

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE

109

HIGHWAY USES OF EPOXY
WITH CONCRETE

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM **109**
SYNTHESIS OF HIGHWAY PRACTICE

HIGHWAY USES OF EPOXY WITH CONCRETE

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TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C.

OCTOBER 1984

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

*By Staff
Transportation
Research Board*

This synthesis will be useful to materials engineers and others seeking guidance on the use of epoxies with concrete. Detailed information is presented on the formulation, mixing, handling, placing, and limitations of epoxy.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Highway agencies are using epoxy for many different purposes including bonding and sealing concrete, filling cracks, anchoring bolts, and coating reinforcing steel. This report of the Transportation Research Board contains information on recommended properties and environmental limitations for epoxies and epoxy mortars for specific end uses.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Adrian G. Clary, Engineer of Maintenance, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

Information on current practice was provided through responses to a questionnaire by many highway and transportation agencies in the United States and Canada. Their cooperation and assistance are gratefully acknowledged.

HIGHWAY USES OF EPOXY WITH CONCRETE

SUMMARY

Epoxy has been used on highways since 1954 when it was used to bond traffic buttons to pavements. Since then it has been used to bond concrete, to seal concrete, to provide a skid-resistant surface, to fill cracks, to anchor bolts, to coat reinforcing steel, and for many other purposes. Most agencies have used epoxy for some purpose; anchorage, crack repair, coated reinforcement, and adhesive applications have been the most widely used.

Results of using epoxies have varied depending primarily on the application involved. Incompatibility with the concrete and failure to follow manufacturer's instructions were the causes of many early problems. As adhesives, epoxies have done well in attaching pavement markers and for bonding new concrete to old. For surface sealing, epoxies have not been successful where the seal is directly exposed to traffic; some success has been reported on other surfaces, such as pier caps. Nor has epoxy been particularly successful when used as a skid-resistant surface; most agencies that have tried this no longer use it.

Most agencies report success with use of epoxy mortar or epoxy concrete for patching spalls and potholes. Crack repair is another area where epoxy has been used with good results, particularly where injected into inactive structural cracks. More recently, most agencies have begun to use epoxy-coated reinforcing steel in bridge decks; although this use is still being evaluated in some states, others report that it is performing well. Epoxies have also been used successfully to set anchor bolts and as bedding for bearing plates.

The use of epoxy on concrete requires clean, sound surfaces and, except when using special epoxy formulations, the surface must be dry. The concrete should also be within the temperature range required for the epoxy that is to be used and should remain within that range during the curing period. Mixing of an epoxy should be done in accordance with the formulator's instructions.

An epoxy is formed by mixing a resin with a curing agent. Many different resins and curing agents are available as well as many modifiers (diluent, plasticizers, fillers, etc.) that can be added to the epoxy system. However, for highway uses with concrete one resin is used almost exclusively and only a few curing agents are used. The type and amount of curing agent and modifier used affects the properties of the cured epoxy system. Among the properties that are affected are viscosity, cure rate, shrinkage, flexibility, plasticity, thermal expansion, strength, and appearance.

Specifications and tests for epoxies have been devised by AASHTO, ASTM, ACI, and several states. For the most part, these are performance specifications. Except for a very few highway agencies, formulations are made by suppliers to meet performance specifications. This practice will probably continue until information is available that will enable highway materials personnel to do their own formulation with confidence of success.

More and simpler information is needed on epoxy products and their behavior—preferably in easily understood handbooks. In addition, research is needed to develop further information and instructions for use of the relatively few formulations that are commonly used with highway concrete.

INTRODUCTION

Epoxy resin was brought to the attention of the highway industry in its intense activity of construction, maintenance, and repair during the years immediately following World War II. The material, discovered only a few years before that war began (1), had properties that were very attractive to the industry. It was an excellent adhesive, it had good strength and durability, and it appeared to be workable and adaptable to the needs of highways.

The first application of epoxy to highways in the United States was by the state of California in 1954 when it was used to bond traffic buttons to pavement (2). A search of literature shows that its use has expanded since that time to include use as:

- (a) manufacturing material for traffic markers;
- (b) binder for traffic markers, broken pieces of concrete, and new plastic concrete to old concrete;
- (c) waterproof surface sealer, membrane, and thin epoxy-mortar overlay;
- (d) skid-resistant surfacing for slick pavement;
- (e) binder for aggregate to produce epoxy concrete and mortar for concrete patches and overlays;
- (f) crack filling and jointing material to prevent leaks;
- (g) structural bond for crack repair, including delaminated concrete pavements and bridge decks;
- (h) bolt, pipe, dowel, and reinforcing bar anchorage in formed and drilled holes;
- (i) additive to portland cement concrete to reduce water absorption;
- (j) coating for reinforcing steel to prevent corrosion;
- (k) adhesive for bonding shear connectors for composite beam action;
- (l) joint material for precast concrete elements; and
- (m) adhesive for bonding flat steel to concrete.

Despite the popularity of epoxy in highways, there have been many problems associated with the material. Not much was known about its properties and behavior at the beginning, and it was not always used properly in light of what was known. Experience, service histories, and research have developed information that enables the industry to make far wiser use of epoxy, but there are still problems that need solving before the material can be used to its best advantage.

This synthesis reports on past and current uses of epoxy with concrete on highways. Problems and successes in its use are discussed and a section is devoted to epoxy as a material. Standard tests and specifications in the use of epoxy have been published by the American Society for Testing and Materials (ASTM), the American Association of State Highway and Transportation Officials (AASHTO), and the American Concrete Institute (ACI). These are cited in Appendix A. Current specifications for uses of epoxy of three state departments of transportation (California, North Carolina, and Ohio) make up Appendix B of this synthesis. Some of these specifications are

compositional, and some are performance types. These specifications might be helpful to a user not having a specification in determining the general characteristics needed of an epoxy for a particular application.

SURVEY ON HIGHWAY USES OF EPOXY

A questionnaire was sent to highway agencies to gather information on their experiences in the use of epoxies. The questionnaire was mailed to each of the United States and to the Canadian provinces. Responses were received from 39 states and 4 provinces. In addition to tabulated information asked for in the questionnaire, a number of the agencies sent their specifications on epoxies. Some of those specifications appear in Appendix B.

A tabulated summary of responses to the questionnaire is shown in Table 1. The totals, and corresponding percentages, shown in the various columns do not always show the agreement that one would expect. For instance, the totals of columns c and d should be equal to the values in column a. And the number of agencies reporting good performance (column e) does not generally agree with the number that continues to use an application (column c). These non-agreements are due in part to discrepancies in responses to the questionnaire. Other differences are due to changes in practice of the user, or other reasons.

The questionnaire did not call for information on quantities of epoxy used in the various categories, and a high or low number of users in a particular category makes no implication of the quantity used.

The uses made of epoxy by the responding highway agencies are tabulated according to the number of users in Table 2. More agencies use epoxy for anchoring dowels, pipes, bolts, and the like in holes (Item G in Table 1) than for any other purpose. Of the 40 agencies reporting on this item, 39 have used epoxy for this purpose at one time or another, and 37 continue the practice.

At least 82 percent of the reporting agencies have used epoxy for the top six items in Table 2, and at least 76 percent of those users continue to do so. It is interesting to note that bonding of traffic markers to pavements, the earliest of all highway uses of epoxy, continues to be among the top in effectiveness and popularity. The greatest complaint concerning it involves the damage inflicted by snow-removal equipment.

All 38 of the agencies reporting the use of epoxy-coated reinforcing steel (the latest application of epoxy with concrete) continue to use it and are satisfied with its performance. This use of epoxy in highway practice lacks the experience record of some of the earlier uses, but it shows promise of being very effective in combatting damage caused by corrosion of reinforcing steel.

The remaining four of the top six items are shown to be effective in repair and maintenance and are very widely used.

There is a relatively wide gap in use between the top six items and the lower 14, although a number of the latter are shown

TABLE 1
USES OF EPOXY WITH HIGHWAY CONCRETE

Application	Responses to Survey ^a					
	Have used		Continue to Use		Performed Well	
	Yes (a)	No (b)	Yes (c)	No (d)	Yes (e)	No (f)
A. Adhesive						
(1) Traffic markers	35	5	30	4	28	5
(2) Broken pieces of concrete	11	27	10	0	9	1
(3) New (plastic) concrete to old concrete	36	4	35	1	34	1
B. Waterproof Surface Seal						
(1) Penetrant	24	16	17	6	14	7
(2) Membrane	18	21	7	9	7	8
(3) Thin overlay (~1/2-in. thick)	12	27	2	7	1	6
C. Skid Resistant Surfacing	17	21	2	13	1	9
D. Patch for Spalls						
(1) Primer coat for concrete	22	17	16	2	15	0
(2) Epoxy mortar	33	7	25	5	27	3
(3) Epoxy concrete	17	21	10	7	10	3
E. Structural Crack Repair						
(1) Epoxy injection	38	2	36	1	31	1
(2) Mortar	19	18	19	0	17	0
F. Joint or Crack Sealer	21	18	18	3	17	3
G. Anchorage for Bolts, Pipe, Re-bars	39	1	37	1	35	1
H. Binder for PCC Overlay	13	28	9	3	9	0
I. Additive to PC Concrete to Decrease Permeability	1	39	0	1	0	0
J. Epoxy-Coated Re-bars	38	3	38	0	35	0
K. Bonding of Shear Connectors for Composite Action	2	36	0	2	0	2
L. Joint Material for Precast Concrete	14	26	13	0	13	1
M. Structural Bonding of Steel Flats or Plate to Concrete	8	30	6	1	5	1

^aFrom a survey of highway agencies; total responses: 39 states and 4 provinces.

to be quite effective in service. The last two items in Table 2 have been used by so few agencies and have been so ineffective that no measurable benefit has come from them.

TABLE 2
APPLICATIONS OF EPOXY RANKED BY NUMBER OF USERS

Item (Table 1)	Application	No. of agencies that have used	No. of agencies that continue to use
G.	Anchorage for bolts, pipe, re-bars	39	37
E.(1)	Structural crack repair: epoxy injection	38	36
J.	Epoxy-coated re-bars	38	38
A.(3)	Adhesive: new (plastic) concrete to old concrete	36	35
A.(1)	Adhesive: traffic markers to pavement	35	30
D.(2)	Patches for spalls: epoxy mortar	33	25
B.(1)	Waterproof surface seal: penetrant	24	17
D.(1)	Patches for spalls: primer coat for PC concrete	22	16
F.	Joint or crack sealer	21	18
E.(2)	Structural crack repair: mortar	19	19
B.(2)	Waterproof surface seal: membrane	18	7
D.(3)	Patch for spalls: epoxy concrete	17	10
C.	Skid resistant surfacing	17	2
L.	Joint material for precast concrete	14	13
H.	Binder for PC concrete overlay	13	9
B.(3)	Waterproof surface seal: thin overlay ~1/2-in. thick	12	2
A.(2)	Adhesive: broken pieces of concrete	11	10
M.	Structural bonding of steel flats (or plate) to concrete	8	6
K.	Bonding of shear connectors for composite beam-slab action	2	0
I.	Additive to PC concrete to decrease permeability	1	0

DISCUSSION OF HIGHWAY USES OF EPOXY

PREPARATION OF CONCRETE SURFACES

There are a number of requirements that must be met if an epoxy treatment of concrete is to perform well. One of these requirements is a clean, sound concrete surface to which the epoxy is applied. Concrete must be sound for strength and durability, and its surface must be clean for good penetration and adhesion. Surface preparation is an extremely important item in the use of epoxy, and it must be done properly for good service.

A brief discussion of procedures for preparing the concrete surface to receive epoxy is given below, but the user should refer to detailed instructions in ACI publications (3,4) or other authoritative publications.

All loose material and accumulations of grease, oil, soil, and the like should first be removed. All unsound and contaminated concrete should then be located and removed. Concrete saws and mechanized chipping hammers are generally required for removing delaminated concrete and shaping up potholes. This is generally followed by sandblasting or scarifying the entire surface to remove the soiled and possibly unsound thin outer layer of concrete. Both scarifying and sandblasting work well on decks, but the scarifier cuts deeper to remove the top 0.10 in. (2.5 mm) or so of material that is the least sound and most heavily impregnated with oil and grease. Other surfaces are generally prepared well by sandblasting. Muriatic acid is sometimes used to clear away efflorescence and chalk. Oil and grease spots that remain after this should be scrubbed with water and strong detergent. Compressed oil-free air and water, if necessary, should be used finally to remove all loose material and dust from the surface. All free water should be removed and the surface should be dry and frost free. High-pressure air and vacuum are helpful in clearing cracks of water and loose material. If the concrete cannot be dried, a moisture-insensitive epoxy must be used to ensure adhesion to the concrete. A surface is considered to be dry enough if no water vapor appears on the concrete side of clear plastic that has been tightly sealed against the concrete for 24 hours (5).

Reinforcing steel that is exposed in an area to be treated should be cleaned by sandblasting, and it should be coated with liquid epoxy before repairing the concrete. In a patch or overlay, the steel is coated at the time that the primer coat is applied to the concrete.

Dowels, bolts, pipe, and the like that are to be anchored in epoxy should be thoroughly cleaned of oil and other substances that might prevent the epoxy from bonding to them. Loose scale can be removed by sandblasting, just as in the case of reinforcing steel.

Because temperature is very important in curing, the treated concrete surface must be within the applicable temperature range of the particular epoxy to be used. It should remain within that range during an acceptable curing period. This temperature might be different for different epoxy formulations, but generally the epoxy is not applied to concrete below 60°F (16°C). The concrete and epoxy material can be heated, but care must be

taken that a uniform condition is maintained over the entire treated surface.

Summer temperatures above 90°F (32°C) (3) can be of concern because pot life decreases as temperature increases, and the higher curing temperatures cause higher shrinkage when the system cools. It is far better to work with epoxy under conditions where natural temperatures are correct for the material than it is to attempt extra control conditions.

PREPARATION OF THE EPOXY

The constituents of an epoxy system are determined by a formulator who designs it to fit the particular purpose. The two basic components, resin and curing agent, mixed with their diluents and modifiers, if any, are packaged separately and must be mixed on the site. Fillers, such as sand and gravel, are sometimes added to these basic components to fit job requirements. It is absolutely essential to a successful job that all components be properly and thoroughly mixed. The formulator's instructions should be followed. Aggregates should be dry and within an acceptable temperature range for proper curing. ACI (3) has information on this.

ADHESIVES

Traffic Buttons

Epoxy provides the strong, durable bond needed to affix traffic-lane markers and reflectors onto the pavement surface. It has been a very successful material for this purpose, and it continues to be widely used. Epoxy for this purpose is easy to apply because only a small area needs to be cleaned on the pavement. The quick-setting characteristic of epoxy allows traffic to move over the site within a few hours. The adhesive bond is strong enough to withstand traffic abuse, and it maintains its effectiveness through all kinds of weather.

Epoxy used for bonding traffic markers should have excellent adherence, high strength, little or no sag, and generally it should cure fast to be able to receive traffic without long shut-down time. California DOT is a successful user of epoxy and has written compositional specifications for a number of epoxies used with concrete. Its specifications for rapid set and standard set epoxies for bonding pavement markers (8040-21M-07 and 8040-21M-09) and method of testing (California Test 425, 1978) appear in Appendix B, which also contains North Carolina's specification (Type 6).

Snow-plow damage to the markers was given in the survey as a disadvantage of epoxy-bonded markers, and at least one state had stopped using epoxy bonding for this reason.

Broken Pieces of Concrete

Excellent bond between broken pieces of concrete can be provided by epoxy, yet only 11 highway agencies reported using

it for this purpose. A patch of new material is probably considered to be easier to install, more effective, and possibly better adapted to the purpose than a repair by bonding the pieces back together. If the pieces have not been separated from the member, bonding by crack injection, discussed later, has proved to be effective.

New Plastic Concrete to Old Concrete

Epoxy is frequently used for bonding fresh concrete to hardened concrete, especially in maintenance work. Thirty-six agencies have used it as a bonding agent for these concretes. Almost all of the agencies found that it performed well, and most of them continue to use it in this way.

The old, or hardened, concrete surface is prepared to receive the epoxy as outlined earlier. A coating of epoxy, up to about 15-mils (0.4mm) thick, is then applied to the prepared surface. It is given enough time to become tacky, then the fresh concrete is added (3). It is important that the concrete be added while the epoxy is still sticky, otherwise no bond will develop. This bonding agent is widely used in this way for patching spalls and potholes in concrete and for placing bonded concrete overlays.

California Specification 8040-21M-08, "Epoxy Resin Adhesive for Bonding New Concrete to Old Concrete," and its method of testing, California Test 428, covering these applications appear in Appendix B. The specification covers one type for use at 60°F (16°C) and higher temperatures and another type for temperatures below 60°F. Other specifications include North Carolina Type 3 (Appendix B), ACI 503.2, and ASTM C 881.

WATERPROOF SURFACE SEALS

The application of epoxy to the external surface of concrete for the purpose of waterproofing or dampproofing has been made for a long time with various degrees of success. Some of the earliest uses of epoxy served the double function of waterproofing and resurfacing rough concrete surfaces. Of the three treatments: penetrant, membrane, and thin overlay, Table 1 shows the first to be the most successful and most widely used.

Epoxy used as a surface seal must have the ability to withstand the temperature cycles encountered without debonding or cracking. When it is used on pavement surfaces or bridge decks, it has the additional requirement of withstanding traffic wear. No epoxy has yet been formulated that serves without fault under these conditions, although some have stood up for a year or more. Today, epoxy as a waterproofing material is used predominantly on surfaces not subjected to wheel wear. Substructure surfaces, such as pier caps below pavement joints, are frequently coated with epoxy to protect them against runoff water from the deck.

Figure 1 shows three applications of epoxy on a bridge deck. The thin coating and mortar overlay are in direct contact with tire traffic, and experience has shown that traffic wear is serious. The epoxy application shown in Type III in Figure 1 has a far better chance for a long life than the other two types.

Penetrant

A penetrant system must have a very low viscosity to enable it to penetrate into the concrete through the pores and minute

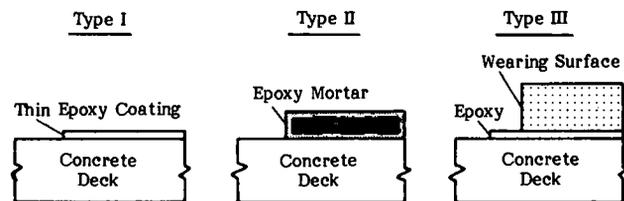


FIGURE 1 Types of epoxy overlays on bridge decks.

surface shrinkage cracks. To do this, the epoxy system is cut back with solvents to approximately 20 to 30 centipoises (0.02 to 0.03 Pa·s) at 25°C (77°F) (5).

The solvent volatilizes soon after the system is applied, and a thin film of epoxy is left as a coating on crack and pore surfaces. The installation, to function to the best advantage, should permit moisture vapor to pass through to prevent a pressure buildup that could blister the sealer and eventually break it away. It is best applied to dry concrete when the temperature is constant or dropping as a precaution against blistering. Application is by roller, brush, or sprayer.

The survey shows that epoxy penetrant has been used by 24 of 40 respondents. Seventeen of those users continue its use, although only 14 indicate that it has performed well.

Membrane

Epoxy used as a seal coat for concrete bridge decks and pavements was among the early applications of the material (6-9). Although the failures of such systems have not been as freely reported as their installations, several of these early treatments were not long-lived. It took only a matter of months to a year for these surface seals to unbond, crack, wear away, and further deteriorate.

In studying the types of failure, it was concluded that the primary cause of failure was the different coefficients of thermal expansion for epoxy and the concrete to which it was bonded. Epoxy has a coefficient of thermal expansion of 4 to 8 times that of concrete, and, if unmodified, it is brittle and easily cracked on an active road surface. The addition of flexibilizers, including coal tar (9), and fillers to give the epoxy greater capacity for elongation and to reduce the thermal expansion led to improved results. Stresses caused by volume changes are discussed in Chapter 3.

A single seal coat of epoxy will develop pinholes, but these can be sealed with a second coat. Cover stone or abrasive grit is applied to the epoxy while it is still tacky to provide skid resistance for vehicles (10).

Epoxy coatings installed by Oklahoma DOT have been monitored for condition since installation in 1975 and 1976 (11). At the end of 1977, all of these coatings showed less than 500 ohm resistance, which was considerably higher than the sections that were not coated. Core tests showed that the moisture content of coated concrete was 25 percent less than uncoated. The field appearance of the coatings was good at the 1977 inspection.

Table 1 shows that epoxy membranes are not popular with highway agencies. Only 18 agencies had ever used them, and only 7 continue to use them. The future of epoxy as a membrane sealer does not appear to be bright.

Thin Overlay—About ½-in. (13-mm) Thick

The initial use of epoxy for this purpose was aimed at providing a new surface and a water seal at the same time. Seasonal freeze-thaw cycles that caused surface scaling of non-air-entrained concrete road slabs and bridge decks left many miles of concrete rough and sometimes polished. Furthermore, the corrosion resulting from deicing salt penetration to reinforcing steel caused extensive spalling in many areas.

Sand-filled epoxy used as a thin overlay to the damaged concrete appeared to be a potential solution and detailed instructions for installations are available (4,12). However, these overlays generally have proved to be a poor solution to the surfacing and waterproofing problem. They were quickly worn away by traffic, especially where chains and studded tires were used; they came unbonded because of differences in thermal expansion, and some of them were slick when they were wet. Only 12 highway agencies have used these overlays. With the exception of one particular material reported by the New York DOT, none have performed well.

SKID-RESISTANT SURFACING

Concrete surfaces that have become polished by traffic can be made resistant to skidding by bonding an abrasive grit to the wearing surface with epoxy. To do this, the concrete surface is thoroughly cleaned; the epoxy is applied and spread thin with a squeegee, and the surface, when it becomes tacky, is broadcast with sand or grit to provide the skid resistance. Such a treatment is usually intended to serve as a waterproofing membrane (discussed earlier) as well as a skid-resistant surface. It can also serve to smooth the surface. Epoxy broadcast with natural sand as a skid-resistant wearing surface has records of wearing badly and becoming slick in the tire paths. More recently, aluminum oxide grits broadcast on epoxy are giving good service. These grits do not wear or polish as much as sand, and they stay in place better. They are, however, more expensive than natural sand. The epoxy must be flexible because if it is brittle it will debond in cold weather.

A detailed report on epoxy mortar surfacing on a steel-grid bridge in Ohio showed that an application in 1973 had an average wear in wheel paths of 0.10 in. (2.5 mm) after 31 months of service (13). Skid-resistance measurements showed a rapid deterioration during the first year of service but improved gradually to acceptable levels after about 4½ years of service. The mortar used a blend of aggregates consisting of hard calcined bauxite (> 48%), granite (> 9%), and relatively softer quartzite particles (< 43%) for the intended purpose of increased abrasion resistance from the harder particles as the softer ones wore away.

Seventeen agencies have used epoxy to prepare skid-resistant surfaces for concrete roadways, and two indicate a continuation of the practice. Thirteen of the 17 users have discontinued its use; some of them giving such reasons as wear, debonding, polishing, lost aggregate, and high costs. Only one of the 17 users indicated that these treatments performed well.

The surfaces using aluminum oxide grits have been giving much better service than those using natural sand. Only surfaces using the wear-resistant grits, such as aluminum oxide, and flexible epoxies that can maintain their bond in cold temperatures have any appreciable chance of survival.

PATCHES

One of the most important and most successful applications of epoxy in highway work has been in patching concrete. The epoxy serves as a binder for aggregates in the patch material and for bonding the patch material to the concrete.

California Specifications 8040-01F-01 and 8040-01F-03 (Appendix B) give the compositions of two epoxies used as binders for patch materials. Examples of other specifications for epoxy binders include North Carolina Type 2 (Appendix B); ASTM C 881 Type II, Grades 1, 2, or 3, Class A, B, or C; and AASHTO M 235, Class II.

Potholes and spalls can spread quickly if they are not repaired. They are more prevalent where traffic is dense, which multiplies the problems of repair. The short downtime permitted by fast-curing epoxy makes it an excellent repair material in these cases.

A filler, usually sand and gravel, is used with the epoxy to reduce cost, for wear resistance, and for thermal reasons. It reduces the coefficient of thermal expansion of the patch to make it thermally more compatible with the concrete. The amount of filler that is used depends on its gradation, but it is usually about 85 to 90 percent of the weight of the patch (5). Only sound, durable aggregate should be used.

When the chemical reaction begins between epoxy resin and the curing agent, heat develops. The heat from this exothermic reaction causes a temperature increase in the material and, if the heat is not dissipated, the temperature might build up so high that it will destroy the epoxy (14). Some of the heat is transferred to the concrete and the aggregates in the epoxy patch absorb part of it. Because of this, the temperature change is not as great as it would be without concrete and the filler and the shrinkage caused by that change is correspondingly lower. This reduces the danger of shrinkage cracking of the epoxy. ACI (3) recommends that multiple lifts be used if the thickness of a patch exceeds 5 in. (125 mm) so that the heat build-up is not excessive and to prevent low spots from developing. An illustration of stresses induced by shrinkage and thermal expansion is given in Chapter 3.

Just as in other uses of epoxy, careful attention must be given to surface preparation, epoxy formulation and preparation, and weather conditions in patching (15). Improper consideration of any or all of these could result in a short-lived repair.

Use of epoxy mortar (or epoxy concrete) to patch spalls caused by reinforcing steel corrosion will create a strongly cathodic area (16). This will cause accelerated deterioration of unpatched areas adjacent to the epoxy-mortar patch.

Most of the survey respondents use epoxy for patching concrete; epoxy mortar being more popular than epoxy concrete for this purpose. Table 1 shows that most continue to use both epoxy mortar and epoxy concrete, but the mortar application has been considerably more successful than the concrete.

CRACK REPAIR

Concrete is low in tensile strength both during and after curing and cracks can be found in it wherever it is used in highways. Some cracks cause no concern but others do because they leak or they interfere with structural performance. Those that are exposed to water should be sealed to prevent contamination of the concrete and the reinforcing steel. Epoxy can be used both

as a sealant for leaking cracks and as an adhesive to bond the cracked pieces back together again. It has been used both ways with success. Specifications from California, North Carolina, and Ohio DOT for epoxy injection materials and procedures are included in Appendix B. If crack repair is done on a structure that will be subject to cathodic protection, the epoxy should be conductive.

The most popular use of epoxy in crack repair is in structural crack injection. Table 1 shows that 38 agencies have used epoxy for this purpose and that 36 continue to do so. Almost all of them report that these repairs performed well. A much smaller number use epoxy mortar in crack repair, but all who have used it continue to do so. None of them indicated that epoxy mortar performed poorly in their installations.

About half of the respondents to the survey have used epoxy as a joint or crack seal material. Most of those who have used epoxy in this way have had reasonable success with it, but three of the agencies reported that it did not perform well.

Structural Cracks

Cracks are not planned, they are not wanted, and they are caused by an action that was not anticipated when the concrete was placed. If the action that caused the crack to form persists, it is likely that it will cause other cracks if the existing one is repaired. For this reason, the cause of the crack should be identified before any repair is made. If shrinkage caused it and if that shrinkage is not complete, the repair should be a temporary one or it should be delayed until the shrinkage is complete. If the crack was caused by live-load stresses, the repair could result only in other cracking under continuing live load. The analysis made in determining the source of the crack might call for measures that would relieve the condition as well as those for repairing the crack. Once the cause is removed, by whatever means, the crack can be repaired. The best policy is to repair only those cracks that are inactive (4).

Cracks that are wide enough can be grouted with epoxy mortar using hand tools. The sand in the mortar not only reduces the cost of the material, it also reduces the coefficient of thermal expansion, increases the modulus of elasticity, and stiffens the uncured material making it easier to place. The grout might need support before it cures to prevent it from flowing out of the crack. The walls of the crack must be clean, as pointed out earlier. The side walls of the crack should be primed with epoxy and the mortar should be placed before the prime coat becomes hard. If the walls are thoroughly wet with the epoxy prime coat and the mortar is well compacted in place, the cured material will have the strength to transfer stresses and it will be durable.

Injection techniques can be used to fill narrow cracks down to about 0.005-in. (0.13-mm) wide, and sometimes narrower. This technique forces the epoxy under pressure to fill the crack, coat the surfaces, and bond the surfaces together when cured. This has developed into one of the most successful methods of concrete repair with epoxy.

Epoxy injection requires that the crack be sealed on the surface of the concrete, leaving openings for introducing the epoxy into the crack. An epoxy paste is usually used for this seal. The entry port can be a hole drilled through the seal into the crack or a short tube with its opening spanning the crack. The tube is temporarily stuck in place with contact cement, then bonded

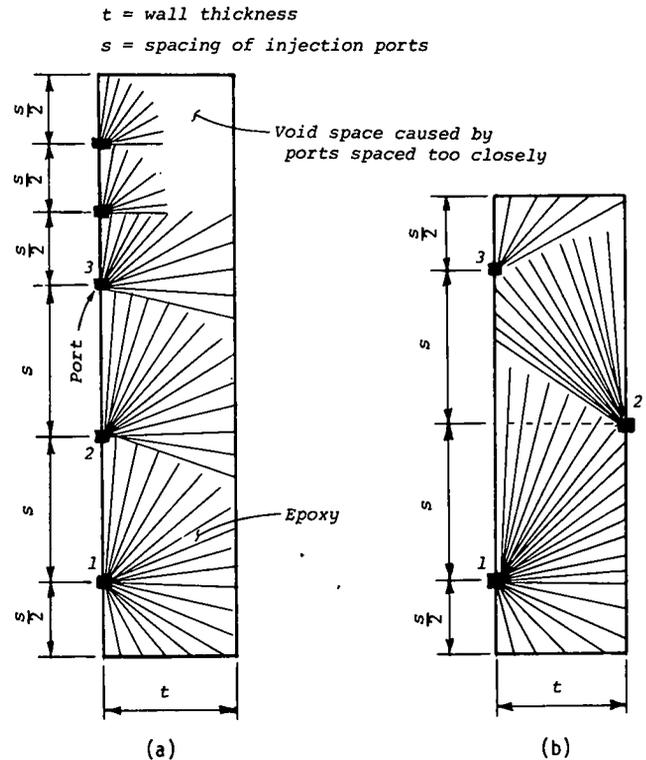


FIGURE 2 Spacing of injection ports on a full-depth crack in a wall: (a) injection ports on one side, $s \geq (t/2)\sqrt{3}$; and (b) injection ports on two sides, $s \geq 2t/\sqrt{3}$.

to the concrete and sealed with the crack surface seal to prevent leakage. Epoxy is injected through the open end of the tube.

A drilled entry port must provide a seat for a gasket on the injecting gun and the hole must be thoroughly cleaned of dust so that it will not block the entry of epoxy. After epoxy has been injected and has cured in the crack, the surface seal is removed from the concrete and the surface cleaned.

The injection-port spacing will depend on the depth of the crack or the delaminated area, the thickness of the cracked slab or wall, the temperature, the viscosity of the epoxy, and the pressure used for injection. If the crack penetrates through a wall or slab and is to be completely filled, the spacing of ports should not be less than the slab or wall thickness. The idealized situation in Figure 2 shows that a lesser spacing would result in voids in the crack. The outlines of a delamination crack should be marked and entry ports be located so that the crack will be completely filled when injected.

The injection pressure should only be high enough to ensure that the crack will be completely filled, because excessive pressure could rupture the concrete. A low pressure, possibly 20 to 30 psi (140 to 210 kPa), might be adequate if a low-viscosity epoxy is used and the crack is not less than about 0.06-in. (1.5-mm) wide. Ports must be spaced closer when pressures are low. For difficult conditions, pressures up to 100 psi (690 kPa) might be needed but care must be taken to prevent damage to the concrete. Usually, pressures under 100 psi are needed (17).

Details covering epoxy injection are given in Reference 4 and typical applications of crack repair by epoxy injection are described by Gaul and Smith (17).

A unique solution to a structural crack problem in bridges where the cracking forces were still active has been developed by the Kansas Department of Transportation (18, 19). Continuous reinforced concrete highway bridge girders developed shear cracks at approximately 45 degrees in regions of high shear adjacent to supports. The Kansas DOT drilled a series of holes at 45 degrees with the deck to cross the cracks at approximately 90 degrees. These drilled holes extended beyond the cracks about 18 in. (460 mm) and dust was removed as the holes were drilled. A special drill with a hollow stem, carbide-tipped vacuum bit, and a supporting stand was developed for this purpose. The bar extended at least 18 in. on each side of the cracks to develop its strength by bond. This system provides No. 4 reinforcing bars at 6-in. (150-mm) centers in $\frac{3}{4}$ -in. (19-mm) diameter holes across the cracks. The bridges have been strengthened by this repair and no relative movement across the repaired cracks could be detected after 17 months of service. Figure 3 illustrates this repair technique.

Continued monitoring showed no relative movement across the repaired cracks after seven years. The technique has evolved into the use of commercially developed equipment. No. 6, grade 60 steel reinforcing bars cut 3 to 4 in. (75 to 100 mm) shorter than full hole depth are now used in 1-in. (25-mm) diameter vacuum-drilled holes. The concrete girders are reinforced from one end of the bridge to the other. Design analysis indicates that this raises the shear-carrying capacity of the girders to about ten percent above the 1981 AASHTO specifications. The as-built condition was as much as 36 percent below those specifications.

In the work by Kansas DOT discussed above, a very interesting phenomenon was revealed in the hardening of epoxy. In laboratory work, a particular epoxy was found to harden rapidly in a plastic beaker. When it was pumped into a hole in concrete containing a reinforcing bar, it took quite a long time to harden. After tests to discover the cause, it was found that much of the heat from the reaction was absorbed by the re-bar. The system was deprived of the heat that accelerated the reaction without the bar and, consequently, the curing time was increased.

Crack and Joint Sealing

Joints are designed and built into concrete structures to absorb calculated movements and to prevent damage to the structure. Sometimes cracks that are not anticipated will develop between the formed joints and act to absorb movements. Both the formed and "cracked" joints are active and subject to water leakage.

Epoxy has been used to seal such joints, although it has less capacity for deformation than some other joint fillers. ACI Committee 504 (20) includes epoxy for use as a joint seal in situations where movement is nonexistent or very small. If it is to be used, the recommendations of that committee should be followed.

Small surface cracks can be sealed by preparing the surface in the same way as for a surface coating, and then applying a coat of epoxy by spray, brush, or roller. The epoxy will either bridge over the crack or penetrate and fill it.

Deeper and wider cracks in a horizontal surface can be filled by routing out the top of the crack to a v- or u-shape and then filling the groove with epoxy. California Specification 8040-01F-02 (Appendix B) is an epoxy that might be used for this purpose. The depth of the groove will vary with crack width. About $\frac{1}{4}$ in. (6 mm) will be satisfactory for smaller cracks and possibly 1 in. (25 mm) for bigger ones (17). The groove serves as a reservoir for the liquid epoxy, which feeds into the crack by gravity until it hardens. It is likely that the full depth will not be filled unless the epoxy has a very low viscosity and a long curing time. If the crack runs all the way through the concrete, the chances are that it is an active crack and measures other than this gravity-fed seal should be investigated.

One report on crack sealing with epoxy that is of particular interest was made on a bridge across the Milwaukee River at Milwaukee, Wisconsin about 1980 (21). Repairs in the counterweight pit were necessary and water leakage through cracks in the concrete had to be stopped before repairs could proceed. It was January, a particularly cold time of the year for epoxy work. The water was stopped by sealing the cracks with a 100 percent solid, water-insensitive epoxy having a viscosity of 156

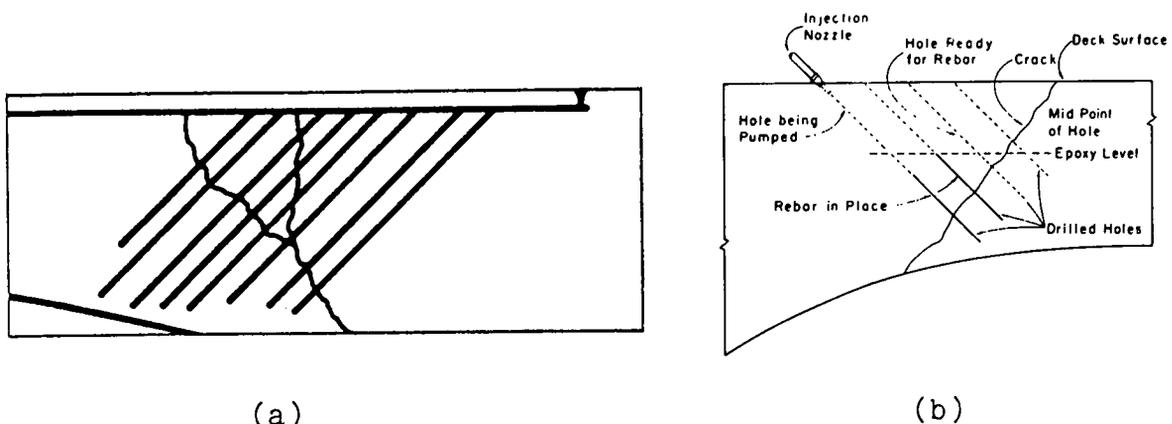


FIGURE 3 Repair of diagonal shear cracks in a reinforced concrete girder by adding reinforcing bars and injecting epoxy: (a) reinforcing bar orientation (4); (b) epoxy level when reinforcement was placed (18).

centipoises (0.156 Pa · s). Holes were drilled on a pattern to half the depth of the walls, and perforated $\frac{3}{4}$ -in. (19-mm) pipes were then inserted into the holes and epoxy was pumped into the pipes. Pressures of 1500 to 3000 psi (10 to 20 MPa) were required. The epoxy was forced into cracks, flowing inward and outward from the perforations until it eventually sealed the concrete. About 6 in. (150 mm) of the inside face of deteriorated concrete was then removed and repairs were made by adding new concrete.

The effectiveness of a crack repair, either for sealing or for stress transfer, should be determined by a leak test or a stress-transfer test. The stress-transfer test is complicated. A good indication of the success of the work can be determined by drilled cores through the epoxy-filled crack. A statistical sample enables one to determine the depth of penetration, the extent to which the crack was completely filled, and how well the epoxy bonded the parts together.

Pulse-velocity measurements are sometimes used in locating cracked and otherwise damaged concrete and in determining the effectiveness of epoxy injection repairs (22). The pulse-velocity technique requires special equipment and highly trained personnel, but it has the advantages of versatility and nondestructiveness.

EPOXY COATING FOR REINFORCING STEEL

Spalling damage, which has been so destructive to reinforced concrete bridge decks, was traced years ago to the corrosion of reinforcing steel brought on by salt used to melt winter ice. Subsequent research found that a coat of epoxy on reinforcing steel would isolate it from chloride-laden concrete and protect it from corrosion (23). It has been the practice for a number of years to coat exposed reinforcing steel in bridge deck patching operations with liquid epoxy (4, 16), but this could not prevent the corrosion that caused the spall in the first place, nor stop corrosion adjacent to the patch.

Precoated reinforcing steel comes to the user ready to install and 38 of the 43 agencies (Table 1) have used it in bridges. All of the 38 agencies that have used it continue to do so and all reported that it performed well or that it was still being evaluated.

Dry-powder epoxy has been used for coating steel pipe since the 1950s (24) and it has been proven to be the best material for protecting bridge deck steel against salt. An epoxy resin that is solid at room temperature is used in preparing the powder. It is brought to a plastic condition by heat and is then mixed with the curing agent. The heat is not high enough to cause a reaction between the resin and the curing agent; thus these two components retain their separate identities during this process. Once the components are mixed, they are brought back to room temperature and become solid again. The solid mixture is then ground to powder in which condition the particles contain the proper amounts of resin and curing agent, as well as any modifiers that might have been added to the mixture.

The reinforcing steel is prepared for the epoxy by sandblasting to a bright finish and then by heating to a desired temperature. This temperature is correct for causing the powdered epoxy resin-curing agent mixture to react. The hot bar passes through a chamber where the epoxy powder is sprayed toward it and, by electrostatic charge, is attracted to the bar. The powder attaches itself to the bar in a uniformly thick layer, the epoxy

reaction begins, and the bar then moves into a heated curing chamber where the epoxy is fused and cured on the bar. The time spent in this chamber permits complete curing and the epoxy becomes a solid, hard, cured, infusible coating on the steel. This coating is some 5 to 12 mils (0.13 to 0.30 mm) thick with few, if any, pinholes (holidays). For all practical purposes, the bar is completely insulated against chloride ions that might find their way into its environment.

The dry-powder coating process has proved to be a very effective one and it permits field handling without serious damage to the coating. Minor damages that do occur are patched in the field with an appropriate liquid epoxy.

The coated bars are supported on nonconductive chairs and they are tied with coated ties to maintain an insulated condition for the bars. The bars are generally used for the top mat steel for bridge decks, but they can be, and sometimes are, used throughout the deck and other elements. They also serve as protective reinforcement in concrete used in structures in a marine environment.

The epoxy coating process is done in a special plant, and it cannot be done at a job site. The coating is far superior to that obtained by using liquid epoxy. Tests have shown that deformed reinforcing bars with epoxy coatings not exceeding 10-mils (0.25-mm) thick develop essentially the same bond as uncoated deformed bars (25).

OTHER USES OF EPOXY WITH CONCRETE

Anchor Bolts

Anchor bolts, dowels, and pipe supports are often set with epoxy in holes formed or drilled for that purpose. The walls of the holes must be free of dust and oil and only moisture-insensitive epoxy should be used with wet concrete. Epoxy makes an excellent material for these uses because of its excellent adhesion to metal and concrete, its very low shrinkage, and its strength, durability, and fast set.

The space between the element and the wall of the hole should be as small as practicable. A non-sag epoxy must be used in horizontal or inverted holes. Both California and Ohio compositional specifications for epoxy used for anchorages appear in Appendix B.

Bedding for Bridge Bearings

Epoxy grout can be used to provide strong and durable bedding for bearing plates. Neoprene bearing pads for beams are sometimes leveled and bonded by epoxy. A filler can be used to reduce creep, sensitivity to temperature change, and cost. A thixotropic agent might be used to stiffen the epoxy and prevent its flowing before gellation occurs.

Bonding Steel Plates to Concrete

External steel plates have been bonded to reinforced concrete beams to increase their flexural strength (26) and, in another case, to increase their torsional strength (27). The flexural application was made to beams in an old concrete building that was being reworked for additional service. The torsional appli-

cation was made to laboratory beams in regions where diagonal tension from twisting forces was high. The applications were successful, but no common application along these lines to concrete construction and none in highways been reported in this hemisphere.

There is understandable caution in using epoxy as the stress-transfer medium in heavy construction joints of this kind. The epoxy and the members joined are individually strong and durable and the effectiveness of the bond has been demonstrated in many ways. But the long-term effectiveness of a load-transfer joint, such as the tensile or shear plates discussed here, has not yet been determined.

Bonding Reinforced Concrete Deck to Support Beams

The transfer of shear stress between the beams and slab of a bridge causes these elements to act as a composite unit, thereby making the system stronger than the sum of its individual parts. A number of cases have been reported in which epoxy was used

to cause that transfer (28–30) but it is not a popular material for this purpose. Only 2 agencies have used it (Table 1) and neither was satisfied with it.

Repair of Bridge Expansion Joints

Chipped, spalled, and fractured concrete is common at the edges of expansion joints in bridges. The expansion joint in the deck slab is particularly vulnerable because it creates a discontinuity in the structure, and it is treated badly by temperature extremes and traffic movement. Epoxy is often used in making repairs to concrete at expansion joints but such repairs require particular care if they are to last (31). Saw cuts are made in the concrete to square off the patch area and to prevent feather-edge patching. All loose concrete, debris, dust, and oil patches are removed as discussed earlier. A primer coat of epoxy is desired to ensure that the concrete surface is completely wet with the adhesive before applying patch concrete or epoxy mortar.

CHAPTER THREE

EPOXY—THE MATERIAL

EPOXY RESIN AND CURING AGENTS

Epoxy is formed by mixing a resin with a curing agent. Many different resins, each having its own distinct structure, are available today. Each of these may be used with a great number of curing agents as well as with many modifiers and diluents (32, 33). The resins and the curing agents are listed by trade names in catalogs distributed by producers. These catalogs, such as Reference 34, give information on properties of the basic components as well as the cured unmodified systems. A number of handbooks and encyclopedia carry information about the resins, curing agents, the uncured systems, and the cured systems (32, 35, 36). Some references give the names of both manufacturers and products (32, 36).

An understanding of the basic system (how the resin and curing agent react with one another, the influence of various properties of the components on the cured system, and the parts played by additions to the mix) is necessary if one is to make the best use of the system. A brief discussion of the components, their behavior, and the parts in the working system is given here. More detailed publications, such as References 34, 37, and 38, give more details that would be useful in formulating a mix for a specific job.

Of the many resins that are commercially available, the one made by epichlorohydrin with bisphenol A in the presence of caustic soda makes up some 95 percent of all used today (35,

39). This resin, diglycidyl ether of bisphenol A (DGEBA), is that used with concrete in highway applications. The information in this report is limited to this particular resin.

The chemical structure of the DGEBA molecule is shown in Figure 4. The terminal elements are the epoxy, or epoxide groups, and the bracketed portion contains the hydroxyl group. Generally, the resin is liquid at room temperature if n , the number of bracketed groups, is less than 1 and solid if n is 2 or more (40). The higher the value of n , the higher the molecular weight, the viscosity, and the hydroxyl value equivalent and the lower the epoxy content equivalent (35).

The resin, to be of value, must be cured or hardened. This is accomplished by mixing it with an appropriate curing agent. A reactive curing agent acts as a link that joins the epoxy groups; a nonreactive agent, a catalyst, causes the groups to react with one another. The chemical reaction binds the groups together in three dimensions to produce a solid system. Once the reaction has begun, it can be slowed down or speeded up, but it cannot be undone (1). The system has essentially no strength until the reaction is complete.

The components can be repeatedly softened by heating, but once cured the system is thermoset and cannot be liquified by heat. High temperatures and repeated heating can break down a cured system, depending on the ingredients and the level of the temperature.

Most of the epoxy used with concrete is cured at ambient

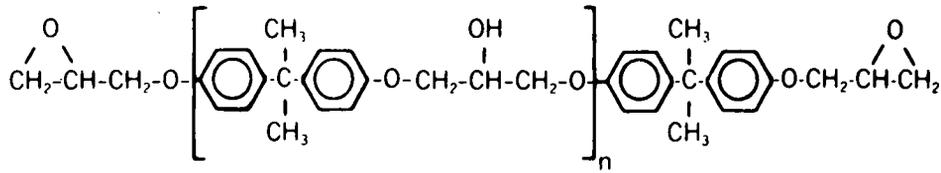


FIGURE 4 Chemical structure of epichlorohydrin-bisphenol A epoxy resin (34).

temperatures in the range of 60 to 90°F (15 to 32°C). Aliphatic amine, polyamide, and mercaptan react well as curing agents in that temperature range (34).

The properties of the cured system are influenced by the type and the amount of curing agent used, as well as by additives that are introduced when the components are mixed together. Heat is generated in the curing reaction and the rate of heat generation varies with the rate of curing. There are no by-products of the reaction. The cured system is thermoset and viscoelastic.

Epoxy lends itself to modification, and its properties can be varied over a rather wide range of values. Schutz (41) in 1971 indicated that with the many different resins, curing agents, flexibilizers, and diluents, over a million different systems could be produced. Only a relative few of these are used with concrete in highway work. One of the reasons for this is that curing must generally be accomplished under ambient atmospheric conditions.

Epoxies used with highway concrete typically have properties within the approximate ranges shown in Table 3, although these can be changed very much by changing the formulation.

MODIFIERS

In addition to the great number of systems that can be produced with different combinations of resins and curing agents, there are a number of modifiers that may be used to change certain properties of the system to best fit the needs of the job.

TABLE 3

PROPERTIES OF TYPICAL EPOXY RESINS USED WITH HIGHWAY CONCRETES

Property	Value	Reference
Specific gravity	1.115	38
Tensile strength	500 to 5000 psi	42, p. 44
Compressive strength	5,000 to 12,000 psi	42, p. 44
Flexural strength	1500 to 5000 psi	42, p. 44
Modulus of elasticity	about 400,000 psi	42, p. 62
Coefficient of thermal expansion (unfilled)	$2.8 \times 10^{-5}/^{\circ}\text{F}$	34, p. 59
Curing shrinkage (linear)	0.13 to 0.35%	34, p. 59
Water absorption (24-hr immersion)	0.1 to 0.5%	33
Application temperature (preferred)	60 to 90°F	42
Pot life	6 min to 5 hr	34, p. 48
Curing time (complete)	1 to 7 days @ 77°F	34, p. 19

Some modifiers are reactive; others are inert. There are modifiers that affect viscosity (during mixing and placing), curing rate, flexibility, plasticity, thermal expansion, strength, appearance, and cost (41, 43). Because of the various roles played by different modifiers, they are listed under separate headings below. Some modifiers block out some of the reactive groups of resin, making the system softer and more flexible.

Diluents

Diluents are used to lower the viscosity for easier handling in mixing and placing the system. In general, diluents lower mechanical properties and resistance to chemicals of the cured system, but because the percentage of diluent is small, the change in these properties also is small (39). Both reactive and non-reactive diluents are used with epoxies. The reactive types combine chemically with the resin leaving no by-product to evaporate or leach out. A list of both reactive and nonreactive diluents is given by Magee (37).

Flexibilizers and Plasticizers

The brittle nature of some cured systems renders them unsuitable for coatings and patches for concrete, and they must be modified. Plasticizers and flexibilizers are added to systems to make them more suitable for use with concrete.

There is a considerable difference in the coefficients of thermal expansion of epoxy and concrete, and this has caused problems when epoxy has been used to repair concrete (44). A modifier can be used to make the epoxy flexible and plastic enough to accommodate differential thermal movements without rupturing or debonding from the concrete. The system that results from such modification has the capability of deforming to adjust to the differences in thermal expansion of the two materials. It also permits the epoxy to bridge cracks and undergo a certain amount of stretching without rupture. These modifiers produce greater flexibility, increase impact strength, increase the capacity for dimensional change under stress, but they lower the strength and chemical resistance of the finished product. Flexible epoxy resins, which alone have little or no value, are blended with DGEBA resins as reactive flexibilizers. Some of the most widely used resins of this type are the polyglycol diepoxides (45). Polysulfides, pine oil, and coal tar are also used as flexibilizers and plasticizers, the last having had particularly wide use on concrete bridge decks in waterproofing. Material costs are reduced with the addition of coal-tar modifier.

Figures 5 and 6 show the effects of two modifiers, one a coal-tar distillate and the other an aromatic diluent, on strength and elongation. Figure 6 also shows how temperature affects tensile strength and elongation of a particular formulation. Figure 7 illustrates the effect of inert mineral aggregate addition on thermal expansion.

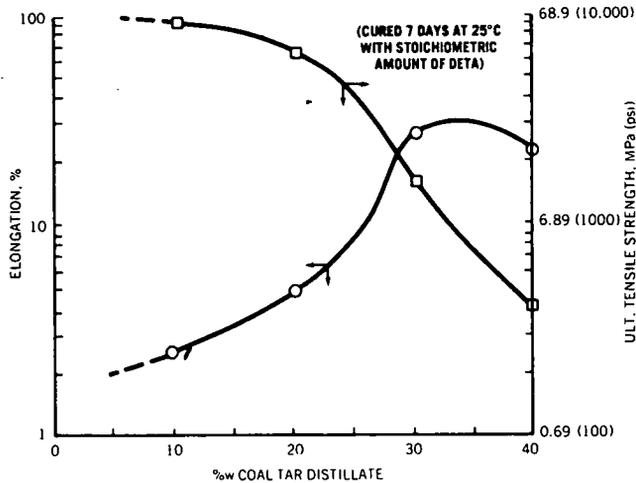


FIGURE 5 Effect of coal-tar distillate content on tensile properties of Epon resin 834 (34).

Inert Fillers

These fillers do not react chemically with the resin, curing agent, or any other ingredient of the mix. They are used to give increased volume at little added cost; to reduce thermal expansion and contraction; to make the system stiffer, stronger, and less creep sensitive; to add strength; to give greater abrasive resistance; and to increase surface friction for traction.

Large volumes of sand-filled epoxy have been used in highways for patching and surfacing of roads and bridges—particularly bridges. The reduction of cost by replacing a large proportion of epoxy with mineral aggregate has been an important consideration in this type of application. The coefficient of thermal expansion of unfilled epoxy is in the range of some 3 to 8 times that of natural sand and gravel (41). When a mortar is made of some 15 to 20 percent epoxy and the remainder natural sand (see Figure 7), the coefficient of the mortar becomes near to that of concrete. This makes a patch of this mortar less susceptible to bond failure from changes in temperature than

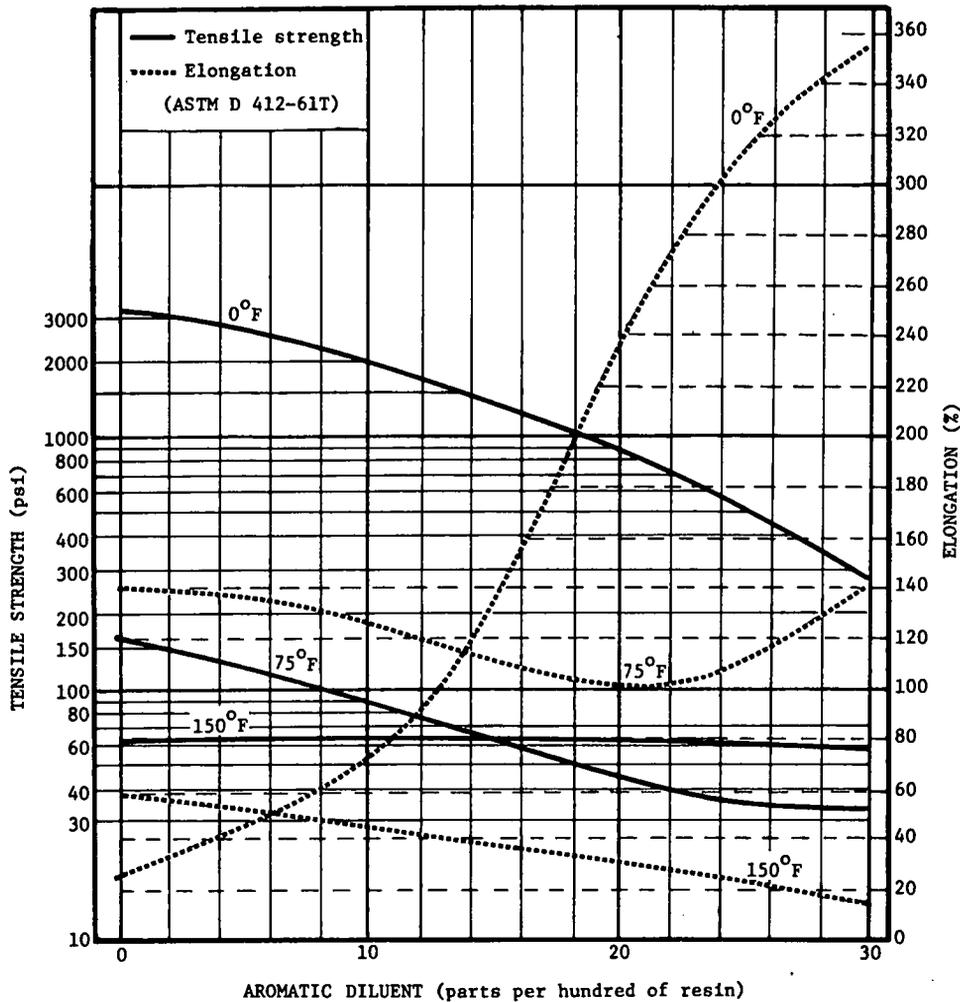


FIGURE 6 Effect of aromatic diluent addition on tensile properties (adapted from 49).

the unfilled epoxy. Abrasive grits have been sprinkled on roadway and sidewalk epoxy coatings before they cure so that the surface will be tractive after curing.

Fire Retardant Additives

The cured DGEBA-based epoxy will burn under intense heat, but it can be made flame-retardant or self-extinguishing by adding brominated resin or brominated diluent to the system (1). Weatherhead (39) names monoglycidyl ether as a fire-retardant additive rather than a diluent. Inert fillers in the resin system are also helpful in retarding fire (37).

PROPERTIES OF CURED EPOXY

The ability to change the values of properties of epoxy through changes in kind or amount of additive is very important to the user. Kampf (46) gives information on tensile strength, elongation, and hardness of epoxies (Fig. 8 & Table 4) and infor-

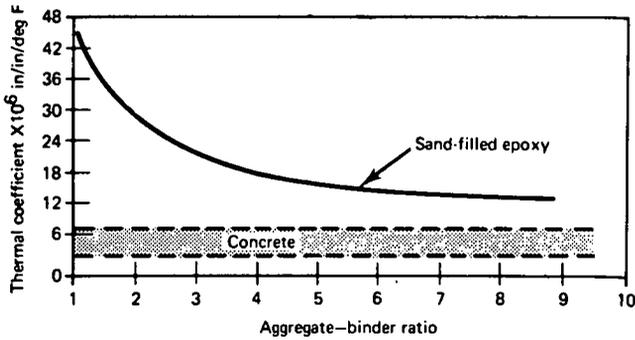


FIGURE 7 The effect of changes in the sand aggregate-binder ratio on the thermal coefficient of an epoxy system (3).

TABLE 4

FLEXIBILITY (STRESS-STRAIN RELATION) OF CONCRETE-REPAIR MATERIALS (46)

Material	Tensile strength, psi		Elongation, percent		Hardness, by Shore durometer	
	30 F	75 F	30 F	75 F	0 F	75 F
Asphaltic cement	76	173	3.0	70.0	52	2
Polyurethane	174	200	60.0	80.0	7	5
Coal tar epoxy A	2,133	787	0.5	17.5	83	45
Coal tar epoxy B	1,316	350	0.25	100.0	68	20
Pine oil epoxy	5,165	2,828	0.65	1.35	82	73
Polysulfide epoxy A	3,805	4,208	4.6	5.5	77	74
Polysulfide epoxy B	3,394	3,690	0.5	1.9	82	77
Epoxy A	2,222	743	2.0	2.2	70	44
Epoxy B	5,138	2,073	0.7	2.1	82	69

Test conditions:

- Tensile strength- ASTM D638--Test for tensile properties of plastics (type 1 test specimen)
- Strain- Moore extensometer (5x magnification) on 2-in. gage length
- Hardness- ASTM D1706--Indentation hardness of plastics by means of a durometer

mation on tensile and compressive strengths and elongation of epoxy mortars (Table 5). Table 6 gives values of various properties of epoxy mortar along with corresponding values for PC concrete. Rates of compressive strength gains of two epoxy mortars from Schutz (47) are shown in Figure 9.

THE EFFECTS OF TEMPERATURE

At low temperatures epoxy is a hard, brittle, glass-like material. It becomes softer, flexible, and rubberlike at sufficiently high temperatures. The temperature at which this change occurs is called glass transition temperature, T_g . It is a narrow band of temperature that corresponds closely to the heat deflection

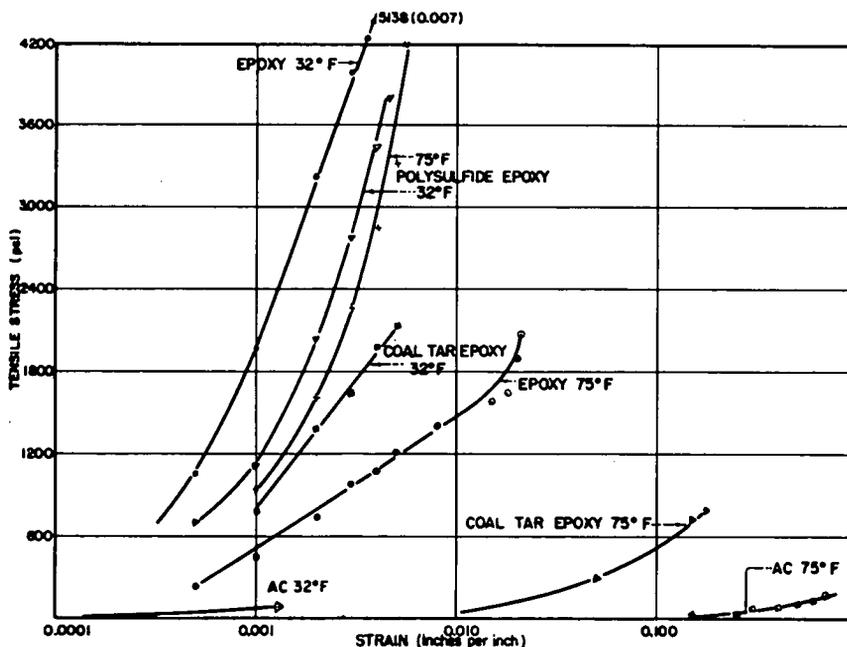


FIGURE 8 Flexibility of epoxy resins (46).

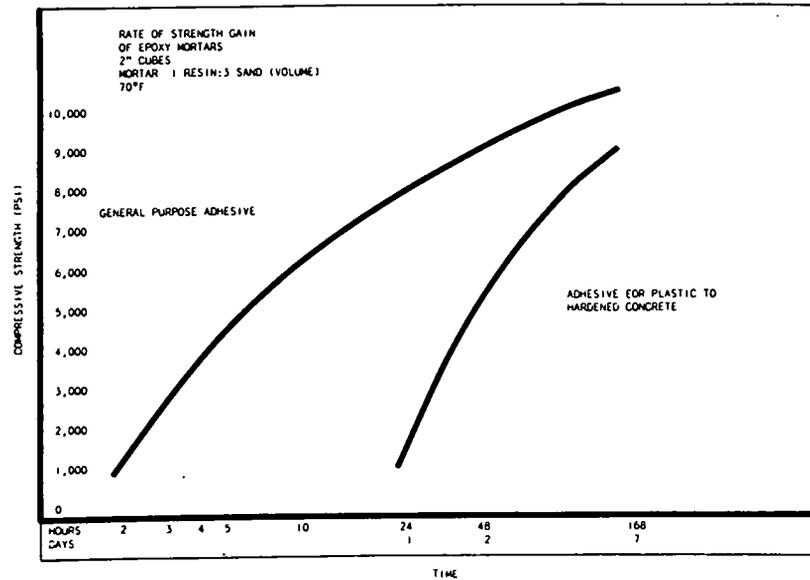


FIGURE 9 Rate of strength gain of epoxy mortars (47).

TABLE 5
PHYSICAL PROPERTIES OF EPOXY MORTARS (46)

Material	Strength, psi			Elongation at break, in./in.	
	Compressive	Tensile		Resin	Mortar
		Mortar	Resin		
Epoxy A	3,606	743	470	0.0220	0.0120
Epoxy B	11,500	2,073	2,020	0.0209	0.0005
Coal tar epoxy B	5,075	1,316	580	1.0000	0.0075

Proportions-- (all mixtures) Resin:Hardener 1:1 by volume
Epoxy:Sand 1:3 by volume

Test conditions:
Compressive strength--2-in. cubes
Tensile strength and elongation: 1 by 1 by 6-in. bars with 1/4-in. round rod embedded 1 1/4 in. in each end

temperature of ASTM D 648-72. Changes brought about by increasing temperature are illustrated in Figure 10.

Whittenwyler (48) associates low temperatures, relatively speaking, with a glassy state; temperature in the vicinity of T_g with a tough leathery state; and still higher temperature with a rubbery state. Essentially all deformation from short-term loading would be quickly recovered upon removal of the load at temperatures below T_g . Riddell and O'Toole (49) give information on time-dependent strain and stress (rheological properties) and this is displayed qualitatively in Figure 11.

ACI Committee 503 gives excellent information on the effects of temperature on epoxy used with concrete (50). In general, low temperature reduces the workability of the resin because it increases viscosity; it also increases pot life and increases curing time. Warm temperatures enhance workability and reduce pot life and curing time. Cold resin and hardeners will work more easily and cure faster if they are heated to the 60 to 90°F (15 to 32°C) temperature range. If fillers, such as sand, are used, they can be heated or cooled, as desired, for better mixing and

curing. When applied to a cold concrete, the curing time of the epoxy system will be increased. Because of this, most epoxy work on highway concrete is done when the concrete temperature and air temperature are in the range of 60 to 90°F, and air temperatures are rising. If the concrete is heated to receive epoxy, care should be taken to heat uniformly and to maintain the heat throughout the curing period.

Fire can cause an epoxy installation to deteriorate to a crumbly material without strength, depending on the heat intensity and duration. An ASTM test (ASTM D 648-82) measures the ability of epoxy to withstand heat while it is stressed. The temperature at which the specimen deforms a specified amount is called the heat deflection temperature (HDT) and this property is sometimes given in the list of mechanical properties of a given resin system. For example, a certain epoxy casting that is cured with a polyamine is reported by Perez (43) to have an HDT of 95°C to 124°C, depending on the mixture. Tests by Plecnik et al. (51) showed that thin epoxy layers used for crack repair suffered little from controlled fire tests, but wider cracks suffered edge burnout and deterioration of the epoxy binder near the concrete surface.

THE EFFECTS OF WATER AND CHEMICALS

No water is produced in the curing of epoxy, and the cured system is a tight, cross-linked system that permits essentially no water to be absorbed into it. Because of this property, it is widely used as waterproofing for concrete and other construction materials. Epoxy is resistant to acids and caustics (Table 7).

Some epoxy formulations will not bond to wet concrete. There are, however, systems available today that displace the water and provide good bonding to wet surfaces. The water-insensitive systems have somewhat less strength than those that are water sensitive. This reduced strength is not a problem, however, because epoxy is generally considerably stronger than the concrete to which it is applied. The nonsensitive systems will bond

TABLE 6
TYPICAL PHYSICAL PROPERTIES OF EPOXY FLOORING COMPOUNDS IN
COMPARISON TO CONCRETE (38)

FORMULAS USED			
	Concrete	Parts by volume	
Type-2 cement	1	
Sand	2	
¼-in. gravel	3	
TESTS PERFORMED AFTER 28 DAYS' AGING			
Property	Value	Property	Value
Rockwell hardness, M:		Formula 2:	
Concrete	64	At 23°C	Taken as zero point
Formula 1	71	At 52°C	0.018
Formula 2	59	At 66°C	0.055
Shrinkage, in./in.:		At 93°C	0.142
Concrete	0.0012	At 121°C	0.155
Formula 1	0.0010	At 149°C	0.22 and 0.36 (2 specimens)
Formula 2	0.0015	At 177°C	0.31 and 0.505 (2 specimens)
Compressive strength, psi:		At 204°C	0.370 and 0.590 (2 specimens)
Concrete		Flexural strength, psi:	
After 3 days	3,110	Formula 1	20,200
After 7 days	3,590	Formula 2	22,800
After 28 days	3,730	Flexural modulus, psi × 10 ⁻⁶ :	
Formula 1:		Formula 1	3.97
After 3 days	6,610	Formula 2	4.55
After 7 days	8,260	Maximum deflection, inches:	
After 28 days	8,270	Formula 1	0.437
Formula 2:		Formula 2	0.465
After 3 days	2,500	Tensile strength, psi:	
After 7 days	6,570	Concrete	250-450
After 28 days	8,320	Formula 1	1,480
Vicat softening, maxi- mum penetration from 23 to 204°C, mm		Formula 2	1,430
1,000-g load:		Adhesion to steel, psi	
Formula 1	0.08	Concrete	Specimen breaks
Formula 2	0.063	Formula 1	1,260
3,000-g load:		Formula 2	990
Formula 1:		Impact-falling ball, ft-lb:	
At 23°C	Taken as zero point	Concrete:	
At 52°C	0.01	At 24°C	10.1
At 66°C	0.025	At 0°C	10.0
At 93°C	0.122	Formula 1:	
At 121°C	0.340 and 0.5820 (2 specimens)	At 24°C	9.5
At 149°C	0.835 and 1.015 (2 specimens)	At 0°C	9.5
At 177°C	1.020 and 1.595 (2 specimens)	Formula 2:	
At 204°C	1.845 and 1.755 (2 specimens)	At 24°C	12.3
		At 0°C	12.3
Abrasion*, loss in thickness per 1,500 cycles, inches:			
Concrete	0.0255		
Formula 1	0.0085		
Formula 2	0.0040		

* Using no. 60-grit carborundum cloth, load of 88 oz. Test run on ¼-in.-thick specimens.

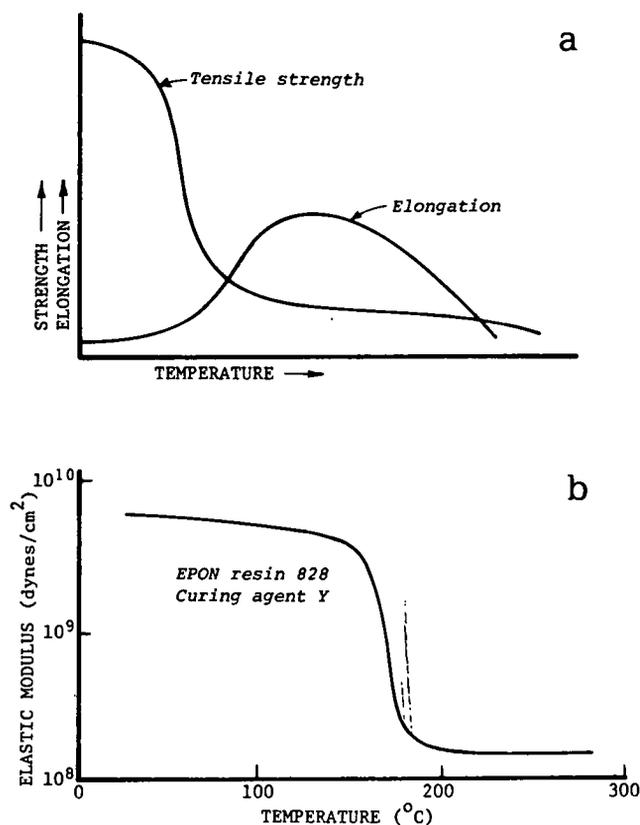


FIGURE 10 The effect of temperature on (a) strength and elongation (49) and (b) elastic modulus (34).

to clean wet concrete and they are used to fill wet cracks, for underwater patches, and other applications to wet concrete surfaces.

VOLUME CHANGES

Shrinkage

The dimensional change that accompanies curing of an epoxy system is called shrinkage. It is a combination of the reduction in volume caused by the development of tight linkages between the molecules and the expansion caused by the heat of the reaction—the exotherm. The initial shrinkage occurs during the

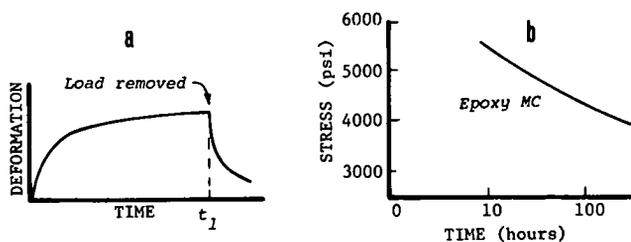


FIGURE 11 Effect of time under load on (a) strain (constant load to time t_1) and (b) stress relaxation (constant strain) (adapted from 50).

TABLE 7

A COMPARISON OF CHEMICAL RESISTANCE PROPERTIES OF EPOXY AND CONCRETE (3)

	Epoxy	Concrete
Wet-dry cycling	Excellent	Excellent
Chloride deicing salts	Excellent	Fair
Muriatic acid (15 percent HCl)	Excellent	Poor
Food acids (dilute)	Good	Poor
Sugar solutions	Excellent	Fair
Gasoline	Excellent	Excellent
Oils	Excellent	Excellent
Detergent cleaning solutions	Excellent	Excellent
Alkalis	Excellent	Good
Sulfates	Excellent	Fair

liquid phase of the system and it is followed by further shrinkage after gellation. That part occurring in the liquid phase is accommodated without a buildup of internal stress, but that occurring in the latter phase develops stresses in the solid system. The part of shrinkage that occurs after gellation has been termed "effective shrinkage" by Whitesides (44) and it is the object of the ASTM C 883-80 test.

The magnitude of shrinkage is influenced by the curing agent, the modifiers, and the curing temperature. In general, a fast curing agent increases shrinkage, as does a high curing temperature. An inert sand filler and a low curing temperature will each reduce it.

The relationship between density and age of a particular resin is shown in Figure 12. For the situation shown, the resin cured at 25°C, expanded for an hour, and then began to shrink. At about 8 hours of curing time the density remained essentially constant. The 125°C cure expanded continuously to about 8 hours age when it leveled off to a constant density. This behavior is further studied in Figure 13, which is from the same source as Figure 12.

In Figure 13, a resin and curing agent are mixed at 20°C (point A in the figure) then heated to 120°C, curing temperature, instantly without any curing taking place. Eliminating time as a factor, an ideal situation, not an actual one, the material expands along the line to point B at 120°C. Curing proceeds at 120°C and the material shrinks to point C in the liquid state. It gels at C and further shrinks to D. When the solid system is brought down to the initial 20°C, it shrinks to E then to F. This shrinkage from D to F is caused by the lowering temperature and the coefficient of expansion of the material, not from curing in itself. Of the total curing shrinkage BD, the portion BC occurs in the liquid phase, and it causes no stresses. The portion CD occurring in the solid phase will cause stresses if there is any restraint to the shrinkage. This latter portion of curing shrinkage is of concern in highway applications. Figure 14 shows that shrinkage during curing is about equal in the solid and liquid phases.

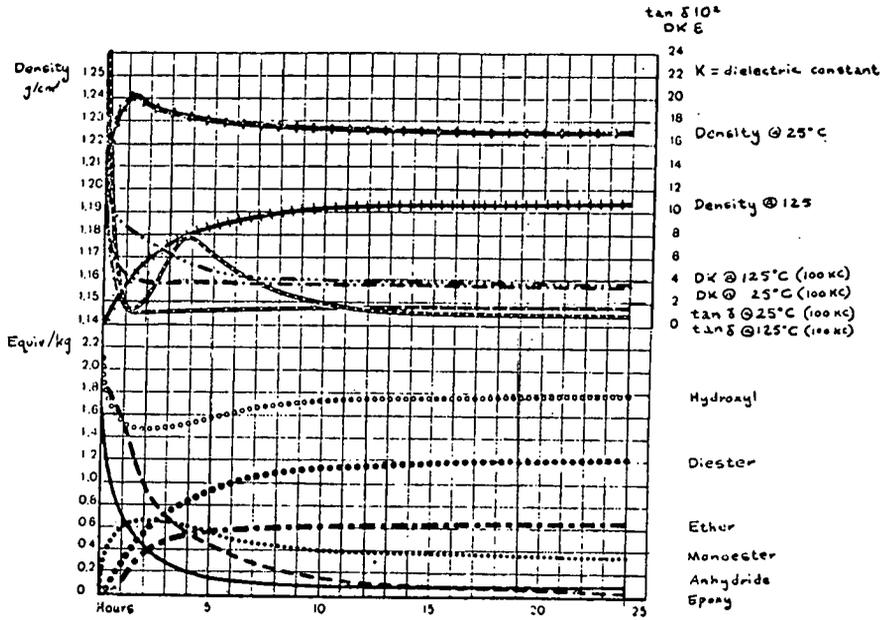


FIGURE 12 Physical and chemical changes during the curing process (52).

In an actual situation there is an exotherm and the reaction curve leaves the straight line and follows the dotted curve to point M (Fig. 13), at 120°C. A slower curing resin heats itself from curing temperature of 120°C to 160°C by the exotherm. Moving from M to P to Q, the shrinkage from closer packing of molecules exceeds the expansion from the exotherm. The

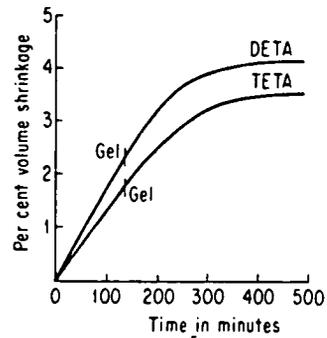


FIGURE 14 Volume shrinkage 25°C of DGEBA cured with aliphatic amines (38).

resulting shrinkage is partially in the liquid phase, MP; the remainder in the solid phase PQ during curing. The cooling to 20°C is accompanied by shrinkage below the line EN. The system that cures quickly moves from M to N; the chemical shrinkage being overcome by the expansion caused by the exotherm. The temperature is raised to 240°C by the reaction, and all of the volume change during curing is expansion. The volume change in returning to the 120°C curing temperature is much greater for the quick cure than for the slower cure.

From Figures 12 and 13 it can be seen that a system should be cured as slowly and at as low a temperature as the situation will permit.

Thermal Expansion

The solid resin system undergoes volume change from temperature changes occurring after its cure is complete. In Figure 13 this is shown by the line FEN. The break at E indicates that

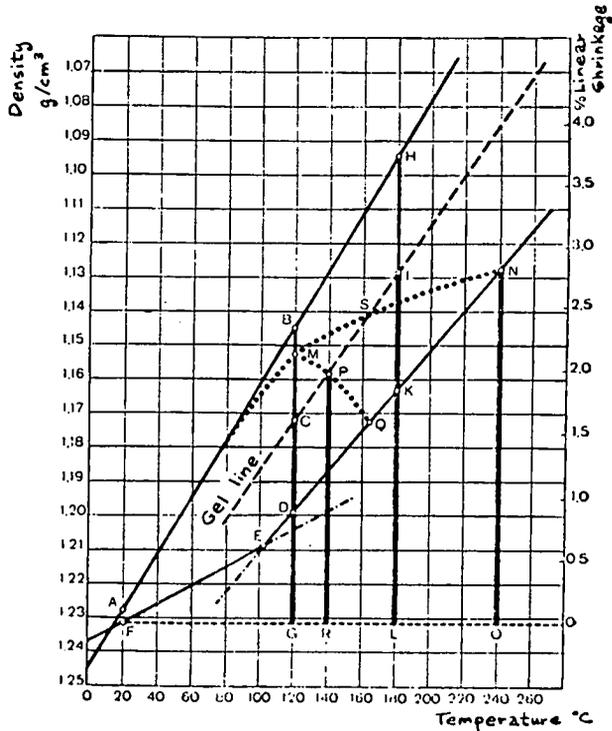


FIGURE 13 Density changes during the epoxy resin curing process (52).

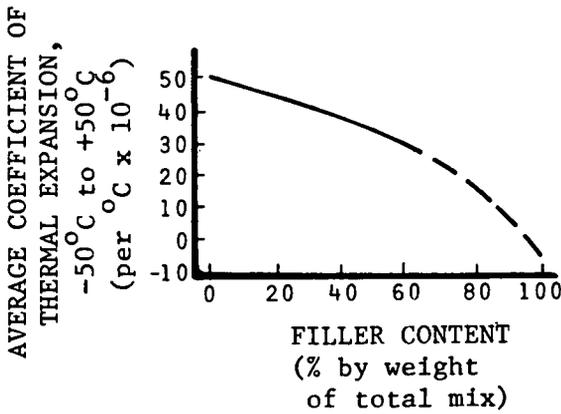


FIGURE 15 Coefficient of thermal expansion of EPON resin 828 casting with silica flour filler (curing agent 15PHR metaphenylene diamine) (34).

the coefficient of thermal expansion below 100°C is different from that above 100°C. In highway uses of epoxies, temperatures do not get this high and a constant coefficient is used over the entire temperature range. The coefficient will vary with sand and other such filler, and for a system filled with sand and other such filler, it will be reduced considerably. Figure 7 shows the effect of a sand filler on the coefficient of thermal expansion of a particular system. Figure 15 shows the effect of silica flour.

Stresses Caused by Volume Changes

There is always restraint to volume change in epoxy when it is used with concrete, and stresses result from this restraint. Curing shrinkage in the solid phase and differences in the coefficients of expansion of concrete and epoxy both contribute to these stresses. A thin membrane of epoxy bonded to concrete is restrained in the plane of bonding—in two directions. The membrane is free to expand or contract linearly in the third dimension. A pothole filled with an epoxy patching material is restrained in the plane of the pavement, but there is also some restraint in the third dimension because of bonding to concrete around the sides. The patch itself loses heat of curing faster to the cool concrete that it contacts than to the air contacting the third face.

Portions of epoxy used as a crack filler are restrained in three dimensions. If a patch is too bulky, the curing heat loss at its center is slower than at its outer regions, and the dimensional changes in these two regions develop stresses within the patch.

The relationship between density changes, volume changes, and lineal changes, regardless of shape, are given below. These are sometimes needed in processing test data for use in stress calculations.

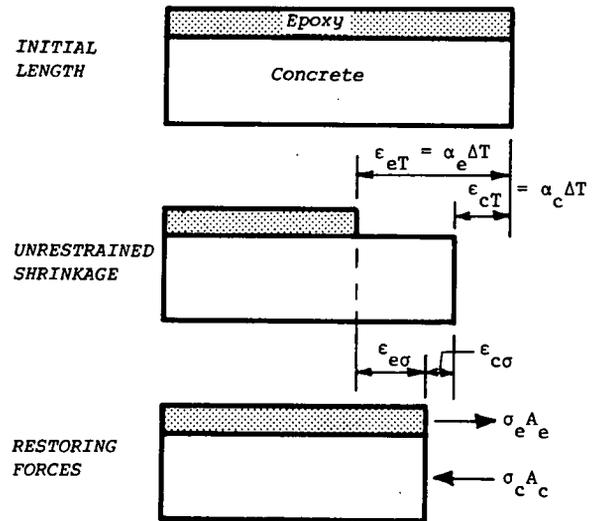
$$\frac{\Delta V}{V} = - \frac{\Delta D}{D}$$

$$\frac{\Delta V}{V} = 3 \frac{\Delta L}{L}$$

where

- V = volume
- D = density
- L = lineal dimensions
- ΔV = change in volume
- ΔD = change in density
- ΔL = change in lineal dimensions

The relationship between material properties and stresses are derived in Figure 16.



- ε = strain
- σ = stress
- e = epoxy
- c = concrete
- E = modulus of elasticity
- α = coefficient of thermal expansion
- A = cross-sectional area
- ΔT = temperature change

$$(\epsilon_{eT} - \epsilon_{cT}) = (\epsilon_{e\sigma} + \epsilon_{c\sigma})$$

Substituting terms:

$$(\alpha_e - \alpha_c)\Delta T = \frac{\sigma_e}{E_e} + \frac{\sigma_c}{E_c} \quad \text{Eq. 1}$$

$$\sigma_e A_e = \sigma_c A_c$$

or:

$$\sigma_c = \sigma_e \frac{A_e}{A_c} \quad \text{Eq. 2}$$

Combining Eq. 1 and Eq. 2:

$$(\alpha_e - \alpha_c)\Delta T = \frac{\sigma_e}{E_e} + \frac{\sigma_e A_e}{E_c A_c}$$

$$\sigma_e = \frac{E_e (\alpha_e - \alpha_c) \Delta T}{1 + \frac{A_e E_e}{A_c E_c}}$$

FIGURE 16 Shrinkage of bonded materials.

The example given below illustrates an approach to determining stresses in epoxy applied to concrete.

Assume that an unfilled epoxy membrane is applied to a concrete bridge deck as a water barrier. The conditions are given below. It is desired to know the stresses in the epoxy caused by curing and by temperature changes that occur later.

Concrete temperature at installation, $T_c = 70^\circ\text{F}$

Epoxy (premixed) component temperature, $T_c = 70^\circ\text{F}$

Concrete thickness, $t_c = 8$ in.

Cured epoxy thickness, $t_e = 1/8$ in.

Modulus of elasticity of concrete, $E_c = 3.5 \times 10^6$ psi

Modulus of elasticity of epoxy system, $E_e = 4 \times 10^5$ psi

No evaporative components in the epoxy

Coefficient of thermal expansion of concrete, $\alpha_c = 5 \times 10^{-6}/^\circ\text{F}$

Coefficient of thermal expansion of epoxy, $\alpha_e = 33 \times 10^{-6}/^\circ\text{F}$

To determine curing stress, assume that the DETA curing agent is used and that the concrete temperature remains unchanged. The volume shrinkage is determined from Figure 14, where the volume shrinkage of cured DETA is 4%, the volume shrinkage at gel is 2.2%, and thus the volume shrinkage during the solid phase ($\Delta V/V$) is $0.04 - 0.022 = 0.018$.

Linear shrinkage is 1/3 of volume shrinkage:

$$\frac{\Delta L}{L} = \frac{1}{3} \times 0.018 = 0.006 = \epsilon_c$$

Therefore, the curing stress can be calculated from the following equation:

$$\sigma_c = \frac{E_e \epsilon_c}{1 + [(A_c E_c)/(A_e E_e)]}$$

where

$$A_e = 0.125 \text{ in.}^2$$

$$A_c = 8 \text{ in.}^2$$

Thus,

$$\sigma_c = \frac{(4 \times 10^5)(0.006)}{1 + [(0.125)(4 \times 10^5)/(8)(3.5 \times 10^6)]} = 2396 \text{ psi}$$

At the end of the curing period the tensile stress in the epoxy is 2396 psi, assuming there is no relaxation because of creep, and there are no further strains from other causes. (Actually, because epoxy is a viscoelastic material, there will be some relaxation of this 2396 psi tension.)

To determine the stress caused by temperature change, assume that there is a drop in temperature of 50°F after curing. This drop in temperature causes a strain in the epoxy:

$$\epsilon_c = (\alpha_e - \alpha_c)\Delta T = (33 - 5)(10^{-6})(50) = 0.0014$$

Therefore, using the equation above, the stress caused by temperature change can be calculated from the following:

$$\begin{aligned} \sigma_{\epsilon\Delta T} &= \frac{(4 \times 10^5)(0.0014)}{1 + [(0.125 \times 4 \times 10^5)/(8 \times 3.5 \times 10^6)]} \\ &= 559 \text{ psi tension} \end{aligned}$$

The effect of shrinkage at curing is more than four times that of the 50°F temperature drop in this situation.

The total stress effect of curing shrinkage and later temperature change is $2396 + 559 = 2955$ psi tension. This 2955 psi tension causes a unit tensile strain of $2955/(4 \times 10^5) = 0.00739$ in./in. in the epoxy.

The shearing stress at the bond line between the membrane and concrete slab will be greatest at the outside corner. If the outer one inch width of bonded material carries the full effect, the shear stress, τ , at the bond line at that corner will be 522 psi (Fig. 17).

$$\begin{aligned} \tau &= 2(2955 \times 1 \times 1/8)\cos 45^\circ \\ &= 522 \text{ psi} \end{aligned}$$

Most epoxies have the ability to absorb the 0.7 percent elongation as well as the 2955 psi tension and the 522 psi shear. Repeated applications of such strains and stresses, however, place far greater responsibilities on the epoxy with attendant greater chances of failure.

Sand-filled epoxy has a much lower strain, both curing and thermal, than the unfilled material considered in the example given above. A 60 percent silica flour filling is shown in Figure 15 to reduce the coefficient of thermal expansion to about half of that of the unfilled epoxy. Figure 7 shows great reductions by filling with sand. Fillers such as these also reduce stresses that would be developed without them during curing. Most epoxy patches are filled with sand when used in highway work, and this patch material will generally meet the curing and temperature strains without cracking. The flexibilizers that are used in such patch material are greatly beneficial in enabling the material to undergo the repeated strain.

PRECAUTIONS IN HANDLING EPOXIES

There are some precautions that should be taken in handling the resin, curing agent, and modifiers when mixing and applying the system. Distributors warn of hazards that might be asso-

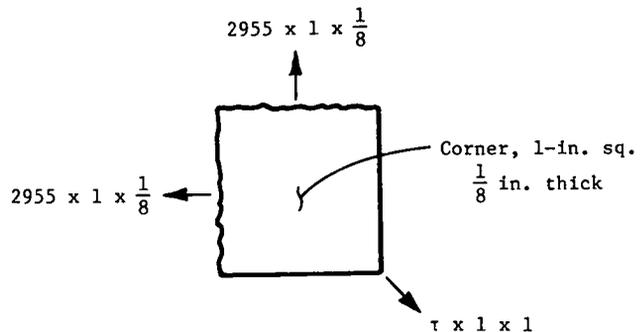


FIGURE 17 Shear stress at bond line between membrane and concrete.

ciated with their products and the user should heed them. References 38 and 54 provide excellent information on toxicity of epoxies and precautions that should be taken in handling them.

Epoxy resin itself is only slightly toxic. There is little or no danger in inhalation of vapor or fumes over brief periods, but one should not expose oneself to them for long periods. The amine curing agents and the resin are skin sensitizing agents. Repeated exposure to them can cause serious irritation, rash, and skin burn.

Epoxy should be prepared in a well-ventilated area away from heat, sparks, and open flames. In enclosed areas or where ventilation is poor, an approved air mask and adequate safety precautions to prevent fire or explosion should be used. Protective gloves, clothing, and goggles should be used when mixing or pouring grout.

Areas of the body that contact the resin or the curing agent should be washed immediately with soap and water. A solvent should not be used because it will carry the epoxy into the skin. If the eyes are affected they should be flushed with lots of clean water and a physician should be consulted immediately.

There are not extreme hazards accompanying the use of epoxy, but judicious care and precautions can prevent injuries that might otherwise occur.

TESTS AND SPECIFICATIONS

Specifications and guides for epoxy materials and applications with concrete have been published by ASTM, AASHTO, and ACI. Those specifications and guides are listed in Appendix A. ASTM gives the requirements of the epoxy materials for various uses and describes tests to ensure that those requirements are met. AASHTO specifies epoxies to meet the various service requirements of highways and classifies epoxies for various conditions. ACI gives information on ways that epoxy can be used with concrete, including repair, preparation of the concrete to receive the epoxy, and preparation and application of the epoxy. In general, ASTM and AASHTO are concerned more with the epoxy material while ACI is concerned with its application. Among the three organizations, the subject is fairly well covered except for formulation and specific mechanical properties of various formulations.

Tests for bond strength, shrinkage, and thermal compatibility between concrete and epoxy overlay are specified by ASTM, which also notes that the data are insufficient in each of these tests to support a statement of precision for the methods.

AASHTO gives requirements for surface preparation and application procedures, but these are covered in more detail by ACI. These are the sources of the best current information in the United States readily available to the user for concrete repair with epoxy. The instructions given in these publications should be followed with care to obtain the best returns for the time, effort, resources, and money spent in the work.

The classifications given epoxy systems, as outlined by ASTM in C 881-78 and by AASHTO in M 200-73, M 235-73, and M

237-73, are of great benefit in writing a job performance specification. AASHTO Designations M 235-73 and M 237-73 give the composition required of the resin and hardener for several epoxy materials, but not for all. This compositional information would enable a chemist to prepare a few epoxy systems, but it still leaves a wide gap where information on modifiers and diluents would be necessary for formulating special systems.

Other than those cited above, there is no uniform set of specifications governing the uses of epoxy among the highway agencies of the United States and provinces of Canada. Some are compositional, giving the components of the epoxy system for various applications. The California DOT has the most complete set of this type of specification. Others are performance specifications, which given property and performance requirements of the system for various types of use. The Ohio DOT and the North Carolina DOT have specifications of this kind. Portions of these three DOT specifications appear in Appendix B.

Some compositional specifications that were issued in the past have been recalled for one reason or another. Two of these (Federal Specifications MMM-B-350 "Binder, Adhesive, Epoxy Resin, Flexible" and MMM-G-650 "Grout, Adhesive, Epoxy Resin, Flexible, Filled") were cancelled in 1979 after the latest revisions of 1973 were issued.

There are arguments both for and against compositional specifications. Most DOTs are not staffed with chemists having the expertise in epoxy that is necessary for formulating epoxy systems. Others that do have the qualified personnel believe that a commercial formulation can provide a better system at less cost than the DOT can produce. There is a belief on the part of some that a specified formulation can stifle innovation in an area of technology that is changing almost daily. The pro-formulators argue that if they can produce a good system, they can do it at an acceptable cost and have a product that is uniform and familiar to the personnel who use it in the field. It is likely that those departments producing satisfactory formulations will continue to do so and commercial formulators will continue to make this very important contribution to those not having their own formulators.

The tests developed through the years to qualify epoxy systems are limited. There have been many installations that have failed because of shrinkage and thermal incompatibility between epoxy and concrete. Shrinkage possibly accounts for cracks that have sometimes formed around edges of epoxy patches in concrete. Whether or not the ASTM specifications are adequate to eliminate or drastically reduce those types of problems can be answered only after sufficient field case histories can be compared with the qualifying test results.

Reports of failures of systems are not as prevalent today as they were some 15 years ago, but it appears that the number of overlays and coatings being placed have also been reduced. There is no doubt that fillers and the modifiers added for flexibility and plasticity have been helpful in producing successful installations. The experience gained in preparation and installation has been very valuable in using epoxy with highway concrete.

CLOSURE

The use of epoxy for highway concrete repair in the United States grew rapidly from the early 1950s, the time of its introduction, through the 1970s. This growth was due largely to the use of epoxy for spall repairs in areas of high traffic intensity where there were severe restrictions on lane-closure time. By the middle of 1960, very large quantities of epoxy were being used for concrete bridge deck overlays, waterproof coatings, and patching for spalled areas. The material was used before knowledge of its service behavior was well developed. It was probably oversold as a "cure-all" for bridge decks that were deteriorating at an alarmingly fast rate.

It was soon learned that the formulations used for many of the initial applications were not compatible with concrete under the severe weather conditions in service. The coatings and overlays cracked and eroded severely under traffic, and epoxy repairs pulled away from the concrete in particles and in large sheets. Although formulators gave explicit instructions for applications, the workers did not always appreciate their exacting requirements. Poor workmanship, resulting from the workers' unfamiliarity with epoxy, was the cause of many failures.

Through the study of failures and research in uses of epoxy, it was learned that formulations could be made that would meet most conditions and serve them well. It was learned that epoxy was simply not the material to use for some of the problems encountered. During this same period, much was learned about the performance of portland cement concrete under freeze-thaw cycling. Air entrainment, good compaction, and low water-to-cement ratio concrete proved to be the best cure for scaling. Dense concrete and greater cover over the steel were found to help in combatting corrosion damage. Concrete specifications were changed to reflect these findings and subsequent construction produced concretes that had far fewer requirements for epoxy repair. New uses were also found for epoxy. These, along with improved materials and methods for old problems, held epoxy at the front as a valuable material in the highway industry.

Today, there are far fewer applications of epoxy as overlays and coatings for bridge decks than in earlier years. Epoxy has gained in popularity as a patching mortar, however, because of the demand for quick-set, durable materials on heavily travelled

installations. The relatively new use of epoxy as a coating for reinforcing steel is proving very popular in bridge structures that are treated with deicing salt and structures in marine environments.

A structural crack-repair epoxy has requirements far different from those of the patch or overlay. This material is required to bond tightly, transfer a considerable load, and deform little. It does not have the erosion problem of a pavement surface patch and the shrinkage problem is not as great because the temperature range is smaller. Shrinkage should always be kept as low as practicable. This calls for slow curing and epoxies with low exotherms.

Expert formulation is required for all installations. One must have both qualitative and quantitative knowledge of the influences of individual and combined additives to develop a system that will meet service requirements. Except for a very few highway agencies, formulations are made by suppliers to performance specifications. This practice will probably continue until information is made available that will enable highway materials personnel to do their own formulating with confidence of success. The knowledge is proprietary or so highly theoretical and technical that there is little hope that this formulating can be commonly done today.

More and simplified information is needed on products and their behaviors. This could be developed for today's products by reducing the current highly technical and sometimes highly theoretical information available to a body of easily understood knowledge. Handbook-type instructions are needed for common applications.

In addition to the reduction of current knowledge discussed above, research should be conducted on a continuing basis to develop further knowledge and instructions for use of available products. Although there are many formulations possible, there are relatively few that are required for common use for repair of highway concrete. These relative few should be explored and formulations for them should be published. This would enable the highway department user to experiment with them on familiar problems.

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APPENDIX A

ASTM, AASHTO, AND ACI SPECIFICATIONS AND GUIDES ON EPOXY

TITLE	DESIGNATION		
	ASTM	AASHTO	ACI
Epoxy-Coated Reinforcing Steel Bars	D 3963-81	M 284-81	
Epoxy-Resin-Base Bonding System for Concrete	C 881-78(1983)		
Bond Strength of Epoxy-Resin-Base Bonding Systems Used with Concrete	C 882-78(1983)		
Effective Shrinkage of Epoxy-Resin Systems Used with Concrete	C 883-80(1983)		
Thermal Compatibility Between Concrete and an Epoxy-Resin Overlay	C 884-78(1983)		
Use of Epoxy Compounds with Concrete			503R-80
Bonding Hardened Concrete, Steel, Wood, Brick, and other Materials to Hardened Concrete with a Multi-Component Epoxy Adhesive			503.1-79
Bonding Plastic Concrete to Hardened Concrete with a Multi-Component Epoxy Adhesive			503.2-79
Producing a Skid Resistant Surface on Concrete by the Use of a Multi-Component Epoxy System			503.3-79
Repairing Concrete with Epoxy Mortars			503.4-79
Guide to Joint Sealants for Concrete Structures			504R-77
A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete			515R-79
Epoxy Adhesives for Highway Construction		M 234-76	
Epoxy Resin Adhesives		M 235-73	
Epoxy Resin Adhesive for Bonding Traffic Markers to Hardened Concrete		M 237-73	
Epoxy Protective Coatings		M 200-73(1982)	

APPENDIX B

SELECTED STATE DOT SPECIFICATIONS FOR EPOXY

CALIFORNIA



STATE OF CALIFORNIA

Specification

8040-01F-01

Epoxy, Fast Setting, Low Viscosity

1.0 SCOPE

This specification covers a low viscosity, rapid set epoxy for use in making high strength epoxy concrete, where low curing temperatures are expected or where a fast cure is required. This epoxy is not suitable for use in bonding of new portland cement concrete to old portland cement concrete. This epoxy is suitable for use in freeze-thaw environments.

2.0 APPLICABLE SPECIFICATIONS

The following specifications, test methods and standards in effect on the date of the Invitation for Bid, form a part of this specification where referenced.

Test Method No. California 432

Federal Standard 595

American Society for Testing and Materials (ASTM) D476

Department of Transportation Standard Specification

State of California Specification 8010-XXX-99

3.0 REQUIREMENTS

3.1 Composition:

Component A

Parts by Weight

Epoxy resin (1)	55.00
Epoxy resin (2)	30.00
Orthocresol Glycidyl Ether (3)	15.00
Aliphatic Glycidyl Ether (4)	3.20
Titanium Dioxide, ASTM D476, Types III or IV	2.00
Silicone Anti Foam, Type DB100, 100% solids	0.005

Component B

High Functionality Polymercaptan Hardner (5)	30.00
N-Aminoethyl Piperazine (6)	17.00
2,4,6-Tri (Dimethylaminomethyl) Phenol (7)	2.00
Furnace Black (8)	0.10
Silicone Anti Foam, Type DB100, 100% solids	0.005

Epoxy, Fast Setting, Low Viscosity

8040-01F-01

3.2 Raw Material Specifications:

- (1) Di glycidyl ether of bisphenol A: viscosity at 25°C, 40-60 poise; epoxide equivalent 172-173; color; Gardner 1933, 1 max.
- (2) Di glycidyl ether of bisphenol A: viscosity, 100-160 poise at 25°C; epoxide equivalent, 180-200; color; Gardner 1933, 3 max.
- (3) Viscosity at 25°C, 5-10 centipose, weight per gallon, 9.00-9.10 pounds; epoxide equivalent, 180-200.
- (4) Aliphatic mono functional reactive glycidyl ether, derived from an aliphatic alcohol. Viscosity 1-15 centipose. Weight per epoxide equivalent 220-250. Specific gravity 0.88-0.95.
- (5) Liquid polymercaptan resin; viscosity 100-130 poise at 25°C; specific gravity, 1.14-1.16; mercaptan value, 3.6 meq/gram; color, Gardner 1933, 1 maximum, infrared curve shall match the curve on file in the Transportation Laboratory.
- (6) Color (APHA) 50 maximum; amine value, 1250-1350 based on titration which reacts with the 3 nitrogens in the molecule; appearance; clear and substantially free of suspended matter.
- (7) Formula weight, 265; specific gravity at 25°/25°C, 0.973; refractive index, 1.514 at 25°C; distillation range, 96% at 130° to 160°C (0.5-1.5mm.); flash point, Tag open cup, 300°F minimum; water content, 0.06% maximum.
- (8) Surface area, square meters/gram, 115-130; particle diameter, millimicrons, 18-30; pH, 7.0-8.5; fixed carbon (moisture free), percent, 96-98; volatile matter, percent, 1-4; oil absorption, stiff paste endpoint, CS/gram, 0.80-0.90.

3.3 Characteristics of Components:

All tests shall be performed in accordance with Test Method No. California 432.

3.3.1 Brookfield viscosity, No. 2 Spindle, at 20 rpm and 77° ± 1°F, Poise.

Component A	4 to 8
Component B	20 to 35

3.3.2 Density, lbs. per gallon at 77 ± 1°F

Component A	9.45 to 9.75
Component B	8.85 to 9.15

- 3.4 Characteristics of combined components when mixed in a ratio of 2 Volumes of A to 1 Volume of B.
- 3.4.1 Gel time, minutes 6 to 10
- 3.4.2 Compressive strength, minimum, psi 12,000
- 3.4.3 Color, approximately that of Color no. 26134 of Federal Standard No. 595
- 3.4.4 Infrared curves of each component shall match those on file in the Transportation Laboratory.
- 3.5 Air Pollution Compliance:
- The material must comply with the anti-air pollution requirements of Regulation 3 of the Bay Area Air Pollution Control District and Rule 66 of the County of Los Angeles Air Pollution Control District. Evidence of such facts shall be available to the California Department of General Services, Office of Procurement.
- 3.6 Certification of Compliance:
- The manufacturer of the finished epoxy components shall furnish a Certificate of Compliance in conformance with the provisions of Section 6-1.07*, "Certificate of Compliance". A copy of the label shall be furnished with the "Certificate of Compliance". The certificate shall include a list, by Title and Section, of the State and Federal packaging and labeling laws and regulations that the manufacturer has complied with.

*Department of Transportation
Standard Specification Jan. 1978 or Jan. 1981.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Inspection:

This material shall be inspected and tested in accordance with State of California Specification 8010-XXX-99, or as otherwise deemed necessary.

5.0 PREPARATION FOR DELIVERY

5.1 Packaging:

Each component shall be packaged in containers of size proportional to the amount of that component in the mix so that one container of each component is used in mixing one batch of epoxy. The containers shall be of such design that all of the contents may be readily removed, and shall meet U.S. Department of Transportation Hazardous Material Shipping Regulations, and the containers shall be of a material, or lined with a material, of such character as to resist any action by the components.

5.2 Marking:

Each container shall be clearly labeled with the State Specification Number, including authorized modifications; designation (Component A or B); type (Standard or Rapid) if applicable; manufacture's name; date of manufacture, batch number (a batch shall consist of a single charge of all components in the final mixing chamber); state lot number; all directions for use (as specified elsewhere) and such warning or precautions concerning the contents as may be required by State or Federal Laws and Regulations.

6.0 NOTES

6.1 Directions for Use:

The mixing ratio is 2 parts by Volume of Component A to 1 part by Volume of Components B.

Add clean, dry aggregate immediately after Components A and B are thoroughly mixed. Since this binder sets rapidly, it is mandatory that the epoxy concrete be placed as soon as possible. The pot life will depend on temperature, but should be about 10-15 minutes at 75°F.

DEPARTMENT OF GENERAL SERVICES
Office of Procurement
June 1980



STATE OF CALIFORNIA
 Specification 8040-01F-02
 Epoxy, Injection Grouting P.C.C. Pavements

1.0 SCOPE

This specification covers an epoxy suitable for injection grouting of portland cement concrete pavements.

2.0 APPLICABLE SPECIFICATIONS

The following specifications, test methods, and standards in effect on that date of the Invitation for Bid form a part of this specification where referenced.

Test Method No. California 425 and 427.
 State of California Specification.

3.0 REQUIREMENTS

3.1 Test Requirements:

<u>Test</u>	<u>Test Method No.</u>	<u>Requirements</u>
Viscosity, Poise	Calif. 427, Part III	9.0 Maximum
Gel Time	Calif. 425, Part I	2 to 15 minutes
Slant Shear Strength on Dry Concrete	Calif. 425, Part IX ^a For slant shear strength on concrete, delete Section C-1 & C-5 of Test Method No. Calif. 425, Part IX.	6000 psi minimum after 4 days of cure in air at 77 ± 2°F.
Slant Shear Strength on Wet Concrete	Calif. 425, Part IX ^a For slant shear strength on concrete, delete Sections C-1 & C-5 of Test Method No. Calif. 425, Part IX.	3500 psi minimum after 4 days of cure in air at 77 ± 2°F.
Tensile Strength	Calif. 427, Part II, except test after 4 days of cure at 77 ± 2°F.	4500 psi minimum

Epoxy, Injection Grouting P.C.C. Pavements

8040-01F-02

<u>Test</u>	<u>Test Method No.</u>	<u>Requirements</u>
Elongation	Calif. 427, Part II, except test after 4 days of cure at 77 ± 2°F.	10% maximum

NOTE: The mixing ratio used will be that recommended by the manufacturer.

*For dry concrete, use "2" below; for wet concrete, use "1" and "2".

- Soak blocks in water for 24 hours at 77 ± 2°F. Remove and wipe off excess water.
- Mix epoxy as described in Test Method No. California 427, Part III-C and apply a coat approximately 0.010-inch thick to each diagonal surface. Place four 1/8-inch square piece of shim stock 0.012-inch thick on one block to control final film thickness. Before pressing the coated surfaces together, leave the blocks so that the coated surfaces are horizontal until the epoxy reacts slightly to prevent excessive flow.

This material shall emit no objectionable odor.

The working properties shall be satisfactory.

3.2 Air Pollution Compliance:

This material must comply with the anti-air pollution requirements of Regulation 3 of the Bay Area Air Pollution Control District and Rule 66 of the County of Los Angeles Air Pollution Control District. Evidence of such facts shall be available to the California Department of General Services, Office of Procurement.

3.3 Certificate of Compliance:

The manufacturer of the finished epoxy components shall furnish a Certificate of Compliance in conformance with the provisions of Section 6-1.07^a, "Certificates of Compliance,". A copy of the label shall be furnished with the "Certificate of Compliance". The certificate shall include a list, by Title and Section, of the State and Federal packaging and labeling laws and regulations that the manufacturer has complied with.

^aDepartment of Transportation Standard Specification Jan. 1978 or 1981.



4.0 QUALITY ASSURANCE PROVISIONS

4.1 Inspection:

This material shall be inspected and tested in accordance with State of California Specification 8010-XXX-99, or as otherwise deemed necessary.

5.0 PREPARATION FOR DELIVERY

5.1 Packaging:

Each component shall be packaged in containers of size proportional to the amount of that component in the mix so that one container of each component is used in mixing one batch of epoxy. The containers shall be of such design that all of the contents may be readily removed, and shall be well sealed to prevent leakage. The containers and labeling shall meet U.S. Department of Transportation Hazardous Material Shipping Regulations, and the containers shall be of a material, or lined with a material, of such character as to resist any action by the components.

5.2 Marking:

Each container shall be clearly labeled with the State Specification Number, including authorized modifications; designation (Component A or B); type (Standard or Rapid) if applicable; manufacturer's name; date of manufacture; batch number (a batch shall consist of a single charge of all components in a mixing chamber); state lot number; all directions for use (as specified elsewhere) and such warning or precautions concerning the contents as may be required by State or Federal Laws and Regulations.

6.0 NOTES

6.1 Directions for Use:

Both components and the mixed material shall contain no solvents. The mixing ratio of the components in terms of volume and weight shall be clearly stated. The material shall be suitable for use in the mixing equipment used by the applicator. Epoxy adhesive samples shall be furnished to the Engineer for testing at least 12 days before the expected time of use.

DEPARTMENT OF GENERAL SERVICES
Office of Procurement
June 1980

1.0 SCOPE

This specification covers a low viscosity liquid polysulfide extended epoxy primarily for use in making high strength epoxy concrete and mortar, fastening metal anchors in vertical holes in concrete and for pressure injection into cracks in concrete. Thick sections of this epoxy are not suitable for use in freeze-thaw environments.

2.0 APPLICABLE SPECIFICATIONS

The following specifications, test methods and standards in effect on the date of the Invitation to Bid, form a part of this specification where referenced.

Test Method No. Calif. 426

American Society for Testing and Materials (ASTM) D476, D281

Department of Transportation Standard Specification

State of California Specification 8010-XXX-99

3.0 REQUIREMENTS

3.1 Composition:

Component A	<u>Parts by Weight</u>
Epoxy Resin (1)	87.00
Aliphatic Glycidyl Ether (2)	13.00
Titanium Dioxide, ASTM D476, Type I or II	3.00

Component B

	<u>Parts by Weight</u>
Polysulfide Polymer (3)	44.00
2,4,6-Tri (Dimethylaminomethyl) Phenol (4)	10.00
Furnace Black (5)	0.10

3.2 Raw Material Specifications:

(1) Diglycidyl ether of bisphenol A, viscosity, 100-160 poise at 25°C., epoxide equivalent 180-200. Color, Gardner 1933, 3 Max.

- (2) Aliphatic mono functional reactive glycidyl ether, derived from an aliphatic alcohol. Viscosity 1-15 centipoise. Weight per epoxide equivalent 220-250. Specific gravity 0.88-0.95.
- (3) Specific gravity, 1.24-1.30 at 20^o/20^oC.; viscosity, 700-1200 centipoise, Brookfield at 25^oC.; pH water extract 6.0-8.0; moisture content, 0.1% maximum; pour point, -15^oF.; average molecular weight, 1000; flash point, ^oF., Cleveland Open Cup, 390 Minimum; sulfur content, percent, 36-40; color; Hellige, 9-12. The product shall be a difunctional mercaptan made from 98 mole percent of bis (2-chloroethyl) formal and 2 mole percent of trichloropropane.
- (4) Formula weight 265; specific gravity at 25^o/25^oC., 0.973; refractive index 1.514 at 25^oC., distillation range 96% at 130^oC to 160^oC (0.5-1.5mm); flash point, Tag Open Cup, 300^oF., minimum; water content 0.06% maximum.
- (5) Surface area, square meters/gram, 115-130. Particle diameter, millimicrons, 18-30; pH, 7.0-8.5 fixed carbon (moisture free), percent, 96-98; volatile matter, percent 1-4; oil absorption, stiff paste endpoint, CCS/gram, 0.80-0.90.

3.3 Characteristics of Components:

All testing shall be performed in accordance with Test Method No. Calif. 426.

Requirements

	Component A	Component B
3.3.1 Viscosity, Brookfield Spindle No. 2 at 20 rpm, Poise at 77 ^o F	5-12	5-12
3.3.2 Density, lbs, per gallon at 77 ^o F	9.45-9.65	9.90-10.10
3.3.3 Infra red curves of the vehicle components shall match those on file in the Transportation Laboratory.		
3.4 Characteristics of Combined Components when mixed in a ratio of 2 Volumes A to 1 Volume B.		

Requirements 20-35

3.4.1 Gel time, minutes

3.5 Air Pollution Compliance:

This material must comply with the anti-air pollution requirements of Regulation 3 of the Bay Area Air Pollution Control District and Rule 66 of the County of Los Angeles Air Pollution Control District. Evidence of such facts shall be available to the California Department of General Services, Office of Procurement.

3.6 Certificate of Compliance:

The manufacturer of the finished epoxy components shall furnish a Certificate of Compliance in conformance with the provisions of Section 6-1.07*, "Certificates of Compliance". A copy of the label shall be furnished with the "Certificate of Compliance". The certificate shall include a list, by Title and Section, of the State and Federal packaging and labeling laws and regulations that the manufacturer has complied with.

*Department of Transportation Standard Specification Jan. 1978 or Jan. 1981.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Inspection:

This material shall be inspected and tested in accordance with State of California Specification 8010-XXX-99, or as otherwise deemed necessary.

5.0 PREPARATION FOR DELIVERY

5.1 Packaging:

Each component shall be packaged in containers of size proportional to the amount of that component in the mix so that one container of each component is used in mixing one batch of epoxy. The containers shall be of such design that all of the contents may be readily removed, and shall be well sealed to prevent leakage. The containers and labeling shall meet U.S. Department of Transportation Hazardous Material Shipping Regulations, and the containers shall be of a material or lined with a material, of such character as to resist any action by the components.

5.2 Marking:

Each container shall be clearly labeled with the State Specification Number, including authorized modifications; designation (Component A or B); type (Standard or Rapid) if applicable; manufacturer's name; date of manufacture; batch number (a batch shall consist of a single charge of all components in the final mixing chamber); state lot number; all directions for use (as specified elsewhere) and such warning or precautions concerning the contents as may be required by State or Federal Laws and Regulations.

6.0 NOTES

6.1 Directions for Use:

The mixing ratio is 2 parts by volume of Component A to 1 part by volume of Component B. No more material shall be mixed than can be used within 10 minutes from the time mixing operations start.

DEPARTMENT OF GENERAL SERVICES
Office of Procurement
June 1980



Specification

8040-310-06

Epoxy Sealant for Inductive Loops

Component B

1.0 SCOPE

This specification covers high viscosity liquid epoxy formulated primarily for use in sealing inductive wire loops and leads imbedded in asphalt concrete and portland cement concrete for traffic signal controls and vehicle counters. This epoxy is to be used for repair work on existing spalls, cracks and other deformations in and around saw cuts housing inductor loops and leads. The rapid cure allows minimum traffic delay. This sealant is suitable for use in freeze-thaw areas and can be used on grades up to 15 percent without excessive flow of material.

2.0 APPLICABLE SPECIFICATIONS

The following specifications, test methods, and standards in effect on the date of the Invitation for Bid form a part of this specification where referenced.

American Society for Testing and Material (ASTM)
Test Method No. California 431
Federal Standard No. 595
Department of Transportation, Standard Specification
State of California Specification

3.0 REQUIREMENTS

Composition:

Component A

	<u>Parts by Weight</u>
Epoxy Resin, *1	85.00
Orthocresol Glycidyl Ether, *2	15.00
Titanium Dioxide, ASTM D 476, Type III or IV	2.00
Colloidal Silica, *3	1.50
Glycerine, ASTM: D 1257	0.50
Silicone Anti-Foam, Type DB100, 100% Solids	0.01

Parts by Weight

High Functionality Polymercaptan Hardener, *4	40.00
N-Aminoethylpiperazine, *5	10.00
2, 4, 6-Tri (Dimethylaminomethyl) Phenol, *6	4.00
Polysulfide Polymer, *7	48.94
Colloidal Silica, *3	1.00
Glycerine, ASTM: D 1257	0.50
Carbon Black, *8	0.10
Silicone Anti-Foam, Type DB 100, 100% Solids	0.01

3.2 Raw Material Specifications:

*1 Di glycidyl ether of bisphenol A, viscosity, 100-160 poise at 25°C; epoxide equivalent 180-200. Color, Gardner 1933, 3 max.

*2 Viscosity at 25°C., 5-10 Centipoise. Weight per gallon 9.00-9.10 pounds. Epoxide equivalent 180-200.

*3 Si O₂ (moisture-free basis), 99% minimum; refractive index, 1.46; surface area, 175-225 square meters per gram; particle size 0.015 microns; pH (4% aqueous dispersion), 3.5-4.2; pour density, 2.3 lbs./cu.ft. maximum; free moisture at 105°C., 1.0% maximum.

*4 Liquid polymercaptan resin, viscosity 100-130 poise at 25°C.; specific gravity 1.14-1.16; mercaptan value, 3.6 meq/gram. color, Gardner 1933, 1. Infrared curve shall match that on file in the Transportation Laboratory.

*5 Color (APHA) 50 maximum; amine value 1250-1350 based on titration which reacts with the 3 nitrogens in the molecule; appearance clear and substantially free of suspended matter.

*6 Formula weight 265; specific gravity at 25°C./25°C., 0.973; refractive index 1.514 at 25°C; distillation range 96% at 130°C to 160°C (0.5-1.5 mm.); flash point, Tag Open Cup, 300°F minimum; water content 0.06% maximum.

*7 Specific gravity, 1.24-1.30 at 20°/20°C.; viscosity, 700-1200 centipoise. Brookfield at 25°C.; pH water extract 6.0-8.0; moisture content, 0.1% maximum; pour point, -15°F.; average molecular weight, 1000; flash point. °F. Cleveland Open Cup, 390 minimum; sulfur content, percent, 36-40; color, Hellige, 9-12. The product shall be a difunctional mercaptan made from 98 mole percent of bis (2-chloroethyl) formal and 2 mole percent of trichloropropane.

*8 Surface area, square meters/gram, 115-130; particle diameter, millimicrons, 18-30; pH, 7.0-8.5; fixed carbon (Moisture free), percent 96-98; volatile matter, percent, 1-4; oil absorption, stiff paste endpoint. CCS/gram, 0.80-0.90.

3.3 Characteristics of Components:

All test shall be performed in accordance with Test Method No. Calif. 431.

Component A

Viscosity, poise, Brookfield	100-250
Shear Ratio	2.0 min.

Component B

Viscosity, poise, Brookfield	100-250
Shear Ratio	1.8 min.

Infrared curves of the vehicle components shall match those on file in the Transportation Industry.

3.4 Characteristics of Combined Components:

Gel Time	13-18 min.
On 1/8" cast sheet, cured 18 hours at 77°F. + 5 hours at 158°F.	
Tensile Strength, psi	400 min.
Elongation, percent	90 min.
Shore D Hardness	45 min.

Color to range from Color No. 26081 to Color No. 26173 of Federal Standard No. 595.

This material shall emit no objectionable odor.

The working properties shall be satisfactory.

3.5 Air Pollution Compliance:

This material must comply with the anti-air pollution requirements of Regulation 3 of the Bay Area Air Pollution Control District and Rule 66 of the County of Los Angeles Air Pollution Control District. Evidence of such facts shall be available to the California Department of General Services, Office of Procurement.

3.6 Certification of Compliance:

The manufacturer of the finished epoxy components shall furnish a Certificate of Compliance in conformance with the provisions of Section 6-1.07* "Certificates of Compliance.". A copy of the label shall be furnished with the "Certificate of Compliance". The certificate shall include a list, by Title and Section, of the State and Federal packaging and labeling laws and regulations that the manufacturer has complied with.

*Department of Transportation
Standard Specifications Jan. 1978 or Jan. 1981.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Inspection:

This material shall be inspected and tested in accordance with State of California Specification 8010-XXX-99, or as otherwise deemed necessary.

5.0 PREPARATION FOR DELIVERY

5.1 Packaging:

Each component shall be packaged in containers of size proportional to the amount of that component in the mix so that one container of each component is used in mixing one batch of epoxy. The containers shall be of such design that all of the contents may be readily removed, and shall be well sealed to prevent leakage. The containers and labeling shall meet U.S. Department of Transportation Hazardous Material Shipping Regulations, and the containers shall be of a material, or lined with a material, of such character as to resist any action by the components.

5.2 Marking:

Each container shall be clearly labeled with the State Specification Number, including authorized modifications; designation (Component A or B); type (Standard or Rapid) if applicable; manufacturer's name; date of manufacture; batch number (a batch shall consist of a single charge of all components in a mixing chamber); state lot number; all directions for use (as specified elsewhere) and such warning or precautions concerning the contents as may be required by State or Federal Laws and Regulations.

6.0 NOTES



Epoxy Adhesive, Rapid Set for Pavement Markers

6.1 Directions:

Saw cuts shall be blown clean and dry with compressed air to remove all excess moisture and debris. For repairing damaged saw cuts, all loose spalled material shall be cleaned away from saw cut, chipping back to sound asphalt concrete or portland cement concrete and all loose material cleaned from loop wires.

The mixing ratio is one part by volume of Component A to one part by volume of Component B. No more material shall be mixed than can be used within 10 minutes from the time mixing operations are started.

When automatic mixing equipment is used for mixing the sealant, the provisions in the sixth paragraph in Section 85-1.06, "Placement", of the Department of Transportation, Standard Specification, shall apply.

DEPARTMENT OF GENERAL SERVICES
Office of Procurement
April 1983

1.0 SCOPE

This specification covers a high viscosity, rapid set, epoxy paste, formulated primarily for use in bonding pavement markers to portland cement concrete and asphalt concrete.

2.0 APPLICABLE SPECIFICATIONS

The following specifications, test methods, and standards in effect on the opening date of the Invitation for Bid form a part of this specification where referenced.

American Society for Testing and Materials (ASTM).

Test Method No. California 425.

Federal Standard No. 595.

Department of Transportation, Standard Specification, January 1978 or 1981.

State of California Specification, 8010-XXX-99, Quality Assurance Requirements for Protective Coatings.

3.0 REQUIREMENTS

3.1 Composition:

Component A

	<u>Parts by Weight</u>
Epoxy Resin (1)	90.00
Orthocresyl Glycidyl Ether (2)	10.00
Titanium Dioxide, ASTM D476	3.00
Talc (3)	50.00
Oleophilic Fumed Silica (4)	4.5*

Component B

Parts by Weight

High Functionality Polymercaptan Hardener (5)	60.00
2,4,6-Tri(Dimethylaminomethyl)Phenol (6)	7.00
Polysulfide Polymer (7)	35.00
Furnace Black (8)	0.10
Talc (3)	52.00
Oleophilic Fumed Silica (4)	3.5*
Silicone Anti-Foam Type DB100, 100% Solids	0.005

*A range of 4.0 to 5.0 parts is permitted in the A Component and 3.0 to 4.0 parts in the B Component, to achieve the required viscosity and thixotropy. Small preproduction batches should be made to determine the oleophilic silica level best suited for manufacturing equipment used.

3.2 Raw Material Specifications:

- (1) Di-glycidyl ether of bisphenol A, viscosity, 100-160 poise at 25°C.; epoxide equivalent 180-200. Color, Gardner 1933, 3 max.
- (2) Viscosity at 25°C., 5-10 Centipoise. Weight per gallon 9.00-9.10 pounds. Epoxide equivalent 180-200.
- (3) Specific Gravity 2.68 to 2.86
Oil Absorption, ASTM D-281 26 to 33
pH 8.9 to 9.6
Hegman Rating 3 to 5
Particle Shape Platey
Maximum Particle Size, microns 55
Percent passing U.S. No. 325 Screen, min. 99
Dry Brightness, minimum 93
- (4) High purity fumed silica, surface treated with a silicone oil, with the following properties: Appearance, fluffy white powder; surface area, N₂ B.E.T. method, 70 ± 15 M²/gram; pH, 4 grams dispersed in 100 mls of 20/80 volume mixture of ethyl alcohol and distilled water, 4.7; weight % carbon, 5.0 minimum; ignition loss (dry basis) 2 hours at 1000°C, 6 to 7; specific gravity, 1.8.
- (5) Liquid polymercaptan resin, viscosity 100-130 poise at 25°C.; specific gravity 1.14-1.16; mercaptan value, 3.6 meq/gram. Color, Gardner 1933, 1. Infrared curve shall match the curve on file in the Transportation Laboratory.
- (6) Formula weight 265; specific gravity at 25°C./25°C., 0.973; refractive index 1.514 at 25°C., distillation range 96% at 130°C to 160°C. (0.5-1.5 mm); flash point, Tag Open Cup, 300°F., minimum; water content 0.06% maximum.

- (7) Specific gravity, 1.24-1.30 at 20⁰/20⁰C.; viscosity, 700-1200 centipoise, Brookfield at 25°C.; pH water extract 6.0-8.0; moisture content, 0.1% maximum; pour point, -15°F.; average molecular weight, 1000; flash point, 0F., Cleveland Open Cup, 390 minimum; sulfur content, percent, 36-40; color; Hellige, 9-12. The product shall be a difunctional mercaptan made from 98 mole percent of bis(2-chloroethyl)formal and 2 mole percent of trichloropropane.
- (8) Surface area, square meters/gram, 115-130, particle diameter, millimicrons, 18-30; pH, 7.0-8.5; fixed carbon (moisture free), percent, 96-98; volatile matter, percent, 1-4; oil absorption, stiff paste endpoint, CCS/gram, 0.80-0.90.

3.3 Component Characteristics*:

Test	Requirements	
	Component A	Component B
(1) Brookfield viscosity, Poise, TE Helipath Spindle at 77°F	3000 to 4000	3000 to 4000
(2) Shear Ratio. Minimum at 77°F.	2.0	2.0
(3) Density lbs. per gallon at 77°F.	11.90 to 12.2	11.90 to 12.2
(4) Skinning (original container)	None	Slight
(5) Infrared Curves, Components A and B	Shall match curves in Test Method Calif. 425	
(6) Storage Stability	The Components A and B shall not change in viscosity and shear ratio by more than + 15 percent when stored for 2 weeks in closed containers at 115°F., + 2°F. All measurements shall be made at 77°F. using the same spindle and apparatus as in Test (1) above. The adhesive shall meet all other requirements for 12 months from date of manufacture. There shall be no settling of the fillers that cannot be easily redispersed with a paddle.	

	(7) Percent Air, Maximum	2.0	2.0
3.4	Characteristics of Combined Components When Mixed In A Ratio of 1 Volume of A to 1 Volume of B*:		
			<u>Requirements</u>
	(1) Gel time, minutes, minimum		7
	(2) Bond Strength to Concrete, Time, minutes (maximum) to reach not less than 200 psi, at 77°F., ± 2°F.		35
	at 50°F., ± 2°F.		45
	at 30°F., ± 2°F.		85
	(3) Slant Shear Strength		
	24 hours at 77°F., ± 2°F., psi, minimum		1000
	24 hours at 77°F., ± 2°F., plus water soak, psi, minimum		800
	(4) Tensile Adhesion and Cohesion,		
	(a) Ceramic marker bottom, psi, minimum		700
	(b) Ceramic marker bottom, including post cure, psi, minimum		700
	(c) Reflective pavement marker bottom, psi, minimum		500
	(5) Color of Mixed Components	Approximately that of Color No. 26152 of Federal Standard No. 595.	
	(6) Sag Test**	No Sag	
	** A 7 inch long by 2-1/2 inch wide by 1/4 inch thick layer of mixed adhesive is applied to the glazed face of a Leneta Chart, Form 2-A opacity, surface levelled with thickness controlled by 1/4 inch thick shims. Remove shims and immediately hang chart vertically until epoxy hardens. Test performed at 77°F.		
	The working properties shall be satisfactory.		
	*All tests shall be performed in accordance with California Test 425.		
4.0	QUALITY ASSURANCE PROVISIONS		
4.1	Inspection:		
	This material shall be inspected and tested in accordance with State of California Specification 8010-XXX-99, or as otherwise deemed necessary.		

5.0 PREPARATION FOR DELIVERY

5.1 Packaging:

Each component shall be packaged in containers of size proportional to the amount of that component in the mix so that one container of each component is used in mixing one batch of epoxy. The containers shall be of such design that all of the contents may be readily removed, and shall be well sealed to prevent leakage. The containers and labeling shall meet U.S. Department of Transportation Hazardous Material Shipping Regulations, and the containers shall be of a material, or lined with a material, of such character as to resist any reaction with the components.

5.2 Marking:

Each container shall be clearly labeled with the State Specification Number, including authorized modifications; designation (Component A or B); type (Standard or Rapid) if applicable; manufacturer's name; date of manufacture; batch number (a batch shall consist of a single charge of all components in a mixing chamber); state lot number; all directions for use (as specified elsewhere) and such warning or precautions concerning the contents as may be required by State or Federal Laws and Regulations.

6.0 NOTES

6.1 Air Pollution Compliance:

This material must comply with the anti-air pollution requirements of Regulation 3 of the Bay Area Air Pollution Control District and Rule 66 of the County of Los Angeles Air Pollution Control District. Evidence of such facts shall be available to the California Department of General Services, Office of Procurement.

6.2 Certification of Compliance:

The manufacturer of the finished epoxy components shall furnish a Certificate of Compliance in conformance with the provisions of Section 6-1.07*, "Certificates of Compliance". A copy of the label shall be furnished with the "Certificate of Compliance". The certificate shall include a list, by Title and Section, of the State and Federal packaging and labeling laws and regulations that the manufacturer has complied with.

*Department of Transportation Standard Specifications Jan. 1978 or 1981.

6.3 Directions for Use:

Just before use, Components A and B shall be mixed in a one-to-one ratio by volume. When automatic proportioning and mixing machine is used, the temperature of the components shall be maintained by indirect heating or cooling, so that the adhesive will meter, mix and extrude properly. The maximum temperature shall be such that after proper mixing there shall be no excess flow of adhesive from under the marker other than that specified in Section 85-1.06, "Placement", of the Department of Transportation, Standard Specifications.

DEPARTMENT OF GENERAL SERVICES
Office of Procurement
December 1982



STATE OF CALIFORNIA

Specification

8040-21M-08

Epoxy Resin Adhesive for Bonding
New Concrete to Old Concrete

1.0 SCOPE

This specification covers a low viscosity polysulfide extended paste epoxy, primarily for use in bonding new portland cement concrete to old portland cement concrete and in fastening metal anchors in holes in concrete where the center line of the hole is horizontal (i.e. in a wall type structure). This system is available in 2 types: Type I for general use and Type II for use when cure temperatures are below 60°F, or when a faster cure is required. Thick sections of this epoxy are not suitable for use in freeze-thaw environments.

2.0 APPLICABLE SPECIFICATIONS

The following specifications, test methods and standards in effect on the opening date of the Invitation for Bid form a part of this specification where referenced.

American Society for Testing and Materials (ASTM).

Test Method No. California 428.

Federal Standard No. 595.

Department of Transportation, Standard Specification, January 1978 or 1981.

State of California Specification, 8010-XXX-99, Quality Assurance Requirements for Protective Coatings.

3.0 REQUIREMENTS

3.1 Composition:

3.1.1 Type I

Component A

	<u>Parts by Weight</u>
Epoxy Resin (1)	87.00
Aliphatic Glycidyl Ether (2)	13.00
Titanium Dioxide ASTM D476	2.00
Colloidal Silica (3)	2.00*
Glycerine, ASTM D1257	0.50
Silicone Anti-Foam, Type DB100, 100% Solids	0.005

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8040-01F-08

Component B

Parts by Weight

Polysulfide Polymer (4)	44.20
2,4,6-Tri(Dimethylaminomethyl)Phenol (5)	5.00
Dimethylaminomethyl Phenol (6)	5.00
Colloidal Silica (3)	2.0*
Furnace Black (7)	0.05
Silicone Anti-Foam, Type DB100, 100% Solids	0.005

3.1.2 Type II

Component A

Epoxy Resin (1)	87.00
Aliphatic Glycidyl Ether (2)	13.00
Titanium Dioxide ASTM D476	2.00
Colloidal Silica (3)	2.0*
Glycerine, ASTM D1257	0.50
Silicone Anti-Foam, Type DB100, 100% Solids	0.005

Component B

Polysulfide Polymer (4)	43.80
2,4,6-Tri (Dimethylaminomethyl) Phenol (5)	10.00
Furnace Black (7)	0.05
Colloidal Silica (3)	2.0*
Silicone Anti-Foam, Type DB100, 100% Solids	0.005

*A range of 1.5 to 2.5 parts is permitted in the A and B Components to achieve the required viscosity and shear ratio.

3.2 Raw Material Specifications:

- (1) Di-glycidyl ether of bisphenol A, viscosity, 100-160 poise at 25°C., epoxide equivalent 180-200. Color, Gardner 1933, 3 Max.
- (2) Aliphatic mono functional reactive glycidyl ether, derived from an aliphatic alcohol. Viscosity 1-15 centipoise. Weight per epoxide equivalent 220-250. Specific gravity 0.88-0.95.
- (3) SiO₂ (moisture-free basis), 99% minimum; refractive index, 1.46; surface area, 175-225 square meters per gram; particle size 0.015 microns: pH (4% aqueous dispersion), 3.5-4.2; pour density, 2.3 lbs./cu.ft. maximum: free moisture at 105°C, 1.0% maximum.

(4) Specific gravity, 1.24-1.30 at 20^o/20^oC.; viscosity, 700-1200 centipoise, Brookfield at 25°C.; pH water extract 6.0-8.0; moisture content, 0.1% maximum; pour point, -15°F.; average molecular weight. 1000; flash point, °F., Cleveland Open Cup, 390 Minimum; sulfur content, percent, 36-40; color; Hellige, 9-12. The product shall be a difunctional mercaptan made from 98 mole percent of bis(2-chloroethyl)formal and 2 mole percent of trichloropropane.

(5) Formula weight 265; specific gravity at 25°C./25°C., 0.973; refractive index 1.514 at 25°C., distillation range 96% at 130°C to 160°C (0.5-1.5mm); flash point, Tag Open Cup, 300°F., minimum; water content 0.06% maximum.

(6) Formula weight 151. Specific gravity at 25°C/25°C 1.023. Refractive index 1.530 at 25°C. Distillation range 78% at 80-130°C. (2mm). Flash point, Tag Open Cup, Dip 215°F, sweep 227.5°F. Water content 1.0% maximum.

(7) Surface area, square meters/gram, 115-130. Particle diameter, millimicrons, 18-30; pH, 7.0-8.5; fixed carbon (moisture free), percent, 96-98; volatile matter, percent, 1-4; oil absorption, stiff paste endpoint, CCS/gram, 0.80-0.90.

3.3 Component Characteristics*:

Test	Requirements	
	Component A	Component B
(1) Brookfield viscosity, Poise, TB Helipath Spindle at 77°F	200 to 450	200 to 450
(2) Shear Ratio, minimum	2.0	2.0
(3) Density, lbs. per gallon at 77°F	9.40 to 9.60	10.10 to 10.30
(4) Percentage of Entrapped Air, Maximum	2.0	2.0
(5) Infrared Curves, Components A and B	Shall match those on file in the Transportation Laboratory.	

3.4 Characteristics of Combined Components When Mixed in a Ratio of 2 Volumes A to 1 Volume B*:

Requirements

(1) Gel time, minutes, Type I	25-50
(2) Gel time, minutes, Type II	15-30
(3) Color, Type I and Type II	Approximately that of color No. 26134 of Federal Standard No. 595.

*All tests shall be performed in accordance with California Test 428.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Inspection:

This material shall be sampled and inspected in accordance with State of California Specification 8010-XXX-99, or as otherwise deemed necessary.

5.0 PREPARATION FOR DELIVERY

5.1 Packaging:

Each component shall be packaged in containers of size proportional to the amount of that component in the mix so that one container of each component is used in mixing one batch of epoxy. The containers shall be of such design that all of the contents may be readily removed, and shall be well sealed to prevent leakage. The containers and labeling shall meet U.S. Department of Transportation Hazardous Material Shipping Regulations, and the containers shall be of a material, or lined with a material, of such character as to resist any reaction with the components.

5.2 Marking:

Each container shall be clearly labeled with the State Specification Number, including authorized modifications; designation (Component A or B); type (Standard or Rapid) if applicable; manufacturer's name; date of manufacture; batch number (a batch shall consist of a single charge of all components in a mixing chamber); state lot number; all directions for use (as specified elsewhere) and such warning or precautions concerning the contents as may be required by State or Federal Laws and Regulations.

6.0 NOTES

6.1 Air Pollution Compliance:

This material must comply with the anti-air pollution requirements of Regulation 3 of the Bay Area Air Pollution Control District and Rule 66 of the County of Los Angeles Air Pollution Control District. Evidence of such facts shall be available to the California Department of General Services, Office of Procurement.

6.2 Certificate of Compliance:

The manufacturer of the finished epoxy components shall furnish a Certificate of Compliance in conformance with the provisions of Section 6-1.07*, "Certificate of Compliance". A copy of the label shall be furnished with the "Certificate of Compliance". The certificate shall include a list, by Title and Section, of the State and Federal packaging and labeling laws and regulations that the manufacturer has complied with.

*Department of Transportation Standard Specifications Jan. 1978 or 1981.

6.3 Directions for Use:

The mixing ratio is 2 parts by volume of Component A to one part by volume of Component B. When measuring as individual Components A and B, stir and tap the measuring containers to remove possible air voids. Do not mix more material than can be spread within 8 minutes from the time mixing operations are started. The spreading rate shall be sufficient to thoroughly coat the surface. Spread the mixed adhesive by brush or roller over blast cleaned concrete at a rate not exceeding 40 square feet per gallon. On very rough surfaces the spreading rate shall be 25 square feet per gallon. The new concrete shall be placed against the adhesive coating on the old concrete within 15 minutes after spreading at temperatures below 90°F or within 10 minutes at temperatures above 90°F.

DEPARTMENT OF GENERAL SERVICES
Office of Procurement
December 1982



Epoxy Adhesive, Standard Set for Pavement Markers

Component BParts by Weight

1.0 SCOPE

This specification covers a high viscosity, standard set, epoxy paste, primarily for use in bonding pavement markers to portland cement concrete and asphalt concrete.

2.0 APPLICABLE SPECIFICATIONS

The following specifications, test methods and standards in effect on the opening date of the Invitation to Bid form a part of this specification where referenced.

American Society for Testing and Materials D-476, D-281 (ASTM).

Test Method No. California 425.

Federal Standard No. 595.

Department of Transportation, Standard Specification, January 1978 or 1981.

State of California Specification 8010-XXX-99, Quality Assurance Requirements for Protective Coatings.

3.0 REQUIREMENTS

3.1 Composition:

Component A

	<u>Parts by Weight</u>
Epoxy resin (1)	87.00
Aliphatic Glycidyl Ether (2)	13.00
Titanium Dioxide, ASTM D476	3.00
Oleophilic Fumed Silica (3)	6.5*
Talc (4)	34.00

N-Aminoethyl Piperazine (5)	23.20
Nonylphenol (6)	52.00
Furnace Black (7)	0.10
Oleophilic Fumed Silica (3)	6.5*
Talc (4)	65.00
Silicone Anti Foam, Type DB100, 100% solids	0.005

*A range of 6.0 to 7.0 parts is permitted in the A and B Component, to achieve the required viscosity and shear ratio.

3.2 Raw Material Specifications:

- (1) Di glycidyl ether of bisphenol A, viscosity, 100-160 poise at 25°C., epoxide equivalent 180-200. Color, Gardner 1933, 3 Max.
- (2) Aliphatic mono functional reactive glycidyl ether, derived from an aliphatic alcohol. Viscosity 1-15 centipoise. Weight per epoxide equivalent 220-250. Specific gravity 0.88-0.95.
- (3) High purity fumed silica, surface treated with a silicone oil, with the following properties: Appearance, fluffy white powder; surface area, N₂ B.E.T. method, 70 ± 15 M²/gram; pH, 4 grams dispersed in 100 mls of 20/80 volume mixture of ethyl alcohol and distilled water, 4.7; weight % carbon, 5.0 minimum; ignition loss (dry basis) 2 hours at 1000°C, 6 to 7; specific gravity, 1.8.
- (4) Specific Gravity 2.68 to 2.86
Oil Absorption, ASTM D-281 26 to 33
pH 8.9 to 9.6
Hegman Rating 3 to 5
Particle Shape Platey
Maximum Particle Size, microns 55
Percent passing U.S. No. 325 Screen, Minimum 99
Dry Brightness, minimum 93
- (5) Color (APHA) 50 maximum. Amine value 1250-1350 based on titration which reacts with the 3 nitrogens in the molecule. Appearance clear and substantially free of suspended matter.
- (6) Color (APHA) 50 maximum. Hydroxyl number 245-255. Distillation range, °C at 760mm, first drop 295 minimum, 5% at 298 minimum, 95% at 325 maximum. Water % (KF) 0.05 maximum.
- (7) Surface area, square meters/gram, 115-130. Particle diameter, millimicrons, 18-30. pH, 7.5-8.5. Fixed carbon (moisture free), percent 96-98. Volatile matter, percent, 1-4. Oil absorption, stiff paste endpoint, CCS/gram, 0.80-0.90.

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8040-11D-09

Epoxy Adhesive, Standard Set for Pavement Markers

8040-21M-09

3.3 Component Characteristics*:

	Requirements	
	Component A	Component B
3.3.1 Brookfield viscosity, Poise, TE Helipath Spindle at 77°F	3000 to 4000	3000 to 4000
3.3.2 Shear ratio, minimum at 77°F	2.0	2.0
3.3.3 Density, lbs. per gallon at 77°F	11.0 to 11.3	11.3 to 11.6
3.3.4 Skinning (original container)	None	None
3.3.5 Infra red curves, Components A&B	Shall match curves on file with Transportation Lab.	
3.3.6 Storage Stability	Component A	Component B
	The Components A and B shall not change in viscosity and shear ratio by more than ±15 percent when stored for 2 weeks in closed containers at 115°F., +30°F. All measurements shall be made at 77°F using the same spindle and apparatus as in paragraph 3.3.1 above.	
	The adhesive shall meet all other requirements for 12 months from date of manufacture. Any settling of the fillers must be easily re-dispersible with a paddle.	
3.3.7 Percent air, maximum	2.0	2.0
3.4 Characteristics of Combined Components When Mixed In A Ratio of 1 Volume of A to 1 Volume of B*:		
	<u>Requirement</u>	
3.4.1 Gel time, minutes	8 to 13	
3.4.2 Bond strength to concrete, time (maximum) hours to reach not less than 200 psi at 77°F ± 20°F	3.5	

Epoxy Adhesive, Standard Set for Pavement Markers

8040-21M-09

3.4.3 Slant shear strength, 24 hours at 77°F ±20°F, psi, minimum	2200
3.4.4 Plus water soak, psi, minimum	1500
3.4.5 Tensile adhesion and cohesion, to ceramic marker bottom, psi, minimum	700
3.4.6 Plus post cure, psi, minimum	700
3.4.7 Tensile adhesion and cohesion, to reflective pavement marker bottom, psi, minimum	500
3.4.8 Color of mixed components	Approximately that of color No. 26152 of Federal Standard No. 595
3.4.9 Sag Test**	No Sag
*All tests shall be performed in accordance with California Test 425.	
**A 7 inch long by 2-1/2 inch wide by 1/4 inch thick layer of mixed adhesive is applied to the glazed face of a Leneta Chart, Form 2-A opacity, surface levelled with thickness controlled by 1/4 inch shims. Remove shims and immediately hang chart vertically until epoxy hardens. Test performed at 77°F.	
4.0	QUALITY ASSURANCE PROVISIONS
4.1	Inspection:
	This material shall be inspected and tested in accordance with State of California Specification 8010-XXX-99, or as otherwise deemed necessary.
5.0	PREPARATION FOR DELIVERY
5.1	Each component shall be packaged in containers of size proportional to the amount of that component in the mix so that one container of each component is used in mixing one batch of epoxy. The containers shall be of such design that all of the contents may be readily removed, and shall be well sealed to prevent leakage. The containers and labeling shall meet U.S. Department of Transportation Hazardous Material Shipping Regulations, and the containers shall be of a material, or lined with a material, of such character as to resist any reaction with the components.

5.2 Marking:

Each container shall be clearly labeled with the State Specification Number, including authorized modifications; designation (Component A or B); manufacturer's name; date of manufacture; batch number (a batch shall consist of a single charge of all components in the final mixing chamber); state lot number; all directions for use (as specified elsewhere) and such warning or precautions concerning the contents as may be required by State or Federal Laws and Regulations.

6.0 NOTES**6.1 Air Pollution Compliance:**

This material must comply with the anti-air pollution requirements of Regulation 3 of the Bay Area Air Pollution Control District and Rule 66 of the County of Los Angeles Air Pollution Control District. Evidence of such facts shall be available to the California Department of General Services, Office of Procurement.

6.2 Certificate of Compliance:

The manufacturer of the finished epoxy components shall furnish a Certificate of Compliance in conformance with the provisions of Section 6-1.07*, "Certificates of Compliance". A copy of the label shall be furnished with the "Certificate of Compliance". The certificate shall include a list, by Title and Section, of the State and Federal packaging and labeling laws and regulations that the manufacturer has complied with.

*Department of Transportation Standard Specifications Jan. 1978 or Jan. 1981.

6.3 Directions for Use:

Just before use, Components A and B shall be mixed in a one-to-one ratio by volume. When an automatic proportioning and mixing machine is used, the temperature of the components shall be maintained by indirect heating or cooling, so that the adhesive will meter, mix and extrude properly. The maximum temperature shall be such that after proper mixing there shall be no excess flow of adhesive from under the marker other than that specified in Section 84-1.06, California Standard Specifications, Jan. 1978, "Placement".

DEPARTMENT OF GENERAL SERVICES
Office of Procurement
December 1982

DEPARTMENT OF TRANSPORTATION

DIVISION OF CONSTRUCTION
Office of Transportation Laboratory
P. O. Box 19128
Sacramento, California 95819
(916) 444-4800



California Test 425
1978

METHOD FOR TESTING EPOXY RESIN ADHESIVES FOR PAVEMENT MARKERS

A. SCOPE

The procedures used for testing epoxy resin adhesives for pavement markers are described in this test method.

This test method is divided into the following parts:

- I. Pot Life
- II. Infrared Curve
- III. Bond Strength Concrete
- IV. Brookfield Adhesion and Cohesion
- V. Brookfield Viscosity
- VI. Shear Ratio
- VII. Weight in Pounds per Gallon
- VIII. Percentage of Entrapped Air
- IX. Slant Shear Strength

PART I. POT LIFE

A. APPARATUS

1. Unwaxed paper cups, 8 oz., 2 inches \pm $\frac{1}{4}$ inch diameter base (Dixie Cup No. 4338 or equivalent).
2. Unwaxed paper cups, 2 oz., 1 $\frac{1}{2}$ inches \times 1 $\frac{1}{2}$ inches at base (Dixie Cup No. 23 or equivalent).
3. Wooden tongue depressor with ends cut square (Puritan No. 705 or equivalent).
4. Stainless steel spatula with blade 6 inches \times 1 inch, and with the end cut square.
5. Stop watch, 1 second or smaller divisions.

B. TEST PROCEDURE

1. Condition both A and B components to $77 \pm 2^\circ\text{F}$.
2. Stir the separate components vigorously with the spatula to redisperse any settled material.
3. Measure components in a ratio of one 2 ounce paper cup of component A to one 2 ounce paper cup of component B into an 8 ounce paper cup.
4. Start stopwatch immediately and mix the components for 60 seconds using a wooden tongue depressor and taking care to scrape the sides and bottom of cup periodically.
5. Place the sample at $77 \pm 2^\circ\text{F}$ on a wooden bench top which is free of excessive drafts.
6. Probe the mixture once with the tongue depressor every 30 seconds, starting two minutes from the time of mixing.
7. The time at which a soft stringy mass forms in

the center of the cup is the pot life.

PART II. INFRARED CURVE

A. APPARATUS

1. Perkin-Elmer Model 137-B Infracord Spectrophotometer, automatic recording system from 2.5 microns to 15 microns with a two speed recorder. Comparable results can be obtained by other double-beam recording spectrophotometers with similar resolution.
2. Disk holder for a one inch diameter disk.
3. Two sodium chloride crystal disks one inch in diameter.
4. Sorvall SS-3 Automatic Superspeed Centrifuge, or a comparable centrifuge which is able to separate the liquid and solid phases of the epoxy components without previous dilution with solvents.

B. PROCEDURE

1. Place about 15 grams of component A into a stainless steel centrifuge tube.
2. Counterbalance with component B in a second centrifuge tube.
3. Centrifuge the two components at 17,000 rpm until there is a supernatant liquid layer present in each tube. This takes 20 to 30 minutes.
4. Place a drop of component A liquid layer on a sodium chloride disk.
5. Place another sodium chloride disk over the drop, rotate, and press down until the liquid has flowed into a uniform layer of proper thickness between the two sodium chloride disks.
6. Place the disks in the holder and run an absorption curve with the infrared spectrophotometer.
7. More or less liquid may be used between the disks so as to produce a maximum absorption of 0.7 to 1.0 for the strongest absorption point on the curve.
8. Clean the disks with toluene and dry.
9. Repeat steps 4 through 8 with the liquid layer from component B.
10. Compare each curve with the attached absorption curves for standard materials. Two materials are considered to be identical if all of the absorption points agree as to wave length and relative magnitude of the peaks in comparison with the other points of absorption.

California Test 425
1978

PART III. BOND STRENGTH CONCRETE

A. MATERIALS

1. A sandblasted concrete block 12 inches by 12 inches by 3 inches prepared with 7 sack concrete and having a tensile strength in excess of 250 psi.

B. APPARATUS

1. Use the same apparatus as specified in California Test 420. Apparatus 1, 2, 3 and 7; or a suitable testing press at a load rate of 5000 lbs./minute.
2. A sandblasted 2" diameter steel rod may be used in place of the pipe cap.
3. Stop watch, 1 second or smaller divisions.

C. PROCEDURE

1. Condition the test equipment, materials and epoxy components for 24 hours at the testing temperature specified.
2. Stir the separate components vigorously for 30 seconds.
3. Place equal volumes of each component on a tin plate and mix with a plaster trowel or spatula for 60 \pm 5 seconds.
4. Immediately start timing.
5. Place the adhesive on the pipe cap, or rod, and the concrete surface.
6. Press pipe cap, or rod, firmly in place and remove the excess adhesive.
7. Just before the required test time insert the hook into the cap (or rod).
8. Proceed according to Part I, Section A-6 of California Test 420, or use a suitable testing press to determine the bond strength.

PART IV. TENSILE ADHESION AND COHESION

A. MATERIALS

1. Class II polyester marker of current State specification, one per test.
2. Classes III and IV ceramic markers of current State specification, two each per test.
3. Reflective pavement marker of current State specification, three per test.

B. APPARATUS

1. Use testing apparatus described in Part III-B above.
2. Cold box capable of maintaining $15^\circ \pm 2^\circ\text{F}$.
3. Oven capable of maintaining $140^\circ \pm 2^\circ\text{F}$.

C. PROCEDURE

1. Stir the separate components vigorously for 30 seconds.
2. Place equal volumes of each component on a tin plate and mix with a trowel or spatula for 60 \pm 5

seconds.

3. Place the adhesive on the pipe cap or rod and the surface to be tested.
4. Press the pipe cap or rod firmly in place and remove the excessive adhesive.
5. Cure all specimens for 24 hours at $77^\circ \pm 2^\circ\text{F}$.
6. Proceed according to Part I, Section A-6 of California Test 420, or use a suitable testing press for the following:
 - a. Class II polyester marker, test one only.
 - b. Class III ceramic marker, test one only.
 - c. Reflective pavement marker, test in triplicate.
7. Post cure one Class III ceramic marker further as follows:
 - a. 48 hours at 140°F .
 - b. Return to $77^\circ \pm 2^\circ\text{F}$ and then place in cold box for 24 hours at $15^\circ \pm 2^\circ\text{F}$.
 - c. Return to $77^\circ \pm 2^\circ\text{F}$ and test as in 6 above.

PART V. BROOKFIELD VISCOSITY

A. APPARATUS AND SUPPLIES

1. Model RVT Brookfield Syncro-Electric Viscometer, Brookfield Engineering Laboratories, Stoughton, Massachusetts.
2. Brookfield Helipath Stand Model C with spindles TD, TE and spindle weight.
3. Round, one pint paint cans.
4. Stainless steel spatula having a blade 6 inches by 11 inches with the end cut square.

B. TEST PROCEDURE

1. Fill a one pint paint can within one inch of the top with well mixed component A.
2. Condition the material to temperatures required for the test.
3. Stir the material vigorously for 30 seconds with a spatula.
4. Remove entrained air bubbles by vigorous tamping.
5. Insert proper spindle according to specifications.
6. Make viscosity reading at 5 rpm within ten minutes of stirring.
7. Make additional readings at 0.5 and 2.5 rpm for use in Part VI—Shear Ratio.

C. CALCULATIONS FOR 5 RPM READINGS

1. Reading on 0-100 scale \times 4000 = viscosity in centipoise, TD spindle.
2. Reading on 0-100 scale \times 10,000 = viscosity in centipoise, TE spindle.

D. CALCULATIONS FOR 0.5 RPM READINGS

1. Reading on 0-100 scale \times 40,000 = viscosity in

centipoise, TD spindle.

2. Reading on 0-100 scale $\times 100,000$ = viscosity in centipoise, TE spindle.

E. CALCULATIONS FOR 2.5 RPM READINGS

1. Reading on 0-100 scale $\times 8000$ = viscosity in centipoise, TD spindle.

2. Reading on 0-100 scale $\times 20,000$ = viscosity in centipoise, TE spindle.

PART VI. SHEAR RATIO

A. APPARATUS AND SUPPLIES

1. Same as Part V.

B. TEST PROCEDURE

1. Same as Part V.

C. CALCULATIONS

1. Shear Ratio = (Viscosity cp at 0.5 rpm) / (Viscosity cp at 2.5 rpm)

PART VII. WEIGHT IN POUNDS PER GALLON

1. Follow Federal Test Method Standard No. 141, Method 4184.

PART VIII. PERCENTAGE OF ENTRAPPED AIR

A. APPARATUS

1. Round, one quart paint cans.

2. Electric hot plate.

3. Vacuum chamber capable of 30" mercury which is equipped with valves enabling manual control of application and release of vacuum and viewing ports or other means of observing controls under vacuum.

B. TEST PROCEDURE

1. Weight in pounds per gallon, Part VII, must be done before proceeding with this test. (W_1)

2. Fill separate round, one quart paint cans half full of each component.

3. Heat cans and contents to 175°-180° F.

4. Place into vacuum oven and evacuate until the samples show signs of frothing over.

5. Vibrate or tamp samples to facilitate removal of entrapped air.

6. As frothing subsides, raise vacuum until 30" is reached.

7. Cool samples to 77° \pm 2° F after removing from vacuum oven.

8. Measure the weight in pounds per gallon as done in Part VII. (W_2)

C. CALCULATIONS

% Air = $[(W_2 - W_1) / W_1] \times 100$

See items 8 and 1 above for W_2 and W_1 , respectively.

PART IX. SLANT SHEAR STRENGTH

A. MATERIALS

1. Ottawa sand, ASTM C109

2. Portland cement Type II

3. Water

B. APPARATUS

1. Suitable mold to make diagonal concrete mortar blocks with a square base with 2 inch sides and having one diagonal face 2 inches x 4 inches starting about 1/4 inch above the base. The diagonal faces of two such blocks are bonded together, producing a block of dimensions 2 inches by 2 inches x 5 inches.

2. Blocks made from the following composition:

Ottawa sand, ASTM C109 30.1 lbs.

Portland cement Type II 12.1 lbs.

Water 4.8 lbs.

Cure blocks 28 days in a fog room. Dry and lightly sandblast diagonal faces.

3. Suitable test press.

C. TEST PROCEDURE

1. Mix epoxy as described in Part III-C and apply a coat to each diagonal surface. Press diagonal surfaces of each block together by hand and remove excess epoxy adhesive.

2. Align the blocks so that the ends and sides are square and form a block 2 inches x 2 inches x 5 inches. Use blocks of wood or metal against each 2" x 2" end to keep diagonal faces from slipping until epoxy hardens.

3. After the required cure time as called for in specification, apply a suitable capping compound to each of the 2 inch x 2 inch bases and test by applying a compression load with a Universal Test Machine or other suitable testing apparatus at the rate of 5000 lbs./min. until failure.

4. Report results in pounds per square inch = Load in Pounds/4

5. For wet shear strength, bond another set of blocks together as described above. Cure 24 hours at 77° \pm 2° F, then soak in water for seven days at 77° \pm 2° F, and immediately test as described above in C-3.

D. RECORDING TEST RESULTS

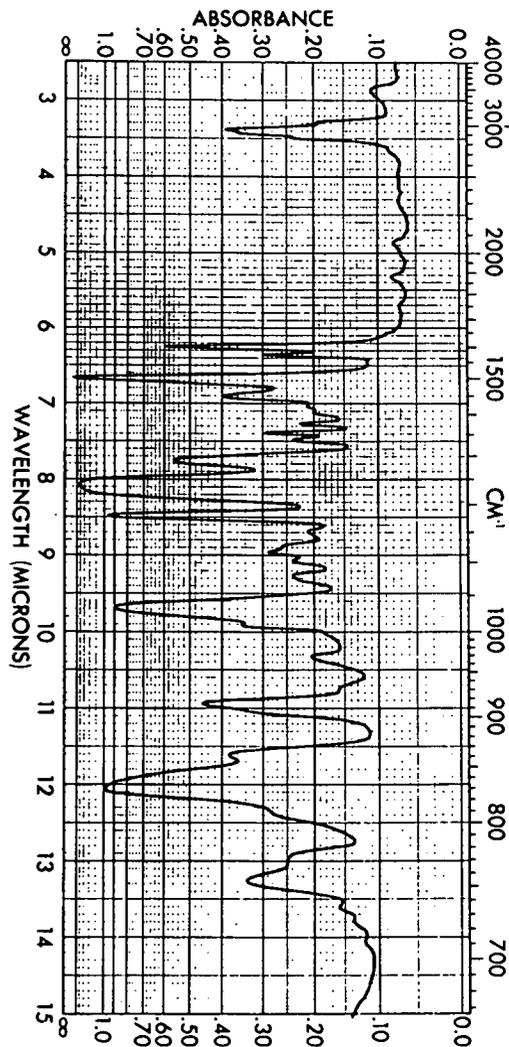
Record all test results on Form T.L.-581

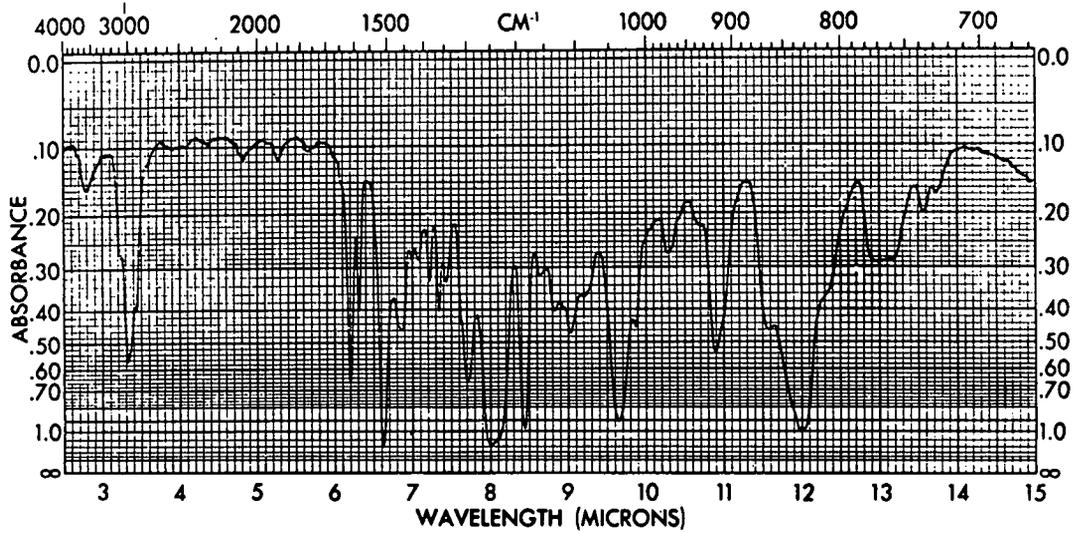
REFERENCES

California Test 425
Federal Test Method Standard No. 141, 4184
End of Text (7 pgs) on Calif. 425

TEST METHOD 425
STANDARD INFRA RED ABSORPTION CURVE
COMPONENT A
RAPID SET ADHESIVE

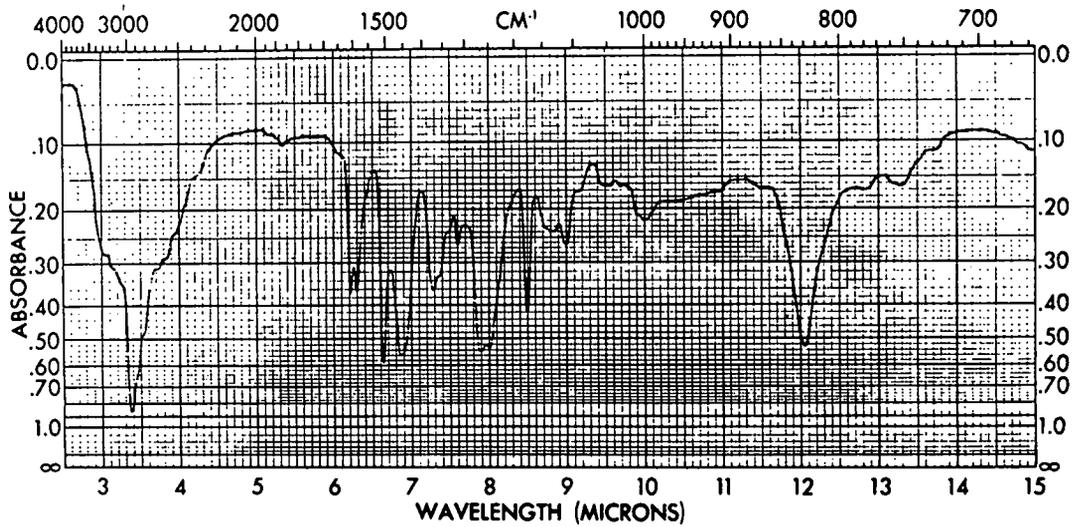
FIGURE 1





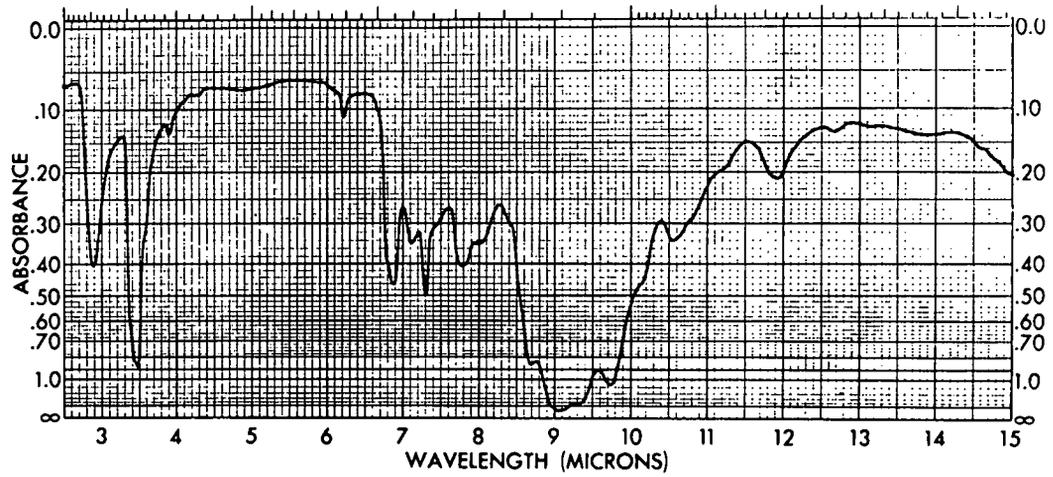
TEST METHOD 425
STANDARD INFRARED ABSORPTION CURVE
COMPONENT A
STANDARD SET ADHESIVE

FIGURE 2



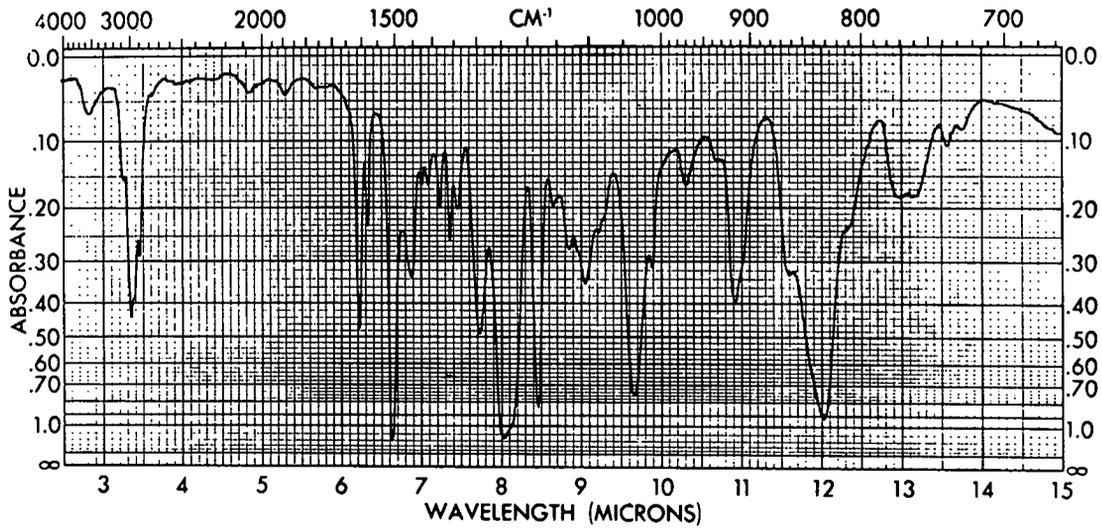
TEST METHOD 425
STANDARD INFRARED ABSORPTION CURVE
COMPONENT B
STANDARD SET ADHESIVE

FIGURE 3



TEST METHOD 425
STANDARD INFRA RED ABSORPTION CURVE
COMPONENT B
RAPID SET ADHESIVE

FIGURE 4



TEST METHOD 426
STANDARD INFRA RED ABSORPTION CURVE
COMPONENT A

FIGURE 1



DEPARTMENT OF TRANSPORTATION

DIVISION OF CONSTRUCTION
Office of Transportation Laboratory
P. O. Box 19128
Sacramento, California 95819
(916) 444-4800

METHOD FOR TESTING COAL TAR MODIFIED EPOXY

A. SCOPE

The procedures used for testing Coal Tar Modified Epoxy Resin are described in this test method.

This test method is divided into the following parts:

- I. Gel time
- II. Tensile Strength and Elongation
- III. Brookfield Viscosity
- IV. Other Tests

PART I. GEL TIME

A. APPARATUS

1. Unwaxed paper cups, 8 oz., 2 inches \pm 1/4 inch at base (Dixie Cup No. 4338 or equivalent).
2. Wooden tongue depressor with ends cut square (Puritan No. 705 or equivalent).
3. Stainless steel spatula with blade 6 inches x 1 inch and with end cut square.
4. Stop watch, 1 second or smaller divisions.
5. Balance, 0.1 gram divisions.

B. TEST PROCEDURE

1. Condition both A and B components to 77 \pm 2 $^{\circ}$ F.
2. Measure equal volumes of well mixed components A and B into an 8 ounce unwaxed cup to yield total mass of 60 \pm 2.0 grams.
3. Start stopwatch immediately and mix components for 60 seconds, stirring with a wooden tongue depressor taking care to scrape the sides and bottom of the cup periodically.
4. Place the sample at 77 \pm 2 $^{\circ}$ F. on a wooden bench top which is free of excessive drafts.
5. Probe the mixture once with the tongue depressor every 30 seconds starting 15 minutes from the time of mixing.
6. The time at which a soft stringy mass forms in the cup is the gel time.

PART II. TENSILE STRENGTH AND ELONGATION

A. APPARATUS

1. Leveling table 12 inches x 15 inches x 1/4 inch with surface milled flat and smooth.
2. 3 mil Mylar sheeting.

3. Milled and polished steel gasket with outside dimensions 8 inches x 11 inches and inside dimensions 6 1/2 inches x 9 1/2 inches. Thickness milled to 0.125 inch.

4. Plate glass, 1/4 inch thick x 8 x 11 inches.
5. Air circulation oven capable of maintaining 158 \pm 0.5 $^{\circ}$ F.
6. Centrifuge capable of 2000 rpm and having cups with a capacity of about 150 mls. each.

B. PROCEDURE

1. Level the table using adjusting screws and a suitable bubble level.
2. Cut 2 pieces of mylar about 8 x 12 inches each.
3. Place one piece of Mylar on surface of the leveling table and place steel gasket over the Mylar sheet.
4. Measure out 6 ounces of each component and mix thoroughly for at least one minute.
5. Place centrifuge tubes on each pan of a suitable torsion balance. Pour mixed epoxy into each tube until tubes are balanced.
6. Immediately place tubes in centrifuge and spin at 2000 rpm for 3 minutes.
7. Remove tubes from centrifuge and pour epoxy into steel gasket, spreading out the epoxy as evenly as possible within the gasket and slightly thicker than the gasket.
8. Roll up the second piece of Mylar sheet, and starting at one edge of the steel gasket, carefully roll the Mylar sheet over the epoxy, taking care not to entrap any air pockets between the epoxy surface and the Mylar sheet.
9. Place flat plate glass over the Mylar sheet and push down hard to extrude excess epoxy from edges of steel gasket.
10. Place a suitable weight on top of glass plate to keep an even pressure on the epoxy sheet.
11. Cure in above condition for 18 hours at 77 $^{\circ}$ F.
12. Strip epoxy sheet from Mylar and gasket and place in oven for 5 hours at 158 $^{\circ}$ F.
13. Cool to 77 $^{\circ}$ F and cut test specimens with die shown in Figure I.
14. Proceed as in ASTM D 638, using 0.2 inch per minute press rate and a 1 inch gauge length.

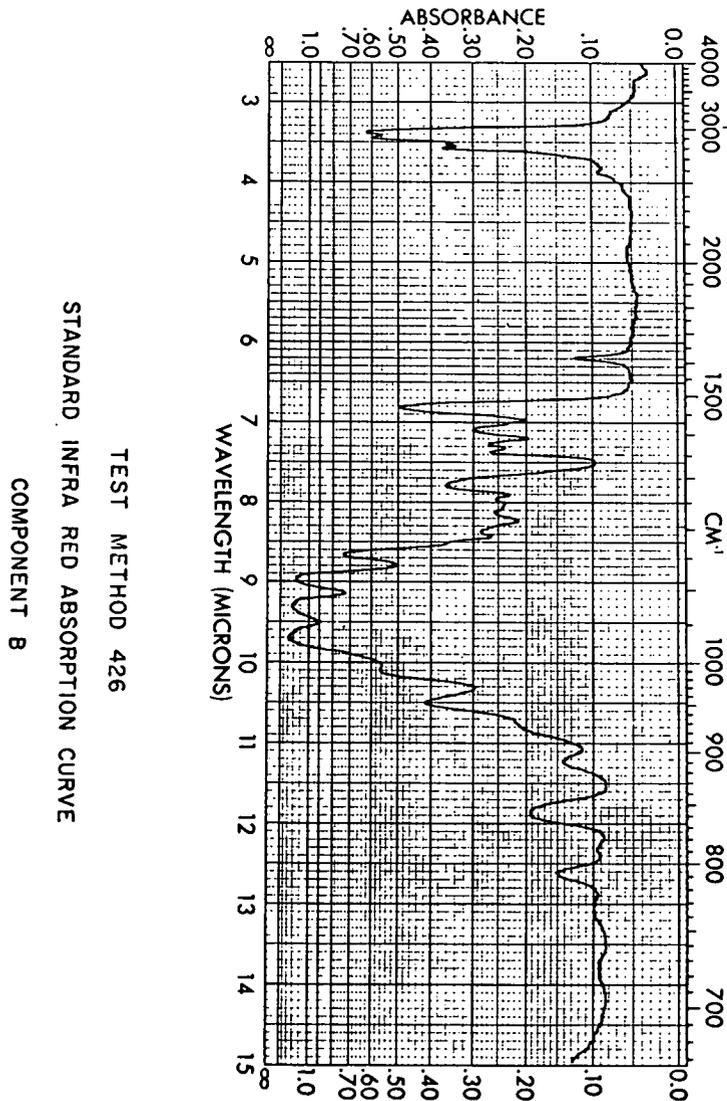


FIGURE 2

PART III. BROOKFIELD VISCOSITY

A. APPARATUS AND MATERIALS

1. Model RVT Brookfield Syncro-Electric Viscometer, Brookfield Engineering Laboratories, Stoughton, Massachusetts.
2. Round one pint paint cans.
3. Wooden tongue depressor with ends cut square (Puritan No. 705 or equivalent).

B. TEST PROCEDURE FOR COMPONENTS A and B

1. Condition both A and B components to $77 \pm 2^\circ$ F.
2. Fill a round one pint can to within one inch of the top with Component A.
3. Attach a No. 3 spindle to the viscometer following the manufacturers instructions.
4. Set rpm indicator at 20 and start motor.
5. When pointer is stable, read scale reading on 0-100 scale.
6. Use appropriate factor and calculate viscosity in poise or
(scale reading $\times 50$) / 100 = viscosity in poise.
7. If pointer reading cannot be read while in rotation, press down clutch lever with thumb and snap off switch. If pointer is not in view when dial has come to rest, throw switch on and off rapidly until pointer reaches vision plate. Be sure to keep clutch lever depressed while doing this so that reading may be held.
8. Clean spindle and repeat for B component.

C. TEST PROCEDURE FOR UNMODIFIED RESIN

1. Repeat above Section B using a No. 5 spindle at 20 rpm.

D. CALCULATIONS FOR UNMODIFIED RESIN

Reading on the 0-100 scale $\times 2$ = viscosity in poise.

PART IV. OTHER TESTS

A. WEIGHT PER GALLON

1. Use procedure specified in Method No. 4184 of Federal Test Method Standard 141.

B. WEIGHT PER EPOXY EQUIVALENT

1. Use procedure specified in ASTM Designation: D 1652.

C. ASH CONTENT

1. Use procedure specified in ASTM Designation: D 482.

D. VOLATILE CONTENT

1. Use test procedure specified in ASTM Designation: D 1078.

E. ALKALINITY

1. Use test procedure specified in ASTM Designation: D 664.
2. Alkalinity, equivalent/100 gm = $[ml(HCl) \times normality (HCl)] / (10 \times weight\ sample)$

F. WATER

1. Use test procedure specified in ASTM Designation: D 95.

G. ASH

1. Use test procedure specified in ASTM Designation: D 482.

H. RESISTANCE TO WATER

1. Use test procedure specified in ASTM Designation: D 570.

I. RESISTANCE TO CALCIUM CHLORIDE

1. Use test procedure specified in ASTM Designation: D 543.

J. LOW TEMPERATURE CREEP

1. Use test procedure specified in California test 419.

K. SHORE D HARDNESS

1. Use test procedure specified in ASTM D 1706.

L. RECORDING TEST RESULTS

Record all test results on form T.L.-579.

REFERENCES

ASTM Designations: D 95, D 419, D 482, D 543, D 570, D 638, D 664, D 1078, D 1652 and D 1706
Method No. 4184 of Federal Test Method Standard 141
California Test 419
End of Text (2 pgs) on 427

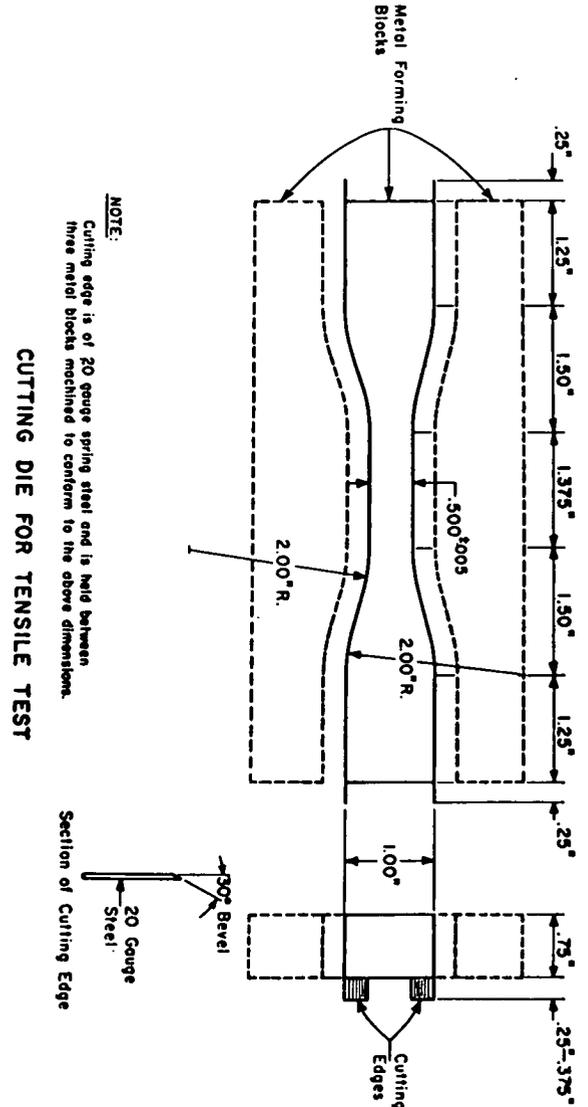


FIGURE 1

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 Office of Transportation Laboratory
 P. O. Box 19128
 Sacramento, California 95819
 (916) 444-4800



California Test 428
 1978

METHOD FOR TESTING EPOXY RESIN BASE BINDER

A. SCOPE

The procedures used for testing epoxy resin adhesive for bonding new concrete to old concrete are described in this test method. This test method is divided into the following parts:

- I Gel Time
- II Density
- III Viscosity and Shear Ratio
- IV Entrapped Air
- V Infrared Curve

PART I. GEL TIME

Use the procedure specified in Part I of California Test 426, except probe mixture starting at 20 minutes for Type I and 12 minutes for Type II.

PART II. DENSITY

A. WEIGHT PER GALLON

- 1. Follow Federal Test Method Standard No. 141, Method 4184.

PART III. BROOKFIELD VISCOSITY AND SHEAR RATIO

Use the procedure specified in Part III of California Test 431, except use Helipath Spindle T-B.

PART IV. ENTRAPPED AIR

Use the procedure specified in Part VIII of California Test 425.

PART V. INFRARED CURVE

Use the procedure specified in Part II of California Test 425.

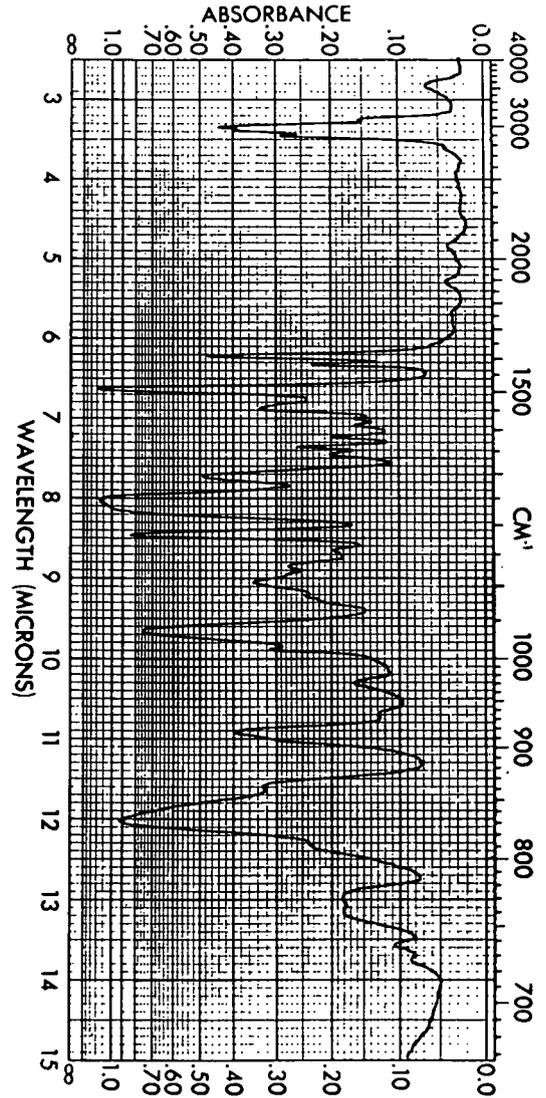
A. RECORDING TEST RESULTS

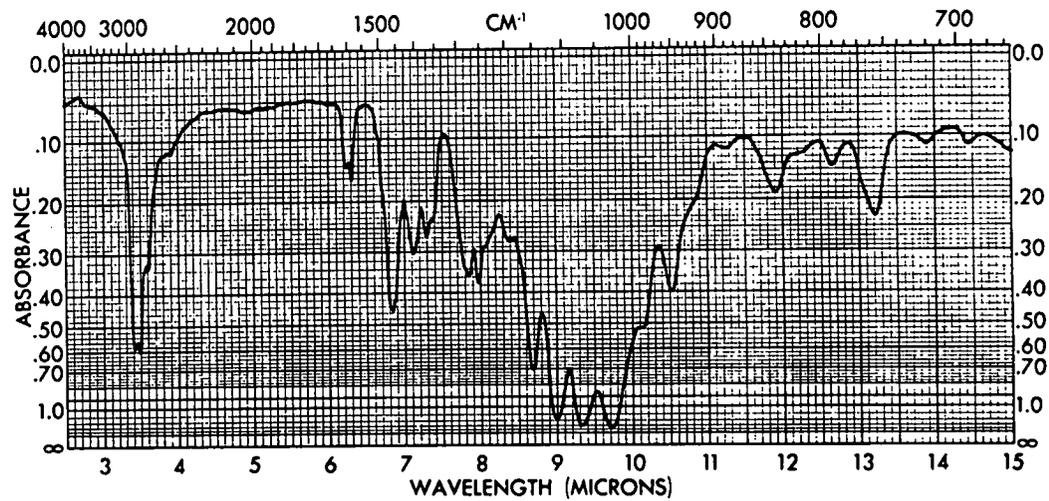
Record all test results on Form T.L.-579.

REFERENCES
 Federal Test Method Standard No. 141
 California Test 425, 426, and 431
 End of Test (4 pages) on 428

TEST METHOD 428
 STANDARD INFRA RED ABSORPTION CURVE
 COMPONENT A
 TYPE I or II

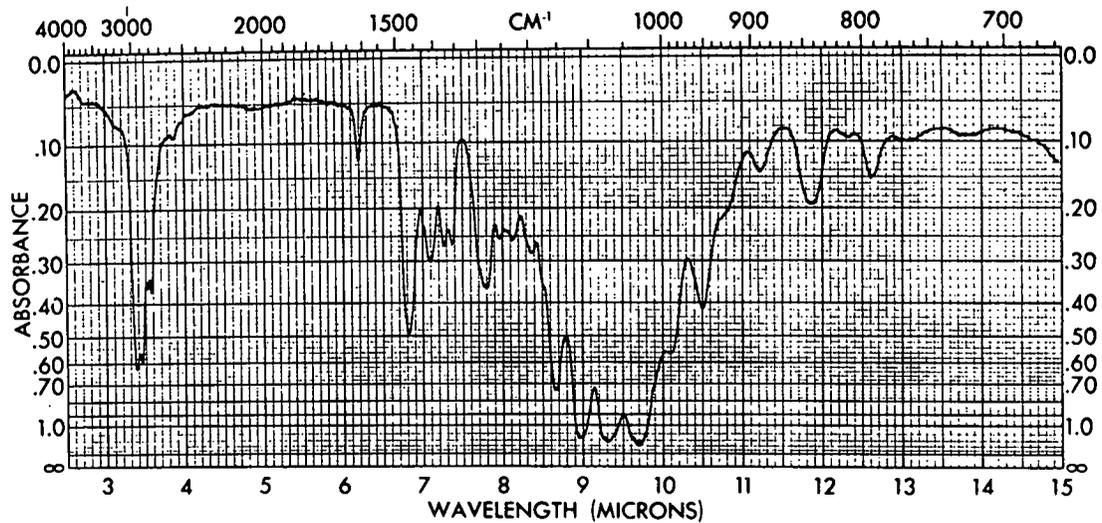
FIGURE 1





TEST METHOD 428
STANDARD INFRA RED ABSORPTION CURVE
COMPONENT B
TYPE I

FIGURE 2



TEST METHOD 428
STANDARD INFRA RED ABSORPTION CURVE
COMPONENT B
TYPE II

FIGURE 3

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California Test 431
 1978

METHOD FOR TESTING EPOXY FOR DETECTOR LOOP SEALANT

A. SCOPE

The procedures used in testing epoxy for Detector Loop Sealant are described in this test method. This adhesive is used to seal and repair saw cuts carrying inductive loops for traffic control and counting.

This test method is divided into the following parts:

- I. Gel Time
- II. Infra Red Curve
- III. Brookfield Viscosity and Shear Ratio
- IV. Tensile Strength and Elongation

PART I. GEL TIME

Use the procedure specified in California Test 429, Part I.

PART II. INFRARED CURVE

Use the procedure specified in California Test 429, Part II.

PART III. BROOKFIELD VISCOSITY AND SHEAR RATIO

A. APPARATUS AND SUPPLIES

1. Model RVT Brookfield Syncro-Electric Viscometer, Brookfield Engineering Laboratories, Stoughton, Mass.
2. Model C Brookfield Helipath Stand.
3. Helipath Spindle T-A (Crosspiece Length 1.894 in.)
4. Round, one pint paint cans.

B. TEST PROCEDURE

1. Condition both A and B components to $77 \pm 1^\circ \text{F}$.
2. Fill a round one pint can to about 1 inch of the top with Component A.
3. Mount the Viscometer on the Helipath stand and attach Helipath spindle T-A to the Viscometer shaft using weight included in spindle set.
4. Adjust length of travel of Helipath so that cross piece of spindle comes to within 1 inch of bottom of can on the downward path and to within 1 inch of the surface of material on the upward path.
5. Take readings in Poise, using appropriate factor provided by manufacturer at 5 rpm, 2.5 rpm and 0.5 rpm.

6. Clean spindle and repeat procedure for the B component.

C. CALCULATIONS

Viscosity = Viscosity in Poise at 5 rpm.
 Shear Ratio = Viscosity in Poise at 0.5 rpm. / Viscosity in Poise at 2.5 rpm.

PART IV. TENSILE STRENGTH AND ELONGATION

A. APPARATUS

1. Leveling table 12 inches x 15 inches x 0.5 inch with surface milled flat and smooth.
2. 3 mil Mylar sheeting.
3. Milled and polished steel gasket with outside dimensions 8 inches x 11 inches and inside dimensions $6\frac{1}{2}$ inches x $9\frac{1}{2}$ inches. Thickness milled to 0.125 inch.
4. Plate glass, $\frac{1}{4}$ inch thick x 8 x 11 inches.
5. Air circulation oven capable of maintaining $158 \pm 0.5^\circ \text{F}$.
6. Centrifuge capable of 2000 rpm and having cups with a capacity of about 150 mls. each.

B. PROCEDURE

1. Level the table using adjusting screws and a suitable bubble level.
2. Cut 2 pieces of mylar about 8 x 12 inches each.
3. Place one piece of Mylar on surface of the leveling table and place steel gasket over the Mylar sheet.
4. Measure out 6 ounces of each component and mix thoroughly for at least one minute.
5. Place centrifuge tubes on each pan of a suitable torsion balance. Pour mixed epoxy into each tube until tubes are balanced.
6. Immediately place tubes in centrifuge and spin at 2000 rpm for 3 minutes.
7. Remove tubes from centrifuge and pour epoxy into steel gasket, spreading out the epoxy as evenly as possible within the gasket and slightly thicker than the gasket.
8. Roll up the second piece of Mylar sheet, and starting at one edge of the steel gasket, carefully roll the Mylar sheet over the epoxy, taking care not to entrap any air pockets between the epoxy surface and the Mylar sheet.
9. Place flat plate glass over the Mylar sheet and

California Test 431 1978

push down hard to extrude excess epoxy from edges of steel gasket.

10. Place a suitable weight on top of glass plate to keep an even pressure on the epoxy sheet.
11. Cure in above condition for 18 hours at 77°F .
12. Strip epoxy sheet from Mylar and gasket and

place in oven for 5 hours at 158°F .

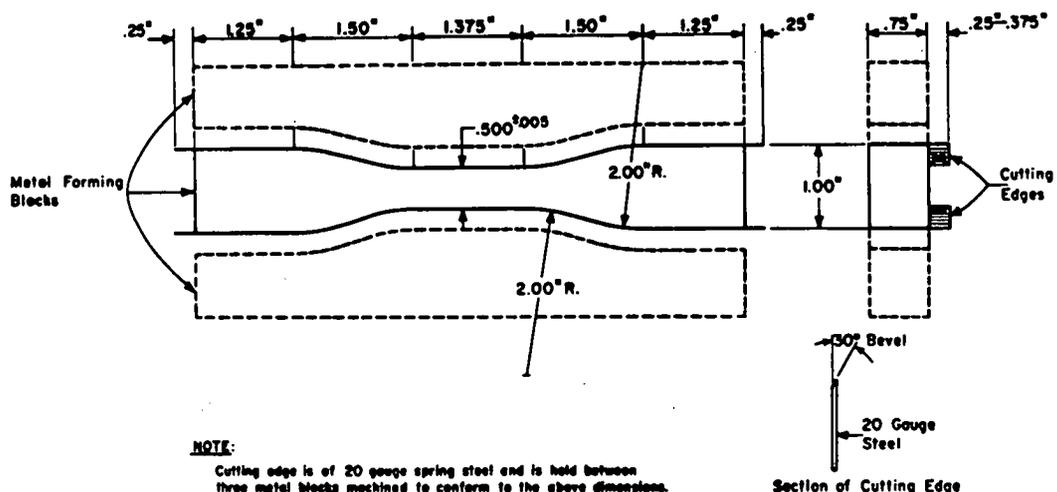
13. Cut test specimens with die shown in Figure 1.
14. Proceed as in ASTM D638, using 0.2 inch per minute press rate and a 1 inch gauge length.

C. RECORDING TEST RESULTS

Record all test results on Form T.L.-579

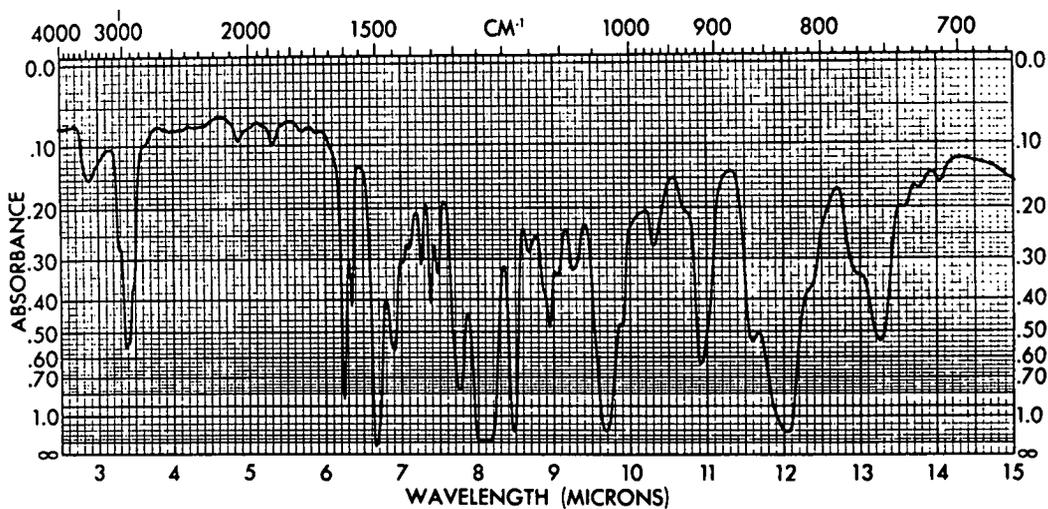
REFERENCES

ASTM Designation: D 638
 California Test 429
 End of Text (5 pgs) on 431



CUTTING DIE FOR TENSILE TEST

FIGURE 1



TEST METHOD 431
STANDARD INFRA RED ABSORPTION CURVE
COMPONENT A

FIGURE 2

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 Sacramento, California 95819
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California Test 432
 1978

METHOD FOR TESTING, BINDER (ADHESIVE), EPOXY RESIN BASE, FAST SETTING

A. SCOPE

The procedures used for testing Fast Setting Epoxy Resin Binder are described in this test method. This test method is divided into the following parts:

- I. Gel Time
- II. Brookfield Viscosity
- III. Compression Strength
- IV. Infra Red Curve
- V. Density

PART I. GEL TIME

Use the procedure specified in California Test 426.

PART II. BROOKFIELD VISCOSITY

Use the procedure specified in California Test 430. Use 5 rpm for viscosity over 40 poise.

PART III. COMPRESSION STRENGTH

A. APPARATUS

1. Brass cylinder, $\frac{1}{8}$ inch thick, 4 inches in height and exactly 2 inches internal diameter. The cylinder is split lengthwise $\frac{1}{16}$ inch in width, such that when clamped tight, the split is drawn together with the 2 faces of the split flush together and the internal diameter is exactly 2 inches.
2. Two screw type hose clamps for each brass cylinder, maximum opening $2\frac{1}{2}$ inches.
3. Hardwood dowel, $1\frac{1}{2}$ inches x 8 inches.
4. Steel spatula.
5. Mylar sheet, 2 inches x 2 inches.

B. MATERIALS

1. A blend of equal parts by volume of Ottawa sand, which each conforms to the gradings specified in ASTM C 190 and ASTM C 109.
2. A wax base release agent, aerosol type preferred.

C. PROCEDURE

1. Position 2 screw clamps around the brass cylinder at equidistant positions and tighten clamps so that the slot is drawn together.

2. Coat inside of cylinder with release agent.

3. Place mylar sheet on flat surface of table and place brass cylinder over mylar sheet.

4. Measure out epoxy components by volume, place in a suitable container, and mix thoroughly for at least 2 minutes or until no streaks are apparent.

5. For each unit volume of mixed epoxy add 4 volumes of Ottawa sand and mix thoroughly with a steel spatula.

6. Fill cylinder to the halfway point and use the hardwood dowel to tamp the mortar into the cylinder with 25 brisk strokes. Fill the remainder of the cylinder with mortar and tamp again with 25 strokes of the hardwood dowel. Strike off the surface flush and flat with the steel spatula.

7. Allow specimen to cure for 1 week at 77° F.

8. Remove screw clamps and mylar sheet from bottom of cylinder. Remove mortar cylinder from brass cylinder.

9. Cap top and bottom of mortar cylinder with suitable capping compound.

10. Load to failure at 10,000 lbs./minute with a test press.

D. CALCULATIONS

Compression Strength in PSI = Load at failure / 3.14

PART IV. INFRARED CURVE

Use the procedure specified in California Test 429, Part II.

PART V. DENSITY

A. WEIGHT PER GALLON

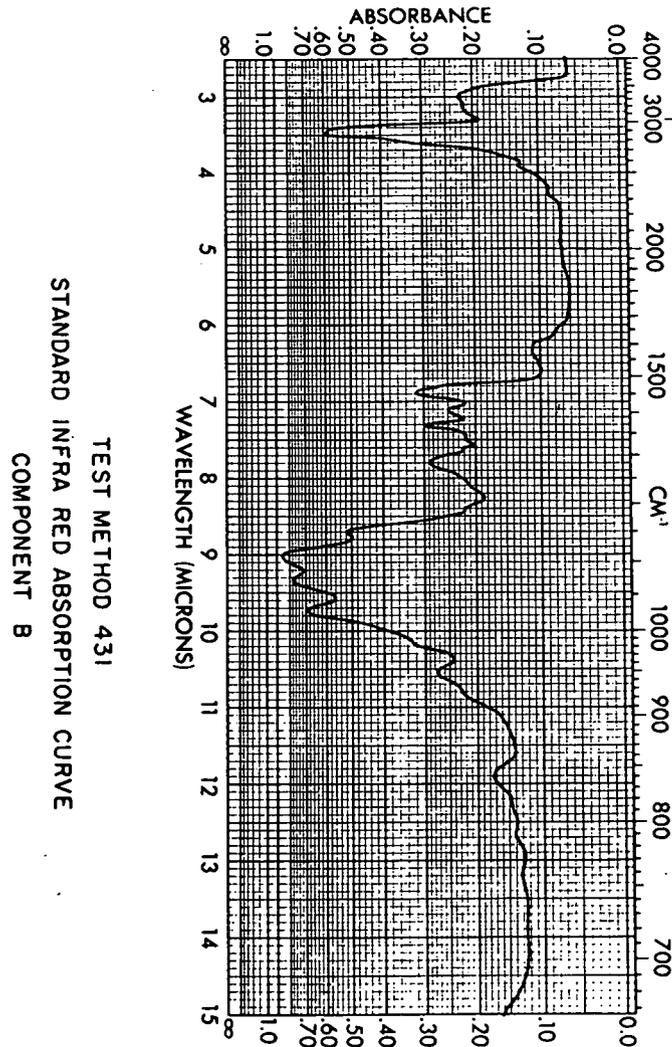
1. Use procedure specified in Method No. 4184 of Federal Test Method Standard No. 141.

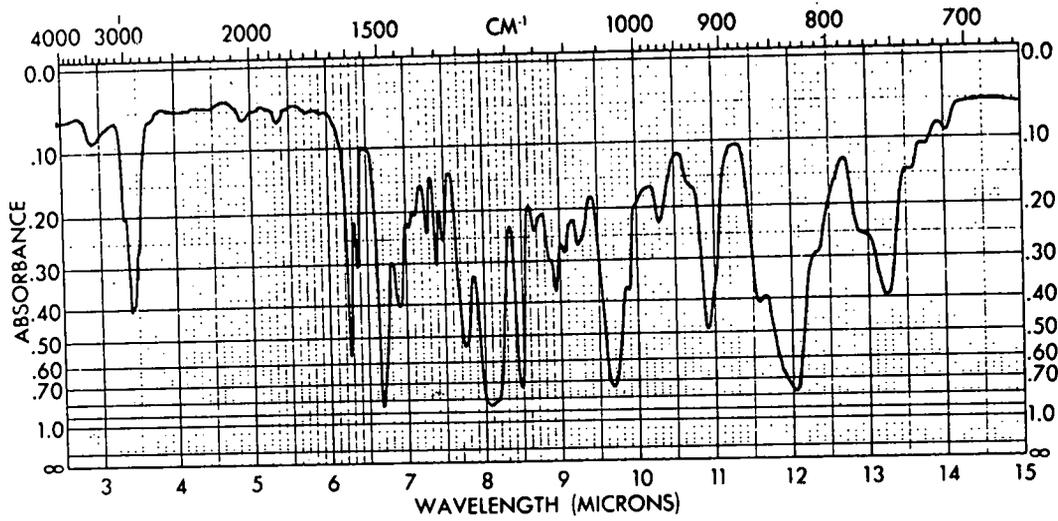
B. RECORDING TEST RESULTS

Record all test results on Form T.L.-579.

REFERENCES

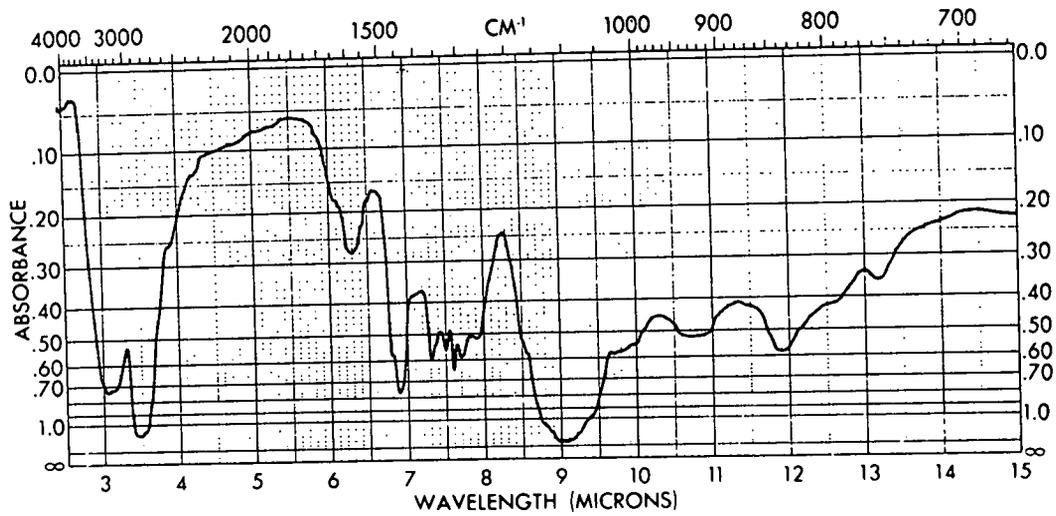
ASTM Designations C109 and C190
 California Test 426 and 429
 Method No. 4184 of Federal Test Method Standard No. 141
 End of Text (5 pgs) on 432





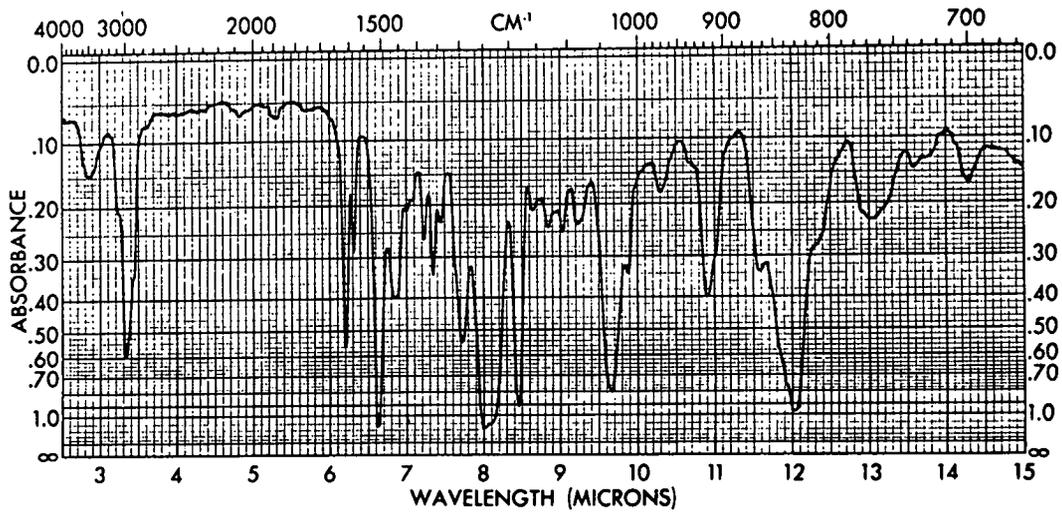
TEST METHOD 432
STANDARD INFRA RED ABSORPTION CURVE
COMPONENT A
LOW VISCOSITY

FIGURE 1



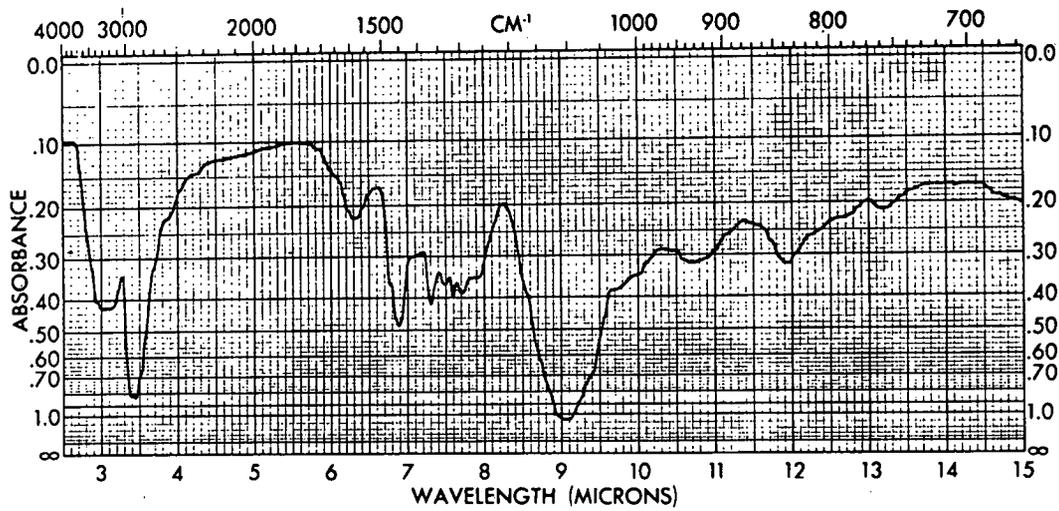
TEST METHOD 432
STANDARD INFRA RED ABSORPTION CURVE
COMPONENT B
LOW VISCOSITY

FIGURE 2



TEST METHOD 432
 STANDARD INFRA RED ABSORPTION CURVE
 COMPONENT A
 MEDIUM VISCOSITY

FIGURE 3



TEST METHOD 432
 STANDARD INFRA RED ABSORPTION CURVE
 COMPONENT B
 MEDIUM VISCOSITY

FIGURE 4

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
SPECIFICATIONS FOR EPOXY RESIN SYSTEMS

TYPE

1. Low modulus, moisture insensitive epoxy gel.
2. General purpose binder, moisture insensitive.
3. General purpose bonding agent, moisture insensitive.
4. Flexible, epoxy coating, moisture insensitive. In certain applications to be used with (Type 4B) base coat.
5. Low viscosity injection grout, moisture insensitive.
6. Epoxy adhesives for bonding Reflective Traffic Markers.

Finish or top-coat be used in conjunction with (Type 4B) base coat where (2 coat) minimum system is designed for protection of concrete exposed to splash zones and tidal water.

Use (Type 4B) as a prime or base coat where (2 coat) minimum system is required for protection of concrete exposed to splash zones and tidal water. Type 4B base coat is to be top-coated with (Type 4A) in a two-coat system.

5. Pressure grouting of structural concrete. Grouting of non-moving cracks and voids in concrete.
- 6A. A standard set epoxy designed for placement of raised traffic markers on asphalt and concrete surfaces.
- 6B. A standard set self-leveling epoxy adhesive for bonding traffic markers in recessed areas on asphalt and concrete.
- 6C. Rapid epoxy adhesive for bonding raised traffic markers on asphalt and concrete.

APPLICATION OF EPOXY CONSTRUCTION PRODUCTS

1. Bonding or repairing damp and underwater surfaces where a non-sagging, low modulus material is required. Patching for vertical and overhead surfaces adhesive for repairing walls, concrete foundations, concrete pipe, conduit and ceilings.

2. Surface sealing and coating to produce skid-proof surfaces and/or chemical resistant surface and/or protect from penetration of deicing salts. Broadcast system for bridge decks as an epoxy mortar. Patching spalled or broken concrete where vibrations, shocks or movement are expected.

Patching dissimilar materials. Grouting of non-moving cracks. Patching where feather edging is critical.

For grouting bolts where vibration may require shock absorption characteristics.

For bonding any fixtures to a surface where a strong bond with concrete can absorb shock are required or where movement due to expansion or contraction may occur.

3. Bonding new concrete (fresh concrete) to hardened concrete, steel, or other structural materials.

Bonding of hardened concrete to hardened concrete or other structural materials.

Grouting of non-moving cracks in concrete or anchor bolts. Binder for properly graded aggregate to produce a high strength, non-porous patching mortar.

NOTES

1. The moisture insensitive systems can be applied on clean, dry, damp, or wet surfaces free of standing water.

2. MODULUS (Flexibility)

- a. High Modulus - rigid, high strength formulation for use where there is no movement, no deflection.
- b. Low Modulus - flexible formulations to absorb movement.

3. VISCOSITY

- a. Low Viscosity - thin, like light weight motor oil.
- b. High Viscosity - like heavy weight motor oil.
- c. Gel - thick (for vertical and overhead work) - non-sag.

4. A primer is required before application when used as protective coatings on skid-resistant or hardened concrete.

5. Since the coefficient of expansion of the cured epoxy is approximately six (6) times that of concrete, applications of pure epoxy in thick layers should be avoided as they will spall and peel during temperature changes. The coefficient of expansion of a 4:1 sand epoxy mortar by weight is approximately the same as concrete.

Epoxy resin shall be furnished in two components for combining immediately prior to use in accordance with the written instructions of the manufacturer. Component A shall contain a condensation product of epichlorohydrin with bisphenol "A" and shall conform to the requirements of the specifications. Component B shall contain one or more hardening agents which on mixing with Component A will cause the system to harden and shall conform to the requirements of the specifications.

When mineral fillers are specified, they shall be inert and non-settling or readily dispersible. Any material that cannot readily be dispersed shall not be used. The filler shall have a fineness such that at least 99 percent shall pass the Number 325 sieve.

The physical properties of a mixture of Components A and B in the proportions recommended by the manufacturer shall conform to the requirements described in the specifications.

The contents of the separate packages containing Components A and B shall be thoroughly stirred before use. The same paddle shall not be used to stir Component A as is used to stir Component B.

Any heating of epoxy adhesive shall be performed by application of indirect heat.

Epoxy resin shall not be mixed or applied when either the equipment, material, or air temperature is below 50 degrees F or above 100 degrees F unless approved in writing by the Engineer.

HANDLING AND STORING MATERIALS - The two components of the epoxy resin system furnished under these specifications shall be supplied in separate containers which are non-reactive with the materials contained therein. The size of the containers shall be such that the recommended proportions of the final mixture can be obtained by combining one container of one component with one or more whole containers of the other component.

Containers shall be identified as "Component A - Contains Epoxy Resin" and "Component B - Contains Hardener", and shall show the type, mixing directions and usable temperature range. Each container shall be marked with the name of the manufacturer, the lot or batch number, the date of packaging, the date of shelf life expiration, pigmentation, if any, and the quantity contained therein in pounds and gallons. Potential hazards shall be so stated on the package in accordance with the Federal Hazardous Products Labeling Act.

WARNING

Epoxies will cause dermatitis if proper precautions are not followed. Avoid contact with the skin and eyes, use gloves and protective creams on the hands. In the event of contact, wash thoroughly with soap and water. Goggles should be used to protect the eyes; however, in the event of eye contact, flush with water for fifteen (15) minutes and secure immediate medical attention.

REQUIREMENTS FOR APPROVAL

The material shall be sampled and inspected at the place of manufacture (or warehouse) by a representative of the Department of Transportation and all containers so designated for delivery shall be sealed as "sampled" by the inspector. Any unauthorized tampering or breaking of the seal between time of sampling and delivery will be cause for rejection of the material.

The sampled material will be packaged by the inspector for forwarding to the Department of Transportation by the manufacturer or vendor. The sample received by the Department of Transportation will be tested for compliance to specifications.

No materials shall be shipped until the supplier has been notified by the Materials and Test Unit, Department of Transportation, that the material is in compliance with the specifications.

The manufacturer shall furnish the Department of Transportation a copy of his test results on each batch, showing that the epoxy resin meets the appropriate specifications, and that the material proposed for use is an epoxy resin.

Manufacturers shall furnish the material in as few different batches as practicable. This will help prevent testing duplications and delays.

MIXING, STORAGE, AND HANDLING OF EPOXIES

1. MIXING OF EPOXIES

The mixing of a two component epoxy material is extremely important and must be done carefully and thoroughly. The effort put into thoroughly mixing the two components will result in a material that will do what is intended. Improper or careless mixing can produce a failure.

When the containers are first opened, Part A and Part B should be examined to determine if any settling has occurred. Filled, liquid epoxies have a definite tendency to settle during storage or transit, and this settling is not always apparent. If you suspect any settling, stir the individual components with a suitable implement until the components are homogeneous. This is the same precaution that is taken with paint.

Mixing of two component epoxies has two phases: Measuring and blending.

Measuring of the two components must be accurate. These chemicals are designed to react completely when the proper amounts are thoroughly blended. When improper amounts of Part A and Part B are blended, the chemical reaction will be incomplete and the resultant material will not perform as it is intended. Never deviate from the specified mix ratio. Never deviate from the specified mix ratio to alter the pot life or viscosity of the material. When measuring the Part A and Part B, be prepared and properly equipped. If measuring volumes of the components, have the proper measuring containers and do it accurately. When measuring weights of the components, have the proper scales and do it accurately. Do not guess or "eye-ball" it. Measure carefully and accurately.

Blending of the two components must be done thoroughly and completely. One component does not want to blend with the other. One component is usually heavier and thicker than the other. They do not want to blend. Blending should take two-three minutes for small amounts and up to five to ten minutes for 5 gallon quantities. The blending should be vigorous. Great care should also be taken to thoroughly scrape the sides and the bottom of the blending container. After two to five minutes of vigorous blending and scraping, examine the material carefully. If any sign of the two components is seen, or if any doubt exists about the blend, continue blending and scraping the sides and bottom for another two to five minutes. Once again, examine the blended material and make sure it is homogeneous.

Two component epoxies are very temperature sensitive. If the components are below 77 degrees F, they will be thicker and more viscous than reported on the technical bulletin; also the pot life will be longer and cure will require more time than reported. If the two components are above 77 degrees F, they will be thinner and less viscous; also the pot life will be shorter and cure will require less time than reported on the technical bulletin. The temperature of Part A and Part B will have an effect on the working time of the mixed material.

1. MIXING OF EPOXIES (CONTINUED)

If sand or any filler is to be added to a liquid epoxy material, it can be done only after the two components have been carefully and thoroughly mixed. The filler should be blended with the mixed epoxy long enough to wet the filler particles; and no lumps or aggregate of filler should be in the mix.

Mixing is extremely important. Mixing is up to you. Carefully measure the components; vigorously and thoroughly blend the components. Allow for the temperature of components in deciding the amount of material to be mixed.

II. STORAGE OF EPOXY

Thought and care should be given to the storage of epoxy materials.

Avoid extreme conditions of temperature in storage. Low temperatures will make the components thick, slower to react, and harder to blend. High temperatures will make the components thin and quicker to react. High temperatures will also accentuate settling and may cause volatilization of certain chemicals in the components.

If your epoxy components have been stored in extreme temperatures, they should be heated or cooled to 77 degrees F before use. Also before use, they should be examined individually and stirred with proper implements prior to measuring and blending.

Temperatures between 50 degrees F and 90 degrees F are considered satisfactory for storage.

The containers of Part A and Part B should always be sealed and air tight. After use, always replace the lids on the containers of the components and seal them as tightly as possible. Unsealed containers of each component will allow the component to absorb moisture from the air - especially Component B. Extensive water absorption by the components will alter the chemistry of reaction and change the properties of the cured material.

The following will act as a guide to assist the contractor when applying epoxies to cooler substrates. This will assist in obtaining the proper viscosity for proper application and good set time. This guide is based on raising the epoxy and hardener components to elevated temperatures for cooler applications. The epoxy and hardener components may be heated in hot water, stored in heated room, heated by microwave oven, or by other approved methods of indirect heat to bring them to an acceptable temperature prior to mixing.

SUBSTRATE TEMPERATURES

50 to 59 degrees F
60 to 65 degrees F
65 to 70 degrees F
70 to 79 degrees F
Over 80 degrees F

TEMP. OF BOTH COMPONENTS
CONDITIONED 2 HOURS PRIOR TO USE

85 to 90 degrees F
80 to 85 degrees F
75 to 80 degrees F
70 to 80 degrees F
65 to 80 degrees F

III. HANDLING OF EPOXIES

Epoxy components are chemicals and they may cause irritation. Be very careful when handling epoxies and do not get them in your eyes, on your skin, in your hair, or on your clothing. Also do not breathe the vapors of either component.

When handling epoxies, wear rubber or plastic gloves and use an apron or protective apparel. Work in a well ventilated area and wash thoroughly after handling the epoxies. When an epoxy container is emptied, replace the lid and seal it tightly; then discard the container and lid. Do not reuse them.

If either component comes in contact with skin, wash immediately with soap and water. If either component gets into the eyes, flush immediately with plenty of water for fifteen minutes and see a doctor as soon as possible. If either component gets on clothing, remove the clothing and wash it before reuse. Discard contaminated shoes.

NOTES

Type 6A Standard Set Epoxy is designed to bond raised traffic markers to road surfaces.

Type 6B is a Standard Set Epoxy designed for bonding recessed traffic markers to road surfaces.

Type 6C is with a Rapid Set Marker Adhesive for bonding raised markers of road surfaces. May be used when the pavement temperature is below 60 degrees F.

GENERAL NOTES (FOR 6A, 6B, AND 6C)

1. The resin component shall be pigmented white and the hardener component black. When combined at a mixing ratio of 1 to 1 by volume the adhesive shall be a uniform gray with no streaks of black or white to conform approximately to Federal color #26132 to 26152 of Federal Standard 595.
2. All fillers, pigments and/or thixotropic agents in either the epoxy resin or hardener component must be of sufficiently fine particle size and dispersed so no appreciable separation or settling will occur during storage.
3. All fillers must be of such a nature that they will not abrade or damage the application equipment. No alumina, silica flour or other hard abrasive materials shall be used.
4. No solvents are to be used in the system.
5. All components must be free of lumps, skimming or foreign material. There shall be no settling of fillers that cannot be easily re-dispersed with a paddle.
6. PROPERTY RETENTION TEST - The brackets for the property retention test shall be performed according to the AASHTO T-237 Paragraph 26.2 and 26.3.
 - A. Place the specimens in a freezer for 8 hours, ± 1 hour at 0 degrees F ± 5 degrees.
 - B. Remove the specimens from the freezer and place in an oven for 16 hours ± 2 hours at 100 degrees F ± 5 degrees F.
 - C. Repeat steps A and B until 5 cycles have been completed.
 - D. After specimens have been subjected to 5 temperature cycles (5 at 0 degrees F and 5 at 100 degrees F). Condition item for 24 hours at room temperature.
 - E. Test the specimens as outlined in AASHTO T-237, Paragraph 26.2 and 26.3.
 - F. Record the test results of each specimen and report the average of the proper retention. (Percentage of original test results).

1. POT LIFE

Samples of each component of the epoxy resin are conditioned at 77 degrees F \pm 2 degrees F. When the samples have reached this temperature, 60 \pm 0.4g total weight of components A and B, in the proportions recommended by the manufacturer, are weighted into an unwaxed paper cup. The time is recorded, and mixing of the components is started immediately by stirring with a wooden tongue depressor. Mixing is continued for three (3) minutes making sure you scrape the wall and bottom of the cup and the depressor periodically. The sample is then poured into an 8 ounce unwaxed paper cup, set on a wooden bench top and probed every one (1) minute with a small stick starting five (5) minutes prior to the minimum specified pot life. The time at which a stringy mass forms in the center of the containers is recorded as the gel time or pot life.

2. VISCOSITY

Using the Brookfield Viscometer (Model RVT Brookfield Syncro-Electric Viscometer), 400 ml. of material will be tested while contained in a 1 pint paint can. The sample shall be conditioned to insure that the temperature is 77 degrees F \pm 2 degrees F. Attach the proper spindle as specified to the machine, being careful to avoid undue side pressure as it might affect the alignment. Only the spindle should be turned in making this connection. Insert guard and spindle into the material to be tested until immersed to the depth indicated by the groove cut into the shaft. This mark indicates minimum immersion and should be observed. After the instrument has been clamped in place, press down the clutch lever and start the motor. Release the lever and allow rotation of the spindle for 8 to 10 revolutions until a stable reading has been reached. Press down the clutch lever and snap off the switch. Be sure to keep the clutch lever depressed so that the reading will be held. Apply the proper factor (from Brookfield Factor Finder) to obtain the viscosity of the material under test.

3. MIXING INSTRUCTIONS

Mix Components A and B at the recommended ratio for a minimum of two (2) minutes. Add three parts by volume of Ottawa silica sand (conforming to ASTM-C-109) to one volume of the mixed A-B and thoroughly blend for a minimum of three minutes. The mixed mortar shall be poured into the appropriate molds in two layers for 2"x2" cubes, and 3 layers for 2"x4" cylinders, with each layer tamped 25 times with a hammer handle. As much mortar shall be packed into the molds as possible. A minimum of six specimens shall be tested for the compression and tensile splitting test at 77 degrees F \pm 2 degrees F after 24 hours cure. In the tensile splitting strength test the specimen shall be loaded at a rate of 2,000 pounds per minute. In the compressive strength test the specimen shall be loaded at a rate of 3,000 pounds per minute.

4. TESTING

Six Moisture Insensitive Specimens (prepared in accordance with Note 3 above) shall be cured at 77 degrees F \pm 2 degrees F for 24 hours and three specimens shall be tested dry at 24 hours. The remaining three specimens shall be immersed in water for 6 days at 77 degrees F \pm 2 degrees F and tested immediately while still wet.

5. HARDNESS

Hardness shall be determined on the cured unfilled material cured at 77 degrees F \pm 2 degrees F for 24 hours as per ASTM Method D-2240. Hardness shall be determined by using a Shore Durometer D scale hardness tester.

6. ABSORPTION

Absorption Specimens 1/8" x 1" x 3" shall be immersed in water for 24 hours and tested as per ASTM D-570.

7. SHELF LIFE

The producer of the products must guarantee to meet all requirements as specified for a minimum of one year from date of manufacture.

EPOXY RESIN SYSTEMS

TYPE		1		2		3		4A		4B		5	
TEST METHOD	PROPERTY	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
COMPONENT A													
ASTM *(2) D-445	Viscosity Poises @ 77°F+ 2°F	Gel		15		70		30	100	60	130		10
Brookfield Model RVT Modified	Spindle No. Speed, RPM			2 20		4 20		4 20		4 20		2 20	
ASTM D-1652	Epoxide Equiv.	240	275	200	250	180	275	190	220	230	275	175	220
ASTM D-1078	Volatile % By Weight Distilled below 350°F		3		3		3		3		3		3
ASTM D-482 By Ignition	Ash Content % By Weight of Component A		20		1				10		50		0.5
*(7)	Shelf Life, Year		1		1		1		1		1		1
COMPONENT B													
ASTM D-445	Viscosity Poises @ 77°F+2°F	Gel		15		120		90	220	90	180		5
Modified Brookfield Model *(2) RVT	Spindle No. Speed, RPM			2 20		4 10		4 10		4 10	5 10	2 50	
ASTM D-1078	Volatile, % By Weight Distilled below 350°F		5		3		3		3		3		3
ASTM D-482 By Ignition	Ash Content % By Weight of Component B		45		0.5				45		40		0.5
*(7)	Shelf Life, Year		1		1		1		1		1		1

MIXED A & B

TYPE		1		2		3		4A		4B		5	
TEST METHOD	PROPERTY	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
ASTM D-445	Viscosity Poises @ 77°F+2°F	Gel		3	10	25	75	30	80	40	100	1	6
Brookfield Model RVT *(2) Modified	Spindle No. Speed, RPM			2 20		4 20		4 10		4 20		2 50	
AASHTO T-237 Modified *(1)	Pot Life, Mins.	20	50	35	60	20	50	40	70	20	70	20	60
TM D-638	Tensile Strength PSI 7 Days	1,500		2,000		4,000		1,500				3,000	
77°F+ 2°F Speed B (C Die)	Tensile Elongation % 7 Days	5	15	5	15	1	5	5	15	5	15	1	10
ASTM C-109-77 *(3) (4)	Compressive Stregt. PSI, 2"x2" Mortar 24 hours 7 days	3,000 5,000		3,000 5,000		3,500 6,000		3,000 5,000				4,000 7,000	
ASTM D-2240 *(5)	Shore D Hardness 24 hours 7 days	60 70		60 70		70 80		70 80		70 80		70 80	
ASTM D-570 *(6)	Absorption in Water %		0.8		0.8		0.8		0.8		0.8		0.8
AASHTO T-237 & ASTM	Bond Strength Fresh & Hardened Concrete to Hardened Con- crete PSI (A) Direct Tensile 7 days	250				250				250			
C-78	(B) Beam Break, 7 days	500				600				600			
ASTM D-482 By Ignition	Ash Content % By Weight of Component A and Component B	5	15		1.0	20	40	10	25	20	30		1.0

*() SEE GENERAL NOTES

EPOXY ADHESIVES FOR PLACEMENT OF TRAFFIC MARKERS
AD-MIXED PROPERTIES
MIXING RATIO 1 TO 1 BY VOLUME

TEST METHOD	PROPERTY	STANDARD TYPE 6A		STANDARD TYPE 6B		RAPID SET TYPE 6C	
		MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
AASHTO T-237	Viscosity poises @ 77°F ± 2°F	1,000	1,800			1,000	1,800
Brookfield RVT w/Helipath Stand	Spindle No. Speed RPM	TD 5	TD 5			TD 5	TD 5
ASTM D-445 Brookfield RVT Modified	Viscosity poises @ 77°F ± 2°F Spindle No. Speed RPM			400 6 10	600 6 10		
AASHTO T-237	Pot Life Min.	8	13	8	13	7	10
AASHTO T-237 Par. 26.2 & 26.3	Bond Strength PSI @ 1 hour 77 degrees F @ 3 hours 77 deg. F @ 24 hrs. 77 deg. F	180 400		180 400		180 400	
AASHTO T-237 Par. 10 to 10.4 incl. 11 to 11.9 incl.	SAG Test, Inches		.125				.125
FED. STANDARD 595	Color	26132	26152	26132	26152	26132	26152
SEE NOTE 6	Property Retention 5 cycles 0 deg. - 100 deg. F	90		90		90	

EPOXY ADHESIVES FOR PLACEMENT OF TRAFFIC MARKERS

TEST METHOD	PROPERTY	TYPE 6A STANDARD SET NON-SAG FOR RAISED MARKERS		TYPE 6B SELF-LEVELING FOR RECESSED MARKERS		TYPE 6C RAPID SET FOR RAISED MARKERS NON-SAG	
		MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
COMPONENT A							
AASHTO T-237	Viscosity poises @ 77°F ± 2°F	1,000	1,800	350	600	1,000	1,800
Brookfield RVT w/Helipath Stand	Spindle No. Speed, RPM	TD 5	TD 5			TD 5	TD 5
ASTM D-445 Brookfield RVT	Spindle No. Speed, RPM			6 10	6 10		
* (7)	Wt. Per Gal. Color Shelf Life, Year		12.0 White 1		12.0 White 1		12.0 White 1
COMPONENT B							
AASHTO T-237	Viscosity poises @ 77°F ± 2°F	1,000	1,800	350	600	1,000	1,800
Brookfield RVT	Spindle No. Speed, RPM Wt. per Gal. Color Shelf Life, Year	4 3	4 3 12.5 Black 1	6 10	6 10 12.0 Black 1	4 3	4 3 12.5 Black 1

ITEM SPECIAL - CONCRETE REPAIR BY EPOXY INJECTION

Description. This specification covers the repair of well defined cracks or fractures (see Method of Measurement) in reinforced concrete members by means of an epoxy injection system. This system shall consist of a paste epoxy used to seal the surface cracks, and an injection epoxy used under low pressure (200 psi max.) to penetrate and fill the cracks and bond the crack surfaces together.

Materials. The paste and injection epoxies shall be materials produced in the United States by a company recognized as an established manufacturer of chemical products. The epoxy injection system shall be one that is described in brochures or technical papers which contain documentation of successful repairs in similar application situations.

The injection epoxy adhesives shall conform to ASTM C881, Type 1, Grade 1, Class B or C depending upon temperature. If the paste epoxy is required to be left in place, it shall be tinted to match the color of the finished concrete surface as nearly as practicable; otherwise, tinting is not required. The epoxy materials shall be designed to bond to damp or dry surfaces; however, field applications preferably shall be made to dry surfaces.

Approvals. The epoxy injection system proposed for use by the Contractor shall be approved prior to the start of the concrete repair. To obtain this approval the Contractor shall furnish certification from the epoxy manufacturer stating that the furnished materials comply in all respects to the referenced ASTM specification and its provisions. The Contractor shall also furnish a copy of comprehensive preparation, mixing and application instructions which have been developed especially for use with the proposed epoxy injection system. Approval of the proposed system shall be based upon evaluation of instructions and certified test data, or upon laboratory tests of material samples, or the evaluation of both certified test data and test samples. Epoxy bond strength shall be determined by AASHTO T237. Concrete compressive strength shall be reached prior to adhesive failure. Testing will be performed by the State.

The Contractor shall also arrange to have a manufacturer's representative at the job site to familiarize him and the Engineer with the epoxy materials, application procedures and recommended pressure practice. This representative shall direct at least one complete crack or area injection and be assured prior to his departure from the project that the project personnel are adequately informed to satisfactorily perform the remaining repairs to his satisfaction.

The project personnel shall also be furnished with a copy of the approved epoxy application instructions. Any significant changes to these instructions which are recommended by the representative for an unanticipated situation shall be approved by the Director prior to the adoption of such changes.

Procedure. Concrete surfaces adjacent to the cracks to be sealed shall be cleaned only to the extent necessary to achieve an adequate bond with the paste epoxy, and only by procedures which will not cause abrasive grits or concrete dust to penetrate the cracks. The use of solvents or thinners in cracks or on bonding surfaces is not permitted.

Cracks greater than 0.5 millimeter in width at the surface of the member being repaired shall have injection ports installed in them. Additional injection ports, along cracks less than 0.5 millimeter in width, may be deemed necessary by the manufacturer's representative. At the direction of the Engineer, the Contractor shall install and use such additional ports. Unless otherwise specified or directed, injection ports shall be spaced at 6 to 12 inches vertically and at 6 to 18 inches horizontally. Ports shall be set in dust free holes made either with vacuum drills or chipping hammers. After injection ports have been inserted into the holes, all surface cracks in the areas to be repaired shall be sealed with paste epoxy to ensure retention of the pressure injected epoxy within the confines of the member. The application of paste epoxy shall be limited to clean and dry surfaces. Substrate temperatures shall be limited to not less than 45°F during epoxy applications.

Epoxy injecting shall begin at the bottom of the fractured area and progress upward using a port filling sequence which will ensure the filling of the lowermost injection ports first. Injection procedures and the depths and spacings of holes at injection ports shall be established with due consideration of the crack widths and depths compatible with flow characteristics of the epoxy and injection pressure to ensure that no further damage will be done to the member being repaired, that injection epoxy will first fill the innermost portion of the cracked concrete and that the potential for creating voids within the crack or epoxy will be minimized.

After the fractured area has been filled and the epoxy has partially cured (24 hours at ambient temperature not less than 60°F, otherwise not less than 48 hours), the injection ports shall be removed flush with the concrete surface. Then the surfaces of the repaired area shall be abraded to achieve a reasonably uniform surface texture. Any injection epoxy runs or spills shall be removed from concrete surfaces.

The Contractor shall obtain, at no additional expense to the State, two 4-inch diameter core samples in the first one hundred lineal feet of crack repaired and one core for each one hundred lineal feet thereafter. The core samples shall be full crack depth and taken from locations as determined by the Engineer. Cores will be visually examined by the Engineer to determine the extent of epoxy penetration.

Method of Measurement and Basis of Payment. The pay quantity for "Item Special - Epoxy injection" shall be the lineal feet of crack repaired. The bid price for this item shall include the cost of furnishing the material and equipment necessary to perform the actual epoxy injection.

The pay quantity for "Item Special - Surface preparation for epoxy injection, and finishing" shall be based upon the length of cracks exceeding 0.5 millimeter in width or as specified on the plans and as established by the Engineer in the field prior to the start of the work. Smaller cracks shall not

be measured for pay purposes but shall otherwise be cleaned and surface sealed to ensure retention of the injected epoxy; however, when additional ports have been provided along cracks less than 0.5 millimeter in width, the length measured for payment shall extend from such ports to the point where the crack width is 0.5 millimeter except that no portion of any crack shall be measured more than once.

The bid price for "Item Special - Surface preparation for epoxy injection, and finishing" shall include the cost of all labor, equipment, materials, tools and all incidentals necessary to complete the work.

Basis of Payment. Payment for complete and accepted quantities as measured above will be made at the contract prices for:

<u>Item</u>	<u>Unit</u>	<u>Description</u>
Special	Lin. ft.	Epoxy injection
Special	Lin. ft.	Surface preparation for epoxy injection, and finishing

at5

STATE OF OHIO
DEPARTMENT OF TRANSPORTATION
SUPPLEMENTAL SPECIFICATION 853
GROUT ANCHORING WITH NONSHRINKING EPOXY MORTAR

June 26, 1978

853.01 Description. This specification covers the grouting with nonshrinking epoxy mortar of structural elements such as bars, bolts, and posts into concrete or metal substrates.

853.02 Material. The material used for grouting shall consist of a mixture of aggregate, epoxy resin and curing agents meeting the requirements of Supplemental Specification 956 Nonshrinking Epoxy Mortar for Grout Anchoring.

853.03 Temperature Limitations. Grouting shall be performed only when the substrate temperature can be maintained at 45F or above during grouting and for five days thereafter. Substrate temperature during grouting shall not exceed 120F.

853.04 Field Holes. Anchor holes in concrete shall be drilled or formed, except that holes adjacent to an unarmored edge shall be drilled by means of rotary tools without hammering or impacting.

The diameter of holes shall exceed the maximum diagonal dimension or diameter of the part to be anchored by 1/2 to 3/4 inches for bars and bolts in vertical holes, 3/4 to 1 inch for bars and bolts in horizontal holes, and 1 inch or more for posts and similar members.

853.05 Anchor Preparation. Anchor bars or other members shall be clean, dry, and free from loose rust and scale. For cleaning, solvents recommended by the manufacturer shall be used.

853.06 Mixing. The components shall be proportioned in accordance with the manufacturer's printed instructions.

The epoxy resin (Component A) and curing agent (Component B) shall be thoroughly mixed to form a homogeneous binder. The aggregate (Component C) shall then be blended into the binder and mixed until all of the aggregate particles are wetted and a homogeneous mortar is formed. During mixing, the paddles shall be kept submerged and moved continuously throughout the mix.

The temperature of the epoxy binder at the time of mixing and the mortar after mixing shall be between 65 and 85F. None of the component materials shall have a temperature exceeding 90F at the time of mixing.

853.07 Sampling and Testing. Representative samples of the mortar mixed in the field shall be obtained for testing. Two 3 by 6-inch cylindrical containers furnished by the Contractor shall be filled and

compacted under the supervision of the Engineer. The 72-hour compressive strength of these cylinders when tested in accordance with ASTM C 39 shall be not less than 6000 pounds per square inch.

853.08 Placement. Surfaces of the holes shall be clean and free of standing water. Laitance shall be removed from formed holes. Dust and debris shall be removed with compressed air or by vacuum. Contaminated surfaces of holes shall be cleaned with suitable solvents.

The mortar shall be placed into the prepared holes immediately after mixing. Vertical holes shall be 3/4 filled with pourable mortar. The member to be grout anchored shall be forced into the mortar to the proper depth and the mortar consolidated with a spatula. Horizontal holes shall have a small amount of trowelable mortar forced to the bottom of the hole to serve as a mortar cushion. The part of the member to be embedded shall be fully coated with epoxy binder and forced into the mortar to the proper depth. The mortar shall be rodded and tamped to consolidate the mortar around the member. After initial mortar consolidation, additional mortar shall be placed and consolidated until the hole is filled flush with the surface of the concrete.

Care shall be taken to obtain the correct protrusion of anchor bars or bolts. The anchored members shall be held in plan position and centered within the holes.

853.09 Curing and Loading. The mortar shall be cured as follows before stressing:

Daily Minimum Ambient Temperature	Minimum Curing Time
60F or above	24 hours
55 to 60F	48 hours
50 to 55F	72 hours
45 to 50F	5 days

853.10 Basis of Payment. The cost of drilling or forming holes, the furnishing and placing of nonshrinking epoxy mortar, and the setting of structural elements shall be included with the anchored members for payment.

STATE OF OHIO
DEPARTMENT OF TRANSPORTATION

SUPPLEMENTAL SPECIFICATION 956
NONSHRINKING EPOXY MORTAR FOR GROUT ANCHORING

June 26, 1978

956.01 Description. This specification covers the formulation and testing of a nonshrinking epoxy mortar for grout anchoring structural elements such as bars, bolts, and posts. The mortar shall be pourable and self-leveling for vertical holes or trowelable for horizontal holes.

956.02 Materials. Mortar shall be a three-component system as follows:

- Component A - Modified epoxy resin (175-200 epoxide equivalent)
- Component B - Curing agent which will copolymerize with Component A
- Component C - Silica or quartz aggregate, kiln or oven dry and free of deleterious substances.

The proportioning and mixing of Components A, B, and C shall be in accordance with the manufacturer's instructions.

956.03 Acceptance. The mortar shall be a mix formulation approved by the Director and will be accepted by certification. The approval will be based on evaluation of certified test data showing compliance with the following requirements, when the mortar is mixed according to the manufacturer's instructions and tested as shown in Table 1 and in the pull-out resistance test.

TABLE 1

Compressive Strength, ASTM C 109 (Modified*)	
24 hours, minimum, psi	4000
72 hours, minimum, psi	7000
7 days, minimum, psi	9000
Splitting Tensile Strength, ASTM C 496 (Modified*)	
7 days, minimum, psi	1500
Freeze Thaw, ASTM C 666 (Modified*)	
300 cycles, DF minimum, percent	95
Freeze Thaw, ASTM C 672	
50 cycles, rating	0
Modulus of Elasticity (Compression), ASTM C 469, psi	(2.0 ± 0.3) x 10 ⁶
Elongation at Ultimate Strength, ASTM D 638, percent minimum	1

*Test procedures for ASTM C 109 and ASTM C 496 are modified so that only the size of the specimens, rate and method of loading, and temperature requirements are applicable. Test procedure for ASTM C 666 is modified to include only epoxy mortar; all other procedures remain in force. Epoxy mortar samples (3000 grams for C 109, 11,000 grams for C 496 and 5000 grams for C 666) shall be prepared in accordance with the manufacturer's instructions. Mixing of materials shall be at low speed in a mixer complying with ASTM C 305. The temperature of Components A and B shall be $72 \pm 5F$ before mixing and the resulting mortar sample shall be cured at $72 \pm 5F$ at a relative humidity of 50 percent.

Pull-Out Resistance. The mortar being tested, when used to anchor a steel bar in a fully cured concrete test block, shall develop a pull-out resistance sufficient to cause either the bar to fail in tension or the concrete block to fail beyond the mortar-concrete bond line. Not less than two pull-out tests are required and a success ratio of at least 66 percent shall be achieved.

The concrete test block shall have a 28-day compressive strength of not less than 4000 pounds per square inch. The block shall have dimensions not less than 24 by 6 by 15 inches. It shall contain a 12-inch deep, 1 1/2-inch minimum diameter round hole centered within a 24 by 6-inch face. The hole may be drilled or formed. The test block shall be maintained at or below 45F during placing and curing of the mortar.

The test bar shall be ASTM A 36 steel, 5/8-inch diameter by 36 inches long, fully threaded (5/8-11), cleaned and degreased.

After the hole has been thoroughly vacuum cleaned, and sidewalls and bottom surfaces saturated with water, the bar shall be grouted into the test block. The mortar components being tested shall be mixed according to the instructions and placed into the still damp hole. For a pourable mixture, the mortar shall be poured into the hole until it is 3/4 full. The bar shall then be forced into the mortar to the proper depth after which the mortar shall be worked with a spatula to consolidate the mortar around the bar. For a trowelable mixture, the mortar shall be forced into the hole until it is 1/4 full. The bar, with threads fully coated with epoxy binder, shall then be forced into the mortar to the proper depth after which the mortar shall be rodded and tamped to consolidate the mortar around the bar. Additional mortar shall then be placed (poured and tamped) to fill the hole flush with the concrete surface. The bar shall be kept perpendicular to the concrete surface and centered within the mortar-filled hole until the mortar begins to harden.

The resulting specimen shall be cured at 45F or below for a period not to exceed 5 days. The bar shall be pulled axially from the concrete block. During the pull-out test, the surface of the test block within a 3-inch radius from the axis of the bar, shall be kept clear of testing fixtures.

956.04 Packaging and Storage. The epoxy resin and curing agent shall be supplied in separate containers which are nonreactive with the materials contained therein. Containers shall be labeled with the name of the mixture, the manufacturer, the component type, the date of manufacture, the batch number, quantity, and instructions relative to proportioning and mixing.

Storage areas shall be maintained above 40F.

The aggregate shall be packaged in water resistant bags.

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