NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 45

RAPID-SETTING MATERIALS FOR PATCHING OF CONCRETE

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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RAPID-SETTING MATERIALS FOR PATCHING OF CONCRETE

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
CEMENT AND CONCRETE
MAINTENANCE, GENERAL

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1977

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

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 Academy 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 responsibilities of the Academy 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

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, 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 the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the 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 they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest and usefulness to maintenance engineers, materials engineers, and others seeking information on materials for patching concrete pavements and bridge decks. Detailed information is presented on the performance of various patch materials.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended 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 synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

The use of rapid-setting materials for patching portland cement concrete pavements and bridge decks has increased greatly during the past several years. This report of the Transportation Research Board reviews information presently available on the performance of such materials. Patch materials evaluated fall into eight groups: 1. portland cement, 2. other chemical-setting cements, 3. thermosetting materials, 4. thermoplastics, 5. calcium sulfate, 6. bituminous materials, 7. composites, and 8. additives used to alter mix characteristics. Recommendations for further study are also included.

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 researchers 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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Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of W. P. Chamberlin, Associate Civil Engineer, New York State Department of Transportation; Kenneth Clear, Highway Research Engineer, Office of Research, Federal Highway Administration; William Crace, Chief Maintenance Engineer–Bridges, Bureau of Highways, Kentucky Department of Transportation; Howard L. Furr, Professor of Civil Engineering and Research Engineer, Texas A & M University; Paul Klieger, Director, Concrete Materials Research Department, Portland Cement Association; Howard H. Newlon, Assistant State Highway Research Engineer, Virginia Highway Research Council; Robert E. Olsen, Highway Engineer, Office of Development, Federal Highway Administration.

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Information on current practice was provided by many highway agencies and manufacturers. Their cooperation and assistance was most helpful.

RAPID-SETTING MATERIALS FOR PATCHING OF CONCRETE

SUMMARY

There is an expanding interest in materials for rapid repair of concrete pavements and structures in high-traffic areas. Many available rapid-setting materials will do a good job if used within the manufacturer's limitations. Some are quite expensive. Using a high-cost material may be justified, provided it can be placed and cured rapidly and is reasonably durable, because the material cost is usually a small percentage of the total repair cost. The issue boils down to deciding where, when, and how to use which material. The ideal is to provide a permanent patch with the least lane-downtime, at the least amount of hazard to the traveling public and the work crews, and at the lowest total cost.

Many repairs have been made to demonstrate materials claimed to be new and improved products. Much of this work has been done without suitable controls. As a reasonable basis for comparison, a Type III cement system is suggested. A rich mixture (7 to 10 bags/yd^3; 700 to 1000 lb/yd^3; 390 to 560 kg cement/m^3 concrete) containing 2 percent calcium chloride, an air-entraining admixture, and minimal mixing water will produce strength and resistance to abrasion sufficient to permit opening to traffic in four or five hours when the temperature is not below 50 F (10 C).

Whatever the patch material, proper preparation of the area to be patched is extremely important. An impact tool tends to leave a damaged layer of concrete, which may cause failure of the patch. Patch preparation is improved by cleaning with high-pressure water as a last step. In fact, research in this area may show that it is possible to perform all preparation with a water jet.

A great variety of patch materials are being offered for sale, and their set times range from a few minutes to about the same as the set time of portland cement. These materials generally fall into eight groups: (1) basically portland cement, (2) other chemical-setting cements, (3) thermosetting materials, (4) thermoplastics, (5) calcium sulfate, (6) bituminous materials, (7) composites, and (8) additives used to alter characteristics of mixtures.

Type III portland cement has been used for patch work for a longer time and more widely than most other materials. Its advantages are its low cost, easy availability, simplicity of use, and reasonable durability. Its disadvantages are that (a) there is high shrinkage if water content is not kept low and (b) in cool or cold weather the rate of strength gain is not sufficient to permit early opening. Calcium chloride is often used to accelerate the rate of strength gain.

High-alumina cements (mono-calcium aluminate) have been widely used in Europe and are now being tested and used in several states. One agency has reported excessive shrinkage with such cements.

A relatively new two-component patching material is being tested in a number of states. The components are magnesia and phosphate. The product must be

mixed in small quantities but results in a high-strength, low-permeability patch. Little is known about its long-term durability.

Epoxy resins have been widely used for several years. They have a wide range of set times and temperatures, and some will bond with damp or wet surfaces. Polyester resins are more recent and less widely used. They are hardened with very small amounts of catalyst, which makes accurate control of proportioning more difficult. A major disadvantage of both epoxy and polyester resins is the difficulty of providing adequate specifications and being assured that delivered material meets the specifications.

Experimental work is under way to use sulfur for patching, and some sulfur-based materials are available commercially.

Patching cements that are basically calcium sulfate gain strength rapidly and can be used at any temperature above freezing, but not all brands have the desired durability when exposed to moisture and freezing weather.

Bituminous materials are inexpensive, are easy to place, and need little cure time. However, the proper material is not always used, many bituminous patches are short-lived, and a bituminous patch in a bridge deck can actually accelerate deterioration of the surrounding concrete.

Although many new patching materials have been introduced in recent years in response to the need for such products, and although some can be justified for a particular repair problem, most of the newer materials do not appear to offer advantages commensurate with their much higher cost, compared with the advantages of portland cement concrete with carefully chosen admixtures.

Some findings of this synthesis include:

- High-alumina cement is sulfate-resistant and should be considered where steel corrosion is a factor.
- Epoxy resin concrete has been used successfully to repair sliver spalls, popouts, partial-depth spalls, and corner breaks. Care in purchasing is necessary.
- Bituminous patches are widely used and offer cost advantages.
- Magnesia-phosphate materials have performed well in limited tests. (No long-term results are available.) They should be considered for the same types of patches as the epoxy resins.
- Some of the calcium sulfate brands have produced good results, but others have not. Use of the more successful brands can be justified for small patches in high-traffic areas.

In short, the fast-setting materials offer minimal advantages, compared with those of conventional materials. Although material cost is a small part of the total cost of patching, the increase in time savings with fast-setting materials must be substantial to justify the higher material cost.

CHAPTER ONE

INTRODUCTION

BACKGROUND

There is an expanding interest in materials for rapid repair of concrete surfaces and structures in heavy-traffic areas of highways and airports. Industry has been aware of the potential market for some time, and the people responsible for concrete maintenance have been flooded with offers of "miracle" materials. Most of these materials are adequate for some situations, although a few may be of little merit. Others may be inappropriate for general use because they are too costly or they lack durability.

In the United States there is a growing tendency toward repair or reconstruction as opposed to a throw-it-away-and-buy-a-new-one policy. This holds true for beer cans, automobiles, highways, and bridges. Although much of the world has pursued such a conservation policy for a number of years, which accounts in part for the many several-hundred-year-old structures still in use, old-world practice has generally required a maximum use of labor in order to hold material costs to a minimum. This is evidenced by such items as hand-shaped and hand-fitted inserts where patches were needed.

Highway repair practices in the United States have tended toward expedient methods, because the traveling public has not been tolerant of inconveniences caused by making more substantial repairs. Using expedient methods keeps the road or bridge open to traffic but merely postpones the day of reckoning. Indeed, some patch procedures in common use are suspected of speeding the rate of deterioration.

Maintenance crews, however, often are faced with a situation where they see no practical alternative to using an expedient patch method. Most of their troubles occur in areas of high-density urban traffic when the weather is wet and cold. They are not able to close a lane long enough to do a more lasting repair job with the materials available to them.

THE PROBLEM

Many of the materials available will do a good job if used within the limitations of exposure recognized and expressed by the supplier. Some may be too costly when compared with others or when the quality of the surface to be repaired is considered. It makes little sense to use a patch material costing $700/yd^3 ($920/m^3) and then watch the surrounding parent material crumble away in a year or two. Nor is there justification in paying a high price for a short lane-downtime when the inconvenience of a closed lane is not very great or when repair work can be done conveniently at night.

The use of a costly repair material may be justified in areas of high traffic volumes and expensive labor, provided it can be placed and cured rapidly and is reasonably durable. It generally can be demonstrated that if all equipment and labor costs are considered, including cost of traffic control, the cost of even the most expensive patch material is a small percentage of the total repair cost.

A patch material should be at least as durable as the surrounding material, require a minimum of site preparation, and be tolerant of a wide range of temperature and moisture conditions. Also, it must not be injurious to the parent material, as might occur through leaching of sulfates or lime or by chemical incompatibility between the patch material and the surrounding concrete. It is preferable that a patch be reasonably similar in color and surface texture to the material being patched.

Special patch materials often are kept on routine maintenance trucks to assure immediate availability; there is thus a temptation to use these materials in situations where a less costly material would be adequate, or perhaps even better, over a long period.

The quality of patches would be improved if chloride-saturated concrete were completely removed. Recently developed simplified procedures for making chloride tests enable chloride-contaminated concrete to be located and removed (*1, 2*).

Although patch preparation is outside the scope of this synthesis, it has such an important bearing on the durability of the repair that it is worth some attention here. It is a rare bridge deck or pavement that has clearly defined lines where patch cutout may be stopped, and deciding just where to stop is among the more difficult aspects of the operation. This is true for depth of patch as well as area, particularly if cutout tools of the pavement breaker type and size are permitted. It is sometimes expedient to cut out full depth even though the bottom half of the total thickness is still sound and salt-free. However, this is generally not the most effective way to get the best possible patch.

The preparation problem on concrete pavement can be quite complex, especially at transverse joints, which are by far the most common areas of pavement trouble. Information on joint problems and repairs is covered in NCHRP Project 20-5, Topic 7-06, "Rehabilitation of PCC Pavement Joints," to be published in 1978.

A simple over-all procedure is important. Although it is likely that several materials with differing properties would be more nearly ideal for different situations, the presence of too many options may lead to waste and errors. For example, a patch material containing calcium chloride may be acceptable for use in unreinforced concrete pavement but may cause problems if used in a bridge deck. Or a very fast setting and high-cost material may be used where its cost can not be justified on the basis of time saved.

Areas requiring patching range from small corner breaks or sliver spalls along joints and cracks to entire sections of pavement or hundred-square-foot (9-m^2) or larger sections of part-depth or full-depth expanses of bridge decks. Almost always, the edges of such deteriorated areas taper out to zero depth. The saw-cut delineated boundaries necessary for obtaining good performance from most patch materials add greatly to the cost. Patch materials capable of maintaining good bond when feathered out offer obvious advantages.

The issue boils down to deciding where, when, and how to use which material. The ideal is to provide a permanent patch with the least lane-downtime, at the least amount of hazard to the traveling public and the work crews, and at the lowest total cost. Total cost must assign some value to an open lane as a trade-off to what might be a faster-setting and higher-cost material, but a limited number of patch materials should be stocked so that a reasonable level of simplicity can be achieved. Of course, the cost of patch material must be computed on the basis of some volume of mixed material, inasmuch as the recommended proportions of binder to aggregate vary so widely. For example, one material costing \$0.23/lb (\$0.51/kg) and used as directed by the manufacturer costs \$850/yd^3 (\$1100/m^3) of mixture. Another material, at \$1.00/lb (\$2.20/kg), may cost \$750/yd^3 (\$980/m^3). There must be some rough estimate of the cost to the road users of a closed lane per unit of time in order to justify the use of an expensive material, but generally charges for labor, equipment rental, and traffic control constitute a major part of the project cost.

THE OBJECTIVE

The objective of this synthesis is to collect, organize, and evaluate present knowledge on the identity, use, and effectiveness of rapid-setting, cast-in-place materials for patching concrete. Consideration is given to materials, costs, preparation time, and weather.

The desirable features of short application time, long service life, suitability over a wide range of temperature and moisture conditions, and low over-all cost are important considerations, but care must be exercised to assure that no property of the patch material or step of the procedure is harmful to the concrete being patched or leads to corrosion of any reinforcing steel. Also, the costs must be evaluated realistically. Further, it should be remembered that workmanship and preparation are as important as the patch material used.

It is unreasonable to consider patch materials without discussing patching methods; such discussion is therefore included in this synthesis. It is not within the scope of this synthesis, however, to discuss methods that do not relate to materials. For example, one procedure consists of placing steel plates over newly made concrete patches to permit immediate opening to traffic. Because the procedure can be used with any patching material, it is not covered here.

The synthesis is confined to a consideration of those patch materials intended to produce a permanent patch rather than a stopgap or temporary one. *Permanent,* as used here, denotes a service life equal to or greater than the estimated remaining service life of the pavement or structure to which the patch is applied. Experience with some of the rapid-setting materials indicates that they should not be considered permanent.

CHAPTER TWO

FINDINGS

WHAT IS BEING DONE

Many repairs have been made throughout the country to demonstrate materials claimed to be new and improved products. Much of this work has been done without adequate means of evaluating the product and comparing its performance with that of other patching materials in the same environment. It may have been that a product was not new at all but just had a new brand name. Sometimes products that have been tested in the past and found inadequate are rediscovered. It should be recognized that the need for faster-setting materials is greater than ever before and that some of the products previously judged inadequate may have been modified and improved to the point where they deserve new consideration. One must not, however, lose sight of what can be done with properly handled conventional materials; knowledge in handling these has also expanded with time.

As a reasonable basis for comparison, Type III cement, with or without additives, is suggested. Rich mixtures, containing 7 to 10 bags (700 to 1000 lb) of Type III cement (390 to 560 kg cement/m^3 concrete), 2 percent calcium chloride by weight of cement, an air-entraining admixture, and minimal mixing water will produce strength and resistance to abrasion sufficient to permit opening to traffic in four or five hours when the temperature is not below 50 F (10 C). Without the calcium chloride, patches placed during the morning hours can still allow opening to traffic the first night, except perhaps under extremely rugged traffic conditions or in weather below freezing.

Some engineers are reluctant to use calcium chloride, and certainly there is ample evidence that even small amounts of chloride can be harmful where reinforcing steel is involved (*3, 4*). In most patch work, however, the benefits gained by the use of calcium chloride may outweigh the disadvantage of either a possible reduction in the life of the patch or damage to wire mesh in concrete pavement. Moreover, *the amount of chloride in the patch may be no more than the amount of chloride already in the surrounding concrete.* A patch job consists of a series of compromises, and the good features of the materials must be weighed against the less desirable ones. For example, patching materials containing calcium sulfate may not be ideal in terms of durability, and epoxy-resin mixes may not be completely compatible with concrete on the basis of thermal coefficient of expansion, but both materials may be useful in some situations.

PATCH PREPARATION

Whatever the patch material, proper preparation of the area to be patched is of extreme importance. Any impact tool used to remove old concrete tends to leave a damaged layer of concrete as it chips away the material. Some epoxy-mortar-bonded portland cement concrete patches that have failed to stay bonded have remained intact within themselves but have pulled away a thin layer of concrete chips, due either to a shattered interface or perhaps to the fact that the deteriorated concrete was not removed to a sufficient depth before the patch was placed (Fig. 1) (*5*).

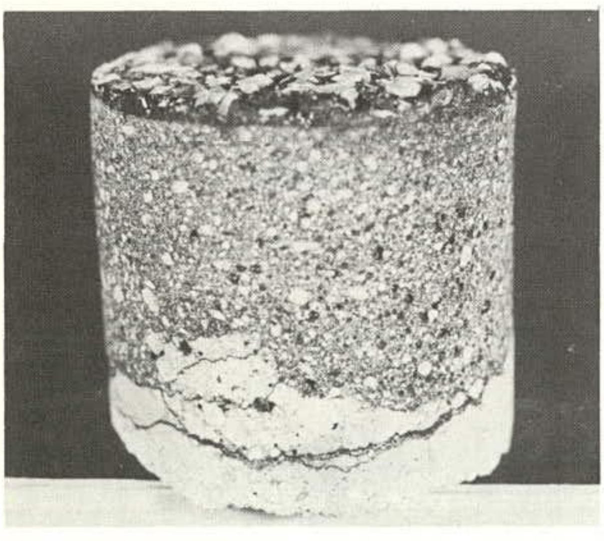

Figure 1. Core from an epoxy mortar patch. Epoxy in the crack plane near the bottom of the core indicates that not all unsound concrete has been removed (5).

In California and Kansas, some tests of equipment used to prepare surfaces of bridge decks for thin concrete overlays indicated that little, if any, improved bond resulted from the impact-tool preparation, compared with the bond to the cleaned but unroughened surface. Because the pull-off tests were made relatively soon after patch placement, the poor results must be attributed to incipient shatter rather than to continuing deterioration of the parent material at the interface. This type of damage may be limited to some extent if lighter-weight tools are specified; at the same time, damage to reinforcing steel will be reduced. On thin decks, such as the top slabs of box girders, it may be necessary to limit the maximum weight of the chipping hammer to approximately 15 lb (7 kg).

Patch preparation is improved by a last-step cleaning with high-pressure water at 4000 to 6000 psi (30 to 40 MPa). In fact, it may be possible in the near future to accomplish all the preparation with a water jet of suitable diameter and pressures of 60,000 to 100,000 psi (400 to 700 MPa). Research in this area, sponsored by the National Science Foundation, is currently under way at the Illinois Institute of Technology Research Institute (IITRI). The procedure has the potential to eliminate dust and noise, eliminate steel damage, and eliminate or reduce the problem of shattered interface.

PATCH IMPERMEABILITY

Most spalls in bridge decks have been shown to result from steel expanded by corrosion products, which has been shown to be accelerated by chlorides and inadequate concrete cover (*4, 6*). Because a patch generally does not increase the cover depth over that of the original configuration, similar problems can be expected in the same location in the future, except that the area and depth involved will certainly be much greater. Other problems may occur also. If the cover depth will be no greater, then some consideration should be given to using a less-permeable patch material. A tar-filled epoxy-resin-mortar patch checked on a Kansas project was found to absorb 12 percent water, a situation that was corrected on later work by the addition of suitable mineral filler (*5*). Portland cement was used as a filler in an amount equal to the volume of the liquid epoxy resin, and absorption was reduced to less than 1 percent.

TYPES OF PATCH MATERIAL

A great variety of patch materials are being offered for sale. As shown in a California report, set times of these materials range from a few minutes to about the same as the set time of portland-cement mortar (*7*). There are also great differences in cost. The long-term durability requirements must be considered, as must the weather conditions during which the work is to be done.

Known producers of rapid-setting patching materials were contacted for information on their products. The results of this survey from those who responded are given in Table 1. All data in the table are as supplied by the producers. A list of patching materials that have been

TABLE 1

RAPID-SETTING PATCHING MATERIALS

Brand and Manufacturer	Basic Material	Other Materials	Approximate handling time - minutes at: 20 F	40 F	60 F	80 F	100 F	Compressive strength/Time at: 20 F	40 F	60 F	80 F	100 F	Agencies that have used the product
Burke Non-Metallic Grout Burke Conc. Access. San Mateo, Calif.	Portland cement	Special cements	-	-	40	-	-	-	-	-	(73 F) 4000/24 hr	-	-
Exide Resurfacer 100 Atlas Minerals & Chem. Div., ESB Inc. Mertztown, Pa.	Portland cement	Polymers, silica	-	-	-	120	-	-	-	-	1000/ 7 day 4000/14 day	-	-
Exide Resurfacer 200 Atlas Minerals & Chem. Div., ESB Inc.	Portland cement	Latex, silica	-	-	-	45-60	-	-	-	-	1000/24 hr 4000/ 7 day	-	-
Fast-Fix Cement *(P)* Custom-Crete, Inc. Dallas, Texas	Portland cement	Calcium sulfate, calcium aluminate	-	40-60	25	15	5-10	-	250/40 min 500/75 min 1000/ 2 hr 2000/ 2 day 4000/45 day	250/20 min 500/50 min 1000/90 min 2000/24 hr 4000/28 day	250/15 min 500/40 min 1000/75 min 2000/24 hr 4000/28 day	250/10 min 500/30 min 1000/60 min 2000/24 hr 4000/ 7 day	Texas
Fix-A-Crete Custom Bldg. Products Bell, Calif.	Portland cement	Barium chloride, latex (optional)	NR	25-35	25-35	25-35	15	-	-	-	1525/60 min 7250/28 day	-	-
Mirament The Seddon Co. Springfield, Ohio	Portland cement	Calcium aluminate	20	-	-	6	-	-	-	385/30 min 400/60 min 3910/24 hr 5580/ 7 day 6040/28 day	-	-	Ind., Ky., & W. Va.; Cities of Pittsburgh and Indianapolis
Set Instant Concrete Set Products, Inc. Macedonia, Ohio	Portland cement	Silica	-	-	12	5	-	-	-	-	500/ 2 hr 2000/24 hr 4000/ 7 day	500/60 min 2000/24 hr	Illinois; Ohio
Sikaset Road Patch *(P)* Sika Chemical Corp. Lyndhurst, N. J.	Portland cement	-	-	-	-	(75 F) 17	-	-	-	-	(75 F) 500/45 min 1000/ 2 hr 2000/ 5 hr	-	-
Fondu Lone Star LaFarge Co. Norfolk, Va.	Calcium aluminate	-	-	15	15	15	-	-	-	-	(73 F) 2200/ 4 hr 5000/ 6 hr 6300/24 hr	-	Calif., La., Ore., Va. and Wash.; FHWA (G.W. Pkwy.)
FS-16 Pre-Krete Pocono Fabricators E. Stroudsburg, Pa.	Calcium aluminate	Fillers and additives	12	11	11	10	8	-	-	-	1430/60 min 2200/ 3 hr 3100/24 hr 4600/ 7 day	-	N.J., Pa., and Va.; Mass. and Pa. Tpks.; Balto. Co. Md. & Nassau Co., N.Y.
Bostik 275 *(P)** The Upco Company Cleveland, Ohio	Magnesia-phosphate	Silica or dolomitic limestone	(30F) 150	-	(55 F) 25	(72 F) 7	(90 F) 5	-	(35 F) 1000/2.5hr 2000/ 5 hr	-	(70 F) 250/30 min 500/45 min 1000/60 min 2000/ 2 hr 4000/ 7 day	-	Calif., Ohio, & Wash.; Indianapolis Airport Authority
FC-100 *(P)** Steelcote Mfg. Co. St. Louis, Mo.	Magnesia-phosphate	-	-	10-15	-	7-10	-	-	-	-	2000/ 2 hr 4000/24 hr	-	Ohio

TABLE 1 (Continued)

Brand and Manufacturer	Basic Material	Other Materials	Approximate handling time - minutes at:					Compressive strength/Time at:					Agencies that have used the product
			20 F	40 F	60 F	80 F	100 F	20 F	40 F	60 F	80 F	100 F	
Set - 45 Set Products Inc. Macedonia, Ohio	Magnesia - phosphate	-	-	30	20	12	6	500/ 2 hr 2000/24 hr	1000/60 min 4000/24 hr	2000/60 min 4000/ 6 hr	2000/60 min 4000/ 4 hr	2000/60 min 4000/ 4 hr	Ill., Ind., Mich., Ohio & Pa.; Cook Co. Ill., Wayne Co. Mich.
Colma Dur LV Sika Chemical Corp. Lyndhurst, N.J.	Epoxy resin	-	-	-	35	16	(90 F) 10	-	(35 F) 2000/24 hr 4000/36 hr	1000/7 hr	(75 F) 1000/ 4 hr 2000/4.5 hr 4000/ 6 hr	(90 F) 1000/3 hr	Missouri, N.J., Pa., & Virginia; Corps of Engineers
Cono/Crete and Cono/Crete FS Con/Chem, Inc. Gardena, Calif.	Epoxy resin	Bauxite	240	120	60	30	15	-	-	250/ 3 hr 500/ 6 hr 1000/ 8 hr 2000/10 hr 4000/16 hr	250/ 2 hr 500/ 3 hr 1000/ 4 hr 2000/ 8 hr 4000/10 hr	500/60 min 1000/ 2 hr 2000/ 3 hr 4000/ 5 hr	Cuyahoga Co. Ohio; Port Auth. N.Y. & N.J.
Exide Surfacer 300 Atlas Minerals & Chem. Div., ESB Inc. Mertztown, Pa.	Epoxy resin	Asphalt, silica	-	-	45	30	10	-	-	4000/24 hr	250/ 2 hr 500/ 4 hr 4000/24 hr	250/60 min 500/ 2 hr 1000/ 6 hr 4000/12 hr	-
Tufchem (Epoxy) Grout Pennwalt Corp. Philadelphia, Pa.	Epoxy resin	-	-	(50 F) 180	180	60	60	-	(50 F) 17,500/ 7 day	17,500/ 5 day (Min. setting temp.: 50 F)	17,500/ 2 day	17,500/ 1.5 day	-
Gold Label *(P)* Preco Plainview, N. Y.	Polyester resin	-	120	120	5-120	18-75	10-40	4000/6 hr	4000/90 min	4000/90 min	4000/60 min	4000/60 min	New York; NYC Transit Authority
Radgrout-H[r] Road & Industrial Concrete Radiation Tech., Inc. Rockaway, N. J.	Polyester resin	-	60	35	40	15	5	10,000/ 90 min	10,000/ 70 min	10,000/ 40 min	10,000/ 30 min	10,000/ 10 min	New York; Pa. Tpk.; Port Auth. NY & NJ; Triboro Bridge & Tun. Auth.; City of Phila.
Vitrobond Atlas Minerals & Chem. Div., ESB Inc. Mertztown, Pa.	Sulfur	Silica	(Hot-melt material)					-	-	-	4000/ 5 min	-	-
Duracal *(P)* U.S. Gypsum Co. Chicago, Ill.	Calcium sulfate	Portland cement	-	35-40	20-35	20-35	15-30	-	2000/60 min	2000/60 min	2000/60 min 4000/ 3 day 5600/ 7 day 7200/28 day	2000/60 min	Colo., Conn., Del., Ga., Mass., N.Y., Okla. Texas, & Va.; Illinois Tollway.
Mari-Crete Atlas Minerals & Chem. Div., ESB Inc. Mertztown, Pa.	Calcium sulfate	Portland cement, silica	-	-	10-15	3-5	-	-	-	-	-	500/ 8 hr 1000/16 hr 2000/24 hr 4000/48 hr	New York; Virginia
DP Concrete Additive Pennwalt Corp. Philadelphia, Pa.	-	-	-	-	-	-	-	(Accelerating additive for any patching formula. Provides 3:28 reduction in time to strength.)					-
Gill #33 B&P Superbond Gill Chemical Co. Hamlin, W. Va.	-	Calcium chloride	60	-	-	30	-	1000/3 hr	-	1000/2 hr 4000/24 hr	2000/2.5 hr	-	Georgia, W. Va.; U.S. Bureau of Mines

(P) Patented * Licensee of Republic Steel Corp. NR Not Recommended
Data from survey of manufacturers, October 1975.

tested by states can be found in the AASHTO/FHWA "Special Product Evaluation List" (*8*).

There are some overlaps in the material groups described below; more or fewer might be as descriptive as those listed here. Some brands appear to fall into more than one group. The following are general groups:

1. Basically portland cement.
2. Other chemical-setting cements (including the magnesia-phosphate but not calcium sulfate types).
3. Thermosetting materials (epoxy resins, polyesters, etc.).
4. Thermoplastics (sulfur and the like, but not bituminous materials).
5. Calcium sulfate.
6. Bituminous materials (asphalt cements, emulsions, cutbacks, tars).
7. Composites (fibrous concrete, steel, asbestos, nylon, etc.).
8. Additives (materials used to alter characteristics of mixtures).

PERFORMANCE OF MATERIALS BY GROUPS—FIELD EXPERIENCE

Basically Portland Cement

Although many of the proprietary products contain varying amounts of portland cement, the products are treated separately below.

Type III Cement

Type III cement has been used, with and without various admixtures, for patch work for a longer time and more widely than most other materials. Its advantages are its low cost, easy availability, simplicity of use, and reasonable durability. Material cost of mortar or concrete is \$25 to \$40/yd^3 (\$33 to \$52/m^3), and it is a lumber yard item in almost any location. Strength gain of rich, low-slump mixtures is rapid in warm weather, and no unconventional equipment is required.

One disadvantage is that there is high shrinkage and a tendency for the patch to crack if extreme care is not exercised to keep water content low. Also, in cool or cold weather the rate of strength gain is not sufficient to permit extremely short-time opening. Storage life may be a problem when cement is provided in carload lots and is not used in a reasonable length of time (90 days). A premium is charged for bag cement. Bag set may be reduced by careful dry storage and frequent turning. Dampness may impair some of the desirable qualities.

Type III Cement With Admixtures

Many available admixtures alter the set time and rate of strength gain and may improve other qualities. The most commonly used accelerator is calcium chloride, added at a rate not exceeding 2 percent by weight of the cement. The calcium chloride is usually premixed with water. Some other accelerators include chlorides, alkaline carbonates, sulfates, nitrates, silicates, hydroxides of alkaline metals, fluorides, fluosilicates, and thriethandamine (*9*). Some proprietary accelerators available purportedly do not contain calcium chloride. Air-entraining admixtures are added, or Type IIIA cement containing plant-added air-entraining additive is used. Calcium stearate is sometimes added at the plant for the purpose of imparting a degree of water repellency.

Regulated-Set Cement

Regulated-set cement was introduced by the Portland Cement Association and used in a number of test installations around the country. It performed well in most instances but was temperature-sensitive to a degree that detracted from its usefulness (higher temperatures decreased handling time). The temperature sensitivity can be compensated for satisfactorily by the use of available retarding admixtures. Regulated-set cement is not being produced regularly in the United States at the present time. As reported by Texas, it performed well when blended with Type III cement (*10*).

Other Chemical-Setting Cements

High-Alumina Cements

High-alumina cements have been used for a number of years in several European countries. They are available in the United States as Fondu and Lumnite. These cements are mono-calcium aluminate types with undetermined additives. One highway department (Missouri) tested Fondu and did not approve it because of excessive shrinkage. Three states have accepted it, however, and it is being field-tested in others. Because conversion causes a reduction of strength with time (*11*), high-alumina cements should not be used in structural concrete unless the strength obtained at 24 hours is above 200 percent of the design strength.

Magnesia-Phosphate

A relatively new type of patching material has been introduced by the Republic Steel Company and, through franchise holders, is offered for sale under various brand names such as Bostik 275, Darex 240, FC-100, Acmaset, and Sur-smooth. The actual suppliers may have made some minor modifications. The product consists of a two-component magnesia-phosphate package. The magnesia component is supplied in dry form with a measured quantity of liquid phosphate to complete the mortar. It must be mixed in small quantities and worked very rapidly, but it usually produces a high-strength, low-permeability patch material with excellent bond to almost any reasonably clean, dry surface. Water will affect the hardening; even very small amounts cause severe strength reduction.

Although the magnesia-phosphate material purportedly has a good long-term service record as a patch material for steel mill refractory repair work, little is known about its long-term performance when it is exposed to conditions peculiar to highways and bridges. One state highway department (Missouri) has not accepted one brand because permeability was considered too high for the department's requirements, and another highway department (Kansas) found the same brand to be not very durable when exposed to laboratory freeze-and-thaw tests. Several departments have accepted this material for patching. It appears to be best adapted to repair of small sliver spalls or for emergency work.

Another product (Set 45) is similar, but both components are supplied in dry form and water is added. Very few results of field-testing have been located.

With either material, the phosphate portion must compete with the commercial fertilizer segment of the petrochemical industry and so may be in short supply at times.

Thermosetting Materials

Patching mortar and concrete containing epoxy resin have been widely used for several years. Epoxy resin has also been used as a tack coat to provide better bond between the old concrete and various patching materials. Polyester resin has been used on a smaller scale for patch material and as a tack coat for polyester patches, but not for other types of patches. Tests in Oregon have indicated that polyester tack coats must consist of more than one application in order to provide a watertight layer (*12*).

Available epoxy resins have a wide range of set times. Some will harden at temperatures of 0 F (−18 C) or below, and some, but certainly not all, will achieve bond with damp or even wet surfaces. Generally, however, surfaces must be thoroughly clean and dry and must be at a temperature between 60 and 100 F (16 and 38 C) (*13*). Although they cost from \$0.60 to \$4.00/lb (\$1.30 to \$8.80/kg) or more, when combined with five parts or more of carefully graded aggregate, cost may vary from \$200 to \$800/yd³ (\$260 to \$1050/m³) or more. Even though an epoxy resin will eventually harden in weather colder than that for which it was formulated, quality likely will be impaired. Further, it can not adhere if a minute film of ice is present on the surface to be bonded.

Polyester resins have not been as widely used as the epoxies. They are generally hardened by additions of very small amounts of catalyst, such as methyl ethyl ketone peroxide, which makes accurate control of proportions and mixing somewhat more difficult than with the two-component epoxies, which are mixed in 1:1 to 1:5 proportions.

One of the major disadvantages associated with the use of both epoxy and polyester resins is the difficulty of providing adequate specifications to prospective sellers and assuring that the material, when delivered, meets such specifications. AASHTO and ASTM specifications can be helpful but do not completely solve the problem. Infrared testing equipment can be used to assure that lots of delivered material are identical with earlier lots. In any case, final acceptance should depend on an actual field demonstration of the material's ability to perform properly. The resins are produced by the petrochemical industry and thus may be in short supply at times under present conditions.

Other Polymers

Other monomers can be hardened by polymerizing and used in various manners to form a patch of entirely new material or perhaps to rebind what remains of the original concrete. Experimental work is under way, and some procedures using these materials have reached the development stage (*22*). The materials include methyl methacrylate, polyester-styrene, furfural alcohol, and polyhydroxylated methyl methacrylate (Hydron). At present it appears that some of these materials may be most useful for such purposes as impregnation of deteriorated concrete rather than as binders for patching aggregate, but much remains to be learned.

Thermoplastics

Little patching appears to have been done with thermoplastics. Sulfur is abundant in some areas (Texas, Canada, etc.) where antipollution legislation has required that it be removed from petroleum. Molten sulfur has long been used to set anchor bolts and iron railing posts. Experimental work has been conducted in an effort to use sulfur as a binder for concrete (*14, 15*), and it seems logical that it could be used for quick-hardening patches. Its use as an impregnating material for deteriorated concrete has also been reported (*16*).

Calcium Sulfate

Many available patching cements are basically calcium sulfate (Duracal, Mari-Crete, etc.). They gain strength very rapidly and can be used in any temperature above freezing, but they have not in all cases been found to be very durable when exposed to moisture and freezing weather. There may also be sulfate damage to surrounding concrete and corrosion of any steel present. However, several highway departments and an airport authority have reported good performance through two winters with patches containing Duracal or Duracrete, U.S. Gypsum Company products (*8*).

Most materials in the calcium sulfate group contain portland cement in varying amounts, and some contain chlorides as well as sulfates. A few have been marketed under names that change from year to year. Some have performed so poorly that there is a temptation to write off the entire group, but because reports of successful use are mixed with the less glowing accounts, each material deserves consideration on an individual basis. Because little or no aggregate is used, the cost is about \$750/yd³ (\$980/m³). Certainly, none should be used on other than a test basis without some evidence of successful use in a similar environment and over a meaningful period of time.

Bituminous Materials

Bituminous materials are used almost everywhere, in all kinds of weather, for patch work. (The Ark was patched with pitch.) They have the advantages of being relatively low in cost, being easy to place with small crews, and generally needing little if any cure time. A load of some kinds of mixed bituminous materials may be carried in a truck all day or all week and used when and where the need arises. Most cost \$30 to \$50/yd³ (\$40 to \$65/m³) for material. A disadvantage is that the proper type of material is not always used and the error is not immediately apparent. A shovelful of "cold mix," dumped in a pothole and left for traffic to compact, is seldom a bargain at any price; unfortunately, many patches are so made. At the other end of the scale, a material approximating Gussasphalt may be an extremely long-lasting and effective patch material. Poorly graded and unconsolidated bituminous patches used in potholes in bridge decks have at times appeared to serve as water-holding mulches, accelerating the deterioration of the surrounding concrete.

Hot-Mixed Dense-Graded Asphalt Concrete

The Asphalt Institute's maintenance manual recommends carefully formulated hot-mixed dense-graded asphaltic concrete for most patch work (*17*), and millions of such patches are in use. Such mixtures require insulated trucks, unless volumes to be used at a single location are large. A tack coat is used, and the surfaces to be patched should be dry and not colder than 40 F (4 C).

Cold-Mixed Cutback Asphalts

Cold-mixed cutback asphalts are made with softer grades of asphalt blended with a slow- or medium-curing lighter-fraction oil in order that they may be handled and placed cold. This is probably the simplest patch to place and the least expensive, but it can not be termed a permanent patch. The use of cutbacks is declining because of energy and environmental considerations (*18*).

Asphalt Emulsions

Emulsions, both anionic and cationic, have been widely used for patching with some success. They can be handled and placed cold, and the pavement can be opened to traffic as soon as the emulsion has "broken." Considerable skill is required to handle emulsions properly (*18*).

Tars

In parts of the United States where coal tar is produced, it has been used for surfacing and patching. Koppers Co. and the Jennite Co. provide literature on its proper use. Coal tars have been extensively used as "waterproof" membranes under overlays on bridge decks (*19*) and for surfacing (Tarvia), but not much information has been located on their use in patching.

Rock Asphalt

Deposits of asphalt-impregnated limestone and sandstone have been exploited in Texas (in Uvalde), Kentucky, New Mexico, Missouri, Kansas, and elsewhere (*20*). This material has been quarried or mined, crushed to ⅜ or ½ in. (9.5 or 13 mm), heated and blended with approximately 3 percent of petroleum asphalt, and marketed as surfacing or patching material. Some deposits contain up to 28 percent (perhaps more) of natural asphalt, but ordinarily the deposit selected contains about 8 percent, which produces finished mixtures of about 11 percent total asphalt. The finished material can be stored, can be easily handled and placed, and is stable and durable if properly consolidated. Renewed interest in these deposits because of the energy shortage may have some effect on whether this product becomes more widely used.

Gussasphalt

As used in Europe (Germany, Austria, Switzerland, etc.), Gussasphalt contains 5 to 25 percent or more (of the asphalt portion) Trinidad asphalt and is laid (more literally poured) very hot, at 400 F (200 C) or higher (*21*). It is generally used in thin applications, ⅜ to ¾ in. (9.5 to 19 mm) thick, for repairing surface deterioration, for preventing surface deterioration, and for providing nonskid surfaces. A "dimpled" surface appears to have been rolled in while hot. Gussasphalt is used indoors or out and seems to be highly impervious to water and resistant to wear. It has also been widely used for membranes on bridge decks under wearing surfaces of other materials.

Materials Used by Other Crafts

Other crafts have used patch materials that may be of value for concrete repair. Perhaps some of these should be explored. For example, iron foundries once used, and some may still use, a product called Smoothon to fill blowholes in castings. These patches were sufficiently hard, tenacious, and durable to go undetected indefinitely. Furnace cements have for years been used in fireboxes. Whether they are related to Republic Steel's patch material is not known.

A host of new glues, including contact cement, are in the process of development; they have different degrees of water resistance and durability and a great range of set times. Some variation of such materials might make possible an "instant" patch.

Kansas used silicone caulking compounds to fill ¾-in.-diam. (19-mm-diam.) chloride analysis holes drilled into bridge decks (*1*). This material could be used to repair small popouts.

CURING PATCHES

Although it is not intended that the curing of most patch materials be disregarded, the very nature of the problem tends to lead to neglect of this procedure. Many cementitious mixtures *with low water-cement ratios and better-than-normal consolidation* probably do manage to perform pretty well without much cure time, at least insofar as deficiencies can be detected through observation of surface wear or cracking.

Some of the bituminous materials, of course, require different attention. Emulsions must be allowed time to "break." If early stability is achieved, some of the lighter material can escape later with no bad effects. Cutback asphalt must have an opportunity to lose its volatile fraction to become stable. Some states prohibit the use of this type of material in smog areas (*17*).

Epoxy-mortar patches, of the "100-percent solids" variety need time only to polymerize and harden. Although some brands may contain volatiles, such as pine oil, that actually combine chemically with other components in the thermosetting process, it may be advisable that epoxy resin use be restricted to the "100-percent solids" type for patch work.

Magnesia-phosphate patches appear to need no cure, although it has been suggested that their obviously good service record in refractory use may be due at least in part to the high temperatures to which such patches are subjected at very early ages.

CHAPTER THREE

CONCLUSIONS AND RECOMMENDATIONS

The many new patching materials introduced to the market in recent years reflect not only increasing problems of maintenance on overcrowded highways and airports but also less-than-complete satisfaction with materials in common use. The fact that maintenance people often seem willing to pay 10 to 20 times more for some of the new products is a measure of their desperation, inasmuch as their funds are generally harder to come by than those of other departments in the highway and airport businesses.

Nevertheless, most of the newer materials offered for sale do not appear to offer advantages commensurate with their much greater cost, compared with the advantages of portland cement concrete in its various forms and with carefully chosen admixtures for specific situations. Some of the new fast-setting materials are perfectly adequate, and their use can be justified on some basis for a particular type of repair problem. Some do not provide a permanent patch but a stopgap only, and even most of these are very costly and difficult to use.

It should be noted that this is an industry in which "new" products are continually being introduced and old ones discontinued; formulation changes behind a product name are not uncommon. There is also a paucity of reliable information on performance from producers and consumers, and there is a lack of uniform evaluation procedures and standards.

CONCLUSIONS

Using types of hydraulic cement other than conventional portland can be justified for some situations. High-alumina cement (mono-calcium aluminate) is sulfate-resistant and should be considered where steel corrosion is a factor. Concrete made with high-alumina cements may be expected to show a decrease in strength of about 50 percent in service. This does not necessarily eliminate them as useful repair materials, inasmuch as there is seldom any difficulty in making high-alumina concrete that has a strength at 24 hours well above 200 percent of what is needed in service. Although set time and strength gain of high-alumina cement are about the same as those of Type III cement, these characteristics can be altered favorably with small additions of admixtures that are chloride-free (e.g., lithium carbonate and Marasperse C21).

Epoxy-resin mortars and epoxy-resin concrete have been successfully used for repair of sliver spalls along joints and cracks, popouts, partial-depth spalled-out areas, and small corner breaks. This, of course, is in addition to the use of epoxy resin as a pressure-injected adhesive filler for cracks of most kinds, including delaminated bridge decks. Epoxy resins should be carefully chosen, and several factors should be considered: proven ability to perform as represented, cost, shelf and pot life, equipment needed for preparation and application, stability when exposed to salt water, and tolerance for low temperatures and moist conditions during application. Epoxy resins should be purchased by brand name on the basis of past experience; if this is not permitted by agency purchasing regulations, performance specifications should be carefully prepared and updated regularly with growing experience. A specification should certainly include package marking requirements of the components in order to preclude, as nearly as possible, confusion in mixing.

Bituminous patches are widely used and offer obvious advantages. They are generally the least costly, although the savings tend to diminish if one is meticulous in choosing materials and attending to the details necessary for high-quality patch work. Their range in quality—from very good to very poor—is no doubt as great as that of other types of patches; and, at their worst, bituminous patches are suspected of acting as water-filled mulches, which speed the deterioration of the concrete surrounding the patch. The color difference is objectionable to some, but it is likely that most road users have become so accustomed to bridge deck overlays and approach leveling work with asphalt that they are not really concerned with color changes. Bituminous patches are probably best adapted to repair of pavements ahead of overlay work, joint breakdown caused by a general D cracking failure, and thin overlays to correct low skid numbers. The Guss-asphalt concept is worthy of further study.

The magnesia-phosphate group of materials has performed well in the limited number of areas in which it has been tested, but there are no long-term service records. There seems to be no reason to consider this material, or others in the same group, for large patches, but it could be used to advantage for repair of sliver spalls or popouts. It costs about the same as epoxy-resin mortar and probably should be used for the same situations. The good service record claimed for refractory repair work may be due in part to the high-temperature curing such patches receive as a matter of course.

Patch materials containing calcium sulfate as a primary constituent are being offered in profusion. Descriptions by users vary from "very good" to "completely useless." Such materials are easy to use, and they set and gain strength rapidly. In at least two states (Oklahoma and Pennsylvania), one brand (Duracal) has an acceptable service record for two years. The Missouri State Highway Department has used the same basic material premixed with aggregate, packaged, and sold under another brand name (Duracrete). This department feels that results obtained with this brand have been good, compared with results obtained with other materials. It appears that using some of the brands of this material can be justified for small patches in high-traffic areas.

Regulated-set cement has been field-tested in a few states and, although it shows some promise as a helpful material, is not at present being offered for sale. At least one state highway department has tested regulated-set cement blended with other cements in order to alter the set time. It appears to be too temperature-sensitive in its present form for routine maintenance operations.

To sum up: the fast-setting patching materials, when compared with more conventional materials, offer advantages that are generally borderline. Although material cost is a small part of the total cost of the patching operation, the possible increases in time savings with the use of fast-setting materials must be substantial in order to justify the additional cost. There are times, of course, when a hole must be filled under conditions so unfavorable that a work crew is justified in doing whatever is necessary to keep traffic moving. In one extreme case, a hole in a pavement, under 6 in. (150 mm) of water, was filled with old truck tire chains; for several days this "patch" served to prevent broken axles and whiplash injuries.

RECOMMENDATIONS FOR FURTHER STUDY

Fast-setting, high-strength materials for patching need not be exorbitant in cost if full advantage is taken of what is already known. The judicious use of admixtures can certainly be helpful. Regulated-set cement shows some promise if used with available retarding admixtures to make it less temperature-sensitive. Although high-alumina cements are roughly 3½ times as expensive as Type III cement, it is not unreasonable to consider them for patch work. Sulfur is a waste product in some areas and can perhaps be developed into a fast and durable patch system at an attractive cost.

High-type, moderate-cost asphalt patches meet the requirements for early opening to traffic and are certainly of value if given the same study and attention to details as are other materials. Although natural rock asphalt is being reexplored as a source of fuel, progress has been slow. For the present and for some time to come, it may be better adapted for use as a patch or paving material; fuel production may eventually provide a usable patch material as a by-product.

Patch preparation deserves serious study because it accounts for a large part of the total cost of the project and has an important bearing on the performance of all the materials. Either chloride-saturated concrete must be more rapidly identified, or some means must be found to reduce its tendency to promote steel corrosion. Patch preparation equipment appears to offer the greatest potential for improving results as well as reducing costs and irritation for the traveler. Work done experimentally with high-pressure water jets by the Corps of Engineers, the Russians, Ingersoll-Rand, IITRI, and others makes it highly probable that some combination of pressure, orifice size and type, and a water additive such as polyethylene oxide is capable of completing the patch preparation operation in a single pass, without dust, appreciable noise, damage to steel, or unnecessary removal of sound concrete.

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