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16. ABSTRACT

Beginning in 1954, the Materials and Research Department of the California Division of Highways initiated research and investigation into the possible applications of the epoxy resins to highway construction and maintenance. Our work has been confined to the epoxy resins derived from epichlorohydrin and bisphenol A, which today account for the bulk of the epoxy resins being marketed. At that time these resins were relatively new on the American market and their utilization in the construction field was virtually unknown.

The types of epoxy resins formed by the condensation of epichlorohydrin and bisphenol A are numerous, ranging from very fluid liquids to relatively high melting point solids. By themselves these resins have little utility until they are polymerized or cured through the action of curing agents which are added just prior to use. When cured, these resins form thermosetting polymers having remarkable chemical resistance, strength and adhesion to most clean surfaces.

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MATERIALS & RESEARCH DEPARTMENT

EPOXY RESINS AS A STRUCTURAL REPAIR MATERIAL

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Herbert A. Rooney*

Beginning in 1954, the Materials and Research Department of the California Division of Highways initiated research and investigation into the possible applications of the epoxy resins to highway construction and maintenance. Our work has been confined to the epoxy resins derived from epichlorohydrin and bisphenol A, which today account for the bulk of the epoxy resins being marketed. At that time these resins were relatively new on the American market and their utilization in the construction field was virtually unknown.

The types of epoxy resins formed by the condensation of epichlorohydrin and bisphenol A are numerous, ranging from very fluid liquids to relatively high melting point solids. By themselves these resins have little utility until they are polymerized or cured through the action of curing agents which are added just prior to use. When cured, these resins form thermosetting polymers having remarkable chemical resistance, strength and adhesion to most clean surfaces.

The first epoxy resins investigated were liquids of the higher viscosity range (135-195 poise at 25°C) unmodified with flexibilizers and cured with low viscosity polyamines, i.e.,

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ethylenediamine and diethylenetriamine. Interest first centered on the making of white reflectorized pavement markers formulated with epoxy resins or polyester resins and cemented to the highway surface with epoxy adhesive in the gaps of the traffic paint stripes in order to provide delineation of the highway lanes during wet weather at night. Photographs Nos. 1 and 2 show a typical installation of this type with the exception that the painted stripe has been completely replaced by reflective units on a concrete highway. The photographs are day and night views respectively, of these reflective pavement markers. Present data indicate these markers, when properly installed, will have a service life in excess of 20 years on portland cement concrete highways when subjected to normal traffic wear. The phenomenal adhesion of the epoxies stimulated a research program to find adaptations of the epoxy resins as a structural repair material for use on concrete highways and bridges. Because of their high cost (about $8.00 per gallon for the raw material) they were not considered competitive as a primary construction material. The sole function of these resins from our standpoint, was their utilization for repair work on conventional structural materials or applications where there were no other known low cost materials which would perform satisfactorily, or because of traffic conditions during repair work, no other material could be used.

As indicated previously, our earliest formulations involved the use of unmodified epoxy resins to which inert fillers were added. The resultant mixtures were cured with low molecular weight volatile polyamines and produced brittle products. These products were not practical for field mixing by untrained personnel because they involved the addition of critically small amounts of volatile, irritating and caustic curing agents, usually about 10% by weight of the epoxy component. Because of the brittleness of the unmodified epoxy systems and their impractical mixing ratio with polyamine curing agents,various flexibilizers were investigated which would not only produce a more flexible product but would in addition provide a more favorable mixing ratio with wider tolerances for field application.

The flexibilizers first studied included the liquid polyamide and polysulfide polymer types. The polyamide type by virtue of its chemical structure, is a curing agent which imparts a degree of flexibility and shock resistance to the cured epoxy. The polysulfide polymer type modifier requires the use of a third component or curing agent. In order to provide that not more than two liquid resin components would be used, a search was made for an effective curing agent which would dissolve in the polysulfide polymer and thereby produce a combination flexibilizer and curing agent in a single package which could be used to cure the liquid epoxy to the solid state. The curing agents incorporated into the polysulfide polymer were the tertiary amine type represented by dimethylaminomethyl phenol and 2, 4, 6 -tri (dimethylaminomethyl) phenol. Formulations were designed in which the liquid epoxy resins could be used with the liquid curing agent flexibilizers in the more favorable ratios of 1 to 1 or 2 to 1 by volume. The polyamide and polysulfide polymer modifier curing agents had the additional advantage in that they were relatively non-volatile with little or no irritation of the mucous membranes and eyes characteristic of the more volatile polyamines.

Epoxy mortars and concretes are formulated with sand and aggregate in which the water and portland cement are replaced by an epoxy binder. The cured products, depending upon the formulation, will frequently have compressive and tensile strengths in excess of 12,000 and 2,000 psi respectively. Rates of cure of these mortars and concretes are directly related to the ambient temperature and type of curing agent used. The time for complete cure varies between 15 minutes at 212°F to about 7 days at 77°F, about 70 to 80% of the cure occurring in the first 24 hours at the latter temperature. By use of an epoxy resin formulation corresponding to the California Division of Highways' Specification 61-F-28, epoxy mortars and concretes used as repair materials on highways will normally have sufficient strength to bear traffic in about 4 hours at 77°F. At temperatures below 50°F, the cure is very slow and at very low temperatures it ceases. When it is contemplated using these materials at low temperatures, cure may be speeded by the application of external heat by means of infrared lamps or hot air convection ovens. Direct flames must not contact the epoxy mortar because the epoxy binder is organic and will burn. When mixed in large masses the epoxy mortars and concretes must be mixed and placed immediately, the time varying between 15 minutes and 1 hour at 77°F depending upon the curing agent used. Since the reaction of the epoxy resin with the curing agent is an exothermic chemical reaction, the heat generated in larger masses causes a chain reaction which speeds the cure. In the California Specification 61-F-28, it is recommended that the mortars and concretes be mixed and in place within about 15 minutes. Not more than about 5 gallons of mortar or concrete should be mixed at one time and the mixing equipment between batches should be cleaned or flushed with an aromatic solvent such as toluene or xylene.

Because of their high cost, ranging up to $300.00 per cubic yard depending upon the size of the aggregate used, epoxy mortars and concretes can be justified for repair work only where cheaper conventional materials are not satisfactory. Examples of such justification are where high strength must be developed quickly such as on concrete highways open to traffic where a lane may not be out of service for more than a few hours, or where thin repair sections are applied and portland cement concrete would not adequately cure. Epoxy mortars do not shrink as do portland cement concrete mortars.

When used for repair work, the epoxy materials must be applied to surfaces which have been first thoroughly cleaned of all oil, grease and dirt. In California, we recommend sand-blasting or mechanical abrasion of the old concrete to expose a fresh surface.

Types of Epoxy Repairs

Repair of portland cement concrete can be achieved either by the application of epoxy mortars or by the bonding of fresh concrete to old concrete with an epoxy-polysulfide adhesive corresponding to California Specification 61-F-28, the latter application being valid only where the fresh concrete is at least one-inch in thickness and having a slump of not more than two inches. For bonding new concrete to old concrete the application rate of the epoxy adhesive ranges between 25 and 40 square feet per gallon depending upon the roughness of the old concrete surface. The bond in both types of repairs is stronger than that existing in the old concrete. This phenomenon whereby new concrete could be successfully bonded to old concrete by an epoxy-polysulfide adhesive was discovered in the Materials and Research Department Laboratory of the California Division of Highways in 1955 and since has been adopted nationwide as a successful procedure. It is more advantageous economically to use the epoxy adhesive as a bonding agent for welding new concrete to old concrete in lieu of using an epoxy mortar where the section to be repaired is one-inch or more thick and the rate of cure of the repaired surface is not an important factor. Furthermore, this procedure presents a better appearance than does an epoxy mortar repair which, no matter how expertly placed, looks like a "patch work" job, the color not completely blending with that of the old concrete.

Limitations of Epoxy
Mortars in Cold Climates

In the Fall of 1960 an epoxy mortar overlay was placed on a section of a new concrete bridge near Kingvale on U.S. 40 in the Sierra Nevada Mountains to bring the deck of the bridge up to grade where a large dip existed. In the Spring of 1961 it was observed that large sections of the bridge deck surface to which the epoxy mortar had been applied, broke loose carrying with them about one-inch of the underlying concrete deck. There was no loss of adhesion of the epoxy mortar to the concrete. This phenomenon had not heretofore been noticed because all previous epoxy mortar repairs to highways surfaces were made in the valley and coastal areas of California where winter temperatures rarely are lower than 25°F, whereas, at Kingvale temperatures as low as -10°F occur. During preliminary investigation of this epoxy failure on the Kingvale Bridge, it was felt that the portland cement concrete was at fault. However, cores taken from the bridge deck indicated that the concrete complied with specifications in all respects. Laboratory investigation was initiated to determine the effect of freeze-thaw conditions on various epoxy mortar overlays on portland cement concrete. Concrete blocks one-foot square and four-inches thick made of 7-sack concrete were coated on one face with 1/2-inch thick layers of various epoxy mortar mixes. After complete cure of the epoxy topping the blocks were placed in a cold room at an average temperature of -5°F for 16 hours and removed to a room at 77°F for 8 hours. These cycles were repeated several times. Failures in the concrete similar to that which occurred on the Kingvale Bridge usually became evident with cracks developing in the concrete about one-inch below the epoxy mortar at the end of the first or second cycle in many of the formulations. This is shown in Photograph No. 3.

In the epoxy mortar formulations tested, the ratio of sand by loose volume to epoxy resin varied between 2/1 and 4.6/1.

At the lower aggregate/epoxy ratio, three formulations did not cause rupture of the concrete. Two of these were not practical for use. The cure rate of one mortar was too slow at 77°F for use where a road must be opened to traffic within a few hours unless external heat were applied to accelerate the cure. The other cured mortar was too soft and had a very low compressive strength. The third formulation, a modified coal tar epoxy marketed under the trade name of Shell Guardkote 140, passed the freeze-thaw cycles at both an aggregate/resin ratio of 2/1 and 4.6/1.

Another mortar which failed at an aggregate/resin ratio of 2/1 did not rupture the concrete when used at an aggregate/resin ratio of 4.6/1. However, this latter mix produced a relatively dry mortar which in some cases might result in poor adhesion to the underlying concrete surface because of inadequate wetting.

The concrete failure when subjected to freeze-thaw cycles is attributed to the coefficients of expansion of the epoxy mortars tested, which varied between 3 to 5 times or more than that of portland cement concrete depending upon the type of epoxy resin formulation and the ratio by loose volume of aggregate to epoxy. This results in excessive tensile stresses being set up in the concrete because the epoxy mortar overlay contracts 3 to 5 times that of portland cement concrete when the temperature drops to sub-zero levels. Mortars formulated with the 2/1 aggregate/resin ratio which passed the freeze-thaw cycles without rupturing the concrete did so because the stresses developed were partially relieved by the plastic flow of the mortars at low temperatures. Mortars having a 4.6/1 aggregate/resin ratio which passed the freeze-thaw cycles and which failed at an aggregate/resin ratio of 2/1 where the same epoxy system was used, did so because the larger amount of aggregate reduced the thermal coefficient of expansion. It thus appears that the amount of aggregate used is a critical factor in the case of most epoxy systems, except that of Guardkote 140 in which there is sufficient plastic flow at low temperatures. There may be other curing agents than those tried which would pass the freeze-thaw test described without rupture of the concrete.

When new concrete was bonded to old concrete with epoxy-polysulfide polymers, failures did not occur at low temperatures. This may be attributed to the fact that the epoxy bonding layer was only 40 to 70 mils thick. This is illustrated in Photograph No. 4.

Epoxy Formulations Used by the California Division of Highways

The California Division of Highways uses four basic epoxy formulations in three of which the complete compositions are specified. The fourth type is a modified coal tar epoxy type which is adequately defined by its physical and chemical properties. These formulations comprise:

1. An epoxy-polysulfide binder, unfilled, for use in epoxy mortars in areas not subject to sub-freezing temperatures and for the bonding of new concrete to old concrete. This is a two-component system in which the mixing ratio of epoxy to polysulfide-curing agent is 2 to 1 by volume.

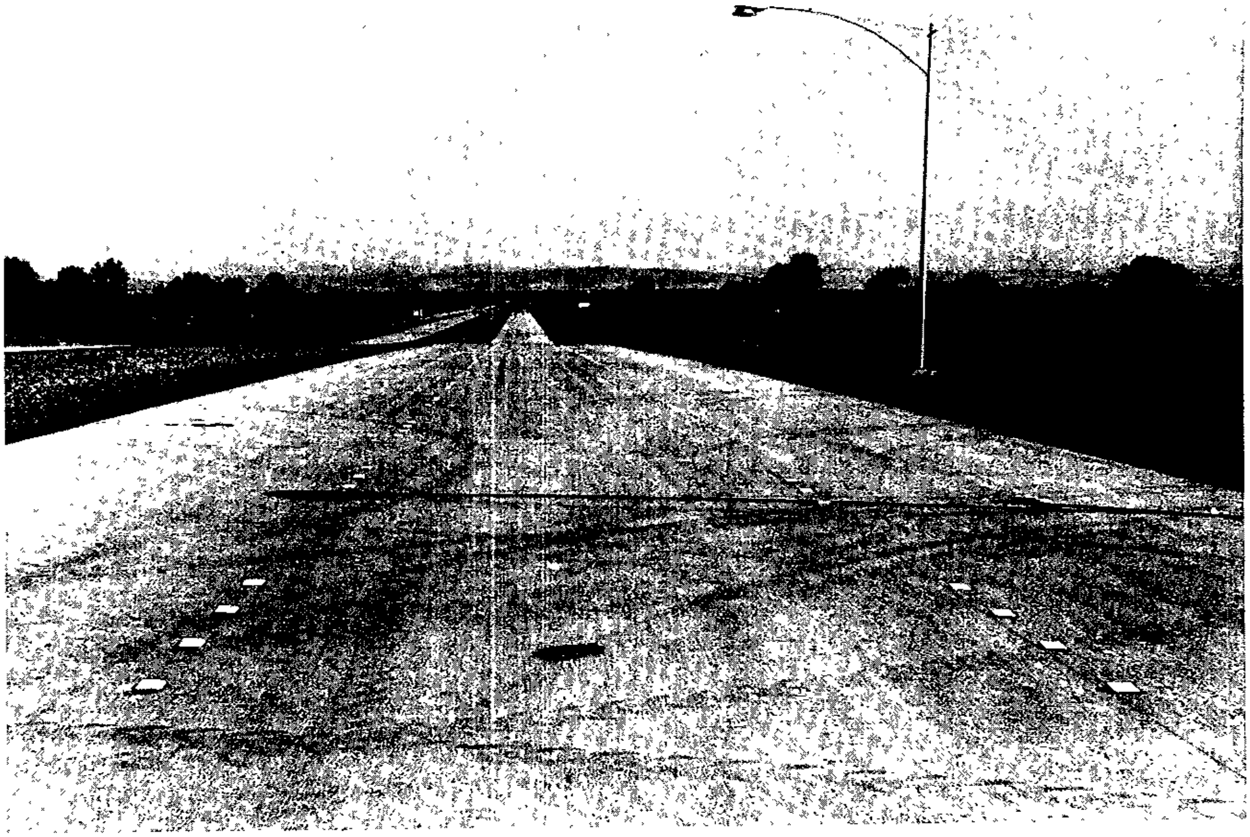
2. A slow setting epoxy-polysulfide binder containing a relatively non-settling and easily redispersed inert filler for use in bonding extruded portland cement concrete curbs to asphaltic concrete. This is a two-component mix with a mixing ratio of 2 to 1 similar to Formulation No. 1.

3. A two-component epoxy-curing paste in which the components are mixed 1 to 1 by volume prior to use. This type is of value in the making of small repairs or in the cementing of reflective pavement markers in place where a "buttery" consistency, non-flowing product is desired.

4. A two-component epoxy-coal tar formulation corresponding to Shell Guardkote 140 for use in epoxy mortars in cold climates or in

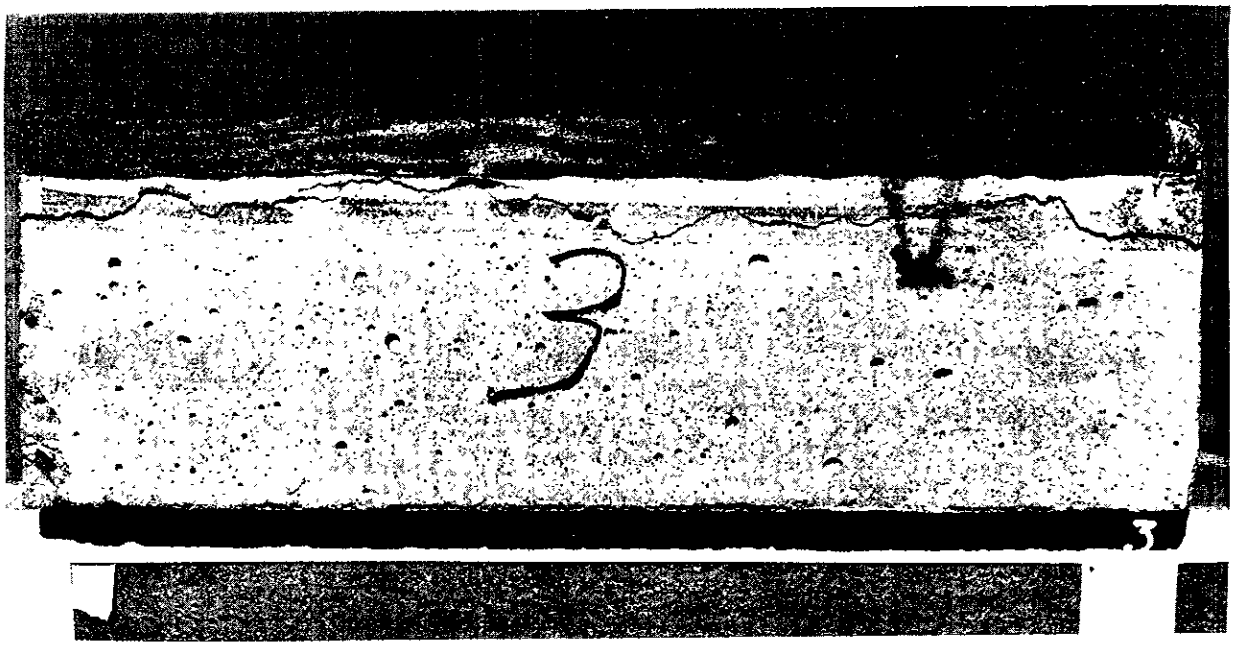
applications where a black color is not objectionable. This material is being used in conjunction with alundum grits to skid-proof a solid steel deck bridge over Ulatis Creek on U.S. 40 near Vacaville.

The California Division of Highways prefers, when possible, to develop compositional type specifications whereby the quality and quantity of the raw materials in products being used on State jobs can be rigidly controlled by its own Laboratory. When such specifications are developed by the Materials and Research Department Laboratory, they have been first thoroughly tested in practical use.

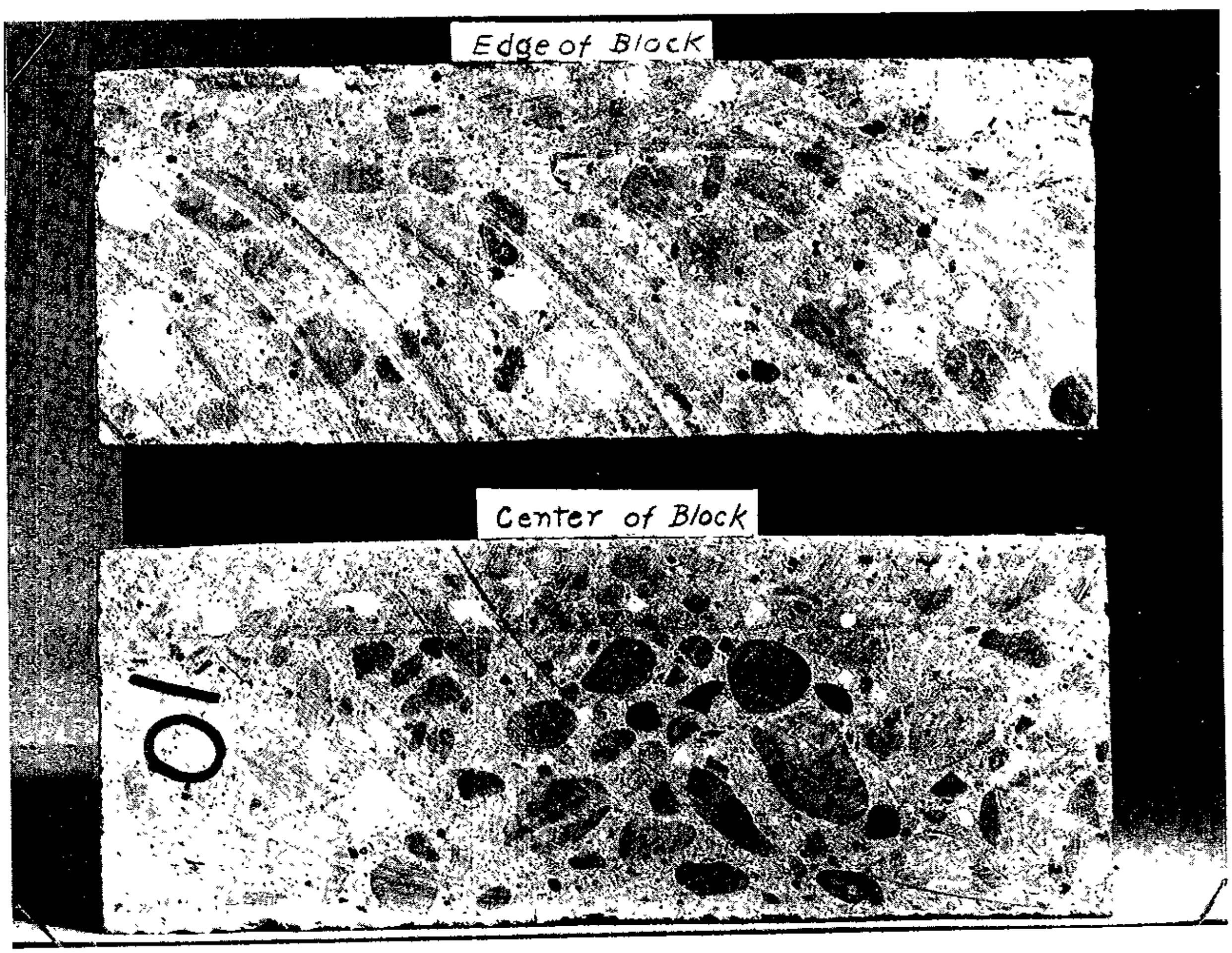


Photograph No. 1

Photograph No. 2



Photograph No. 3



Photograph No. 4