by wetting out the finer aggregate that have more surface area. The finer aggregate should be added slowly.



Fig. 6.4 -- A continuous mixing head gun being used for crack injection. Note that a thermoplastic surface seal was first applied, then through entry ports in the sealer the gun pumps the adhesive (courtesy Adhesives Engineering)

6.4.4.2 Avoid segregation -- Just as in portland cement concrete and asphaltic concrete mixes, care should be taken to avoid segregation of the aggregates prior to adding them to the binder material. If segregation does occur, the epoxy polymer concrete will not be uniform.

6.4.5 Epoxy modified concrete

6.4.5.1 Order of addition -- Mixing order and methods vary from one product to the next product. Each manufacturer's instructions should be carefully followed.

6.5 -- Cleaning of equipment

6.5.1 General -- Except in cases where disposable mixing equipment is used, special care should be taken to prevent the cured epoxy compound from bonding to mixers and containers. There are five general approaches which are used, either separately or in combination with one another.

6.5.2 Solvents -- The most widely used cleaning method is to immerse the tools and wash the containers prior to the epoxy compound gelling with strong semipolar solvents such as ketones and certain chlorinated solvents like methylene chloride. Mineral spirits or toluene may also be used, with greater safety, although not as efficient as the above solvents. In each case complete cleaning and drying are necessary before reuse. For emulsifiable epoxy systems, water can be substituted for solvents as a cleaning agent.

6.5.3 Strippers -- Once the epoxy compound has cured, commercial strippers may be used which will attack the cured epoxy compound. Some epoxy compounds are more readily attacked by strippers than others.

6.5.4 Mechanical abrasion -- Cured epoxy compounds

can be abraded with the use of a grinding wheel, although the process is generally slow if the buildup of material is large.

6.5.5 Burning -- Most epoxy compounds will burn if their temperature is raised to about 500 F (260 C). Thus, metal tools and containers which might not be damaged by these temperatures can be cleaned in this manner. Because the products of combustion can be harmful if inhaled, ventilation must be provided.

6.5.6 Preventing the bond -- An alternative technique for maintaining equipment is to prevent a bond of the cured epoxy to the tools or containers in the first place. Release agents such as dry silicone sprays, spray-on films, and special wax emulsions are useful where excessive abrasion is not encountered. Care should be taken that the type of release agent used does not contaminate the epoxy compound and interfere with proper cure or bonding.

6.6 -- Caution on solvents and strippers

The common solvents and strippers may be highly toxic and flammable. The reader is referred to [Chapter 9](#) for a discussion of precautions which must be taken in handling these chemicals.

CHAPTER 7 -- APPLYING EPOXY COMPOUNDS

7.1 -- General considerations

7.1.1 -- The applicator should be assured that the epoxy to be applied has the proper rate of hardening and viscosity for the job. Both are affected by the temperature at which the epoxy is applied ([Section 6.2.1](#)), and both can affect the ultimate thickness of the epoxy layer. The amount of sag and thickness that will be achieved in the adhesive layer also depends partly on whether it is applied to a vertical surface, to the top of a horizontal surface or the bottom and whether the surface is flat or irregular.

7.1.2 -- Highly porous concretes or concrete made of very absorptive aggregate may absorb enough epoxy to starve the glue line. Such concrete should be given a first seal coat of the same epoxy adhesive to penetrate into the absorptive aggregate. Allow the seal to become tack free and then apply the second coat. To assure adhesion most epoxy manufacturers recommend that subsequent coats be applied within 24 hrs. If a longer time is required before recoating, sandblast the last coat to remove the gloss and immediately apply the next coat.

7.1.3 -- Spray applications are suitable for many purposes, but they do not always establish a full, uniform contact as do brush and roller applications. The brush and roller methods of application are preferred. However, they require more time to apply and it is harder to maintain the desired thickness of the epoxy application on cold surfaces.

7.1.4 -- Intimate contact is essential for maximum effectiveness and all necessary measures should be taken to

assure complete wetting. Thorough wetting by the epoxy may be more difficult to achieve with an epoxy mortar or concrete than with a plain binder.

7.2 -- Specific applications

7.2.1 Skid-resistant protective aggregate broadcast overlays

7.2.1.1 General -- The proper epoxy resin system should be selected for the expected application temperatures and in-service environmental conditions. The following aggregates are suitable to provide skid resistance: aluminum oxide, silicon carbide, silica sand, blast furnace slag, roofing granules, and trap rock.

7.2.1.2 Application methods -- Two acceptable ways to apply an aggregate broadcast overlay are in common use.

7.2.1.2.1 One method is to apply one coat of mixed resin first, using brushes, rollers, brooms, screeds, or spray equipment, then, within 1 to 10 mm, broadcasting the aggregate by hand or machine, taking care not to cause "shoving" of the resin from the impact (**Fig. 7.1-7.3**). The aggregate determines the final texture or smoothness and should be applied at about the rate of 1.5-14 lb/yd² (0.8-7.3 kg/m²).

7.2.1.2.2 Another method is to apply two or three coats of resin where protective treatment is required against deicers or other aggressive agents. The aggregate is added to the second and third coat as in Section 7.2.1.2.1 above. When the epoxy is tack free the excess (loose) aggregate is removed and the next coat is applied over the remaining aggregate, encapsulating the aggregate. A three coat system provides better protection. This method is known as a "seeded system."



Fig. 7.1 -- Epoxy seal and skid resistance binder coat sprayed onto pavement by automatic mixing, metering and application machine followed by sand broadcasting (courtesy Adhesives Engineering)



Fig. 7.2 -- Squeegee and roll on application of seal coat followed by skid resistant layer spread by a hand seeder (courtesy Sika Chemical Corp.)



Fig. 7.3 -- Skid resistant calcined bauxite being applied by an automatic seeder for improved uniformity of coverage (courtesy Adhesives Engineering)

7.2.1.3 Bridges, parking decks and pavements

7.2.1.3.1 Bridge decks, parking decks, and pavements have been treated or surfaced with epoxy materials in many ways. These can be categorized as:

- a) Aggregate broadcast overlays (covered in **Section 7.2.1**)
- b) Epoxy polymer mortar overlays (covered in Section 7.2.2)
- c) Surface and penetrating sealants (covered in Sections 7.2.2 and **7.2.3**)

7.2.2 Epoxy polymer mortar overlays -- The general se-



(a)



(b)



(c)

Fig. 7.4 -- Mortar overlay sequence: (a) epoxy mortar is dumped onto primed surface, (b) mortar then troweled onto surface restoring deck to grade, (c) epoxy seal coat is squeegeed onto cured mortar surface and a skidproof finish of sand broadcast over fresh epoxy

quence for installing epoxy polymer mortar overlays is shown in Fig. 7.4.

7.2.2.1 Surface evaluation and preparation should follow the same procedures as set forth in [Chapter 5](#). Joints and cracks should be evaluated and repaired as outlined in [Section 7.2.5](#). In the case of working cracks or

joints, a joint should be made in the epoxy overlay so that flexible joint sealants may be used. Generally speaking, deep holes should be filled with epoxy mortar and properly compacted and the patch brought within $\frac{1}{4}$ in. (6 mm) of the final grade before the epoxy mortar overlay is applied. The patching procedures in [Section 7.2.4](#) should be followed. Since the epoxy mortar must adhere to any patching mortars used, the recommendations of the manufacturer of the patching mortar must be followed.

7.2.2.2 Polymer epoxy mortars used for overlays consist of a liquid binder filled with from 4 to 7 parts (by weight) of a graded aggregate to one part of binder. The amount of aggregate used depends on particle shape and void characteristics. A single gradation of fine aggregate has been used with some resin systems. Single gradation aggregate contain a larger volume of voids than graded aggregate. Therefore, to obtain a nonporous mortar when using single gradation aggregate, high resin contents are required. From a theoretical standpoint, just enough binder should be used to fill all the voids in the aggregate matrix. This amount produces optimum physical properties, lowest cost, and lowest shrinkage. The maximum amount of aggregate used is governed by the void content of the aggregate. For freeze-thaw durability and chemical resistance, the air voids in the finished mortar should be less than 12 percent.

The thermal coefficient of expansion of epoxy resins is much greater than that of concrete, but the thermal coefficient of aggregate is similar to that of concrete; consequently the maximum quantity of aggregate consistent with freeze-thaw durability and workability should be used to reduce the stresses that develop between epoxy mortar and concrete during changes in temperature.

ASTM C 884 can be used to anticipate problems caused by the differential thermal expansion and contraction of epoxy mortars and portland cement concrete.

7.2.2.3 The binder system itself consists of two or more liquid components that are combined and thoroughly mixed prior to incorporation of the aggregate. Once the components are mixed, chemical reactions start immediately and the application procedure must be followed to completion. Pot life and working time will vary considerably, depending on the system, the temperature, and the handling procedure. An applicator must therefore be thoroughly familiar with the particular system being used before attempting an application of any large size.

7.2.2.4 For any mortar system to perform, it must bond strongly and permanently to the concrete surface. To do this, it must completely wet the surface, leaving no voids or dry areas at the interface. To assure this complete wetting it is the usual practice to apply a prime coat of the clear binder system to the prepared surface just prior to application of the mortar. This thin primer may be applied with rollers, by spray equipment, or with squeegees if the surface is relatively smooth. Brooms and large brushes have also been used.

7.2.2.5 After the binder is mixed it should be added immediately to the aggregate in a mortar mixer. In most cases the aggregate specified will be a clean, dry, properly graded silica sand. A very workable sand has a small amount of fines passing the No. 100 (149-micron) sieve and usually has little or no material retained on the No. 8 (2.38 mm) sieve (see Section 7.2.4.1). The grading should be uniform between these limits. Formulators may supply special sands which they have found to be optimum for their systems.

7.2.2.6 It is important to control the temperature of the aggregate, both before mixing and during that part of the mixing cycle that precedes the addition of the binder. If the mix gets hot due to the sun, hot equipment, or frictional heat from mixing, the curing reactions will be accelerated and premature hardening may occur. In cool weather the aggregate is sometimes preheated in order to accelerate the cure. Once everything is in the mortar mixer, mixing should continue only long enough to get a completely wetted aggregate and a uniform mix. Extending the mixing time will develop heat and shorten the time available for spreading. Viscosity will also increase making the system less workable. As soon as mixing is complete the mortar should be dumped on the surface in the area where it will be applied and spread out into a relatively thin layer. This helps to dissipate exothermic reaction heat and extend work time.

7.2.2.7 After the mortar is placed on the uncured primed surface and spread out with rakes or hoes to the approximate thickness desired, a vibrating screed operating on rails set to give the desired thickness is passed over the mortar. For bridge and parking decks and highway pavements the resulting surface is usually satisfactory. Touchup can be done with trowels if necessary. The usual practice is to then broadcast a light layer of sand over the surface to eliminate any slick spots or resin-rich areas. This not only improves the appearance but assures uniform antiskid characteristics. Minimum thickness for an overlay applied in this manner is $\frac{1}{4}$ in. (6 mm). These guides can vary depending on requirements of the application and the system used.

7.2.2.8 In areas where it is impractical to use a screed or if a fine finish is desired, the mortar can be troweled either by hand or with power equipment. This technique approaches an art and the variations are specific for each formulation. The use of solvents, oils, or other troweling aids is prohibited, as these materials weaken the system and lead to early failure.

Prompt cleanup of all equipment and tools is a must (see Section 6.5). As epoxy systems cure, they become insoluble in practically all common solvents. If solvents are to be used, as recommended by the formulator, they must be used before the epoxy cures. If the epoxy cures on the equipment, cleaning must be performed with a hammer and chisel or with blowtorch and scraper. Caution in all aspects of cleanup is emphasized (see Chapter 9).

7.2.3 Surface and penetrating sealers for waterproofing

-- The sealing of surfaces for waterproofing should conform to ACI 515.1R. Working joints should be sealed in accordance with ACI 504R. If there are cracks that require repair by epoxy compounds before sealing the surface, they should be repaired in accordance with appropriate provisions of Section 7.2.5.

7.2.4 Patching

7.2.4.1 Epoxy patches may be used either to repair an exposed surface or to prepare a surface to receive an epoxy overlay. For thin patches a sand should be added to the epoxy that has a gradation falling within the range given in Table 7.1. For patches of $\frac{3}{4}$ in. (19 mm) or greater thickness the sand should be combined with a coarse aggregate whose maximum size is one-third the thickness of the patch or less. The use of coarse aggregate reduces the coefficient of thermal expansion. The binder to aggregate ratio, parts by volume, is generally less than 1-5, depending on the grading of aggregate.

Table 7.1 -- Sand grading for thin epoxy patches

U.S. standard sieve No.	Size of opening	Amount passing, percent
4	4.76 mm	100
8	2.38 mm	95-100
16	1.19 mm	60-80
30	595 μ	35-55
50	297 μ	15-50
100	149 μ	5-15
200	74 μ	0-4

7.2.4.2 The following steps should be followed:

7.2.4.2.1 Prepare patch areas following guidelines given in Chapter 5, extending the newly exposed abrasive blasted surface beyond the patch perimeter by 1 ft (300 mm).

7.2.4.2.2 Prime all newly chipped or abrasive-blasted concrete with the neat binder epoxy. Evenly apply the epoxy to wet all surfaces including the steep sides and the reinforcement steel. Do not allow the epoxy to puddle in the low areas of the hole. The epoxy mortar must be placed before the prime coat becomes tack free.

7.2.4.2.3 Place the mixed epoxy patching material in the hole. If the depth of the hole is greater than 6 in. (150 mm), place each lift no thicker than 6 in. (150 mm) and allow lift to cool before placing the next lift. Troweling of each lift is not necessary. On the final lift, place the epoxy mortar thicker than the surrounding concrete edges. Compact and screed the surface. For smoother surfaces, trowel the epoxy until the desired smoothness is obtained. Follow the epoxy manufacturer's recommendation for the maximum depth of lift and maximum time of application between lifts. If the maximum time is exceeded, then the surface of the previous lift may require mechanical abrasion.

7.2.4.2.4 All texturing of the epoxy surface should be accomplished by the screeding or troweling techniques, not by adding sand to the uncured epoxy mortar. Sprinkling sand on the surface of the patch to

provide added skid properties often shows rubber build-up faster than the surrounding surfaces.

7.2.4.3 When a faster cured patching system is required, select a product that has the desired capabilities. Heating of the concrete surface of the newly placed epoxy mortar to shorten the cure time is often less than cost effective. Curing the epoxy below the manufacturer's recommended low cure temperature will probably result in failure. Follow the manufacturer's instructions for best results.

7.2.4.4 On vertical or overhead repairs, select an epoxy mortar that is capable of hanging in $\frac{3}{4}$ to 1 in. layers (19 to 25 mm). Carefully follow the epoxy manufacturer's recommendations for temperature controls and sand gradation.

7.2.5 Grouting and sealing cracks and joints -- ACI 504R describes practices for sealing of joints, including joint design, material available, and methods of application. Fig. 7.5 shows one method for sealing cracks. Before grouting or sealing structural cracks it should be determined if the crack is active, and if so, what are the causes? ACI 224.1R discusses causes and evaluation of cracks in hardened concrete. Cracks that are active should be treated as described in 504R. However, most cracks are dormant and should be low pressure epoxy injected to fill the entire void and return the concrete, including the reinforcement steel, to its original monolithic design state.

7.2.5.1 Surface seal -- The first step in filling a crack by injecting liquid epoxy resin adhesive is to provide a surface seal on all faces of the crack so that the liquid resin will not leak and flow out of the crack prior to gelling and curing. If unexposed faces of the concrete cannot be reached, crack repair by pressure injection is extremely difficult unless special steps are taken. Where the crack face cannot be reached but where there is backfill or where a slab on grade is being repaired, the backfill material or subbase material is often an adequate seal in itself. There are two methods used to provide this seal:

7.2.5.1.1 Routing -- Creating a V-groove by routing is not required unless the surface concrete at the edge of the grade has deteriorated. Routing is then required to remove the deteriorated concrete down to a sound substrate. The crack is vacuumed to remove debris and dust. The surface ports are placed and the routed void is filled with epoxy mortar or a non-sag epoxy adhesive.

7.2.5.1.2 Surface seal -- A non-sagging epoxy adhesive is applied to the face of the crack completely bridging the crack. An epoxy adhesive that sets at the desired interval should be selected. Slow to rapid curing adhesives are available in clear or pigmented formulas. In some cases a thermoplastic adhesive is used where the sealing material is applied at an elevated temperature.

7.2.5.2 Entry ports -- To inject the adhesive material through the surface seal, entry ports must be provided. Three methods are in general use:



(a)



(b)

Fig. 7.5-(a) Prior to crack injection holes for entry ports are drilled into debris-filled cracks and vacuumed to remove contaminants, (b) injection of epoxy compound is then performed on each part (courtesy Adhesives Engineering)

7.2.5.2.1 Vacuum drilled holes - entry ports inserted -- A hole is drilled with a vacuum chuck or core bit over the crack to a depth of $\frac{1}{2}$ to $\frac{3}{4}$ in. (13 to 19 mm). The hole diameter varies among entry port manufacturers. Most are typically about $\frac{5}{8}$ in. (16 mm) in diameter. It is important to select a vacuum bit that is compatible in diameter size with the entry port diameter. The vacuum bit is attached to a vacuum chuck, which has an exit port to which a vacuum hose connecting to a wet-dry vacuum unit is attached. As the hole is being drilled, all dust and debris are removed from the hole during the drilling process, leaving a clean, uncontaminated open crack. After drilling, the entry port is placed into the hole and the entire exposed crack surface sealed and all entry ports are anchored with an epoxy adhesive.

7.2.5.2.2 Bonded flush fitting -- When the cracks are V-grooved or the concrete surface is wet, a method frequently used is to place an entry port called a tee over the crack. The tee is bonded to the concrete surface with the epoxy adhesive at the time of covering the entire crack with the surface sealer.

7.2.5.2.3 Interruption in seal -- Another system of providing entry is to omit the seal from a portion of the crack. This method can be used when special gasket devices are available that cover the unsealed portion of the crack and allow injection of the adhesive directly into the crack without leaking.

7.2.5.3 Mixing the surface seal and injection adhesives -- This is done either by batch or continuous methods. In batch mixing the epoxy components are premixed according to the manufacturer's instructions, usually with the use of a mechanical stirrer, like a paint mixing paddle. Care must be taken to mix only the amount of epoxy that can be used before the material begins to gel. When the epoxy material begins to gel, its flow characteristics change and pressure injection becomes more and more difficult. In the continuous mixing system the two liquid epoxy components pass through positive displacement metering pumps, prior to passing through an automatic mixing head. This system allows the use of fast-setting adhesives that have a short pot life.

7.2.5.4 Pumping the injection adhesive -- To fully fill the crack with mixed injection adhesive, some means of providing pressure and flow is required. The following methods are typical.

7.2.5.4.1 Pressure pot -- A frequently used method is that of forcing the material with air pressure from a standard paint pressure pot through hoses into the entry port. The injection adhesive may be placed in a disposable container within the paint pot.

7.2.5.4.2 Caulking gun, air or hand actuated -- A common method is to use a caulking gun cartridge filled with mixed adhesives.

7.2.5.4.3 Pumps -- Another method is to pump the injection components separately through positive displacement pumps. The resin and curing agent can be either gravity-fed or force-fed to the pumps. The pumps force the individual epoxy components through the hoses to a hand-held mixing chamber that properly mixes the material into the finished curable adhesive. This method of pumping and mixing eliminates problems caused by short pot life.

7.2.5.5 Injecting the adhesive -- The mixed adhesive enters the injection port through a connection fitting appropriate to the type of port fitting which has been attached to the concrete. The adhesive is injected into the crack through successive adjacent ports. Care must be taken to inject the adhesive at such a rate that the pressure required to inject does not exceed that pressure which the surface seal can tolerate or which might damage the structure. Low pressure pumping, typically in the range of 14 to 21 psi (1 to 1½ MPa), is desirable to properly allow the entire fissure to be filled.

7.2.5.5.1 Horizontal surfaces -- In a horizontal member, such as a floor, injection proceeds from one end of the crack to the other through adjacent ports. When possible, the crack is injected from the bottom of the horizontal concrete member filling upward.

7.2.5.5.2 Vertical surfaces -- In vertical surfaces

the injection takes place from the bottom up through adjacent ports. Care must be taken not to entrap air or water in the crack during the filling process.

7.2.5.6 Making sure the crack is filled -- During injection operations it is very difficult to be sure that the crack is completely filled. Personal experience of the applicator and low pressure pumping techniques are very important. Ultrasonic testing methods to determine whether the crack has been filled have been perfected but the limited dissemination of this technology restricts the availability of this control method. The only practical method widely available is by drilling concrete cores. One or the other of these methods is absolutely necessary when assurance of a sound structural bond is required.

7.2.5.6.1 Order of injection -- The crack must always be filled through successive ports starting with the lowest one. Injection must continue through one port until the epoxy adhesive starts flowing out of the adjacent port in a steady stream without air or water. At this point, the first port must be capped off and injection started on the port which has begun to show adhesive.

7.2.5.6.2 Location of ports -- Entry ports should be spaced far enough apart to assure that when the adhesive material shows at the adjacent port it has completely filled the crack to its full depth. Normally they would be spaced about as far apart as the depth of penetration desired

7.2.5.6.3 Calculation of theoretical amount required -- A useful technique in helping to indicate whether the crack is filled is to estimate the theoretical void by measuring the width of the crack and the dimensions of the concrete member. Injection proceeds until the theoretical amount has entered the crack plus an allowance (50 percent additional has proved suitable). If the theoretical amount cannot be injected, the cause should be determined. The possibility of undetected voids of undetermined size connecting with a crack must be recognized and the gross amount of material to be injected determined and limited.

7.2.5.6.4 Maintaining pressure -- If pumping pressure cannot be maintained in a crack that is otherwise apparently full, the reason should be determined. Inability to maintain pressure indicates that the adhesive material could be leaking out through a broken seal or vent hole, or could be draining into connected cracks, or passing through the member into voids on the other side.

7.2.5.7 Removing the surface seal -- After the injected adhesive has cured, the surface seal should be removed by grinding or whatever means are necessary. Fittings and holes at entry ports should be painted with an epoxy patching compound.

7.2.5.8 Adhesive properties -- Ideally, the adhesive used should be compounded for pressure injection into cracked concrete. It should be pumpable, be readily assimilated into small cracks by capillary action, and should have the capability of bonding to wet concrete above 33 F (1 C). On dry concrete surfaces it should also be cap-

able of wetting out a layer of dust or concrete fines that might exist inside the crack. It should also be capable of maintaining a low viscosity when pumped into colder (0 F [-18 C]) concrete and fully cure at the lowest substrate temperature during the curing period. The best bond is obtained to dry crack surfaces.

7.2.5.9 Contaminated cracks -- Cracks which have been contaminated with oils, grease, food particles or chemicals present special problems. Unless the crack can be cleaned sufficiently, to allow adequate adhesive penetration and bond, pressure grouting will not be an effective repair procedure.

Dirt or fine particles of concrete also prevent penetration. They must be removed in larger cracks by flushing with water, followed by drying or blown out using compressed air.

7.2.6 Bonding fresh concrete to hardened concrete

7.2.6.1 General

7.2.6.1.1 -- Epoxy bond coats must be manufactured specifically for the purpose of bonding fresh portland cement concrete to existing hardened concrete. They should be thixotropic (to avoid pooling) and able to hold at least a 15 mil (0.4 mm) film without sagging. Although an epoxy bond coat will provide satisfactory adhesion prior to the time the film is tacky to the finger, it usually is desirable to delay placement of new concrete until some degree of tack has developed. (Note: When vibrators are used it is essential to allow the epoxy bond coat to reach an appreciable tack, since vibration can, by emulsifying a fluid epoxy bond coat, displace it from the existing concrete to the detriment of the bond.) If, inadvertently, the epoxy bond coat reaches a soft rubber-like stage (no tack) prior to the placement of the new portland cement concrete, a second application of the epoxy bond coat is required. Also a highly viscous bond coat may not adequately penetrate the base concrete and eventual bond strength will be reduced. The concrete should be a nonbleeding mix of not more than 2 in. (50 mm) slump for best results.

7.2.6.2 Formed concrete -- The concrete surface should be prepared as in [Section 5.4](#). Forms suitable for placement of the new concrete should be made in a way that permits them to be assembled and put in place within the time limit imposed by the gel time of the epoxy bond coat. The epoxy should be mixed in the proportions recommended by the manufacturer, and applied with a stiff brush roller or spray equipment. Sufficient force should be used to assure thorough and complete wetting of the concrete and exposed aggregate. Coating of the reinforcing steel improves adhesion and provides added protection. The forms should then be placed, and filled with portland cement concrete in the usual manner, before the epoxy becomes tack-free.

7.2.7 Bonding hardened concrete to hardened concrete

7.2.7.1 Before bonding, both surfaces should be thoroughly cleaned and both should be dry (see [Chapter 5](#)). Epoxy compound should be applied to both surfaces. If the surfaces are vertical, thixotropic epoxy compound

should be used. The compound should be worked into the surfaces thoroughly with a brush. For horizontal surfaces an epoxy should be used which is so formulated as to be absorbed to a greater depth. It can be applied by brush, roller, or spray.

7.2.7.2 The surfaces should be pushed firmly together, and clamped in place if there is any likelihood of movement in the first several hours. Provision should be made to prevent any leakage from the joint during the hardening period.

7.2.8 Reflectorized traffic points -- Some traffic paints are essentially pigmented adhesives for bonding glass beads or reflecting aggregate. These should be applied to clean, dry surfaces during a period when traffic can be kept off the pavement for a period sufficient for the epoxy to attain some strength -- usually a minimum of about 3 hr. The normal coverage should be about 100 ft²/gal. (2.5 m²/L). About 6 lb (2.7 kg) of glass beads should be evenly distributed over 100 ft² (9.3 m²) of fresh paint.

7.2.9 Coatings to prevent chemical attack -- When epoxies are used as coating, they should be used in accordance with ACI 515.1R.

7.2.10 Bonding concrete to steel -- Before applying epoxy to steel, the steel must be prepared as detailed in [Section 5.4](#). The epoxy should be applied to the steel if it is to be bonded to fresh concrete, and the concrete placed while the epoxy is still tacky, as in [Section 7.2.6](#). If the steel is to be bonded to hardened concrete, the epoxy should be applied to both surfaces. The materials should be clamped or held together with just sufficient force to prevent movement during hardening. Excessive force should be avoided to prevent introduction of stresses when the clamps are removed. Provision should be made to prevent epoxy from running out of the joint.

7.2.11 Bonding concrete to aluminum -- Aluminum surfaces should be prepared as in [Section 5.4.4](#). The same procedures are used as in bonding concrete to steel. It should be noted, however, that aluminum is susceptible to attack by the alkalis of concrete, as well as by calcium chloride if it is present. Such attack can be prevented in most circumstances by insuring a pinhole-free film on the aluminum surface. Two coats should first be applied to the aluminum and allowed to set before applying the coat that bonds it to the concrete. The second and third coatings should be applied while the previous one is still tacky. Uncoated aluminum must never be allowed to come into contact with reinforcing steel in concrete, because it sets up a galvanic couple that results in corrosion of metal followed by fracture of the concrete.

7.2.12 Bonding concrete to other metals -- Other metals to be bonded to concrete should be prepared as in [Section 5.4.4](#). Precautions should be taken to prevent galvanic couples ([Section 7.2.11](#)). Epoxy should be applied intimately to the surface. Fresh concrete, or hardened concrete with a freshly applied epoxy coating, should be brought into contact with the prepared surface while the epoxy is still tacky. An example of bonding concrete to metal is shown in [Fig. 7.6](#).

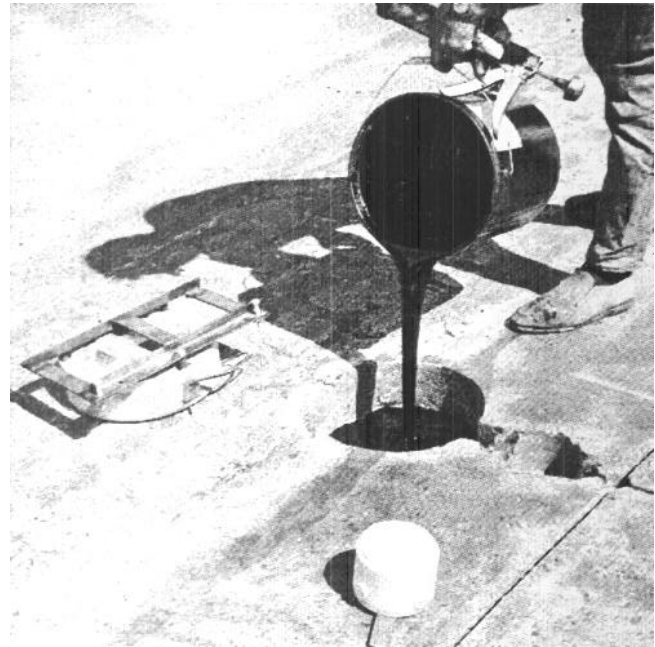


Fig. 7.6 -- Embedment of center line lighting in runway. Holes were cored, mixed epoxy poured therein and the light and junction boxes set and grouted (courtesy Adhesives Engineering)

7.2.13 Bonding concrete to wood -- For surface preparation, see [Section 5.4.5](#). The epoxy should be applied to both the wood surface and the concrete surface if the wood is to be bonded to hardened concrete. If it is to be bonded to fresh concrete, the epoxy should be applied to the wood surface. The wood should be protected against absorption of moisture during the concreting operation so that no dimensional changes will occur in it at this time. Because of high volume changes on alternate cycles of wetting and drying some woods are not suitable for bonding to concrete.

7.2.14 Bonding concrete to plastics -- Bonding concrete to plastics presents special problems. Tests should be made to determine how bond can best be obtained, and consultations held with the manufacturers.

7.3 -- Underwater applications

With most formulations bonding can be achieved best under dry conditions. When dewatering and surface drying of the concrete is not possible, special epoxies should be chosen. Some can be applied directly to surfaces while they are underwater. Preparation should include trial applications by the user and subsequent testing of bond results since application techniques are critical in most cases.

CHAPTER 8 -- HARDENING

8.1 -- Rate of hardening

8.1.1 -- Epoxy compounds are available with a wide range of hardening rates, varying from a few minutes to

several weeks. For use with portland cement concrete, the six following classes of epoxy compounds are designated in ASTM C 881.

Type I through V

- Class A: For use below 40 F (4.5 C)
- Class B: For use between 40 and 60 F (4.5 to 16 C)
- Class c: For use above 60 F (16 C)

Types VI and VII

- Class D: For use between 40 and 65 F (4.5 and 18 C)
- Class E: For use between 60 and 80 F (15.5 and 26.5 C)
- Class F: For use between 75 and 90 F (24.0 and 32.0 C)

The temperatures indicated for each class refer to the temperature of the concrete substrate. The use of these materials outside the designated temperature range is discussed in [Section 8.2](#).

8.1.2 -- The most important factors influencing the rate of hardening, other than the composition of the compound, are temperature of the concrete substrate, the air temperature, and the temperature attained by the mixed compound. As soon as the epoxy resin and hardener are mixed together the hardening reaction begins. If the mixture is allowed to remain in a mass, the heat of reaction cannot escape and, consequently, the temperature of the mass increases, accelerating the reaction. As soon as the epoxy compound has been spread, it rapidly acquires the temperature of the surface onto which it was spread and

is greatly influenced by the temperature of the air to which it is exposed.

8.13 -- To obtain the desired rate of reaction, it is important first to select the proper class of compound; second, to adequately mix the compound, while maintaining a minimum thickness of material by proper selection of a mixing container; third, to spread the mixed compound on a surface having a temperature within the desired range; and finally, to expose to air temperatures within the desired range.

8.2 -- Adjusting the hardening rate

8.2.1 -- Natural environmental conditions will not always be such that the concrete surfaces (to a depth of about 3 in. or 7.5 mm) and the air and epoxy temperatures are within the optimum range for the application. Preheating or cooling the surface to a satisfactory temperature, preheating or cooling the epoxy compound constituents before mixing, or both will then be necessary. Preheating the epoxy compound will increase its hardening rate thereby shortening the period available for application. Excessive preheating may shorten the application period to the extent that proper application cannot be accomplished thereby resulting in poor bond. Precooling the epoxy compound will increase its viscosity consistent with the amount of temperature reduction. The more viscous the material, the more difficult it is to properly apply. Excessive precooling can increase the viscosity to the extent that the mixed epoxy compound cannot completely wet the surface thereby resulting in poor bond. The formulator's recommended temperature range for mixing the epoxy compound should be followed for all field applications.

8.2.2 Acceleration of hardening rate -- An accelerated hardening rate will be needed when the concrete surface and air temperatures are unavoidably below the proper temperature range for the class of epoxy compounds chosen for the project. Many methods and combinations of methods can be devised, but most are impractical for large areas over thick concrete. The following are methods used for accelerating the hardening rate:

8.2.2.1 Infrared heaters to preheat the concrete surface and also to heat the epoxy compound after it is spread,

8.2.2.2 An inclosure heated by circulating warm air,

8.2.2.3 Clear polyethylene film placed over the completed job,

8.2.2.4 Heated aggregate mixed with the prepared compound in producing epoxy mortar or concrete.

In any event, uniform heating [not over 125 F (51 C)] is essential, and direct flame heating is prohibited.

8.2.3 Deceleration of hardening rate -- A decelerated hardening rate is needed when the concrete surface and air temperatures are inadvertently above the proper temperature range for the class of epoxy compounds chosen for the project. The following methods have been used to decelerate the hardening rate:

8.2.3.1 Protection of the application area from

direct sunlight prior to, during, and after application of the mixed compound.

8.2.3.2 Use of ice bath to lower the temperature of the components before mixing.

8.2.3.3 Rapid spreading of the mixed compound in a thin film.

8.3 -- Opening the job to service

The strength requirements of the epoxy compound will differ with each end use. In many instances, the surface of the cured epoxy compound is not accessible for evaluation of the degree of hardness and strength attained. Therefore, it is necessary to rely on the supervisor's judgment and experience and on the manufacturer's data as to the anticipated strength. For some purposes, it is necessary for the epoxy compound to achieve almost full strength before opening the project to service, and the time required might be only a few hours at summer temperatures.

CHAPTER 9 -- HANDLING PRECAUTIONS

9.1 -- General hazards

9.1.1 -- Just as there are proper, safe practices for handling lime, acid, portland cement, etc., there are also precautions which should be observed when handling epoxy resins and materials used with them.

9.1.2 -- A number of different basic epoxy resins can be combined with an even greater number of curing agents, flexibilizers, fillers and other chemicals to produce several hundred different end products with various combinations of their unique properties. This versatility, which makes the epoxies so useful, also contributes to handling problems for the user (and, indeed, the manufacturers) of epoxy products. On the one hand, a few epoxy formulations are nonhazardous; on the other hand, there are a few formulations which are extremely hazardous; and in between are compounds with varying degrees of hazard.

9.1.3 -- Two typical health problems which may be encountered when epoxy materials are carelessly handled are:

9.1.3.1 Skin irritation, such as burns, rashes, and itches.

9.1.3.2 Skin sensitization, which is an allergic reaction similar to that caused in certain people by wool, strawberries, poison ivy, or other allergens.

9.1.4 -- It should be noted that sensitization reactions may sometimes occur immediately, but at other times they occur only after long periods of continual exposure. Workers should be aware of the possibility of delayed sensitization and not assume that they are immune.

9.1.5 -- The variety of the epoxy compounds marketed today make it essential that the labels and Material Safety Data (MSDS) sheets be read and understood by those people working with the products. Code of Federal Regulations (CFR) 16, Part 1500 regulates the labeling

of hazardous substances including epoxy compounds.

ANSI standards: ANSI Z 129.1 and ANSI K 68.1 provide further guidance regarding classification and precautions.

9.1.6 -- Many epoxy resin formulations are classified as “corrosive” or “flammable” in 49 CFR Transportation Subchapter C “Hazardous Materials Regulations.” Packaging, labeling, and shipping for such materials is controlled by 49 CFR Transportation.

9.2 -- Safe handling

Safe handling of epoxy materials can be accomplished by:

9.2.1 -- Working in a well-ventilated area. As with most chemicals, materials should be stored below eye level.

9.2.2 -- Disposable suits and gloves, available from many suppliers of work garments, are suitable for this use. Gloves should be tested for resistance to resins and solvents. Disposable rubber or plastic gloves are recommended and should be discarded after each use. Gloves should be tested for resistance to resins and solvents. Cotton gloves, if used, should never be reused if they have become soiled with epoxy compounds.

9.2.3 -- Careful attention to personal cleanliness and protection. Safety eye-glasses or goggles are strongly recommended both when handling epoxy compounds and acids. Involuntary habits such as face scratching or eyeglass adjustment should be avoided. For similar reasons, handling important tools, eating or smoking should not be done until the individual has washed up. When wearing soiled gloves, the workers should avoid touching door handles and other equipment which may subsequently be touched by a person not wearing gloves.

9.2.4 Federal regulations -- CFR 29, Part 1910 (OSHA Standards) regulate handling of hazardous substances including epoxy compounds.

9.3 -- What to do in case of direct contact

9.3.1 To the clothing -- Remove soiled clothing at once and change to clean garments. If the soiled garment cannot be thoroughly cleaned, it should be destroyed.

9.3.2 To the body -- Shower immediately with soap and water to remove spilled epoxy compounds from the body. Avoid contact with the genital areas until after the hands are carefully cleaned of all epoxy.

9.3.3 To the eyes -- Flush out with large amounts of water for at least 15 min, followed by immediate medical attention. (Safety goggles will usually prevent getting chemicals into eyes.)

9.3.4 Other places -- Do not use solvents other than soap and water or water soluble proprietary cleaners. Most solvents merely dilute the epoxy compounds, aiding them in penetrating the skin. At the same time, solvents tend to dry out the skin and any subsequent exposure is more likely to cause problems.

9.4 -- Use of solvents

9.4.1 General -- The epoxy compounds considered for

concrete applications are usually solvent free. However, solvents may be used as a convenience for cleanup of equipment and areas on which epoxies might be spilled. The solvents used will require additional precautions depending on the characteristics of the type used. It is generally true that solvents should not be used to remove epoxy products from the skin. They tend to dry the skin and may themselves cause dermatitis. Additionally, they dissolve the epoxy compound and carry it into more intimate contact with the skin, thus aggravating the dermatitic problems which already exist due to skin contact with the epoxy compound. The following hazards might be encountered in the use of solvents and should be taken into consideration. It may be emphasized that when using a solvent, the combined hazards of both the solvent and the epoxy compound are encountered.

9.4.1.1 Flammability and explosion hazard -- Many solvents having low flash points are not recommended and should be avoided. Cleaning solvents such as ketones are red label materials and present a fire hazard. If used, adequate ventilation should be provided, equipment should be grounded and smoking or other fire initiating devices should be barred from the area of use. The chlorinated solvents, while not representing a fire hazard, will present a toxicological problem if a person smokes in their presence or if a fire occurs in the immediate area.

9.4.1.2 Vapor hazard -- Most solvents have some degree of volatility and the vapors can be toxic when inhaled. Avoid using solvents which may be harmful.

9.4.1.3 Contact hazard -- Some cleanup solutions contain phenols or other very aggressive chemicals which can cause burns or other serious effects when contacting any part of the body directly or indirectly. Use such materials with great care following the recommendations of the supplier.

9.4.1.4 Dispose of spent solvents in accordance with local and federal regulations.

9.5 -- Education of personnel

No amount of equipment will substitute for worker education. Those involved in using epoxy materials should be thoroughly informed of the characteristics and hazards of the particular materials they must handle. Not only label instructions but also the manufacturer's literature and MSDS sheets should be reviewed and pertinent information passed on to each worker. The handling of epoxy materials is not a dangerous occupation as long as reasonable care is taken and personnel and equipment are kept clean. Instances of sensitization are rare but the possibility of a burn, a damaged eye, or other loss-of-time accidents makes knowledge and observance of safe handling practices absolutely essential. A sensitized person must not be allowed to continue working with epoxy materials.

APPENDIX A -- TEST METHODS

A.1 -- Field test for surface soundness and adhesion

A.1.1 -- Clean a portion of the area to which the epoxy compound is to be applied according to prescribed cleaning methods. The area selected for testing should represent the worst of surface conditions within the area to be repaired. The test area should be large enough so that the cleaning equipment and methods of cleaning to be employed in full scale operation may be used. This avoids the possibility of attaining a degree of cleanliness in a small test area which could not be matched later with the equipment to be used on a continuing basis. The surface must be thoroughly dry before undertaking Step A.1.2.

A.1.2 -- Mix materials and apply a test patch according to applicable procedures of [Chapters 6 and 7](#) using the epoxy compound to be used in the work. The test patch should cover enough of the surface to include all the typical surface conditions found in the larger areas to be covered. For example, in a warehouse subjected to considerable forklift truck traffic, the test patch should span a line to include the wheel tracks where applied load and wear are most severe, and the center areas where deposition of oil and traffic soil is heaviest.

A.1.3 -- After the test patch has hardened, core drill through the coating and down barely into the subsurface by means of an electric drill fitted with a carbide-tipped or diamond core bit ([Fig. A.1](#)). The core bit should be of such size as to produce a cored disc 2 in. (5 cm) in diameter which will have the appearance of a small island of coated material ([Fig. A.2](#)).

A.1.4 -- Bond a standard 1½ in. (3.7 cm) diameter pipe cap, the bottom surface of which has been machined smooth and shoulder-cut to provide a 2 in. (5 cm) diameter surface ([Fig. A.3](#)), to the cored disc using nearly any commercially available room temperature rapid curing epoxy compound adhesive. Mix the epoxy components according to the supplier's recommendations just

prior to use. A 2 oz (50 gm) portion of this material should have a working life of 20-25 min at 70-90 F (20-32 C). Apply a small amount of the mixed adhesive to the cored disc and to the bonding face of the pipe cap by spatula. Where desired, the bonding face may be heated to facilitate spreading of the adhesive. However, the cored disc should never be heated directly. Place the pipe cap on the cored disc. Direct a flame from a small gasoline blow-torch (an electric heat lamp or a portable gas radiant heater may be used as alternatives) into the interior of the pipe cap in such a way that no direct heat reaches the cored disc or the pavement bond line, and heat the pipe cap to about 160 F (70 C). (This temperature can readily be checked with a surface pyrometer.) Under these conditions the adhesive should harden in less than 1 minute. The bonded cap will be ready for testing as soon as it has cooled to air temperature.

A.1.5 -- After cooling the pipe cap and core, test the core by applying tension to it using a testing device similar to the one shown in [Fig. A.4](#) and [A.5](#). To prepare the testing device, screw the lower hook into the threaded pipe cap and attach to the loop on the lower portion of a Dillon dynamometer. Screw the upper hook, which has a threaded shaft, into the loading arm at the top of the rig, and attach to the loop on the upper portion of the dynamometer. When force is applied, the axis of the dynamometer must coincide with the axis of the pipe cap extended. Rotate the loading arm so that the threaded shaft and its connections are lifted, placing the pipe cap (and core) in tension. Tensile load should be applied at the approximate rate of 100 lb (45 kg) every 5 sec. The tensile load is indicated on the dynamometer gage. Record the load at which the pipe cap and connected core is separated from the concrete surface and convert to unit stress. Note the type of failure of which there are three possibilities or combinations thereof:

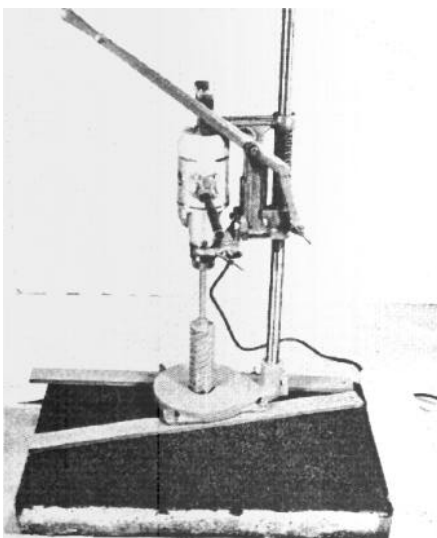


Fig. A.1 -- Portable carbide-tipped core drill in position for drilling

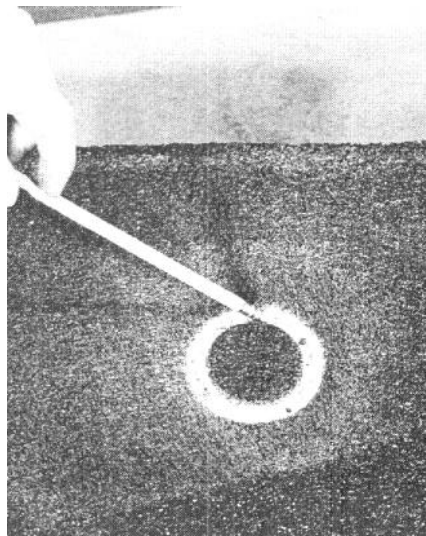


Fig. A.2 -- Cored disc after drilling and ready for the attachment of the pipe cap

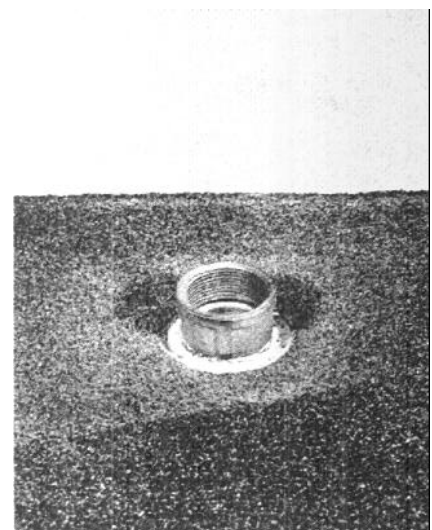


Fig. A.3 -- Machine faced pipe cap bonded to cored disc with epoxy compound

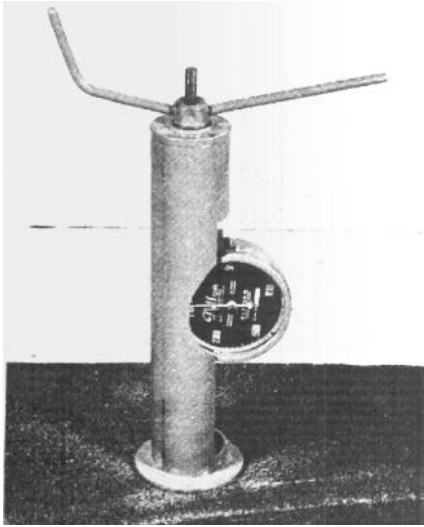


Fig. A.4 -- Mechanical testing device for pulling bonded pipe cap in tension

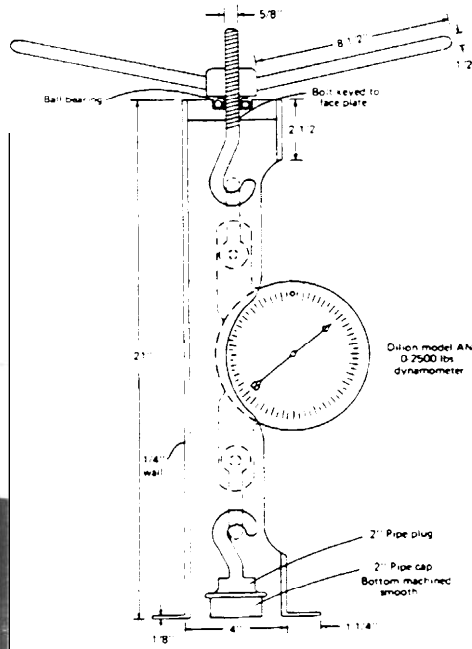


Fig. A.5 -- Functional sketch of mechanical testing device

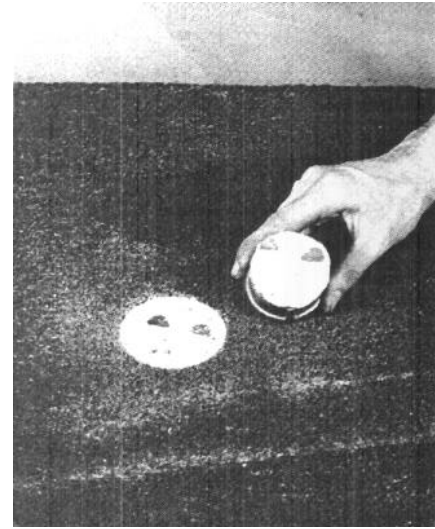


Fig. A.6 -- Typical failure in concrete; dark spots on cap and in aggregate indicate split aggregate

- a) Failure in the concrete (cohesive concrete failure)
- b) Separation of the epoxy compound from the concrete surface (adhesive failure)
- c) Failure in the epoxy compound (cohesive resin failure)

Record the percent of each type of failure along with the load required to bring about the failure. A properly formulated epoxy compound applied to a properly prepared surface should result in a concrete failure as shown in Fig. A.6. When the pipe cap and core have been separated from the surface, the hole created by the test can easily be repaired using either an epoxy resin compound or the remaining epoxy adhesive if there is a surplus. When the strength of a concrete surface is to be tested alone, Steps A1.1 through A1.3 may be eliminated, except that a small area must be cleaned for bonding the pipe cap directly to the concrete surface. Tests should be performed in several areas which represent the worst conditions, and which give a statistical estimate of results to be expected.

A.2 -- Simplified field test for surface soundness

A.2.1 -- If this test is being employed to ascertain the need for surface preparation and detecting relative differences in potential surface strength over an area to be repaired, skip to Steps, A.2.2 and A.2.3. If the test is employed to ascertain adequacy of surface preparation, clean the area, or portions thereof if a large area, according to the prescribed cleaning methods. Portions of large areas to be test cleaned should be sufficient in number to be representative of the total area and each

portion should be large enough so that the cleaning equipment intended for the full scale application can be used in a standard cleaning operation. Provision should be made for conducting the test at the rate of at least one test per 100 ft² (9.3 m²) of area to be repaired. The surface to be tested must be dry before proceeding with Step A.2.2.

A.2.2 -- Cut 1 in. lengths of 1 in. aluminum T-section to provide a one in². bonding surface at the bottom of the flange. Drill a hole in the stem of each T-section for subsequent attachment of the testing device. Thoroughly clean the aluminum surface by abrading with crocus or emery cloth being careful to water wash and dry before using. Bond the aluminum T-section to the concrete surface using a fast setting epoxy compound mixed just prior to its use in accordance with the supplier's recommendations. This is accomplished by applying a small quantity of the epoxy compound to the concrete surface followed immediately by working the T-section into the epoxy in a manner to establish thorough contact between the epoxy, the concrete and the aluminum T-section. Upon completion of this operation, score around the perimeter of the T-section to remove excess epoxy which has squeezed out so that the bonded area will be the desired one square inch.

A.2.3 -- The following day, or as soon as the epoxy has set, attach a testing device similar to the one shown in Fig. A.7 to the aluminum T-section or the mechanical device described in Step A.1.5. Apply tension at an uninterrupted, uniform rate. The tensile load is indicated on the dynamometer gage. Record the load at which each T-section is separated from the concrete surface and express it as unit stress. Note the type of failure, as in Step A.1.5.

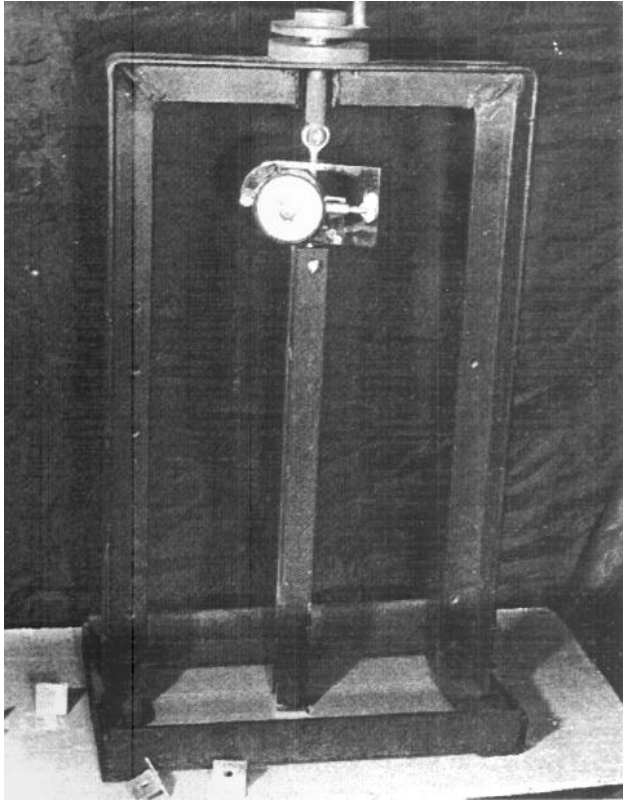


Fig A.7 -- Tension frame for pulling T-sections bonded to a surface (courtesy George W. Whitesides Co., Inc.)

APPENDIX B -- TERMINOLOGY

Ambient: Usually used to describe temperature; meaning the same as the surroundings. Ambient usually, but not always, implies a temperature that is in the range of 60 to 90 F (15 to 32 C).

Broadcast: To toss granular material, such as sand over a horizontal surface so that a thin, uniform layer is obtained.

Delamination: Loss of adhesion and separation between coatings or between a coating and its substrate.

Diluent: A liquid ether which lowers the viscosity of epoxy formulations and which reacts chemically with them.

Epoxy concrete: A combination of epoxy resin and fine and coarse aggregate in a consistency similar to portland cement concrete.

Epoxy grout: A fluid epoxy compound used to fill cracks, set dowels, etc., in a manner similar to conventional grout.

Epoxy mortar: See resin mortar.

Extender: A nonreacting liquid substance added to epoxy compounds to extend pot life, increase flexibility, and lower the cost.

Flexibilizer: A substance which will react with epoxy compounds to impart flexibility.

Filler: A finely divided material, such as mica or talc, incorporated in an epoxy formulation to increase the hardness and lower the cost.

Hardener: A substance formulated so that when mixed with an epoxy resin it will cause the epoxy to solidify and harden.

Ionic: An adjective used to describe substances that dissolve to form ions. Upon dissolving, each molecule of the ionic substance splits into two or more ions. The ions always carry an electrical charge, either positive or negative. The positive and negative charges are always equal, so that the overall electrical charge is neutral.

Mil: One-thousandth of an inch.

Non-ionic: An adjective used to describe substances that dissolve without formation of ions. (See ionic)

Non-polar: Used to describe molecules characterized by a uniform distribution of electrons so that there is essentially no electrical charge, separation in the molecule. (see semi-polar)

Overlay: To apply a mortar to sufficient thickness, usually $\frac{1}{4}$ in. (6 mm) or more, to form a new surface. (see semi-polar)

Pot life: The period of time during which the epoxy compound is in a suitable condition for use,

Resin mortar: A combination of epoxy resin and fine aggregate in a consistency suitable for troweling.

Rout: To deepen and widen a crack to prepare it for patching or sealing.

Semi-polar: An adjective used to describe molecules that are intermediate between non-polar and polar types. Non-polar molecules are characterized by a uniform distribution of electrons such that there is essentially no electrical charge separation in the molecule. Polar molecules are characterized by a nonuniform distribution of electrons such that there is a difference in electrical potential from one end of the molecule to the other. Polar molecules tend to have higher solvent strength than non-polar molecules.

Stripper: A liquid compound formulated to remove coatings by chemical and/or solvent action.

Substrate: The uncoated surface upon which a coating is applied.

Thermoplastic plastic: A plastic that generally does not require curing agents and can be dissolved in a solvent or melted without permanent chemical change.

Thermosetting plastic: A plastic that, once cured, cannot be melted or dissolved in a solvent without undergoing drastic chemical change.