Guide for Polymer Concrete Overlays

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This guide provides an overview of thin (less than 1 in. thick) polymer concrete (PC) overlays for concrete and steel substrates. Emphasis is placed on their use in the transportation sector, specifically for bridge decks and parking garages. Surface preparation, application, evaluation, maintenance, and safety aspects are included.

Keywords: application; bonding; bridge decks; epoxies; maintenance; methacrylates; overlays; parking garage decks; permeability; polyesters; polymer concrete; polyurethanes; resurfacing; skid resistance; surface preparation.

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CHAPTER 1-INTRODUCTION

1.1-General

Today’s environment is becoming increasingly hostile to reinforced concrete, steel grid, and steel decks from exposure to deicing salts, and environmental factors such as acid rain and pollution chemicals. Escalating costs of renovation and replacement for bridges and parking structures have promoted such construction and maintenance options as high-density concrete overlays, latex-modified concrete overlays, membrane/asphalt systems, cathodic-protection systems, epoxy-coated reinforcing bars, and thin polymer concrete (PC) overlays.

Each option has advantages and disadvantages that should be carefully analyzed before a choice is made. Costs vary by region with the availability of materials and experienced contractors. In addition, the life expectancies of these systems are different and in many cases not fully known.

Although designed for a definite service life, bridges and parking decks contain structural elements that are susceptible to premature failures due to exposure and to wear from high traffic volumes. Improved maintenance costs and the limited downtime available for repairs make PC overlays an attractive solution.

1.1.1 Advantages-Compared to other overlay systems, PC overlays can be cost effective. Rapid cure characteristics minimize disruptions and traffic control costs, and ease the inconvenience of repair scheduling. With typical dead load increases of 2 to 6 lb/ft² (10 to 30 kg/m²), their use results in relatively greater live load capacity than conventional systems, a critical factor for aging structures. At application thicknesses of up to 3/8 in. (9.5 mm), PC overlays do not require modification of expansion dams or drainage gratings. They are highly impermeable and exhibit better chloride resistance than other concrete overlays, offering a nonskid wearing surface in addition to both concrete and steel protection (Carter 1990; Krauss 1988; and Sprinkel 1989).

Lastly, PC overlays can be installed without expensive equipment. However, technical expertise is required. Maintaining quality control is important, and surface preparation is a job aspect that requires close attention.

1.1.2 Disadvantages-A disadvantage associated with PC overlays is that they must be applied to dry surfaces. The workability and curing rate of PC overlays are dependent on application temperature.

1.2-History of PC overlays

PC overlays date back to the 1950s, with original systems consisting of a single layer of coal tar epoxy broomed over the substrate and seeded with fine aggregate. These overlays were relatively porous and did not stand up well to heavy traffic. In the early 1960s, a light-colored, oil-extended epoxy came into use in an attempt to improve waterproofing capability.

By the mid 1960s, broom-and-seed polyester resins and methyl methacrylate overlays were introduced. The first premixed and screeded polymer and aggregate systems also appeared at this time. Thicker, more brittle layers were used, frequently debonding due to thermal incompatibility with the concrete substrate. Through trial and error, resin formulations have been modified to provide better thermal compatibility and improved physical properties. Resistance to chemical and mechanical attack and performance under adverse installation conditions have also been the subject of extensive development.

Polymer overlays have become successful, although some problems still exist. Many of these problems are the result of improper application techniques, often due to a lack of understanding of polymer materials.

There has been some improvement in PC materials and technology in recent years. PC overlays are now generally specified with flexible resins and wear-resistant aggregates. Workmanship and inspection techniques have also improved, as an understanding of the causes and prevention of PC overlay defects continues to increase at a rapid rate.

1.3-Scope

This guide is intended to aid in the proper selection and use of PC overlays for structures in the transportation industry, focusing primarily on bridge and parking garage decks. Materials discussed are epoxies, polyesters, methacrylates, and polyurethanes, for application on either concrete or steel surfaces.

In general, these overlays are used for the protection of the underlying substrate and are designed to be flexible, waterproof, etc. Although similar polymeric materials are used in PCs for patching and repairs, overlays are formulated with greater resiliency and stress-relieving characteristics. Such characteristics are necessary to withstand breakdown from repeated freeze-thaw cycles.
These are, therefore, a distinctly different class of materials and should be treated as such.

In addition to describing the characteristics of PC overlays, this guide includes chapters on surface preparation, application, evaluation, maintenance, and safety. The information should allow the reader to select materials for a given application, and may serve as the basis for the preparation of overlay specifications.

1.4-Glossary

AAHSTO-American Association of State Highway and Transportation Officials.

A/B component-The individual parts of a polymer binder system. The components typically consist of (a) promoted resin and (b) curing agent/hardener.


AWWA-American Water Works Association.

Binders-Materials such as asphalt, resins, and other materials forming the matrix of concretes, mortars, and sanded grouts (ACI 116R).

Bond strength-The ability of a PC to adhere to its substrate. Bond strengths of PCs depend on the adhesion and cohesion properties of their respective binders and primers. Minimum acceptable bond strengths for PC overlay systems should be equal to or greater than the shear strength of the substrate.

Broom and seed-The method of PC application in which alternate layers of resin and aggregate are built up to form an overlay. In the simplest form of application, the resin is distributed onto the deck with brooms immediately followed by the broadcasting or seeding of aggregate.

Catalyst-A substance that markedly speeds up the curing of a binder when added in minor quantity as compared to the amounts of primary reactants (ASTM D 907).


Coefficient of thermal expansion-Change in linear dimension per unit length, or change in volume per unit volume, per degree of temperature change (ACI 116R).

Compressive strength-The measured maximum resistance of a concrete or mortar specimen to axial loading; expressed as force per unit cross-sectional area (ACI 116R).

Crazing-The formation of small crack-like cavities in a material running perpendicular to the direction of stressing in the polymer (Alger 1989).

Creep-Time-dependent deformation due to sustained load (ACI 116R).

Cross-linking-The joining of preformed linear polymer chains to each other to form three-dimensional networks.

Cross-linking agent-Bifunctional or polyfunctional monomer or polymer whose addition to a polymer system increases the rigidity, the resistance to solvents, and the softening point of the polymer (ACI 503.5R).

Cure time-The interval after mixing in which a PC system gains adequate strength for fast and/or vehicular traffic; see also Curing, Working Life.

Curing-The change in properties of a chemical by an increase in molecular weight via polymerization or cross-linking, usually accomplished by the action of heat, catalyst, cross-linking agent, curing agent, or any combination, with or without pressure (ACI 503.5R).

Curing agent--See Hardener.

Dermatitis-Inflammation of the skin (Webster’s 1973).

Epoxy resin-A condensation product of bisphenol A and epichlorohydrin, terminated by at least two highly reactive epoxy groups, from which they derive their name.

FHWA-Federal Highway Administration, U.S. Department of Transportation.

Filler-Finely divided inert material such as pulverized limestone, silica, or colloidal substances sometimes added to portland cement, paint, or other materials to reduce shrinkage, improve workability, or act as an extender (ACI 116R).

Flammable liquid--Any liquid having a flash point below 100 F (38 C) (49 CFR*173.115).

Flash point-The minimum temperature at which a liquid gives off vapor within a test vessel in sufficient concentration to form an ignitable mixture with air near the surface of the liquid.

Flexural strength-A property of a material or structural member that indicates its ability to resist failure in bending (ACI 116R).

HMWM (high-molecular-weight-methacrylate)-A low-viscosity substituted methacrylate monomer that is characterized by low volatility.

Hardener-The chemical component that causes the resin to cure (ACI 116R).

Impermeable-Not permitting passage, as of a fluid, through its substance (Webster’s 1973). See Permeability, Permeance.

Initiator-A substance capable of causing the polymerization of a monomer by a chain reaction mechanism (ACI 503.5R); often incorrectly called a catalyst (ACI 548R).

Laitance-A layer of weak and nondurable material containing cement and fines from aggregates brought by bleeding water to the top of overwet concrete, the amount of which is generally increased by overworking or overmanipulating concrete at the surface by improper finishing or by job traffic (ACI 116R).

Methacrylate-One of a group of resins formed by polymerizing the esters or amides of acrylic acids (ACI 503.5R).

Methyl methacrylate-A colorless, volatile liquid derived from acetone cyanohydrin, methanol, and dilute sulfuric acid.

MSHA-Mine, Safety & Health Administration.

MSDS-Material Safety Data Sheet.

Modulus of elasticity-The ratio of normal stress to...
corresponding strain for tensile or compressive stresses below the proportional limit of the material; referred to as “elastic modulus of elasticity,” “Young’s modulus,” and “Young’s modulus of elasticity,” denoted by the symbol E (ACI 116R). A low modulus generally indicates a higher elongation but lower strength than a high modulus.

Mohs scale-A relative scale of the hardness of minerals, arbitrarily reading from 1 to 10 (Mottara, Crespi, and Liborio 1978).

Monomer-An organic liquid of relatively low molecular weight that creates a solid polymer by reacting with itself or other compounds of low molecular weight or both (ACI 116R).

NACE--National Association of Corrosion Engineers.

NIOSH--National Institute for Occupational Safety and Health.

OSHA--Occupational Safety and Health Administration.

Organic peroxides--Sources of free radicals used as 1) initiators for free radical polymerization and/or copolymerization of vinyl and diene monomers; 2) curing agents for thermoset resins; and 3) cross-linking agents for elastomers (Kamath 1967).

Permeability-The arithmetic product of permeance and thickness (ASTM E 96).

Permeance-The time rate of water vapor transmission through unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions (ASTM E 96).

Plasticizer-A substance or a material incorporated into a plastic or elastomer to increase its flexibility, workability, or distensibility.

Polishing-The excessive abrasion of wearing course aggregates due to traffic loads and the environment.

Polyester-One of a group of resins, mainly produced by reaction of unsaturated dibasic acids with dihydroxy alcohols; commonly dissolved in a vinyl group monomer such as styrene (ACI 548R).

Polymer--The product of polymerization; more commonly a rubber or resin consisting of large molecules formed by polymerization (ACI 548R).

Polymer concrete (PC)--Polymer concrete is a composite material in which the fine and coarse aggregates are bound together in a dense matrix with a polymer binder (ACI 548R).

Polymer mortar (PM)--Polymer mortar is a composite material of fine aggregates bound together by an organic polymer.

Polyurethane-Reaction product of an isocyanate with any of a wide variety of other components containing an active hydrogen group (ACI 503R).

Portland cement concrete (PCC)--A composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate; the binder is a mixture of portland cement and water (ACI 116R).

Pot life-Time interval after preparation during which a liquid or plastic mixture is usable (ASTM D 907).

Premix system-Aggregates and binder are combined or mixed together before placement of the system.

Prepolymer--A polymer, often of low molecular weight, i.e., a few hundred or thousand, which is subsequently to be converted to a higher molecular weight polymer (Alger 1989).

Promoters--Often called accelerators, promoters are reducing agent compounds added to the monomer system to cause the decomposition of the peroxide initiators in the system (ACI 548R).

Reflective cracking-The phenomenon where cracks form in the overlay directly over existing cracks in the substrate.

Resin--Certain liquid prepolymer products, such as unsaturated polyester and epoxy prepolymers, which are subsequently cross-linked to form hardened polymer (Alger 1989).

Rutting--The formation of a depression in the overlay due to the excessive loading and abrasive wearing action of traffic.

Scarification--Scarification is the process of scratching, cutting, or chipping the substrate surface for the purpose of cleaning and texturing it.

Schmidt hammer--A device used to measure the “rebound number” of concrete, which is an indicator of the concrete properties (ACI 228.1R).

Sensitization--The act, process, or result of sensitizing or making sensitive.

Skid resistance--A measure of the frictional characteristics of a surface (ACI 116R).

Skinning--In PC, the loss of patches of material from the top surface of the overlay, usually associated with overworking it.

SSPC--Steel Structures Painting Council, 4516 Henry Street, Suite 301, Pittsburg, PA, 15213-3728. Specifies preparation and painting for steel in their Steel Structures Painting Manual, V. 2, Systems and Specifications, SSPC No. 5.

Substrate--The material surface on which a PC overlay is placed.

Surface failure--In PC, the loss of top surface aggregates from the polymer binder.

Surface seeding--The application of aggregate to the freshly applied PC overlay to provide intercoat adhesion or to act as the wearing course.

Surface timing--The scoring or grooving of the PC overlay to provide for drainage and/or additional skid resistance.

Tensile strength--Maximum unit stress that a material is capable of resisting under axial tensile loading; based on the cross-sectional area of the specimen before loading (ACI 116R).

Thermal compatibility--The ability of a PC to withstand thermally induced stresses and strains without debonding from a substrate (ASTM C 884).

Ultraviolet (UVI) light--Invisible light having a wave length between 290 and 400 mm (Winter and Shing 2011).


CHAPTER 2-POLYMER BINDERS

2.1-General

Polymer concrete (PC) is a class of composite materials which includes a broad group of organically bound mortars and concretes, each with its own distinctive properties. Familiarity with the properties of each group is essential to understanding PCs.

The resins used as binders for the formulation of PCs are monomers or polymer/monomer solutions that are mixed at the time of application with their respective curing agents. Selected, graded aggregates are used as the filler component. The cured polymer serves as the binder for the aggregate particles in the same manner that portland cement acts to bind conventional concrete together.

The polymer families most commonly used for the preparation of PC overlays are epoxies, polyesters, methacrylates, and polyurethanes.

The chemical compositions of each of these polymer binders are distinctly different, and the PCs they form have varying properties. While more than one system may be used for most applications, some systems are more suitable for specific conditions.

2.2-Properties of polymer binders

Polymer binders are classified by both uncured and cured properties that are measured in the laboratory according to industry standards. The nature of these properties and their relationship to the performance of the PCs are described as follows.

2.2.1 Uncured properties--The uncured properties of polymer binders are related to their handling characteristics. In addition to methods of application, environmental conditions may dictate the use of selected systems.

Polymer binders may be distinguished by the viscosities of the individual or mixed components. These values may range from 1 to 10,000 cps (1 to 10,000 \( \times 10^{-3} \) Pa \( \cdot \) s). In comparison, the viscosity of water is near 1 cps (1 \( \times 10^{-3} \) Pa \( \cdot \) s); 200 to 500 cps (200 to 500 \( \times 10^{-3} \) Pa \( \cdot \) s) may represent the consistency of light motor oil, over 100,000 cps (100,000 \( \times 10^{-3} \) Pa \( \cdot \) s) would be typical of molasses. Binder resins with a low initial viscosity are suitable for highly filled PCs prepared by the “premix” method. Higher viscosities may be required for “broom-and-seed” methods of application, where the proper coating of aggregates and reduction of binder “runoff” must be insured.

The working life of the binder is dependent upon the amount mixed, its temperature, and the ambient temperature. As more material is mixed in bulk, or as the ambient temperature increases, the working life is reduced. Working life of the catalyzed binder can be determined by observing a sample weighing of 2 to 4 oz (approximately 50 to 100 g), in a container until it begins to solidify. The time recorded does not describe the exact working life of the aggregate-filled PC, which should be determined separately. It is useful, however, in that it is related to the reactivity of the resin and is indicative of the time required to cure.

Resins and their curing agents may be toxic before cure. Toxicity potential varies widely from one system to another, even within the same polymer family. Contact may result in simple allergic reactions such as dermatitis, which generally disappears when the affected individual stops handling the material. Unprotected exposure could lead to more serious hazards. It is for these reasons that toxicity information, handling precautions, and disposal procedures supplied by the manufacturer be understood and observed. In general, protective clothing, adequate ventilation, and cleanliness are necessary.

All resins will burn under certain conditions. Flammable components of a polymer system may ignite under high concentrations of vapor in air, especially when their flash points are within the range of temperatures found under ambient conditions.

Handling and safety of PC are covered in Chapter 8.

2.2.2 Cured properties-Properties of cured polymer binders contribute to the behavior of the PCs made from them and thus dictate their uses. Knowledge of properties of the binders such as compressive, tensile, and flexural strength are important in determining key characteristics not easily measured in the PC.

The bond strengths of polymer binders directly affect the bond of their corresponding PCs to various substrates. They are also important factors when these binder resins are used as primers prior to the application of an overlay system.

Bond strength depends upon the cleanliness, soundness, texture, and moisture content of the substrate, a fact to be kept in mind when considering the use of any polymer system. Methods of preparation, testing, and general precautions described in Chapter 3 should be carefully observed.

2.3-Epoxies

2.3.1 Description-Epoxy systems used as binders for
Table 2.3.2(a)-Typical uncured properties of epoxy binders for PC overlays

<table>
<thead>
<tr>
<th>Property</th>
<th>Value, U.S.</th>
<th>Value, SI</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond strength</td>
<td>Min. 1000 psi</td>
<td>Min. 7 MPa</td>
<td>ASTM C 882</td>
</tr>
<tr>
<td>Coefficient of thermal expansion</td>
<td>$3.5 \times 10^5$ in/in/deg F</td>
<td>$5.9 \times 10^5$ mm/mm/deg C</td>
<td>ASTM D 696</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>Min. 200 psi*</td>
<td>Min. 14 MPa</td>
<td>ASTM D 638</td>
</tr>
<tr>
<td>Modulus of elasticity, tensile &amp; compressive</td>
<td>0.6-1.2 $\times 10^5$ psi</td>
<td>4.83 $\times 10^5$ MPa</td>
<td>ASTM D 638</td>
</tr>
<tr>
<td>Curing shrinkage, Appendix</td>
<td>0.02 - 0.08 percent</td>
<td>0.02 - 0.08 percent</td>
<td>DuPont</td>
</tr>
</tbody>
</table>

* Tensile strengths lower than 2000 psi (14 MPa) may indicate improperly flexibilized binders.

* Follow the manufacturer’s safety instructions.

† Some epoxy systems may contain solvents and have lower flash points. They should not be used as binders for PC overlays.

Table 2.4.2(b)-Typical physical properties of cured polyester binders for PC overlays

<table>
<thead>
<tr>
<th>Property</th>
<th>Value, U.S.</th>
<th>Value, SI</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond strength</td>
<td>Min. 1000 psi</td>
<td>7 MPa</td>
<td>ASTM C 882</td>
</tr>
<tr>
<td>Coefficient of thermal expansion</td>
<td>$20-50 \times 10^5$ in/in/deg F</td>
<td>$36-90 \times 10^5$ mm/mm/deg C</td>
<td>ASTM D 696</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>Min. 2000 psi</td>
<td>14 MPa</td>
<td>ASTM D 638</td>
</tr>
<tr>
<td>Modulus of elasticity, tensile and compressive</td>
<td>3.5-9.0 $\times 10^4$ psi</td>
<td>24-6.2 $\times 10^2$ MPa</td>
<td>ASTM D 638</td>
</tr>
<tr>
<td>Curing shrinkage†</td>
<td>1-3 percent</td>
<td>1-3 percent</td>
<td>ASTM D 955</td>
</tr>
</tbody>
</table>

PC overlays are two-component systems, one component containing the epoxy resin and the second the curing or hardening agent. Because of their specific molecular structure, epoxy polymers develop strong bonds to Portland cement concrete, steel, and many other surfaces. Neither the uncured nor the cured binders are affected by the presence of alkalinity; therefore, they are particularly useful when applied to concrete. A variety of curing agents, plasticizers, and other additives affect the properties of the cured epoxy. These properties include mechanical properties, flexibility, creep resistance, rate of strength development, and the ability to cure and perform within a wide range of temperatures and moisture levels. Epoxy systems can be formulated to resist attack from a variety of chemicals such as acids, bases, solvents, fuels, and many others. They have very low curing shrinkage and flammability and can be formulated to cure under damp conditions, including underwater. This versatility results in the availability of many binders that represent a wide variety of properties suitable for bridge and parking garage deck overlays.

2.3.2 Epoxy properties

2.3.2.1 Fire resistance—After the incorporation of epoxy polymer binders with aggregate, the resulting PC falls within accepted fire ratings. If required, fire resistance can be increased by incorporating special additives with the binder and/or aggregates.

2.3.2.2 Chemical resistance—Epoxy binders are resistant to water, deicing chemicals, dilute acids, gasoline, and other petroleum products.

2.3.2.3 Weathering—PC overlays based on properly formulated epoxy binders show good resistance to weathering (Better Roads 1986).
2.3.3 Primers—Many currently used application methods do not require the use of a primer. Where required to achieve improved bond and watertightness, primers can be used.

2.4-Polyesters

2.4.1 Description—Polyester binders used for the preparation of PC are two-component systems, one containing the polyester resin and the second containing the hardener or initiator, which is usually an organic peroxide. The properties of the polyester binder primarily depend upon the chemical composition of the polyester resin component and are much less influenced by the selection of the promoter/initiator system, the primary contribution of which is to control the rate of cure.

The peroxides, used as initiators, gradually lose their reactivity at elevated temperatures (over 90°F or 32°C) (Lucidol, Penwalt). Inert liquids or fillers are incorporated by the manufacturer to minimize the explosion hazard. Both polyester resin and initiator components should be stored in cool protected areas.

2.4.2 Polyester properties

2.4.2.1 Fire resistance—polyester, being organic in nature, can burn. Incorporation of aggregate and other additives increases the fire resistance of PC.

2.4.2.2 Chemical resistance—Cured polyester binders are resistant to water, deicing chemicals, dilute acids, gasoline, and other petroleum products. Some polyester resins may not be resistant to alkaline substrates.

2.4.2.3 Weathering—Experience indicates that polyester resins have good freezing-thawing and weather resistance.

2.4.2.4 Primers—Priming is always necessary when premixed polyester systems are used to establish intimate contact with the substrate. Special primers improve the performance of all polyester overlays. The following types of primers can be used, but the manufacturer of the polyester should be consulted before selection is made.

Polyester resins—If recommended by the manufacturer, the same resins used for PC binders may be used with premixed systems.

Epoxies—Epoxies are resistant to the styrene or other monomers present in the polyester resin. Epoxies can improve the bond of PC overlays to damp or alkaline substrates, although the application of PC overlays to damp substrates is not recommended.

Methacrylates—These are solutions of acrylic polymers in methyl methacylate (MMA) or high molecular weight methacrylate (HMWM) monomers.

2.5-Methacrylates

2.5.1 Description—Methacrylate PC binders are normally two-component systems, a promoted resin, and an organic peroxide initiator. The resins are generally based on MMA monomer. Low viscosity grades are available as monomer blends, while those with high viscosities may be solutions of polymers in monomer.

| Table 2.5.2(a)—Typical uncured properties of methacrylate binders for PC overlays |
|------------------------|---------|----------|--------|------------------------|
| Type                  | Viscosities | Working life, gel time | Health hazard | Flash point |
| Monomers              | 1-50 centipoise (1-50 x 10^3 Pa * s) | 20-40 min* | Yes† | Below 100°F (38°C) Flammable |
| Polymer/monomer solutions | 250-1700 centipoise (250-1700 x 10^3 Pa * s) | 20-40 min* | See Section 8.3.5 | Below 100°F (38°C) Flammable |

* Working life can easily be maintained from application temperatures of -20 to 100°F by varying the promoter and/or initiator, however, the manufacturer should be consulted before any such adjustments are made. † Follow the manufacturer's instructions.

| Table 2.5.2(b)—Typical physical properties of cured methacrylate binders for PC overlays |
|------------------------|---------|----------|--------|------------------------|
| Property               | Value, U.S. | Value, SI | Test method |
| Bond strength*         | 1000-2000 psi  | 7-14 MPa  | ASTM C 882 |
| Coefficient of thermal expansion | 12-30 x 10^2 in/in/F  | 22-54 x 10^5 mm/mm/C  | ASTM C 531 |
| Tensile strength       | 500-1200 psi  | 3-8 MPa  | ASTM D 638 |
| Tensile elongation     | 100-200 percent | 100-200 percent | ASTM D 638 |
| Modulus of elasticity  | Max. 1 x 10^5 psi  | Max. 7 x 10^5 GPa  | ASTM D 638 |
| Curing shrinkage       | 1-2 percent | 1-2 percent | DuPont (Appendix) |

*See Section 2.5.2.4

PCs based on methacrylate resins can be prepared using two basic premix methods: a) slurry, or b) mortar. Although both are classified as MMA systems, they are considerably different in their formulation, application, and performance properties.

As a slurry, high-viscosity resins are combined with graded aggregates, producing self-leveling, low-modulus overlays of 1/8- to 1/4-in. (3.2- to 9.5-mm) thickness. These materials possess the stress-relieving characteristics required to endure stresses created by temperature changes and substrate movement.

Where greater thicknesses and heavier loading capabilities are principal requirements, mortar systems are recommended. Mortars make use of low-viscosity monomers to which precisely graded aggregates are added, producing highly filled systems with significantly higher moduli than the slurry previously described. These are suitable for screed applications of 1/2 to 1 in. (13 to 25 mm) (Degussa 1990; Silikal 1987; and Transpo 1990).

2.5.2 Methacrylate properties—The properties that appear in the preceding tables reflect those of high-viscosity resins used in slurry-type methods of application. Due to
the high filler contents found in mortars, the properties of the PC are more significant than those of the binder; mortar properties can be found in Chapter 3.

2.5.2.1 Fire resistance-Methacrylate polymers can burn, being organic in nature, but the incorporation of proper aggregates and fire retardants can provide increased fire resistance.

2.5.3.3 Chemical resistance-Methacrylate polymers are resistant to water, deicing chemicals, dilute acids, and alkalines. Solvent resistance is limited (Degussa 1990; Silikal 1987; and Transpo 1990).

2.5.2.3 Weathering-Methacrylate polymers are highly UV light-resistant, and withstand environmental exposure and weather (Redfoot 1985).

2.5.3 Primers--PCs based on methacrylates require a penetrating primer of generally lower viscosity than the binder resin prior to their application to achieve proper bond. These primers may be based on MMA or HMWM that have the ability to penetrate hairline cracks. Methacrylates are generally sensitive to damp and wet conditions, and their use should be restricted to dry surfaces.

2.6-Polyurethanes

2.6.1 Description-Polyurethanes can be formulated as one- or two-component systems. The polyurethanes used as binders for polymer overlays are of the elastomeric type and, in their cured state, they have the characteristics of hard rubber. Polyurethane binders usually contain pigments and fillers and are seldom combined with large amounts of aggregate. They are used primarily in their liquid form in multiple layers with larger aggregates incorporated into the top layer. They are frequently used for overlaying parking garage decks and on bridge deck applications as waterproofing membranes between concrete or steel decks and asphaltic overlays.

2.6.2 Polyurethane properties

2.6.2.1 Fire resistance-Cured polyurethanes, being organic, can burn. Incorporation of special additives helps them meet accepted fire codes. In case of fire, special caution must be exercised because poisonous cyanide fumes may be generated.

2.6.2.2 Chemical resistance-Cured polyurethanes are resistant to water, salt solutions, and a wide variety of acids, alkalies, and particularly to solvents and fuels.

2.6.2.3 Weathering-Weathering effects are not accurately known at the present time, but alicyclic isocyanate-based resins will weather better than their aromatic counterparts.

2.6.2.4 Primers-Manufacturers’ recommendations for polyurethane PC overlays should be followed.

CHAPTER 3-POLYMER CONCRETES

3.1-General

PCs are made by combining monomeric or polymeric binders with aggregates. The aggregates and binders can be premixed and spread with screeds, or the binders can be applied to the surface and the aggregate broadcast onto the liquid binder. PCs used for overlays should normally have a low modulus of elasticity to withstand the stresses created by temperature changes. For a full description of PC binders see Chapter 2.

Since the addition of aggregates to the particular polymer system defines the resulting mix as a PC or mortar, a brief description of the most commonly used PC aggregates follows.

3.2-Aggregates

A variety of aggregates such as quartz, silica sand, basalt, or aluminum oxide may be used in PC overlays. In general, aggregates should be hard, dense, durable, dry, clean, and resistant to polishing and crushing.

In applications where aggregate particles are to be broadcast on the surface of a PC overlay to produce high-degree skid resistance, angular aggregate particles with a Mohs hardness of 7 to 9 should be used.

3.3.1 Fine fillers-Some PC systems are supplied as two-component mortars, the second component containing well-graded silica aggregates and fine fillers such as calcium carbonates. These filled systems are important to methacrylate and polyester overlays since keeping the overall aggregate content high will minimize the adverse effects of curing shrinkage.

3.3-Properties of PC

PCs exhibit many properties that are far superior to the substrate being repaired. Working life and cure times

Table 2.6.2(a)--Typical uncured properties of polyurethane binders for PC overlays

<table>
<thead>
<tr>
<th>Viscosity</th>
<th>Working life, gel time</th>
<th>Health hazard</th>
<th>Flash point</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000-8000 centipoise (1000-8000 x 10³ Pa - s) (ASTM D 2393)</td>
<td>15-60 min*</td>
<td>Yes† (See Section 8.3.5)</td>
<td>Over 400 F (204 C) non-flammable</td>
</tr>
</tbody>
</table>

*One-component moisture-cured polyurethanes have very long working times in the absence of moisture.
†Follow the manufacturer’s safety instructions.

Table 2.6.2(b)--Typical physical properties of cured polyurethane binders for PC overlays

<table>
<thead>
<tr>
<th>Property</th>
<th>Value, U.S.</th>
<th>Value, SI</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond strength*</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>800-1500 psi</td>
<td>6-10 MPa</td>
<td>ASTM D 412</td>
</tr>
<tr>
<td>Tensile elongation</td>
<td>150-600 percent</td>
<td>150-600 percent</td>
<td>ASTM D 412</td>
</tr>
<tr>
<td>Modulus of elasticity, tensile</td>
<td>50-200 psi</td>
<td>0.3-1 MPA</td>
<td>ASTM D 638</td>
</tr>
<tr>
<td>Curing shrinkage</td>
<td>0.02-0.08 percent</td>
<td>0.02-0.08 percent</td>
<td>DuPont (Appendix)</td>
</tr>
</tbody>
</table>

*Insufficient data available.
for some PCs are adjustable to suit needs at different application temperatures. A wider range of mechanical properties is available depending on both the binder selection and the aggregate loading. Bond strength to concrete is good, often exceeding the tensile strength of concrete. Wear and chemical resistance are excellent.

An important factor when considering PC overlay materials is their thermal compatibility with the substrate. Polymers, being organic in nature, have coefficients of thermal expansion several times higher than those of inorganic materials such as concrete or steel. Therefore, when a PC overlay is subjected to temperature changes, it undergoes greater volumetric changes than the substrate, creating stresses at the bond line. The cumulative effect of these stresses, particularly at very low temperatures, may cause debonding due to 1) adhesive failure at the interface or 2) shear failure in either the PC or the substrate. The failure mode is dependent on compatibility of the substrate and the overlay. By incorporating inorganic aggregates into PC overlays, it is possible to lower the coefficient of thermal expansion of the PC to two to four times that of concrete or steel. Attempting to decrease the coefficient of thermal expansion of the PC by increasing the aggregate loading may further compensate for the difference, but this is at the expense of reduced impermeability and flexibility of the overlay (Peschke 1981).

**Table 3.3(a) - Typical properties of epoxy polymer concrete**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value, U.S.</th>
<th>Value, SI</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working life, gel time</td>
<td>30-60 min</td>
<td>30-60 min</td>
<td>AASHTO T 237</td>
</tr>
<tr>
<td>Cure time</td>
<td>3 hr @ 70 F</td>
<td>3 hr @ 21 C</td>
<td>Not available</td>
</tr>
<tr>
<td>Bond strength</td>
<td>1500 psi</td>
<td>10 MPa</td>
<td>ASTM C 882</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>5000 psi</td>
<td>33 MPa</td>
<td>ASTM C 579</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>2000 psi</td>
<td>14 MPa</td>
<td>ASTM C 580</td>
</tr>
<tr>
<td>Modulus of elasticity, compressive</td>
<td>0.9-1.5 x 10^5 psi</td>
<td>0.6-1.0 x 10^5 MPa</td>
<td>ASTM C 579</td>
</tr>
<tr>
<td>Thermal compatibility*</td>
<td>10 cycles</td>
<td>10 cycles</td>
<td>ASTM C 884</td>
</tr>
</tbody>
</table>

*Overlay materials used in regions where temperature ranges exceed those specified in ASTM C 884 should be tested at temperatures that reflect those ranges.

**Table 3.3(b) - Typical properties of polyester polymer concrete**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value, U.S.</th>
<th>Value, SI</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working life, gel time</td>
<td>10-60 min</td>
<td>10-60 min</td>
<td>AASHTO T 237</td>
</tr>
<tr>
<td>Cure time, initial</td>
<td>1-5 hr</td>
<td>1-5 hr</td>
<td>Not available</td>
</tr>
<tr>
<td>Bond strength</td>
<td>1500 psi</td>
<td>10 MPa</td>
<td>ASTM C 882</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>4000 psi</td>
<td>28 MPa</td>
<td>ASTM C 579</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>2000 psi</td>
<td>14 MPa</td>
<td>ASTM C 580</td>
</tr>
<tr>
<td>Modulus of elasticity, tensile</td>
<td>0.9-1.5 x 10^5 psi</td>
<td>0.6-1.0 x 10^5 MPa</td>
<td>ASTM C 579</td>
</tr>
<tr>
<td>Thermal compatibility*</td>
<td>Not available</td>
<td>Not available</td>
<td>ASTM C 884</td>
</tr>
</tbody>
</table>

*Overlay materials used in regions where temperature ranges exceed those specified in ASTM C 884 should be tested at temperatures that reflect those ranges.

**Table 3.3(c) - Typical properties of methacrylate polymer concrete**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value, U.S.</th>
<th>Value, SI</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working life, gel time</td>
<td>20-40 min</td>
<td>20-40 min</td>
<td>AASHTO T 237</td>
</tr>
<tr>
<td>Cure time</td>
<td>1-3 hr</td>
<td>1-3 hr</td>
<td>Not available</td>
</tr>
<tr>
<td>Bond strength</td>
<td>1000-2000 psi</td>
<td>7-14 MPa</td>
<td>ASTM C 882</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>2000-9000 psi</td>
<td>14-62 MPa</td>
<td>ASTM C 579</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>1300-3000 psi</td>
<td>9-21 MPa</td>
<td>ASTM C 580</td>
</tr>
<tr>
<td>Modulus of elasticity, compressive</td>
<td>0.05-1.0 x 10^5 psi</td>
<td>0.34-6.9 x 10^5 MPa</td>
<td>ASTM C 579</td>
</tr>
<tr>
<td>Thermal compatibility*</td>
<td>Not available</td>
<td>Not available</td>
<td>ASTM C 884</td>
</tr>
</tbody>
</table>

**Table 3.3(d) - Typical properties of polyurethane polymer concrete**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value, U.S.</th>
<th>Value, SI</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working life, gel time</td>
<td>10-60 min</td>
<td>10-60 min</td>
<td>AASHTO T 237</td>
</tr>
<tr>
<td>Cure time, initial</td>
<td>4-8 hr</td>
<td>4-8 hr</td>
<td>Not available</td>
</tr>
<tr>
<td>Bond strength</td>
<td>Not available</td>
<td>Not available</td>
<td>Not available</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Modulus of elasticity, compressive-flexural</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Thermal compatibility*</td>
<td>10 cycles</td>
<td>10 cycles</td>
<td>ASTM C 884</td>
</tr>
</tbody>
</table>

*Overlay materials used in regions where temperature ranges exceed those specified in ASTM C 884 should be tested at temperatures that reflect those ranges.
Based on the factors previously described, Tables 3.3(a), 3.3(b), 3.3(c), and 3.3(d) are presented to distinguish the various types of PC overlay materials from each other. The reader is encouraged to consult PC overlay manufacturers for specific information regarding individual products.

When premixed systems are used, especially with polyesters, methacrylates and polyurethanes, use of primers may be necessary.

For a discussion of appropriate primers for the different types of PCs, see Chapter 2.

CHAPTER 4-SURFACE PREPARATION

4.1-General

The purpose of surface preparation is to improve bonding between the PC overlay and the substrate. Since these materials have very different coefficients of thermal expansion and permeability, surface preparation is a most important factor in achieving proper bond.

Polymer overlays should be applied only to clean, dry, physically sound substrates. Proper surface preparation increases surface roughness and the subsequent mechanical bond between the overlay and the concrete substrate. In addition to mechanical bond, there may also be a chemical bond, depending on the type of polymer.

The manufacturers of PC overlay materials provide literature on recommended procedures for proper application of the product. For surface preparation, these instructions typically state that all bond surfaces are to be free of loose and unsound materials as well as contaminants and bond breakers such as oils, grease, paints, sealers, curing compounds, water, waxes, dust, solvents, and laitance. No overlay site will be free of all of these without surface preparation. Owners, specifying agencies, and contractors need to be aware of all future exposure conditions that could lead to failure of the system as well as the consequences of improper surface preparation.

Overlay surfaces of parking structures and bridges may be exposed to abrasion, rapid temperature changes, ultraviolet radiation, salt, moisture, acid rain, oil, heavy wheel loads, deicing salts, tracked-on abrasives such as rocks, snowplow blades, reflective cracks from the substrate, vapor pressure from the substrate, temperature-induced shear stresses due to different coefficients of thermal expansion, live load shear stresses caused by turning, braking, or accelerating vehicles, and impact stresses caused by roughness in the riding surface. The ability to survive these conditions is highly dependent on the sound bond of the overlay to the substrate.

4.2-Concrete

4.2.1 Preliminary surface evaluation-This first requirement for the concrete deck is that it be structurally sound and strong enough to withstand temperature-created shear stresses below the bond line. Cores may be extracted for compressive strength testing and comparison with Schmidt impact hammer readings. The impact hammer can then be used to locate isolated weak areas in the deck.

The deck should also be checked for delamination at the top reinforcing steel mat level. This is most easily done by chain dragging or hammer sounding to locate hollow-sounding areas. Particular attention should be paid to cracks in the deck that are allowing salt and water to access the reinforcing steel or that have been created by the expansion of corroding reinforcing steel. Copper sulfate electrode tests (ASTM C 876) may be conducted to locate areas of active reinforcing steel corrosion that will eventually result in delaminated concrete. Corroded reinforcing steel must be exposed for sandblast cleaning. Since overlays are passive and preventive in nature, all delaminated and deteriorated areas must be repaired prior to overlay placement.

The age of the concrete surface should also be considered. New cast decks should be cured a minimum of 28 days to allow the moisture content of the concrete to drop to a level that will prevent excessive moisture vapor pressure. Old decks should also be dry before application of the PC overlay.

While it is an accepted practice to assume that contaminants will be removed before overlay placement, determining acceptably sound concrete requires some judgment. Concrete that is high in porosity, low in strength, or that is delaminated within the mass can create serious problems. When low strength or deep delamination is suspected, coring may be the best method of evaluation, providing both a visual inspection and a sample for subsequent testing.

Proper surface evaluation, therefore, requires trained personnel familiar with concrete, contaminants, methods of preparation, and PC materials to determine how best to prepare the concrete substrate.

4.2.2 Substrate repairs-Surface preparation for overlays frequently includes the repair of defects such as honeycombed areas, small and large holes, ruts, sharp protrusions, broken edges, and cracks. Sounding around the defect is important to determine whether there is further deterioration. Damaged sections should be removed with tools that will not further damage adjacent areas, including reinforcing steel. Methods of removal may include chipping, needle gunning, bush hammering, and wire brushing.

4.2.2.1 Crack repair-Careful attention should be given to the repair of cracks in the concrete substrate. ACI 224R is an excellent reference on the causes of cracks and provides a summary of many repair methods. It is important to prevent reflective cracking in the polymer concrete overlay. The cause of movement in bridge and parking garage decks should be prevented if possible, or the movement should be accommodated by the overlay.

4.2.2.2 Patching-Deteriorated concrete should be removed and the areas patched prior to surface preparation. Selection of patching materials is governed by the
depth and volume of the areas to be repaired. Large deep areas are more economically repaired with portland cement concrete, which is compatible with the deck concrete being repaired. These repairs may require 21 to 28 days of curing prior to overlay placement, to allow the patching concrete to hydrate and excess water to evaporate. If the repairs are overlaid too soon, the overlay may lose bond over the repaired area. Repairs that are less than 1 in. thick may be repaired with polymer concrete if desired. This will allow placement of the overlay once the repair has cured. Potholes and large defects should be patched prior to surface preparation.

Thin layered patches often debond from the substrate due to moisture loss by absorption and evaporation of water from the patch. Patches deeper than 1/2 in. (13 mm) should generally be saw cut around the perimeter. This has been shown to greatly extend the service life of the patch. Patches less than 1/2 in. (13 mm) thick are usually made with a polymer mortar that is thermally compatible with both the substrate and overlay. The polymer mortar should usually be mixed with the maximum possible amount of aggregate that can be fully coated with resin, usually three to five parts of aggregate to one part of resin by volume. Too much aggregate results in a porous patch, while too little aggregate causes problems of incompatibility with the substrate. After the patch is correctly placed and leveled, an extra layer of sand should be placed on top to create a good bond surface for the overlay. Once the patch is cured, the loose sand is removed.

Magnesium phosphate patching materials require 30 days of curing prior to being overlaid. These materials generate gasses during curing that should be allowed to escape prior to sealing, to prevent later deterioration of the patch below the overlay.

4.2.3.3 Roughness-PC overlays should not be placed on overly rough surfaces, causing premature wear and failure on the high spots due to impact stresses. Thin layers of liquid polymer cannot be expected to correct deficiencies in roughness. Instead, surface roughness must be corrected prior to placement of PC.

All surface patching and repair must be properly screeded and hand finished to minimize roughness. The most practical way of evaluating roughness is with a straightedge.

For further information on evaluation, patching, and repair of concrete beyond the scope of this guide, the reader is referred to ACI 546.1R and ACI 548.1R.

4.2.3 Surface preparation methods-The polymer manufacturer should generally be consulted before deciding on the best type of surface preparation. However, the selection of proper surface preparation techniques often depends less upon the type of PC overlay than upon the economical and environmental considerations. Many U.S. cities have placed restrictive regulations on sandblasting due to health and environmental problems. Since some methods are prone to filling the air with respirable silicates, respirators or filter-masks may be required for all on-site personnel, and strict local pollution standards may have to be met. Also, disposal of all waste materials must conform to local regulations.

4.2.3.1 Shotblasting-Steel or grit shotblasting is an abrasive method of cleaning horizontal surfaces which incorporates a vacuum pickup, and thereby reduces dust. It has replaced sandblasting on most overlay projects where shotblast equipment is available (Fig. 4.2.3.1). Two passes of the blasting machine are normally required to remove sufficient quantities of laitance and contamination. Measurements have shown that removal of ½ lb/ft² (2.5 kg/m²) of concrete exposes enough of the large aggregates to produce a suitable surface profile. Production rates of up to 1500 ft³/hr (140 m³/hr) are normal.

4.2.3.2 Sand/gritblasting-Sand or gritblasting is one of the most economical and efficient methods of removing rigid contaminants from substrates, but difficulty in removing flexible coatings is a limitation. Wetblasting applications are labor-intensive regarding final cleanup; residual moisture and sand remaining on the substrate will prevent proper adhesion of the overlay.

4.2.3.3 Hydroblasting-This method may be suitable for parking structures in certain situations. Special care must be exercised to be sure that hydroblasting, which uses nozzle pressure above 10,000 psi (70 MPa), removes enough mortar at the surface to provide adequate roughness for best bonding. Nozzle pressures less than 7000 psi (48 MPa) are generally called hydrocleaning and may be inadequate to sufficiently prepare the substrate. When high-pressure hydroblasting is used, the wet surface must be dried sufficiently to minimize potential vapor pressure below the PC overlay. The time required for sufficient drying will depend on temperature and air humidity but could require a week prior to the overlay placement. Disposal of wastewater is a problem that must be considered. For these reasons, hydroblasting is not normally used.

4.2.3.4 Scabbling impact took-One mechanical method includes the use of scabblers to chip away the
surface by pulverizing it with vertical hammer blows. However, the dust generated by this method can cause environmental and equipment problems, and the noise is extremely harsh. Another factor that cannot be controlled is the vertical fracturing of the concrete, which leads to crack development. This method is only used to remove deep contamination, but one should be aware that invisible damage to the substrate may result from its use.

4.2.3.5 Scarifiers—Another common mechanical method is the scarifier or cold mill. It works by rotation of a tungsten carbide drum or series of toothed wheels which chip and scratch the substrate to a coarse but uniformly textured surface. The scarifier is more controllable than scabblers because of the variety of wheels available. The problems with this method are the same as for the scabblers, although scarifiers are dustier and noisier.

4.3-Steel

The mill scale on orthotropic steel bridge decks has been found to be detrimental to the adhesion of polymer concrete overlays. Mill scale forms as a discontinuous layer and is subjected to electrolytic attack and eventual rust, which destroys the adhesion of the scale. Other contaminants can also accelerate the deterioration of steel bridge decks.

Surface preparation methods have been well defined by organizations such as SSPC, NACE, and AWWA. ASTM and SSPC have developed pictorial standards, which show the abrasive blast standards for new mill scale-bearing steel, rusted steel, and visibly pitted corroded steel. The surface preparation standards are similar to those for concrete and use the same methods of abrasive blasting. Basically, the steel is blasted to a white metal condition. After cleaning the steel substrate, a thorough evaluation should be made, including checks for cracks or section loss due to corrosion.

4.4-Evaluation of surface preparation

The amount of substrate preparation needed for a PC wearing surface will vary from site to site, due to different surface conditions as well as for different polymer resins. This may create problems between the owner and the contractor if the contractor has not correctly assessed the amount of work required to prepare the surface or if his interpretation differs from the owner’s or inspector’s. Field tests measuring tensile bond strength (ACI 503R) may be used to determine the amount of work needed.

CHAPTER 5-APPLICATION OF PC OVERLAYS

5.1-General

PC overlay placements generally consist of three steps that include preparing the substrate surface, placing the resin and aggregate, and curing the PC.

Surface preparation is necessary to achieve good bonding and best performance for any overlay. Any preparations should insure that the substrate is clean, sound, and as dry as possible. (See Chapter 4.)

Once surface preparation is completed, application techniques will be determinant in obtaining the maximum performance from any PC overlay. Two methods of placing the PC are commonly employed. The first one is the multiple layer method. This type of PC overlay is commonly known as “the broom-and-seed method,” because it is constructed by building up alternate layers of resin and aggregate; brooming the resin on the surface and then seeding it with sand. The second PC overlay type, known as the premixed placement method, is constructed by placing a single application of the premixed resin and aggregate matrix onto a cleaned concrete substrate.

This chapter details these methods of application for PC overlays.
5.2-Multiple-layer overlay

The multiple-layer method is especially suited for higher viscosity binder systems and when thin overlays are desired [Fig. 5.2 (a) and 5.2 (b)]. These overlays are easy to install, requiring little, if any, mechanized equipment and less skilled labor. For these reasons, installation costs in some instances may be lower than premixed overlay installations.

There are several drawbacks to using multiple-layer overlays. As the name implies, more than one application is required. Therefore, in addition to being more dependent on the weather, traffic safety control must be maintained for longer periods of time as well [Fig. 5.2 (c) and 5.2 (d)]. Sometimes the additional costs of traffic safety control may override the possible savings in labor installation costs.

5.2.1 Applying the resin-The resin is first properly proportioned and mixed well with its curing system and is immediately applied to the substrate surface. Both the ambient temperature and the temperature of the substrate surface to which the material is applied are typically specified to be between 50 to 95 F (10 to 35 C), although methacrylate systems can be readily adapted for much wider temperature ranges when necessary.

The resin system is normally applied by either of two methods. Most often the resin is simply poured onto the concrete surface directly from buckets and spread with brooms, rollers, or squeegees. To control the quantity of resin per unit area, the deck is marked into sections that are to be covered with a unit quantity of resin. This provides the workers with a visual guide as they are spreading the resin across the surface.

The resin system can also be applied using a pressurized spray distribution system. A resin-measuring device is built into the spray distribution system so that the quantity of resin per area of concrete surface can be con-

![Fig. 5.2(c)-Automated resin application for large-scale multiple layer overlay projects](image1)

![Fig. 5.2(d)-Automated aggregate seeding used for large-scale multiple layer overlay](image2)

### Table 5.2.1--Typical application rates of resin and aggregates for multiple-layer PC overlays

<table>
<thead>
<tr>
<th>Resin type</th>
<th>Layer</th>
<th>Resin application rate</th>
<th>Aggregate application rate</th>
<th>Aggregate size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ft²/gal</td>
<td>m²/liter</td>
<td>lb/ft²</td>
</tr>
<tr>
<td>Methacrylates</td>
<td>1</td>
<td>100</td>
<td>2.5</td>
<td>0.1-1.0</td>
</tr>
<tr>
<td></td>
<td>2-4</td>
<td>25-100</td>
<td>0.6-2.5</td>
<td>0.5-2.0</td>
</tr>
<tr>
<td></td>
<td>Sealer coat</td>
<td>50-100</td>
<td>1.2-2.5</td>
<td>0</td>
</tr>
<tr>
<td>Epoxies</td>
<td>1</td>
<td>30-40</td>
<td>0.7-1.0</td>
<td>0.9-1.1</td>
</tr>
<tr>
<td></td>
<td>2-4</td>
<td>20-30</td>
<td>0.5-0.7</td>
<td>1.3-1.6</td>
</tr>
<tr>
<td>Polyester-styrene</td>
<td>1</td>
<td>40-50</td>
<td>1.0-1.2</td>
<td>0.8-1.0</td>
</tr>
<tr>
<td></td>
<td>2-4</td>
<td>30-40</td>
<td>0.7-1.0</td>
<td>2.0-3.0</td>
</tr>
</tbody>
</table>
Fig. 5.3-Premixed PC overlay epoxy mortar for steel grid decking in lift-span bridge

trolled.

The resin and aggregate application rates are dependent upon the type of resin and aggregate size for the installation of multiple-layer PC overlays. Table 5.2.1 gives the recommended application rates; however, these are to be considered as general guides. Some specifying agencies and manufacturers’ application rates may vary from those given in the table.

5.2.2 Applying the aggregate-Immediately after the resin has been applied, the specified aggregate is broadcast to a slight excess over the resin. This assures embedment of sufficient aggregate into the resin. The preferred method of application is one that utilizes a mechanical spreader that will uniformly broadcast the aggregate in a manner that will not mark or rut the overlay. The spreader should broadcast the aggregate from as close to the surface as possible to avoid displacement of the resin.

5.2.3 Curing-Depending on the deck and ambient temperatures and on the type of polymer binder, the cure time may vary from 1/2 to 8 hr. Any excess aggregate that is not embedded in the cured resin is then removed, and the overlay application is repeated until the proper number of layers have been applied and the specified depth is met. Depending on the type of resin and aggregate size, a typical multiple-layer overlay might consist of three to five applications.

5.3-Premixed polymer concrete application

Premixed PC overlays achieve the required thickness in a single application. They can be made using methacrylate, epoxy, or polyester binders (Fig. 5.3).

Placement of these overlays requires the use of mechanical mixers and placement equipment. The use of vibrating screeds to place the premixed PC overlay gives better compaction and results in higher density and lower permeability in the overlay.

The equipment required for mixing and placement of these types of overlays requires a more skilled labor force. Therefore, labor costs will be higher than those for multiple layer overlays. However, total installation costs may not vary much from multiple layer overlays, because the single application required will minimize traffic control costs.

5.3.1 Mixing-Several mixing procedures can be used for premixed PC overlay installations. Generally, the type of resin used for the PC binder and the size of the overlay placement dictate the preferred mixing procedure.

5.3.1.1 Hand-mixing-Hand-mixing of the resin and aggregate is the simplest and least expensive mixing method. This method is used for most two-component methacrylate mortar systems. These systems normally come prepackaged and preproportioned; therefore, field batching operations are generally eliminated. Most manufacturers of prepackaged two-component methacrylate mortar systems recommend that the mixing be done in polyethylene bags supplied with the materials. This is acceptable for small jobs, but for large decks it can be a slow and tedious mixing method. In most cases with the hand-mixing procedure, hand-screeding and/or troweling is used to obtain the desired overlay thickness.

5.3.1.2 Machine batch-mixing-Machine mixing of the resin and aggregate systems in small concrete or mortar mixers has been used for many PC overlays. It is important to maintain the proper ratio of resin to curing agents as well as resin to aggregate for each batch. Otherwise, finishing of the overlay becomes extremely difficult, and cured properties may not match specifications. In all batch-mixing operations, it is necessary to have good quality control procedures to minimize variations between batches. This machine batch-mixing method is typically used for jobs where the area of overlay is too small to justify the high cost of continuous mixers.

5.3.1.3 Continuous mixing-This method is a higher technology approach that facilitates uniform batching and placement on large overlay jobs. Two types of machinery have been used for the continuous mixing of polymer concrete for overlay applications.

One of the continuous mixers is a modified mobile concrete batching plant [Fig. 5.3.1.3 (a)]. In this machine, large hoppers feed aggregates onto a conveyor belt that carries the aggregates into an auger trough where the aggregate is blended with the resin system and then discharged onto the pavement or into a paving machine. The resin is contained in the original water tanks. A catalyst pump must be installed to inject the catalyst into the resin stream before it is mixed with the aggregate in the auger trough. The length of the mixing time is regulated by adjusting the angle of the mixing trough. To clean the mixing trough, large quantities of solvent may be required. This type of equipment has been used with polyester and methacrylate PCs.

Another type of machinery for the continuous preparation of polymer concrete overlay materials can be pro-
5.3.1 Hand-screeding/troweling—On small jobs, PC overlays are often placed using aluminum or magnesium box beams with vibrators attached. This type of vibratory screed works well for easily flowable PC mixes. First, guide rails are used to establish the thickness of the overlay, and then laborers push and pull the screed back and forth in a transverse sawing motion as they advance the screed longitudinally. Difficulties in maintaining uniform screed rates often cause uneven surfaces. This hand-screeding is not recommended for overlays wider than 8 ft (2.4 m). Gage rakes utilizing pins that determine application thickness have also been used for self-leveling premix overlays.

5.3.2.2 Vibrating screeds—Manually advanced—There are several pneumatic vibrating screeds that can be used with various PC mixes for overlay installations. These screeds can span across a full lane width without problems when the deck is uniform. Some screeds can be adjusted to give a uniformly thick overlay, even though the concrete substrate may be slightly contoured. Experience indicates that placing premixed overlays in half-lane widths seems to eliminate most of the problems associated with nonuniform concrete surfaces, even with the most simplified vibrating screeds used. Screed rails or guides are necessary to control the thickness of the overlay being placed. In most cases, the vibratory screed is manually advanced using a winch. These screeds work well when the leading edges are kept clean. Once the PC material gels on the leading edges, the overlay surface tears and is no longer uniform in thickness. The leading edges of vibratory screeds used for PC overlays should be made of UHMW (ultra-high molecular weight) polyethylene or Teflon. The entire screed should be Teflon coated so that it is easier to keep clean. Advancing the screed at a slow and constant rate is essential to obtaining a uniform surface across the PC overlay.

5.3.2.3 Self-propelled finishing machines and screeds—Self-propelled finishing machines and vibrating screeds are used to place large PC overlays on large bridge decks and/or roadway surfaces. The self-propelled finishing machines can be adjusted to place overlays evenly across an entire lane. Some of the machines have an auger strike-off to provide a uniform thickness of PC in front of an oscillating screed. The oscillating screed consolidates the PC by vibration. The speed of the finishing machine is variable so that as the PC is placed before the leveling auger, the finisher can maintain a continuous pace without stopping. All surfaces that contact the PC should be Teflon coated or machined from UHMW polyethylene wherever possible.

5.3.2.4 Surface texture—Nonskid surface textures are obtained by broom finishing, tining, or by broad-casting a coarse aggregate on the PC surface before it has gelled.

Broom finishing is the result of dragging the bristles of a coarse street broom over the uncured overlay to provide a skid-resistant surface. The texturing must be completed before the PC begins to gel or the surface will

perly described as “continuous metering, mixing, and dispensing machines.” The basic machine consists of a hopper through which the filler is metered and dispensed to the mixing auger. The resin and curing agent are metered and also dispensed to the mixing auger via variable speed (output) pumps. The mixing auger, a continuous screw, transports and mixes the metered fillers and resin to a homogenous consistency and delivers a steady stream of reactive polymer concrete to the overlay placement area. Provisions are also provided to clean the mixing auger with a minimum amount of solvent as required. These machines have been used for epoxy, methacrylate, and polyester resins [Fig. 5.3.1.3 (b)].
Surface tining has been used on overlay systems with excellent results. This method employs a rake-like beam fitted with spring metal teeth that leave uniform grooves when dragged across the uncured overlay. Since PC overlays are generally less than 1/8 in. (19 mm) thick, it is necessary to keep the tined grooves less than 1/4 in. (6 mm) deep. Thinner overlays require shallower tining. Surface seeding is employed in some cases, particularly with epoxy and some methacrylate or polyester PCs. The overlays are put down as a slurry premix design which is resin-rich. Once the matrix is compacted and screeded, the excess resin rises to the top. At this point, a coarse aggregate provides a durable skid-resistant surface. A rake-like beam is employed to remove the excess resin. When the PC cures, the top layer of aggregate provides a durable skid-resistant surface.

5.3.2.5 Curing—Cure times for the overlay are dependent upon the binder system, the depth of the overlay, the substrate and aggregate temperature, and the ambient temperature. Overlays are normally placed when temperatures are between 50 F (10 C) and 95 F (35 C). At these temperatures, cure times can range from 30 min to 12 hr. Some systems can be installed at temperatures below freezing and still cure in less than 2 hr; however, any ice in the pores of the substrate may act as a bond breaker. Quality control checks should be done to assure proper cure of the PC before returning the overlay to traffic.

CHAPTER 6-EVALUATION PROCEDURES FOR QUALITY CONTROL AND LONG-TERM PERFORMANCE

6.1-Quality control needs

After the proper materials and techniques are decided upon and specified, a program of monitoring materials both before and after application is required to assure quality control and the expected performance. The responsibility for operations and material control should not be taken lightly, as inattention to details may result in costly problems. Table 6.1 lists recommended tests for different materials and performance properties. Specific recommended values can be found in Chapters 2 and 3.

6.2-Prequalification tests for polymer components

Samples may be taken at random and tested to insure that the binders and aggregates meet the requirements of the specification. At a minimum, the binder should be tested for viscosity (ASTM D 2393) and gel time (AASHTO T 237) for the conditions under which the materials will be used. When possible, the binder should also be tested for tensile elongation and strength. The grading and dryness of the aggregates should also be monitored. When in doubt, a sieve analysis (ASTM C 136) will determine whether the aggregate meets the specified grading. The aggregate moisture content can be determined by using ASTM C 566 method and should not be higher than 0.5 percent.

6.3-Other considerations

Delaminations—When delamination, i.e., debonding of the overlay, is suspected, various methods of sounding are employed. Areas over a debonded overlay generally produce a lower pitched, hollow sound, and the use of a Laps Delam-Tech apparatus (Silika 1987), tapping the surface with a hammer, or dragging a chain over it are common practices.

Ride quality, profiling and drainage—The quality of the deck performance depends, to a large extent, on the ride quality, profile, and drainage. Although these properties may be measured after placement, it is important to note that PC overlays are too thin to be expected to improve or degrade roughness profiles or drainage characteristics of any traffic surface. These considerations should be discussed and the substrate improved well before the overlay is applied.

CHAPTER 7-MAINTENANCE AND REPAIR

7.1-General

It would be unwise to consider any repair foolproof. Causes of the original substrate damage may have gone undiscovered and eventually damage to the overlay due to normal use and abuse is almost inevitable.

Although toughness and durability are two advantages of PC overlays, eventually they, too, will need some attention. Although simply mixing up PC and patching the damaged area is relatively easy, understanding PC and the nature of the need for repair will provide the user with the necessary information to make effective, long-lasting repairs.

This chapter addresses the sources, influences, problems, methodology, and equipment that should be considered in the maintenance and repair of PC overlays.

7.2-Sources of maintenance needs

Because there are so many PC binder systems and matrixes in use and so many inexperienced applicators, consistent reliable information regarding real performance is difficult, even for the experts, to ascertain. Discrepancies in workmanship and application techniques often make it difficult to clearly distinguish normal-wear-related from nonwear-related failure in an overlay. Because of the importance of finding correctable causes of failure before repairing overlays, the following are presented for consideration.

7.2.1 Wear-related problems—Some wear should be expected and designed into a useful life amortization schedule. At some point, wear will probably be significant enough that maintenance will dictate replacement. The sources and effects of wear can be diverse and must be evaluated for each type of damage to the overlay. Com-
Table 6.1-Typical test methods for polymer concrete overlays

<table>
<thead>
<tr>
<th>Material</th>
<th>Property</th>
<th>Source of test method</th>
<th>Common test name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder</td>
<td>Viscosity</td>
<td>ASTM D 2393</td>
<td>Viscosity of epoxies and related components</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM D 2849</td>
<td>Viscosity of urethanes and related components</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM D 1824</td>
<td>Viscosity of plastisols and organosols by Brookfield viscometer</td>
</tr>
<tr>
<td></td>
<td>Gel time</td>
<td>ASTM D 2471</td>
<td>Gel time of reacting thermosetting resins</td>
</tr>
<tr>
<td></td>
<td>Tensile elongation</td>
<td>ASTM D 638</td>
<td>Tensile properties of plastics</td>
</tr>
<tr>
<td></td>
<td>Tensile strength</td>
<td>ASTM D 638</td>
<td>Tensile properties of plastics</td>
</tr>
<tr>
<td></td>
<td>Grading</td>
<td>ASTM C 136</td>
<td>Sieve analysis for fine and coarse aggregate</td>
</tr>
<tr>
<td></td>
<td>Moisture content</td>
<td>ASTM C 566</td>
<td>Total moisture content of aggregate by drying</td>
</tr>
<tr>
<td>Polymer concrete</td>
<td>Compressive strength</td>
<td>ASTM C 579</td>
<td>Compressive strengths for chemical-resistant mortars and monolithic surfacings</td>
</tr>
<tr>
<td></td>
<td>Flexural strength</td>
<td>ASTM C 78</td>
<td>Simple beam with thud-point loading</td>
</tr>
<tr>
<td></td>
<td>Flexural strength</td>
<td>ASTM C 580</td>
<td>Flexural strength and modulus for chemical-resistant mortars and monolithic surfacings</td>
</tr>
<tr>
<td></td>
<td>Shrinkage</td>
<td>ASTM C 293</td>
<td>Simple beam with center-point loading</td>
</tr>
<tr>
<td></td>
<td>Bond strength, tension</td>
<td>ACI 503R</td>
<td>Field test for surface soundness and adhesion</td>
</tr>
<tr>
<td></td>
<td>Bond strength, shear</td>
<td>ASTM D 4263</td>
<td>Plastic sheet method</td>
</tr>
<tr>
<td></td>
<td>Moisture content of sub-</td>
<td>ASTM E 501</td>
<td>Burnout method (see Appendix)</td>
</tr>
<tr>
<td></td>
<td>strate surface*</td>
<td>ASTM E 524</td>
<td>Treaded tire skid test</td>
</tr>
<tr>
<td></td>
<td>Skid resistance</td>
<td>ASTM E 303</td>
<td>Bald tire skid test</td>
</tr>
<tr>
<td></td>
<td>Chloride permeability</td>
<td>AASHTO T 277</td>
<td>Rapid chloride permeability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FHWA-RD-81/119</td>
<td>6-hr permeability test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM C 876</td>
<td>Half-cell potentials field method</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM C 1202</td>
<td>Chloride permeability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM D3633</td>
<td>Electrical resistivity method</td>
</tr>
<tr>
<td></td>
<td>Cracking</td>
<td>None</td>
<td>Sounding: hammer, or chain (10-ft 3-m)</td>
</tr>
<tr>
<td></td>
<td>Delaminations</td>
<td></td>
<td>straigntedge</td>
</tr>
<tr>
<td></td>
<td>Ride quality</td>
<td>ASTM E 1274</td>
<td>Porfilo graph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM E 1215</td>
<td>Mays meter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ASTM E 950</td>
<td>Rolling straigntedge</td>
</tr>
</tbody>
</table>

* The concrete surface must be dry before PC overlays are applied to provide a common practice to wait a full day after a rain to insure minimum moisture in surface pores of the substrate. Long soaking rains, poor drying weather conditions, and excessively porous substrate concrete are factors requiring longer drying times prior to overlay. The presence of moisture can be determined using ASTM D 4263, which involves the securing of a polyethylene sheet to the concrete with tape and observing the condensation of water over a period of time (up to 4 hr).

7.2.1.1 Binder problem-The type of binder system, its proper proportioning, mixing, and application are the most important links to overlay maintenance problems.

PC can be stronger, more impact-resistant, elastomeric, chemically resistant, or more abrasion-resistant when it is applied and cured properly. Problems occur, however, when the wrong system is used or when applicators or resin manufacturers are not careful.

Some binder systems may still contain residual volatiles even after they have cured. These volatiles may consist of unreacted monomers, resins, diluents, or plasticizers which escape from the matrix over time. This may cause shrinkage or brittleness, which then can result in premature cracking and delaminations in the overlay.

Unreacted or incompletely reacted binder is also frequently the source of poor adhesion to aggregates and the substrate.

Some shrinkage is inevitable in pure polymerization processes, but chemical additives, fillers, and aggregates all help to reduce the shrinkage to acceptable levels. Some binder systems shrink more than others, and, if higher shrinkage systems cure into polymer-rich rigid matrixes, they may experience premature delam-
Some methacrylate and polyester systems seem to suffer from this more than the epoxies.

Thermal effects can greatly influence the performance of PC overlays because of the significant differences in the thermal expansion-contraction properties of the substrate and the polymer binder in the overlay. This property alone may account for more delamination problems in otherwise properly applied PC overlays than all the others. Particularly in rigid polyester and the rigid methacrylate binder systems, every effort must be made to insure the leanest matrix that still maintains good bond to the substrate and uniform integrity throughout the thickness of the overlay. Even flexible systems are subject to contract, which pulls the cold (and the stiffer) binder away from the edges of the cracks in the substrate. Then these temporarily rigid systems, too, may crack and delaminate.

Oxidation and other chemical changes in some binder systems may cause cracking or delamination long after the placement of the PC overlay.

**7.2.1.2 Aggregate problems**—Wear symptoms clearly show the importance of the choice of aggregates in a PC overlay. It is well known that the rate of abrasion can be reduced significantly by the choice of proper aggregates. The suitability of aggregates used in PC overlays very closely follows the guidelines for any aggregate to be used in wearing surfaces. That is, the aggregates must be dry, sound, strong, nonexpansive, nonfriable, and they must exhibit good abrasion (polishing) resistance.

**7.2.1.3 Traffic-induced problems**—Rutting is the result of vehicles traveling in the same wheel paths until a rigid pavement’s surface is abravely worn down, or a flexible pavement’s surface is actually compressed into a thinner section than the surrounding pavement. Either action results in the rutted tracks, which are poor riding surfaces and sources of pavement failures. Since the PC overlay itself is frequently less than ½ in. (13 mm), rutting in PC overlays is at most marginal, and then only where traffic has first worn out coarse surface aggregates and then worn down the resulting poorly paved road.

**Loss of skid resistance** is a proper concern for highway maintenance crews everywhere. It is the result of any number of the wear problems previously mentioned.

**Studded tires** are a necessary evil to many pavements and bridges in areas that have heavy snowfalls or icing conditions, particularly in mountainous regions. The studs impact the pavement surface whenever there is no ice or snow covering it. Although PC overlays withstand studs better than do PCC surfaces, the coarse aggregate is eventually broken out of the matrix, which is then finally chipped away.

**Contamination** is the cause of many failures in portland cement concrete, but some acids and strong bases may damage even PC overlays. Sources of harmful contaminants are some deicing solutions and airborne emission pollutants in acid rain, but the primary contamination source for PC is traffic accident spills. Unfortunately, by the time contamination-related deterioration is discovered, damage and latent problems can be extensive. Unless the contamination, its source, and its ensuing progressive deterioration are eliminated, the PC overlay can be spalled off with the bonded, damaged substrate.

**7.2.2 Overlay failure**

**7.2.2.1 Substrate caused**—The primary cause of overlay failure is poor surface preparation. Other reasons for failure may include stresses developed from differential movement of the substrate with respect to the overlay. Additional causes are given in the following paragraphs.

Cracks may be a source as well as a symptom of many of the problems listed. Since cracked substrates are one of the reasons for the use of overlays, close examination of the conditions following is required to determine the real underlying cause of the failure.

**Joints** are necessary to allow lateral movements in the pavement due to temperature changes, but joints should not allow vertical movements of the pavement. Overlays should not be applied over joints. Overlays that cover joints will usually crack, sometimes spalling or breaking off base slab joint edges in the process. Open joints that fill with incompressible materials will spall out as the summer temperatures cause the concrete base slab to expand.

**Flexibility** in the substrate is a serious problem since not only the overlay itself, but also the bond between the base slab and the overlay, will be stressed every time the base flexes. Even if the overlay can withstand the first flexing, over a period of time fatigue may cause delaminations or extensive cracking. Flexibility in concrete decks usually comes from working joints.

**Freezing and thawing** cycles can also cause water-filled cracks to expand until they spall under the overlay, lifting it off with the broken-off substrate. Similarly, water trapped in delaminations and later frozen will expand, forcing the delamination further.

**Chemical reactions** with the overlay at the interface sometimes occur when the binder cannot withstand the alkalinity of the particular cement or aggregates. Polyester systems sometimes have this problem. A protective primer coating of the substrate prior to overlayment can often prevent this reaction from occurring.

**7.2.2.2 Overlay caused—Delamination** may be caused by the inability of the cured binder to withstand the forces applied by the traffic or temperature changes. This inability may be inherent in the particular polymeric binder itself, but frequently air bubbles, moisture, incomplete cure, poor consolidation, and incomplete wetting of the substrate surface by the resin are caused by improper mixing or placement by the applicators.

**Cracking** overlays allow water to penetrate to the interface and cause previously mentioned hydraulics or freeze-thaw problems or expansive PCC substrate problems. Some high-shrinkage systems seem to be more prone to fatigue failure delaminations that start at edges and gradually progress until large chunks of overlay material spall or flake off.
Crazing is seen as an extensive network of closely spaced, randomly oriented cracks particularly visible in resin-rich overlays. Crazing which appears while the overlay is still new is usually caused by exotherm temperatures that became too high during the curing.

Crazing which appears long after the overlay has been in service is usually attributable to ultraviolet degradation, oxidation, or poor weathering. Again, too much pure resin was probably left at the surface for exposure to the elements. A highly filled mortar allows very little of the cured resin to be exposed to the direct rays of the sun.

Large cracks in the overlay may be reflective cracking, a phenomenon in which new cracks form in the overlay directly over the old ones in the base slab. If the base slab is not deflecting and causing the cracks, the binder is either too weak in tension, too rigid, or else the matrix does not have enough resin in its design.

Edge cracking is seen wherever the overlay boundaries have become too lean in binder or lack good finishing detailing such as consolidation and grade control.

Spalling of the overlay alone is normally associated with delaminations and cracking. Rigid binders tend to spall more than flexible ones.

7.2.3 Repair needs due to faulty workmanship and application techniques—Many of the overlay-caused failures can be prevented by knowledgeable applicators if they are attentive to details before and during the PC application. If they are not careful, the following problems can plague the overlay. For the contractor who learns from his mistakes, the symptoms can indicate where more attention is needed on future placements.

Porosity is a common problem in many coatings, particularly in viscous ones that are highly filled. During the mixing process, air is trapped into the viscous binder and matrix. Without good vibration, the air bubbles have a difficult time escaping the matrix before it gels and cures. Those bubbles that do make it to the surface burst and may leave small craters where the bubbles were. The bubbles trapped in the bottom of the overlay at the interface provide little adhesion to the substrate and are possible initiation points of delamination when the overlay is stressed. Those bubbles that are trapped in the middle of the overlay matrix are weak points in the overlay, providing sites for cracking under stress, and they ultimately may provide paths for water and waterborne contaminants and for freeze-thaw, as described earlier.

Tearing is a symptom of poor application technique in monolithic PC overlays. It typically occurs when overly conscientious concrete finishers overwork the surface of the PC overlay as they try to get a very smooth and consolidated finish like that found in concrete floors. In trying to work the surface too fine, the finishers take so much time that the binder polymerizes to a sticky viscous consistency. This material adheres to the trowel, which then stretches the surface, causing tears or even pulling off large portions. Trying to screed a thin viscous overlay too quickly or without enough vibration may also tear the overlay. A good guideline to remember is to put the matrix down quickly, consolidate it, and level it with a vibratory screed, and then leave it alone.

Interlayer adhesion problems occur in broom-and-seed applications of PC almost exclusively because of application mistakes. Sometimes the source of the problem may be as simple as contamination that has occurred between successive resin applications. The contamination may have been brought in by environmental conditions, leeking equipment, trafficking between applications of successive layers, incomplete removal of excess aggregates, and rain or dew from one day to the next. Other sources of interlayer adhesion problems include mixing an inadequate amount of curing agent into the resin, or nonuniform mixing of the resin and cure system.

Wet aggregate is a guarantee of poor bond of the binder to the aggregates as well as an inhibitor in many of the binder systems. Thus, ultimately, it is a source of delaminations, cracking, and spalling.

Priming is often recommended for binder systems that may have wet-out-related problems with certain substrates, or in mortar systems that may not be compatible with the alkalinity of the PCC substrate. Manufacturer's recommendations must be closely followed. Some primers are designed to be cured before covering them with the overlay, and others are to be covered immediately while they still are tacky. Neglecting details here could result in major delaminations after the entire job is finished.

Skinning is a term that describes the loss of patches of material from the top surface of the overlay. In monolithic applications, this is usually the result of over-finishing or improper consolidation techniques that leave unseen voids or cracks under the surface. In broom-and-seed applications, it is the result of poor interlayer adhesion.

Inadequate compaction is a likely cause of delaminations and other overlayment failures. Sufficient vibration is necessary to minimize air bubbles, voids, and resin-rich areas.

Cure inhibition resulting in incomplete cure of the PC overlay may be due to several factors. For improperly catalyzed systems placed in cold weather, polymerization may eventually go to completion when ambient temperatures increase, but many systems will never recover and attain the full design properties expected from normal cure conditions. Uncured residual components may either remain in the matrix or evaporate over time.

Entrapped air due to improper filler selection and mixing results in incomplete cure of methacrylate systems. Excessive finishing can disturb the cure as well, resulting in tacky surfaces.

7.3 Repair methods

7.3.1 Problem analysis and procedures—Maintenance personnel should expect occasional damage to the PC overlay from various sources. An important advantage in the use of a PC overlay is that it is easily repaired, whenever the need arises. A listing of typical failures and
their recommended repair methods is included in the following paragraphs.  

7.3.1.1 **Substrate failure** is frequently the reason for overlay failures. If the overlay only covered the substrate failure without any repair of the cause of the substrate failure, then temporary cosmetics is probably the best the owners can attain. Covering up the problem is not the same thing as fixing it.  

Contamination of the substrate can be a real problem because once the pores of the PCC are filled with PC-incompatible contaminants like chemicals, silicones, oils, or even water, the PC probably will not bond well until the contaminant is removed. First the unbonded PC must be removed, then the contaminant or the contaminated concrete must be removed by sandblasting. For large repair areas, a trial PC repair may then be placed in a small test area so that the bond strength can be quickly evaluated before proceeding with the rest of the repair (Chapter 6).  

**Deterioration** in the form of badly cracked or broken substrates requires that the full extent of the damage be assessed before determining the next course of action. The substrate may be in bad enough condition that replacement may actually be the cheapest alternative. If chloride, sulfate, or other contamination is the cause of the deterioration, every effort must be made to clean out as much of the seriously affected concrete and to get back to solid strong concrete surfaces in the cracks and on the undersides of bridge decks and parking structures.  

For pavement, base failures should be repaired through injection or cutouts and grouting. Once the source of base failures are identified, the damaged substrate can be injected, repaired, or replaced. Often full-depth repairs must be made and cured before overlayments are placed. After proper surface preparation, the overlay can be repaired with the same type of PC.  

7.3.1.2 **Primer failure** as a cause of PC overlay failure can be an expensive experience. Delaminated areas can be spot-repaired by chipping back to soundly bonded PC, the applying a better primer to the cleaned exposed substrate and reoverlaying the delaminated area. This sounds easier than it probably is because poor bond from primer failure usually shows up in large areas, and eventually may debond the entire overlay. Even the stress of chipping back to soundly bonded PC may continue to delaminate the bonded PC. When in doubt about the proper primer selection, more information from the manufacturer and as many technical sources as possible should be obtained; a trial on a small test area should be performed.  

If the primer bond fails, it may be possible to use low-pressure epoxy injection to bond the overlay to the substrate. Extreme care should be taken when doing this to avoid lifting the entire overlay.  

7.3.1.3 **Overlay matrix failures** come with many symptoms. Bulk failures usually mean the matrix has not sufficiently cured or that the aggregates were damp or contaminated. These causes are discussed in detail in Section 7.2.2. The faulty material must be removed and the substrate cleaned for a new overlay. Do not reoverlay until the cause of the bulk failure is determined and corrected. As always, a small test patch may be a good safeguard to prevent recurrence of the same problem.  

**Interlayer failure** symptoms are widespread, light, surface flaking or erosion. After close inspection, it may be possible to determine to what extent the problem still exists under the remaining surface. The unbonded layers should be chipped away, and the lost surface areas should be sandblasted and carefully retreated with the same method as that originally used.  

**Surface failures** usually refer to loss of the top surface aggregates from the binder. It is upon these aggregates that surface friction is based, giving acceptable tough, nonwearing, skid-resistant textures. Once these are lost from the surface, the overlay may wear quickly and the surface may become dangerously slick when wet. A typical cause of this is waiting too long after the resin coating is applied before the aggregate is spread and forced into the surface. Thus, the aggregate never gets embedded deeply enough to be retained by the binder. Also, surface inhibition may have left the top course too soft when traffic was returned to the deck area or pavement. Waiting a little longer or testing a small area for complete cure before exposing the overlay to traffic may prevent this from recurring.  

Fortunately, retexturing the surface usually requires only a light sandblasting, followed by an additional broom-and-seed application to provide the needed friction.  

**Joint failures** and their causes have been described in detail in previous sections. Once the cause of the joint failure is determined (substrate, incompressibles in the substrate’s joints, poor consolidation of matrix at joint edge, poor cure, or an abrupt change of grade) and corrected, the joint failure is cleaned out, sandblasted, carefully reformed, and consolidated with the same PC as the rest of the overlay.  

**Cracking** is a generalized problem caused by many different factors such as: binder failures due to shrinkage or thermal changes (7.2.1.1), wet or low-strength aggregates (7.2.1.2), studded tires (7.2.1.3), previously occurring substrate failures (7.2.2.1), overlay problems (7.2.2.2), and workmanship (7.2.3). The job of finding out what the actual cause is may not be as complicated as it sounds because the size, number, and relative location of the cracks are often indicative of their origins. Studded tire traffic is probably the only source of damage that cannot be corrected, and some reflective cracking may have to be tolerated, filling the crack with rubberized or silicone flexible joint-filling material.  

7.3.2 **Material selection**—Since most of the same PC overlay materials can also be used to repair failures in the PC overlay, the same guidelines for selecting binders and aggregates that are found in Chapters 2 and 3 apply. Talk to commercial PC manufacturers’ technical field representatives and to others who have experience with PC overlays and their repair before ordering PC mater-
ials for patching.

7.3.3 Techniques and tools-The tools and techniques necessary to accomplish most repairs to PC overlays are for the most part basic. Typical PC-repair tool boxes might include a copy of the PC manufacturer’s instructions and MSDS, a wheelbarrow, buckets, large plastic pitchers or beakers, plastic syringes for initiator and promoters, some sheet polyethylene, stirring paddles, screed, rod, pointing trowel, finishing trowel, hammer, coal chisel, and shovels. A small storage tank for clean, dry compressed air may prove useful, too. Also an air compressor equipped with a drier and an oil separator is needed, as is a small sandblast unit.

For large repairs, specialized equipment may be necessary; however, advice from experienced PC overlay applicators should be sought. In addition to PC manufacturers’ technical representatives, many states and provinces have highway department personnel who can direct PC-related questions to reliable experts.

Proper repair procedures include determining the cause of failure, correcting that cause, removing unsound or contaminated materials, sandblasting the bond surface, and repairing it with the correct PC. Specific techniques vary for different failures, different repair materials, and different sizes of repair areas. However, placement of the repair is probably the same as for the original overlay, except that the application of the repair will probably be on a smaller scale (hand-batched and hand applied). It is always best to consult manufacturers before beginning any major repairs.

CHAPTER 8-HANDLING AND SAFETY

8.1 general

The information that follows is meant to present general guidelines in the safe handling and use of PC components, cleanup solvents, and application equipment. It is not intended to provide safety guidelines on the use of PC products. Information on safety and handling of raw materials and PC types covered is for those materials most commonly used in overlays and is not intended to be all-inclusive. These guidelines are not intended to replace manufacturers’ recommendations. This chapter covers safe practices for handling and storing the liquid components of the polymer binders and the aggregates, and it outlines the safe use of tools and equipment. It is the supervisor’s responsibility to obtain and become familiar with manufacturers’ warnings and the MSDS available on all products.

8.2-General hazards

Just as there are proper, safe personal hygiene practices for handling lime, acid, portland cement, etc., there are also precautions that should be observed when handling epoxy, polyester, methacrylate, polyurethane resins, and the materials used with them. A number of different resin binders can be combined with an even greater number of curing agents, hardeners, flexibilizers, fillers, and other chemicals to produce a number of different PC products with various combinations of their unique properties. This versatility that makes overlays so useful also contributes to handling problems for the applicator, since the number and degree of hazardous materials and their combination may vary greatly.

Some typical health problems that may occur to varying degrees when chemical materials are improperly handled are eye irritation, redness, tearing, blurred vision, skin irritation, dermatitis, burns, rashes, nasal irritation, dizziness, nausea, headache, and gastrointestinal irritation. In some instances, sensitization may not occur immediately, and sometimes only after long periods of continuous exposure. Workers should be warned against being careless in thinking they are immune to sensitization. The 16 CFR Part 1500 regulates the labeling of hazardous materials such as resins, their modifiers, hardeners, and curing agents. Individual states may also have labeling guidelines that supplement federal regulations.

Prior to formulating, manufacturing, and installing PC products, it is good practice for all workers and supervisors to be instructed on the proper safe handling practices for chemicals, cured PC waste material, and all related equipment.

8.3-Safe handling of overlay components

Safe practices for handling of PC overlay components that should be put into effect are:

1. Persons handling these materials should be instructed to thoroughly wash their hands immediately afterward.

2. During mixing and applications, persons handling these materials and cleanup chemicals should wear protective clothing (disposable, if possible including gloves, dust masks, aprons, safety glasses, and footwear, as required, to prevent all contact with the skin and eyes. If soiled garments cannot be thoroughly cleaned, they should not be reused.

3. Fumes, vapors, or dust from handling overlay components must be controlled in the work area. In confined areas or where no fresh air movement is available, equipment should be installed so that vapors and dust are pulled away from and not into the breathing zone of the worker.

4. Most liquid components of PC overlays and cleanup solvents are flammable, including their concentrated vapors, and extra care must be taken to prevent them from coming in contact with an open flame source. This is especially important when handling peroxide initiators, since they present a potential for a violent reaction in addition to being a fire hazard.

All peroxide catalysts are decomposition hazards that may explode if not properly handled. Care must also be taken to keep them away from any heat source, such as
steam pipes, radiators, sparks, etc., and from mechanical shocks like impact or friction. It is good practice not to keep more than 1 day’s requirement of peroxide initiator at the job site.


6. Fillers and aggregates are considered hazardous under dusty conditions. In such cases, proper eye and breathing protection such as safety goggles and dust masks or a MSHA/NIOSH-approved dust respirator should be employed when necessary. During manual handling of these materials, one should wear long sleeves and close-weave cotton gloves with tight-fitting wristlets. When pouring fine fillers into a container of flammable liquid, both containers should be grounded electrically to prevent a static electric spark.

8.4-What to do in case of direct contact

8.4.1 Clothing—If chemical contact with a worker’s clothing occurs, the worker should wash skin contact area well and change clothing immediately.

8.4.2 Body—If chemical contact with a worker’s body occurs, the worker should shower immediately with large amounts of soap and water, removing all traces of the contaminant.

8.4.3 Eyes—If chemicals enter the eye, immediately flush the eyes with large amounts of water and obtain medical attention.

8.4.4 Cleaning agents—Use soap and water only to clean the body. Do not use solvents, since they will only dilute the chemical contaminant and possibly promote further skin penetration, causing irritation, itching, or a burning sensation.

8.5-Transferring safely

Liquid components of PC that are flammable should be handled only in areas free of ignition sources and never heated by using an open flame. Peroxide initiators should never be handled or stored near heat sources or sources of contamination. Containers receiving resin components should be cleaned and grounded to prevent static-generated sparks. Containers for transferring fine powders should also be grounded. Areas where liquid transfer is to take place should have adequate ventilation to prevent the accumulation of flammable vapors. Whenever transferring chemical components to new containers, care should be taken to identify them properly, including fixing appropriate warning labels on each container.

8.6-Cleanup solvents

Solvents that are flammable and used for cleanup should be used only in spark-free areas and in containers that are grounded to prevent static electricity. Tools used for cleanup should be nonsparking types. Adequate air ventilation or movement should be present to prevent concentration of flammable vapors. Suitable fire extinguishers, such as carbon dioxide and dry powder for Class B and C fires, should be readily accessible and their method of operation known. Wear goggles and face shields to protect the eyes. Protect skin and clothing with rubber gloves and aprons. Care should be taken in selecting safe solvents to remove resinous products from the skin. Care must be taken to prevent inhalation of solvent vapors. Labels on containers should tell what precautions are necessary when solvents are used. Information indicating health and fire hazards is extremely important. If a solvent is not properly labeled, it should not be used.

8.7-Disposition

Some of the chemical ingredients used in PC binders are generally classified as either hazardous or irritants. That classification includes all waste materials and possibly the cured PC product. Indiscriminate disposal of chemicals is unacceptable and, in most instances, against local, state, and federal regulations. Since disposal laws are frequently updated and vary from state to state and at the municipal level, it is beyond the scope of this publication to provide set guidelines on disposal of PC wastes or waste products. It is important that manufacturers and applicators of PC products become familiar with these disposal ordinances for proper disposal of chemicals and waste PC. Appointment of a coordinator and establishment of a safety plan that will provide for the regular disposal of waste chemicals and products is recommended.

8.8-Equipment

All equipment used for the manufacture or application of PC should be kept in good condition, clean, free of dirt, grease, and other chemicals prior to use and should be immediately cleaned after use. A list of recommended safe cleaning solvents should be supplied by the manufacturer. Mechanical equipment should be operated by spark-free induction motors and be grounded during use. Operators of equipment should be fully instructed in their use, care, and safe operation. In areas of excess noise, operators should use ear plugs.

8.9-Education of personnel

It is imperative that specific recommendations for proper handling, storage, transport, and use of any raw materials and products be obtained from the manufacturer or supplier. These recommendations should also include information on fire fighting and hazardous decomposition products that may form in a fire situation. It should be the supervisor’s responsibility to obtain and become familiar with the MSDS available on all products. Prior to installing PC overlays, it is good practice to have supervisors fully instruct the hands-on operator(s) on the safe handling of these products and all related equipment and tools. Assistance to address emergency situations, in addition to local medical sources, may be found under first aid recommendations section in the MSDS for each product used in PC.
8.10-Safety publications


CHAPTER 9-REFERENCES

9.1-Specified references

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

American Association of State Highway and Transportation Officials
T 237 Testing Epoxy Resin Adhesive
T 277 Rapid Determination of Chloride Permeability of Concrete

American Concrete Institute
116R Cement and Concrete Terminology
224.1R Causes, Evaluation, and Repair of Cracks in Concrete Structures
228.1R In-Place Methods for Determination of Strength of Concrete
503R Use of Epoxy Compounds with Concrete
503.5R Guide for the Selection of Polymer Adhesives with Concrete
546.1R Guide for Repair of Concrete Bridge Superstructures
548R Polymers in Concrete State of the Art (out of print)
548.1R Guide for the Use of Polymers in Concrete

American Society for Testing and Materials
C 33 Specification for Concrete Aggregates
C 42 Methods of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
C 78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
C 136 Method for Sieve Analysis of Fine and Coarse Aggregates
C 192 Method of Making and Testing Cured Concrete
C 293 Test Specimens in the Laboratory
C 531 Test Method for Linear Shrinkage and Coefficient of Thermal Expansion of Chemical-Resistant Mortars, Grouts, and Monolithic Surfacing
C 566 Test Method for Total Moisture Content of Aggregate by Drying
C 579 Test Method for Compressive Strength of Chemical-Resistant Mortars, Grouts, and Monolithic Surfacing
C 580 Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, and Monolithic Surfacing
C 876 Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete
C 882 Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete
C 884 Test Method for Thermal Compatibility Between Concrete and an Epoxy-Resin Overlay
C 1202 Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration
D 412 Test Method for Rubber Properties in Tension
D 638 Test Method for Tensile Properties of Plastics
D 695 Test Method for Compressive Properties of Rigid Plastics
D 696 Test Method for Coefficient of Linear Thermal Expansion of Plastics
D 955 Test Method for Measuring Shrinkage from Mold Dimensions of Molded Plastics
D 1824 Test Method for Apparent Viscosity of Plastisols and Organosols at Low Shear Rates by Brookfield Viscometer
D 2393 Test Method for Viscosity of Epoxy Resins and Related Components
D 2471 Test Method for Gel Time and Peak Exothermic Temperature of Reacting Thermosetting Resins
D 2849 Method of Testing Urethane Foam Polyol Raw Materials
D 3633 Test Method for Electrical Resistivity of Membrane-pavement Systems
D 4263 Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method
D 4417 Test Method for Field Measurement of Surface Profile of Blast Cleaned Steel
E 96 Standard Test Methods for Water Vapor Transmission of Materials
E 303 Test Method of Measuring Surface Frictional Properties Using the British Pendulum Tester
E 950 Test Method for Measuring the Longitudinal
Profile of Vehicular Traveled Surface with an Inertial Profilometer
E 1215 Specification for Trailer Used for Measuring Vehicle Response to Road Roughness
E 1274 Test Method for Measuring Pavement Roughness Using a Profilograph


Better Roads, 1986, “Rehabilitating with Skid-Resistant Surfaced Aluminum Decks,” V. 56, No. 11, p. 34.


Sprinkel, M.M., 1989, “Performance of Multiple Layer Polymer Concrete Overlays on Bridge Decks,” Polymers in Concrete: Advances and Applications, SP-116, American Concrete Institute, Detroit, p. 61.


APPENDIX

Curing shrinkage test*

The apparatus shown in Fig. A.1 employs a Teflon-lined mold with inside dimensions of 3 in. wide x 3 in. deep x 12 in. long (76 x 76 x 305 mm) and a removable device for measuring strain.

The strain-measuring device consists of two detachable prongs that are attached to a horizontal rod in a manner that allows one prong to slide freely along the rod on roller bearings, while keeping the other prong fixed. Attached to the top of the fixture is a displacement transducer that is fixed to the horizontal rod in such a manner as to measure the movement of the free prong. The transducer’s wires are connected to a data logger or chart recorder for recording the movement of the prong. A barrel-micrometer is also affixed to the top of the free prong to enable zeroing and calibration of the displacement transducer. Initially, a lock pin holds the free prong rigid for placement into the fresh mortar or concrete. The entire strain-measuring device is suspended above the filled mold, with only the ends of the prongs submerged into the matrix.

The matrix is mixed and placed into the mold either immediately before or immediately after the strain-measuring device is properly positioned (whichever is easier for the specific matrix). Once the device is properly positioned and the disturbed matrix stops flowing to equilibrium, the lock pin is pulled and the transducer is zeroed with the micrometer. The recorder then tracks the shrinkage of the matrix for whatever period of time required.


Curing shrinkage test: The Ohama and Demura method

This method utilizes a 3 x 3 x 12-m. (76 x 76 x 305-MM) specimen cast in a Teflon-Lined mold. Each end of the mold has a 1-in. (25-mm) diameter circular depression cut in the Teflon. A 1-in. (25-mm) diameter circular brass fitting with a stem is placed in the depression with the stem extending through a hole in the end of the mold (Fig. A-2). A displacement transducer is then placed on each end of the mold and, with a small spring, is kept in contact with the brass stem. Thus, shrinkage can be measured simultaneously from both ends. Stopcock grease is applied to the stem to minimize friction. The two direct current displacement transducers (DCDT) are connected in a series, and the results are printed on a chart recorder. Mixing and placing of the PC is accomplished as previously discussed.

Guillotine shear test

General--Currently there are no ASTM standards available for measuring the direct shear strength of concrete materials. The procedure used at BNL (Brookhaven National Laboratory) utilizes a simple guillotine fixture to obtain comparative shear values for concretes, polymer concretes, etc.

Equipment--Specimens are held in a fixture, as shown in Fig. A-3.

Load is applied with a 60-kip (300-kN) compression or universal testing machine.

Specimens--Specimens are either cast or cored to fit the fixture and are prepared according to ASTM C 192 or ASTM C 42.

Procedure--Measurements are made of the specimen diameter to the nearest 0.01 in. (0.25 mm). An average of two measurements made at right angles to each other in the shear area of the specimen is used to determine the diameter. Load is applied to the shear fixture through a spherical bearing block. The load rate is 2000

*This test method was originally proposed by DuPont de Nemours Chemical Company. This test has been submitted to ASTM C 9 for review.
psi/min (14 MPA/min). The shear strength then is calculated

\[ S_s = \frac{P}{A} \]

where \( S_s \) is the shear stress, \( P \) is the maximum load carried by the specimen, and \( A \) is the average cross-sectional area of the specimen.

Ashing procedure for determining the proportions of constituents in polymer concretes—Equipment needed

- 4.5 lb (2.0 kg) capacity (or greater) balance sensitive to nearest 0.001 lb (0.5 g).
- 8.5 fl. oz. (250 ml) crucibles [approximately 4-in. (102-mm)] diameter x 2.5 in. (64 mm) with lids.
- long-handled tongs, or crucible holders
- muffle furnace (min. 5 in. W x 4 in. H x 5 in. D (127 mm x 102 mm x 127 mm)

- small electro-magnet (only if PC matrix contains steel fibers or metallic fillers)
- sieve shaker and stack consisting of No. 4 (4.76 mm), No. 16 (1.00 mm), No. 50 (300 mm), No. 100 (150 mm), and No. 200 (75 mm) sieves

Test specimen shall be at least 1.5 x 1.5 x 1 in. (38 x 38 x 25 mm) prism cut and ground from a larger piece.

1. The specimen shall be cleaned and dried and then placed into a clean dry crucible. The crucible shall then be covered with its porcelain lid and then weighed to the nearest gram.

2. Place the covered crucible into the muffle furnace and turn up the temperature control to 1000 F (538 C). Let the furnace run for 6 hr. Then allow furnace to cool to approximately 400 F (204 C) and remove the crucible from the furnace with tongs. Allow the crucible to cool to room temperature with the lid on. Weigh (and record to the nearest unit) the combined crucible, lid, and remains of the PC.

3. Using the electromagnet, remove all the metal fibers and metallic fillers from the matrix, recording these weights (masses).

4. Sieve the remaining material and record the weight of each fraction retained on the sieves.

5. Weigh the empty crucible and its lid.

Calculations

a. Subtract the weight in item No. 2 from the weight in item No. 1. This gives the resin weight.

b. Subtract the weight in item No. 5 from the weight in item No. 1. This gives the weight of the PC specimen.

c. The resin weight divided by the PC weight is the resin weight percentage.

D. The weight from item No. 3 divided by the PC weight is the steel fiber or steel filler weight percentage.

e. Each sieve fraction weight divided by the PC weight is the weight percent of that retain.

This report was submitted to letter ballot of the committee.