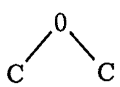
PAPER SP 21-1

The name, origin, history, and development of epoxy resins over the last 20 years are described. While early developments made use of the properties as adhesives, electrical insulation, and protective coatings, these resins are now used extensively in the building industry. In order to use the epoxy, the components of the resin and hardener must be well mixed and then the resulting liquid gradually gets warm, solidifies, and cools to form a hard, infusible solid.

Epoxy Resins

By G. M. SCALES

☐ "Epoxies" are a group of synthetic resins ranging from low-viscosity solventless liquids to high-melting-point solids. The name for this group--"epoxy"--has its origin in the Greek description of the chemical symbol for the epoxy group which is



Thus "epoxy" is derived from the word "epi" meaning "on the outside of" and oxygen which, when the words are combined, describes the portion of the oxygen atom in the molecular structure.

Epoxy resins were known for a long time before practical ways of using them were discovered by P. Castan in Switzerland in 1938 and similar work was in progress by S. Greenlee in the United States.

These functional epoxy groups can be designed as part of other chemical groups in many ways, but the most usual way is to make the epoxy from intermediates derived from oil. These intermediates, known as Epichlorhydrin and Bisphenol, are "cooked" together in a long and complicated process, at the end of which an epoxy resin results (Fig. 1-1). The ratio of Epichlorhydrin to Bisphenol largely controls the type of resin produced. For example, the higher the ratio of Epi to Bis the lower the viscosity of the final resin and the lower its molecular weight. An epoxy resin made this way would be described as a "condensation product of Epichlorhydrin and Bisphenol A."[1]

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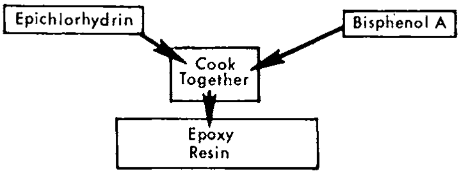

FIG. 1-1 THE MAKING OF AN EPOXY RESIN

The basic epoxy resin most often used in the construction industry is a light amber-colored liquid about the viscosity of heavy motor oil. This liquid will remain a liquid almost indefinitely. To use it as an adhesive, a hardener must be added. This hardener combines with the epoxy resin and changes it from a liquid to a solid. This change is due to a chemical reaction when the hardener combines with the epoxy resin. To accomplish this reaction effectively, the hardener must be adequately dispersed in the epoxy. This is why so much attention[2] is paid to thorough mixing. Just casual mixing is not enough because every particle of hardener has to connect and join with its epoxy counterpart. A perfect mixture will harden into a solid with each molecule firmly attached to the next. If the mixing is not perfect, there will be weak spots where the molecules are not firmly attached to each other; the result is somewhat like a chain-link fence with some of the links cut (Fig. 1-2). These spots are weaknesses where failure can begin. Correct mixing is therefore vital to the success of using an epoxy.

The process of setting, together with the terminology most often used, is illustrated in Fig. 1-3.

The principal properties and characteristics of epoxy resins are:

(1) High strength adhesion to almost every material

(2) Very low shrinkage during cure

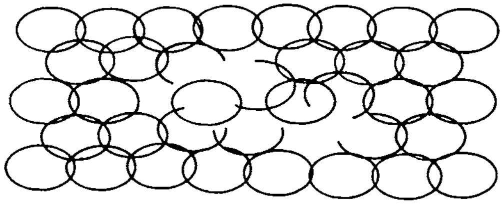

FIG. 1-2 WEAK SPOTS DEVELOP WITHIN THE MOLECULES WHEN THERE IS INADEQUATE MIXING

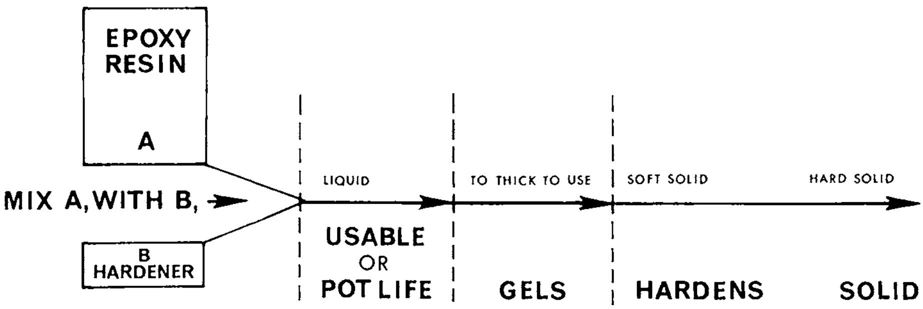

FIG. 1-3 THE PROCESS OF SETTING

(3) Exceptional dimensional stability after cure

(4) Natural "gap filling" qualities

(5) Thermosetting (it will not melt)

(6) Resistance to most chemicals

(7) Good electrical insulation.

There are other properties such as fatigue resistance, creep resistance, and the ability to withstand thermocycling that also are of great interest to engineers.

A good example of what an epoxy can be made to do is shown by its use in the construction of the present supersonic bomber fleet. The composite construction of the aircraft is made possible by the extensive use of an (epoxy) adhesive. It is not difficult to imagine the extremes of temperature, high and low, as well as fatigue and other factors which this adhesive must withstand both on the ground and in the air. Epoxies are in everyday use in the construction of television sets, radios, and other electronic equipment; epoxy primers are used for automobile and appliance finishes. The new one-piece automotive battery is put together with an epoxy. Thirty percent of the stained-glass windows made in the United States are of glass embedded in epoxy. Even solvent-resistant paint rollers are epoxy bonded. It is hard to find an item that does not have an epoxy somewhere in it.

Use of epoxies in building and construction began in the mid-1950's when epoxy was first used as a concrete bonding adhesive. Since then it has served many functions but most of the volume goes into concrete bonding, patching, floor toppings, crack sealing, and bridge-deck sealing.

REFERENCES

1. New Jersey Turnpike Authority, "Standard Specifications," Third Edition, 1965, p. 210.

2. ACI Committee 403, "Guide for Use of Epoxy Compounds with Concrete," ACI JOURNAL, Proceedings V. 59, No. 9, Sept. 1962, pp. 1127-1128.

PAPER SP 21-2

This article describes the work done by the Materials and Research Department of the California Division of Highways, since 1954, in adapting epoxy resins to the maintenance and repair of concrete highways and bridge decks. It discusses how the high coefficient of thermal expansion of cured epoxy mortars, which causes portland-cement concrete over which the epoxy mortars are applied to rupture in tension, may be neutralized by the formulation of epoxy mortars having high creep values at sub-zero temperatures. The first use of adhesives of the epoxy-resin type to bond new portland-cement concrete to old portland-cement concrete was made by the Materials and Research Department in 1954 and is described in this article.

Epoxies in Concrete Construction and Maintenance

By H. A. ROONEY

☐ As early as 1954 the California Division of Highways, Materials and Research Department, became interested in the use of epoxy resins as an adhesive for the cementing of raised traffic-line markers to highway surfaces. At that time the Department initiated a research program for better delineation of traffic-lane lines at night in wet weather. It had long been observed by motorists that during periods of moderate to heavy rainfall at night, water tends to accumulate on the pavement to a depth sufficient to cover and obscure the beaded-painted center-line traffic stripe.

As an approach to solving this problem, the Department installed raised reflectorized white "buttons," made of epoxy resin, 4 in. in diameter and 3/4 in. high, the shape corresponding to the outer segment of a sphere. These markers were cemented to the highway surface in the gap in the painted stripe with an epoxy adhesive.

The excellent adhesion of these markers to portland-cement concrete prompted the Department to investigate the possible adoption of epoxy resins to the maintenance and repair of concrete highways and bridges. Accelerated tests initiated in September 1954 indicated that the life and adhesion of these markers would be about 20 years if they were installed in lane lines on portland-cement concrete pavements. It was realized

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early that the epoxy resins, because of their high cost, could not be considered as a primary construction material in competition with portland-cement or asphaltic concrete. Their important function concerns repair work on concrete structures where no known cheaper material will give the desired performance.

In highway and bridge repair work, epoxy resins are used in two different ways. In some applications aggregate and epoxy are mixed and the epoxy mortar is used as a patching material. In other applications the epoxy is used as a bonding agent for the welding of new or old concrete to old concrete.

Epoxy mortars are normally used where the volume of material is not large and where rapid curing can be obtained, even when the mortar is troweled to a feather edge. The repair of potholes and spalled joints on portland-cement concrete highways and bridge decks is an excellent example for the use of epoxy mortar especially where a lane cannot be closed to traffic for more than a few hours. The rate of curing of the epoxy mortar is directly dependent on the ambient temperature. In cold weather, small patches of mortar can be easily heated artificially to provide a rapid cure.

Epoxy mortars, when fully cured, have compressive and tensile strengths far in excess of that of portland-cement concrete. Their coefficients of thermal expansion are more than five times that of portland-cement concrete, the ultimate value being determined by the ratio of aggregate to binder. This excessive linear thermal expansion is detrimental unless it is compensated by sufficient creep (plastic flow) at low temperatures to offset the internal strains resulting when the epoxy mortar is used as an overlay on concrete. With insufficient creep at low temperatures, the epoxy mortar will rupture the underlying concrete in tension, failure not occurring at the bond line but in the underlying concrete. The Materials and Research Department observed these phenomena a few years ago when an epoxy bridge-deck patch placed in the high Sierra Nevada mountains, where the winter temperatures sometimes are -10 F, ruptured the underlying concrete about one in. below the bond line. This condition was subsequently duplicated in the laboratory with various epoxy mortars placed as overlays on concrete blocks and, after curing, subjected to freeze-thaw cycles between 77 F and -10 F. The epoxy binder mixes which were designed to have sufficient creep at low temperature did not rupture the concrete. Modified coal-tar epoxies and aromatic high-boiling petroleum-oil modified epoxies exhibit adequate creep when sufficient plasticization is used. In the summer of 1964 California placed epoxy overlays on 34 bridge decks in the high Sierra Nevada mountains on Interstate Highway 80. The object was to restore the top surface of the badly eroded concrete bridge decks in an area where tire-chain and snow-plow action is very severe and where salt is used for de-icing. The epoxy material used on these bridges was a gray petroleum-oil modified system conforming to a performance specification. It was applied at a rate of 3 lb per sq yd by means of a Broyhill machine, and sand in excess was manually applied to the binder immediately following the application of the binder. The Materials and Research Department has since developed a compositional specification for a petroleum-oil modified epoxy which is currently being tested on sections of portland-cement concrete highway in the mountain and valley areas to determine its durability under various climatic and traffic conditions.

Aromatic-oil modified epoxies which are pigmented gray to match the color of concrete darken on exposure to sunlight. This is a characteristic of these materials which, although not detrimental to the performance of the overlay, might be somewhat objectionable from the aesthetic standpoint. The compositional specification binder material has a tensile strength of 1,000 psi minimum, a tensile elongation of 75 percent minimum, a Shore D hardness of 50 minimum, and when mixed with 4 parts by volume of ASTM C-190 Ottawa sand has a compressive strength of 2,000 psi. The creep characteristics at low temperatures are sufficient to prevent rupture of the underlying concrete. Creep on the epoxy is measured by standard laboratory test methods, both in the unfilled state and when combined with aggregate as an overlay on concrete. Current investigation is being directed toward the use of non-discoloring alkyl benzene hydrocarbons used in conjunction with coupling agents to provide compatibility with the epoxy resins.

In 1954, the late Dr. E. D. Botts, former Senior Chemical Testing Engineer for the California Division of Highways, Research Laboratory, discovered that certain epoxy adhesives would bond new portland-cement concrete to old portland-cement concrete. A formulation developed by the author containing an epoxy-polysulfide polymer cured with tris (dimethylaminomethyl) phenol has been used nation-wide since 1957 for this purpose. The old concrete is first thoroughly cleaned by sandblasting or jackhammering, and the new concrete having a slump not greater than 2 in. is placed at a minimum thickness of one in. over the epoxy bond layer. The epoxy is applied at a rate of 25 to 40 sq ft per gal. The new concrete must be placed immediately over the applied epoxy before the latter has achieved an initial set. This technique not only is less costly than the use of epoxy mortar or epoxy concrete but also the surface presents a better appearance in that it blends in with the rest of the portland-cement concrete structure. The new portland-cement concrete should, of course, be thoroughly moist-cured. In cases where a traffic lane cannot be closed for more than a few hours, the use of an epoxy mortar or epoxy concrete would be required for surface patches.

Severely spalled expansion joints on the San Francisco-Oakland Bay Bridge were repaired in 1957 with epoxy concrete and have to this date been successful. The repair work was started about 10 o'clock each morning and the lanes had to be opened to traffic by 3 o'clock that afternoon. Prevailing low temperatures (55 F to 60 F) on the bridge necessitated the application of external heat to hasten the curing of the epoxy concrete. This heating was accomplished by placing channel irons over the repaired joints and heating the channel irons with propane torches. The hollow air space in the channel irons heated the epoxy mortar by convection with no danger of burning the mortar.

It must be emphasized that epoxy resins must be judiciously used in the repair of concrete structures. They are not intended to be a "cure-all" and should not be used where cheaper satisfactory conventional materials can be employed. When the correct epoxy-resin system is used and properly applied, results are usually very satisfactory.

PAPER SP 21-3

Widespread acceptance of epoxy surface treatments for pavements has been limited in part by problems associated with pinholing, poor surface appearance, and sheet detachment. Recent laboratory and field investigations promise to improve this situation markedly by use of 20 to 40-mesh rounded aggregates to stop pinholing, development of mechanical sand-spreading equipment to improve appearance, and improved techniques for deck preparation to obtain better adhesion. In addition, new application techniques permit one-step placement of pre-mixed epoxy mortars in 3/8-in. lifts, which offer numerous advantages in increased wear, improved wetting of both deck and aggregate, and greater structural integrity of the overlay treatment. These new techniques appear to be adaptable to even very large contracts. Despite existing problems, the protection afforded by epoxy treatments, together with the combination of thin courses and long life, continue to indicate a permanent place for these treatments in the highway industry.

Epoxy Surface Treatments for Portland Cement Concrete Pavements

By W. R. McCONNELL

☐ In the past 10 years the use of epoxy-resin binders in surface treatments for portland-cement concrete pavements has grown from a gleam in the epoxy producers' eye to a multi-million dollar highway maintenance program. This paper describes successes and failures in this program and explores the future for these unique materials in light of some recent research on application technology.

WHY EPOXY BINDERS

Highway agencies first became interested in epoxy resins back in 1954. At that stage the idea was to use their well-known adhesive properties and high strength characteristics to bond small, sharp aggregates to slick roadway surfaces for the purpose of improving skid resistance.[1,2] During field evaluations, other useful properties of the epoxy binders were quickly recognized,

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namely: (1) excellent film-forming properties; (2) low moisture and moisture-vapor transmission; and (3) good chemical resistance. Investigating the practicality of utilizing these properties to solve the increasingly serious problem of portland-cement concrete deterioration, particularly in bridge decks,[3] then took preference over de-slicking.[4] By 1958 most state highway agencies in this country were evaluating epoxy seal coats as protective sealing surfaces on bridge decks.

In spite of the highway industry's keen interest in solving the problem of concrete deterioration, these new products still had difficulties to overcome. Material costs of the epoxy binders were sufficiently higher than conventional portland-cement or bitumen binders to require special attention to the economics of their use. Not only was it important that the surface treatment incorporating epoxy resins perform better than those with conventional products but also they had to perform far better to justify their expense.

This economic hurdle, however, was crossed during the field testing period, not only because epoxy seal coats out-performed useful conventional products but also because in many cases conventional surface treatments are not considered adequate. For instance, on bridge decks and in toll booths which have an abnormally high traffic count conventional seal coats, slurries, and thin sand asphalt treatments wear rapidly and must be replaced frequently. Here the cost of replacement and the inconvenience to the public of lane closings limit their usefulness. Thick asphalt pavements require raising of expansion joints, drains, and curbs and increase the dead load by a significant amount.[5] In addition to these structural, elevation, and longevity problems, with thick asphalt overlays highway engineers at this time were beginning to