NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 64

BITUMINOUS PATCHING MIXTURES

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

AREAS OF INTEREST:
- BITUMINOUS MATERIALS AND MIXES
- MAINTENANCE
- (HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. SEPTEMBER 1979

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 materials engineers and others concerned with the use of bituminous mixtures for patching highway pavements. Detailed information is presented on mixture design.

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.

Bituminous patching is done by highway maintenance employees for the purpose of restoring rideability. This report of the Transportation Research Board includes detailed information on materials, testing for desirable properties, mixture design, and methods of production, inspection, and storage. A list of related research needs is 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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Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

BITUMINOUS PATCHING MIXTURES

SUMMARY

Bituminous patching mixtures are combinations of bituminous binders and aggregates that have special characteristics needed for filling holes in pavements. The different types of patching mixtures can be placed in one of three groups: (a) hot-mixed, hot-laid; (b) hot-mixed, cold-laid; or (c) cold-mixed, cold-laid.

Among the properties that a bituminous patching mixture should have are: stability, to allow the patch to resist displacement by traffic; stickiness, so the patch will stick to the sides of the hole; resistance to water action, to keep the binder from stripping off the aggregate; durability, so the patch does not ravel or crack; skid resistance as good as the pavement in which it is placed; workability, to enable the material to be easily shoveled, raked, and shaped; and storageability, so the mixture can be stockpiled without hardening excessively or having the binder drain off the aggregate.

Binders used in hot-laid patching mixtures are the same asphalt cements used in bituminous paving. For cold-laid mixtures, liquid asphalts or emulsions usually are used. Aggregates generally are the same as in normal pavement construction, although more attention is paid to obtaining angular, rough-surfaced material and compatibility with the binder. Additives are frequently used for antistripping purposes and to improve workability. Proprietary products, either additives or an entire mixture, usually entail increased costs and thus their performance and cost-effectiveness need to be carefully evaluated.

Various tests are used for specifying, designing, and approving patching mixtures. Stability tests are rarely used and then only to control hot-laid mixtures. Adhesion tests are used more often. These include coating tests, stripping tests, or an immersion-compression test (only for hot-laid mixtures). There are few laboratory tests to measure workability; most agencies control workability with a subjective field test. Storageability is another property that is not measured by laboratory tests but by a subjective rating based on field experience. Additives and proprietary mixtures are usually accepted on the basis of satisfactory field experience.

Design of hot-laid patching mixtures is essentially the same as for dense-graded, hot-mixed asphalt concrete. For cold-laid mixtures, there is no widely adopted formal design process; however, successful procedures, usually involving trial-and-error, have evolved over time.

Production methods for patching mixtures are essentially the same as for other bituminous mixtures. The hot-laid materials are used immediately, and cold-laid mixtures are stored for use as needed. Recently, two kinds of portable equipment have been developed—one can mix small batches of material at the job site; the other kind heats and remixes stockpiled material.

In recent years, composite bituminous mixtures have been developed. These include sulfur-asphalt mixtures, addition of portland cement, and reinforcement

with polyester fibers, rubber, or inorganic fibers. However, there is only limited field experience with these composites.

Research areas that warrant special consideration include: collection of data on the longevity of bituminous patching mixtures, development of a technique for simulating and accelerating storage conditions, development of a test to measure workability, development of a design procedure for stockpiled mixtures that would have workability and storageability, and a demonstration project to compare the performance of different types of patching materials and techniques.

CHAPTER ONE

INTRODUCTION

Extreme climatic conditions, including freezing temperatures and excess water, have caused severe and rapid deterioration of highways and streets in recent years. In many areas, major maintenance efforts are required to keep the road surface in a travelable condition, and more and more of the road dollar is being spent on maintenance. A good portion of this maintenance work consists of filling holes and other deteriorated areas with bituminous patching mixtures.

The quantity of patching material used is relatively small when compared to the total amount of bituminous mixtures produced. However, it is an essential material for pavement maintenance. Ideally, it affords rapid patching, can be used in a wide range of weather, and can fill most holes, regardless of shape or depth.

DEFINITION OF BITUMINOUS PATCHING MIXTURES

Patching is the filling of deteriorated areas or holes in a road surface to keep traffic moving safely or to prevent rapid deterioration of an area that could become unsafe. Patches are used to repair potholes, badly spalled cracks, and utility cuts of less than approximately 250 sq ft (23 m^2) and raveled areas up to several hundred feet in length. Although patches are made with several types of bituminous materials, this synthesis is restricted to patching mixtures of bitumen, aggregate, and antistripping agents.

Bituminous patching mixtures are combinations of aggregates and bituminous binders that have special characteristics needed to fill holes. Workability is a major consideration and may take precedence over other desirable properties.

Bituminous patching mixtures range from hot-mixed asphalt concrete that must be placed hot to mixtures that can be stockpiled for long periods of time. Bituminous patching mixtures can be shoveled and placed by hand and are often needed in relatively small amounts [150 lbs (68 kg) or less]. They are not used to cover extensive areas for general rehabilitation of a pavement.

Bituminous patching mixtures are probably the most versatile of all the patching materials. They can range widely in cost, stability, quality, and application. They are very popular because they provide a wide choice of mixtures to meet a range of patching needs.

GENERAL TYPES OF BITUMINOUS PATCHING MIXTURES

There are several types of bituminous patching mixtures. Each has its individual properties. Most patching mixtures can be placed in one of three groups depending upon the type of mixing and the temperature of the mixture at the time of placement.

Hot-Mixed, Hot-Laid Patching Mixtures

These are essentially asphalt concrete patching mixtures. They usually contain asphalt cement binder and a well-graded aggregate. Materials are accurately proportioned and are mixed hot. They are used while hot, usually immediately after being produced. These mixtures are the highest quality of all bituminous patching mixtures.

Hot-Mixed, Cold-Laid Patching Mixtures

These are materials produced with liquid bituminous binders in a plant that uses a dryer to heat the aggregate or in a drum-dryer plant. These mixtures are carefully controlled and thoroughly mixed. They are used cold from a stockpile and are workable in all weather.

Cold-Mixed, Cold-Laid Patching Mixtures

These mixtures are composed of liquid bituminous binders and aggregates that have not been heated. Mixing is done either in a plant where the materials are proportioned or on a paved surface with few controls. The mixtures are stockpiled until needed and used cold in any season. They have the lowest quality of all the patching mixtures.

ENVIRONMENTAL CONSIDERATIONS

Some atmospheric contaminants, such as dust, develop during mixing of bituminous materials but are now adequately controlled. The major environmental concern is the amount of hydrocarbon volatiles that escape. Only those patching mixtures made with cutbacks have large quantities of volatiles. The hydrocarbon thinners in cutbacks escape into the air when the cutbacks are mixed with the aggregates. Evaporation also takes place in the stockpile, but the amount of volatiles released may be quite small once a crust is formed and they are held within the stockpile. The greatest portion of the volatiles is given off at the patching site while the mixture cures.

Recently, the environmental protection agencies in many states have placed controls on the amount of hydrocarbon volatiles that can be released into the atmosphere. The total concentration of volatiles in the air and the temperature of the air are important factors in this contamination. Thus, regulations are being written that control the use of cutbacks in two different ways. They prohibit the use of cutbacks either in densely populated areas or during the warm summer months. The exact regulations vary from state to state, but all have essentially one or both of these controls.

Because of environmental and energy concerns, the use of cutback patching material is being reduced. Therefore, the use of patching mixtures made with liquid asphalt emulsions is increasing.

FAILURES AND HANDLING PROBLEMS

When an unsatisfactory mixture or poor construction practices are used, the patch will not perform as intended. The most common failures of bituminous patching mixtures are given in Table 1.

Failure due to lack of stickiness is peculiar to bituminous patches. This type of failure occurs when the hole is not properly prepared before placing the patching mixture. If the hole is wet, for instance, the mixture may not stick adequately and will be forced out by traffic. This problem occurs most frequently in the winter. Thus, all bituminous patching material used in winter maintenance must be "sticky."

Failures due to lack of stickiness are reduced by drying the hole and spraying the sides and bottoms with an asphalt tack coat. The normal tack coat is a diluted emulsion and is used especially when the hole is wet. Thin, rapid curing (RC) cutbacks are used occasionally on dry surfaces. This, of course, is a construction technique that produces the highest type, longest lasting patch. This operation, though, can create another failure common only to bituminous patches. If too much tack coat material is sprayed in the hole, the excess can be squeezed out around the edges of the patch, resulting in unsightly tracking.

TABLE 1

FAILURES, HANDLING PROBLEMS, AND RELATED MIX PROPERTIES COMMON TO BITUMINOUS PATCHING MIXTURES

Failure* or Handling Problem	Principal Related Mixture Properties
Shoving (rutting)	Stability
Lack of adhesion to sides and bottom of hole	Stickiness
Binder stripping from aggregate	Resistance to water action
Ravelling	Durability
Slick surfaces	Skid resistance
Excess binder tracking and sticking to surfaces	Bleeding
Mix difficult to handle and shovel	Workability
Mix hardening in stockpile	Storageability

*This listing does not include failures produced by improper construction practices, such as bumps caused by placing too much mixture in the hole.

Table 1 also lists some special handling problems of bituminous patching mixtures. These can occur while the patching mixture is being stored or handled prior to placing.

Handling and Shoveling

Unlike bituminous mixtures placed by machine, bituminous patching mixtures are normally moved and placed in the pothole by hand. Consequently, laborers prefer a mixture that can be shoveled, raked, and leveled with little difficulty.

Hardening in Stockpiling

When the bituminous patching mixture remains in a stockpile for a long time, volatiles in the binder evaporate and the surface of the stockpile hardens. A front-end loader may be required to remove the hardened mixture. Also, the crust may produce lumps that are difficult to shovel and compact adequately.

PROPERTIES NEEDED IN BITUMINOUS PATCHING MIXTURES

Although many failures may be traced to improper construction practices, such as the lack of adequate compaction, failures often are related to the lack of a desirable property in a patching mixture. For instance, a bituminous patching mixture that will shove out of the hole does not have adequate stability. Thus, also listed in Table 1, are the principal mixture properties that are most closely related to the various types of failures. For instance, the durability of the mixture should indicate the probability that raveling or hardening failures will occur.

Stability

Stability allows the bituminous patching mixture to resist vertical and horizontal displacement due to imposed traffic loads. This property is related to most characteristics of the materials used in producing patching mixtures. Shoving will take place if too soft a binder or too much binder is used in the mixture. The more stable mixtures are well-graded and have large top-size aggregates, although in some instances large, one-size aggregates have been used quite successfully. Aggregates (sand, crushed stone, gravel, etc.) are more stable when they have rough surface texture and are angular. Material properties that interact with compactability of the mixture also influence stability.

Stickiness

Stickiness, as used in this synthesis, is the property that causes a patching mixture to adhere to the underlying pavement or sides of the pothole. It especially is needed when a patching mixture must be feathered to thin edges.

The stickiness of a patching mixture is related to the temperature of the mixture and binder. Hot mixtures normally have adequate adhesion while they are still hot. However, when they cool, they lose their stickiness. Cold mixtures taken from stockpiles often lack adequate stickiness.

Both the type and amount of binder influence the stickiness of the patching mixture. Soft binders usually adhere better than harder binders. Adequate stickiness is obtained normally by increasing the quantity of binder in the mixture.

Why should the mixture designer worry about increasing the stickiness of a cold-laid mixture when a tack coat can easily do the job? Granted, a tack coat is an excellent sticking material, but it can only be applied satisfactorily when the surface and sides of the hole are clean and dry. Often maintenance personnel will not take the time to clean and dry the hole thoroughly so that proper tacking can be accomplished. Thus, the mixture designer puts in more than the normal amount of binder to produce a stickier patching mixture.

Resistance to Water Action

Resistance to water action is the property that prevents separation or stripping of the bituminous binder from the coated aggregate in the mixture. Bituminous patching mixtures in potholes are especially susceptible to water action when they are under-compacted, which often occurs. Cold-mixed bituminous patching mixtures also may strip due to poor coating of the aggregate during mixing. This problem is evident from the extensive use of antistripping agents. Probably larger quantities of these agents are used in patching mixtures than in any other type of bituminous mixture.

Resistance to stripping is affected by both the binder and the aggregate. Binders have good resistance only when they are used properly. For instance, asphalt cement must be hot and the aggregate both hot and dry to obtain satisfactory coating. Emulsions, on the other hand, may be used fairly well when water is present on the surface of compatible aggregates. When asphalt emulsions are used, aggregates and emulsions must be compatible. Good coating can be obtained more easily if soft binders and/or more-than-optimum amounts of asphalt are used.

Durability

Durability is the resistance of the patching mixture to deterioration and disintegration due to traffic and weathering forces. Deterioration may first appear with the loss of aggregates from the surface of the patch. This is usually referred to as "raveling." Other forms of disintegration, such as cracking, can occur over a period of time but are not too common in patching mixtures.

High-quality, hot-mixed, hot-laid materials used for permanent patches have essentially the same durability characteristics as asphalt concrete that is used for pavement surfacing. Cold-laid materials vary considerably in durability. Even though they are laid cold, patching mixtures that are mixed hot and produced under ideal conditions can last for many years when properly designed and correctly used. Cold-mixtures used as temporary patching material during winter and replaced with a hot mixture during warmer weather are not expected to have high durability. These materials are mixed cold, often with poor-quality, wet aggregates and have less care taken in their use and placement.

The durability of patching mixtures is closely related to the quantity and type of binder. For instance, surface raveling is usually due to a less than optimum binder content. Greater durability is produced with optimum asphalt contents. The viscosity or hardness of the binder also can significantly influence durability. Soft binders with soft residues are often considered more desirable. Aggregate gradation also influences the rate of hardening. Dense-graded mixtures that contain large amounts of air voids seem to harden faster.

Some engineers believe that because a relatively small amount of bituminous patching material is used, there is little need to be concerned about its durability. Therefore, durability is sometimes sacrificed in favor of other properties such as stability.

Skid Resistance

As with all paving materials, bituminous patching mixtures should provide good skid resistance. Low resistance often occurs when the surface of a pavement produced with excess binder is wet or covered with water. Slipperiness also can occur in patches when the surface aggregates are polished smooth. Most states do not permit fast-polishing aggregates to be used in patching mixtures.

Although many patches are small and have little effect upon the overall stopping distance of the braking vehicle, there are conditions when low skid resistance in patching mixtures has caused serious problems. One occurs when a patch is more than 100 ft (30 m) long. Accidents have taken place when the driver did not realize the long patched area was slick. Accidents also have occured when large numbers of patches have been placed in the outer wheel path, creating a significant differential friction between it and the inner wheel path. Short patches on horizontal curves may also cause skidding if poor materials are used.

Patching mixtures should be designed to have adequate skid resistance. This means good, low-polishing, coarse and fine aggregate should be used and the bitumen content closely controlled to prevent excess binder.

Bleeding

Bleeding is related to excess binder in the patching mixture. Bleeding rarely occurs when the optimum amount of binder is used. There is greater chance of bleeding occuring in nonplant-mixed patching mixtures when fewer controls are taken in proportioning the mixture. Adequate air voids also are needed for expansion of the binder when the pavement is warmed.

Bleeding patching mixtures rarely cause accidents but can be an irritation. Not only can tracking mar the adjoining pavement, but when excess bituminous material gets on cars and clothes, the public usually complains. Warm temperatures aggravate the problem. When heated, binders expand rapidly and may flush to the surface of the patch. At the same time, the binder becomes thinner and is more easily tracked.

Workability

Workability perhaps is of more concern in patching mixtures than in any other type of bituminous mixtures. The patching mixture must be soft and pliable for easy shoveling, raking, and shaping. The mixture should not contain large lumps that are difficult to shovel. Workmen may refuse to use a patching mixture when it is difficult to handle.

There is a lot to learn about the workability of patching mixtures. Mixtures with sizable quantities of large aggregate are difficult to handle. Temperature has a pronounced effect on workability because it controls the hardness of the bituminous binder. At cold winter working temperatures, the bituminous binder can be relatively stiff, which results in a difficult-to-work mixture. Improvements can be made by using low viscosity binders, such as some emulsions and cutbacks. Mixtures made with liquid binders that harden rapidly lose workability fast.

Storageability

Two significant problems can occur when patching mixtures prepared with liquid binders are stockpiled. The mixture may harden after several months and be difficult to handle, or the binder might drain off the surface of hot aggregate and puddle at the bottom of the stockpile.

Cold-laid patching materials, when allowed to stand for a long time, will lose volatiles, and the liquid bituminous binder in the surface will harden into a crust. In order for it to gain the necessary strength to support traffic, hardening, of course, is necessary when the mixture is put in a pothole. However, hardening is not desirable while the mixture is being stored. The mixture should be as pliable and workable when needed several months after the mixing as it was when it was put in the stockpile.

Sometimes when hot-mixed patching materials are put into stockpiles, warm liquid binder drains from the aggregate before the mixture has cooled down. As the aggregate cools, the viscosity of the binder is increased and drainage stops. This problem does not seem to be widespread, but it does indicate there is a practical limit on the maximum amount of liquid bituminous binder that can be used in stockpiled, hot-mixed patching mixtures.

CHAPTER TWO

MATERIALS FOR PATCHING MIXTURES

BITUMINOUS MATERIALS

Function of the Bituminous Material

Bituminous material in patching mixtures performs several functions that are of little importance in other mixtures. The function of the binder varies depending upon the type of mixture. For hot-mixed, hot-laid materials, the function is to bind the aggregate together to provide good stability and durability. To be effective, the binder must be fluid enough at elevated temperature to be mixed with and adhere to the hot aggregate.

In cold-laid patching mixtures, the binder must maintain workability without the aid of warm temperatures. Regardless of the age or temperature of the stockpile mixture, the binder must be fluid enough so workmen can shovel and handle the mixture easily. It also must be able to increase its consistency quite rapidly once the mixture is compacted. It must change from a workable, low-consistency binder before placement to a viscous, high-stability binder afterwards. To compound the problem, it must do this in a relatively short period of time.

Often the binder must provide stickiness to cold-laid patching mixtures. It is not always feasible for the maintenance forces to apply a tack coat to the sides of a pothole. To make up for this deficiency, the stickiness of the mixture is increased. Materials engineers can do this quite easily by increasing the binder content slightly.

In some patching mixtures, the binder acts primarily as a waterproofer. The strength of mixtures containing open-graded aggregates is almost directly developed by aggregate interlock. In these mixtures, the binder has little influence upon the structural strength and is used primarily to help prevent moisture from entering the mixture.

Binders For Hot-Mixed, Hot-Laid Patching Mixtures

Hot-mixed, hot-laid patching mixtures are essentially the same as the asphalt concrete used in regular paving construction. They contain the same type of bituminous materials (see Table 2). Some asphalt cements as hard as AC-20 or 60-70 penetration are used, whereas other mixtures are made with as soft a grade as AC-5 or 120-150 penetration. These patching materials have few workability problems. They are normally used immediately after mixing, while still hot. If stockpiled, they are reheated and remixed in a portable mixer-heater (see Chapter Five).

As with asphalt concrete, patching mixtures made with hot asphalt cements cool and increase in consistency quite rapidly. To prolong the workability of hot-laid patching mixtures, some agencies use liquid bituminous binders that remain workable at lower temperatures. Indiana, for instance, uses a hot asphalt emulsion binder for patching mixtures (Indiana Specification Sections No. 620.04 and No. 402). The emulsion is an Indiana AE-60, which is a high-float emulsion (HFE) with a residue penetration of 50-100. A few agencies use MC and SC-3000 cutbacks for hot mixes.

Binders for Hot-Mixed, Cold-Laid Patching Mixtures

Workability at air temperatures is the principal factor that influences the selection of binder for hot-mixed, cold-laid patching mixtures. Often mixtures have to be workable at temperatures around freezing, and consequently liquid binders are used that have low viscosities at these temperatures. Binders suggested for cold-laid mixtures are given in Table 2. These binders are divided into two groups: those suggested for normal stockpiled mixtures and those for mixtures that must be used within a short time after mixing. Although liquid binders are used for both of these groups, the binders for the normal stockpiled mixtures retain their low viscosity and are workable for at least a month. The viscosity of the binders for the other mixtures tends to increase quite rapidly. If left in the stockpile for an extended period of time, these patching mixtures will harden so the mixture is difficult to handle.

Binders for normal stockpiled mixtures consist of both cutbacks and emulsions. MC-250 and 800 and SC-250 and 800 are used. The thicker grade (800) is used during the fall and spring, whereas the thinner grade (250) is preferred during the winter for longer stockpile life. The medium-setting and slow-setting asphalt emulsions are also used, as well as high-float emulsions. A number of agencies have not been pleased with the performance of the medium- and slow-setting emulsions because they become hard, brittle, and generally unworkable after stockpiling for some time. This workability problem does not seem to exist with high-float emulsions, which are used to temperatures as low as 15 F (−9 C). Usually the HFEs have softer residues (HFE-150 and 300). A few states allow the use of road tars (RT) and road tar cutbacks (RTCB) for stockpiled patching mixtures. Usually the thinner grades (e.g., RT-4) are used for cold mixtures stockpiled for longer periods, whereas thicker grades are for summer and early fall use.

Some agencies produce their own liquid binder by thinning asphalt cement with a liquefier on the job so that the patching mixture will have good workability after a period of stockpiling. Minneapolis, Minnesota, for instance, uses a combination of 85-100 penetration asphalt cement with an SC-250. These materials are not mixed and stored prior to use, but are combined at the time of hot-mixing with the aggregate (see Chapter Five).

If the hot-mixed patching material is to be used shortly after mixing, liquid asphalts with quicker curing times are used, such as RC-250 and 800 and the medium-setting

TABLE 2

GUIDE FOR USE OF BITUMINOUS MATERIALS IN PATCHING MIXTURES

TYPE OF PATCHING MIXTURE	A. C.[1]					RC			
	AC - 40	AC - 20	AC - 10	AC - 5	AC - 2.5	70	250	800	3000
HOT-MIXED, HOT-LAID									
Immediate use		X	X	X					
HOT-MIXED, COLD-LAID									
Normal Stockpiling									
Short Stockpiling									
COLD-MIXED, COLD-LAID									
Normal Stockpiling									
Short Stockpiling								X	X

TYPE OF PATCHING MIXTURE	MC					SC			
	30	70	250	800	3000	70	250	800	3000
HOT-MIXED, HOT-LAID									
Immediate use					X				X
HOT-MIXED, COLD-LAID									
Normal Stockpiling			X	X			X	X	
Short Stockpiling			X	X	X		X	X	X
COLD-MIXED, COLD-LAID									
Normal Stockpiling			X	X	X		X	X	X
Short Stockpiling				X	X			X	X

TYPE OF PATCHING MIXTURE	Anionic Emul.							Cationic Emul.						HFE	Road Tars	Sp. Mixtures[2]
	RS - 1	RS - 2	MS - 1	MS - 2	MS - 2h	SS - 1	SS - 1h	CRS - 1	CRS - 2	CMS - 2	CMS - 2h	CSS - 1	CSS - 1h			
HOT-MIXED, HOT-LAID																
Immediate use														X		
HOT-MIXED, COLD-LAID																
Normal Stockpiling						X	X					X	X	X	X	X
Short Stockpiling				X	X	X				X	X	X				
COLD-MIXED, COLD-LAID																
Normal Stockpiling						X	X					X	X	X	X	X
Short Stockpiling				X	X	X				X	X	X				

[1]Penetration Graded Designations: 40-50, 60-70, 85-100, 120-150, 200-300
Viscosity-Residue Graded Designations: AR-160, AR-80, AR-40, AR-20, AR-10.

[2]Mixtures of commonly available bituminous binders with other bituminous binders or hydrocarbon volatiles.

emulsions. Because the stockpile life of these mixtures is relatively short, care should be taken to use them before they get too hard.

Binders for Cold-Mixed, Cold-Laid Patching Mixtures

Not only do the binders for cold-mixed, cold-laid patching mixtures have to provide good workability in the stockpiled mixtures, they must also have low viscosity during mixing. Because the aggregate is cold during mixing, i.e., at air temperature, the binder also must be fluid so it and the aggregate can be mixed with little or no heating.

Suggested binders for cold-mixed, cold-laid patching mixtures are given in Table 2. For normal stockpiling, MC and SC-250, 800, and 3000 are used, as well as asphalt emulsions with soft residues. MC-250 and HFEs are used the most. However, some RTs and RTCBs are used also.

The grade of binder used in a patching mixture is usually dependent upon the gradation of the aggregate. Heavier grade liquid binders are used for open- or coarse-graded mixtures, whereas thinner liquid bituminous grades are used with dense-graded aggregate mixtures.

Some agencies prefer a binder with curing characteristics different from the commercially produced liquid asphalts and use their own specially prepared binders. Usually asphalts are thinned with a petroleum liquefier. In Ontario, for instance, an 85-100 penetration asphalt cement is thinned with a petroleum distillate such as kerosene or fuel oil. Naphtha and thin cutbacks are also used as liquefiers. Water, too, can be used as a liquefier for cutbacks. Pennsylvania, for instance, has an emulsion-cutback asphalt (specifications ME-250 and ME-800). Essentially, these materials are medium-curing cutbacks emulsified with 3 to 12 percent water.

Care must be taken when using liquid binders with short curing times. Because their stockpile lives are fairly short, they should be used before they get too hard.

AGGREGATES

Types of Aggregates

Essentially, the same types of aggregates are used for patching mixtures as for normal bituminous construction: crushed stones and gravels, natural sands, stone sands, and mineral fillers. Relatively small amounts of manufactured aggregates, such as slags, also are used.

The quality of aggregates used in patching mixtures is essentially the same as used for construction mixtures. Both aggregates meet the same requirements as to hardness, abrasion resistance, absorption, durability (soundness), deleterious materials, and contaminants, such as clay. When a range in quality is allowed, the aggregates for patching mixtures are usually of the medium to highest quality class. For instance, if quality classes A, B, and C are used in the specifications, with Class A being the highest quality, the aggregates for patching mixtures should be Class A or B.

Aggregate properties critical to good patching mixtures are gradation, top size, and compatibility with the binder.

Gradation

Although many different gradations are used for patching mixtures, they can be grouped primarily into dense, intermediate, or one-size gradations. Examples of these gradations as used in patching mixtures are given in Tables 3, 4, and 5. Included in these tables are gradations that vary according to maximum aggregate size.

The dense-graded aggregates are used primarily for hot-mixed, hot-laid patching mixtures. This gradation is essentially the same as the dense-graded aggregates used for hot-laid paving mixtures containing well-graded aggregates with a reasonable amount of mineral filler passing the No. 200 (75 μm) sieve (see Table 3).

TABLE 3

TYPICAL GRADATIONS OF DENSE-GRADED PATCHING MIXTURES

Sieve Size	Percent Passing		
	A*	B*	C*
3/4 in. (19.0 mm)	100		
1/2 in. (12.5 mm)	90-100	100	
3/8 in. (9.5 mm)	75- 90	90-100	100
No. 4 (4.75 mm)	47- 68	60- 80	80-100
No. 8 (2.36 mm)	35- 52	35- 65	65-100
No. 16 (1.18 mm)	24- 40	-	40- 80
No. 30 (600 μm)	14- 30	-	20- 65
No. 50 (300 μm)	9- 20	6- 25	7- 40
No. 200 (75 μm)	2- 9	2- 10	2- 10

*Gradations A, B, and C correspond to gradations 5A, 6A, and 7A, respectively, given in ASTM Designation D 3515, "Hot-Mixed, Hot-Laid Bituminous Paving Mixtures," except that A is slightly more restrictive than gradation 5A.

The intermediate gradation was developed specifically for patching so stockpiled mixtures would have good workability and reasonable stability. It is coarser than the dense-graded aggregate and contains less material on the middle fractions (No. 50 to No. 4) (see Table 4).

The concept behind the use of one-size graded aggregates is quite different than for dense- and intermediate-graded aggregates. The one-size is a very coarse aggregate, containing very little material finer than the No. 4 (4.75 mm) sieve (see Table 5). In one-size aggregate patching mixtures, strength is obtained primarily through aggregate interlock like a macadam, with the binder used essentially as a waterproofer. This gradation has reasonable workability. It cures fairly fast after compaction, because it contains a large amount of voids, which allows relatively quick escape of the volatiles.

TABLE 4

TYPICAL GRADATIONS OF INTERMEDIATE-GRADED PATCHING MIXTURES

Sieve Size	Percent Passing		
	A	B	C
3/4 in. (19.0 mm)	100		
1/2 in. (12.5 mm)	75- 94	100	100
3/8 in. (9.5 mm)	64- 78	90-100	90-100
No. 4 (4.75 mm)	32- 50	40- 75	20- 40
No. 8 (2.36 mm)	25- 37	18- 45	15- 30
No. 16 (1.18 mm)	15- 27	-	10- 25
No. 30 (600 μm)	8- 18	8- 22	5- 15
No. 50 (300 μm)	5- 12	-	0- 10
No. 200 (75 μm)	0- 5	1- 5	0- 5

In some instances, little effort is given to controlling aggregate gradation. Patching mixtures have been made with crusher-run aggregates from quarries and pit-run gravels that have had little, if any, gradation control. Some of these patching mixtures have had reasonable success, but most have been fairly low quality.

The frequency of use of the different gradations varies from one area to another. Hot-mixed, hot-laid patching mixtures are almost always dense-graded. They have excellent stability and durability. When compacted, they are dense and absorb less water. Stockpiled mixtures are preponderantly dense- or intermediate-graded, with the use of intermediate gradations on the increase. One-size gradations are used in only a few areas, and most agencies do not have a specification for one-size patching materials.

The gradation of the aggregate selected is often dependent upon the binder used. When an asphalt cement is

TABLE 5

TYPICAL GRADATIONS OF ONE-SIZE GRADED PATCHING MIXTURES

Sieve Size	Percent Passing	
	A	B
3/4 in. (19.0 mm)	100	
1/2 in. (12.5 mm)	90-100	100
3/8 in. (9.5 mm)	60- 90	95-100
No. 4 (4.75 mm)	0- 25	35- 65
No. 8 (2.36 mm)	0- 15	0- 25

needed as the binder, the dense gradation is used. If a liquid binder is needed (e.g., for workability), the intermediate gradation is usually selected. The liquid binder usually varies with the gradation. Dense-graded mixtures need thinner liquid binders than open- or intermediate-graded aggregates. However, this matching of binder and gradation is not always done. For instance, one agency will use a dense-graded aggregate with a medium-curing cutback, whereas another will use an intermediate-graded aggregate with the same cutback.

Maximum Size of Aggregate

The majority of all patching mixtures have a ⅜- or ½-in. (9.5- or 12.5-mm) maximum size. These top sizes seem to be preferred, as they provide good stability and workability and can be used to fill almost all types of holes. Although a few agencies have specifications for patching mixtures with a maximum size of ¾ in. (19 mm) or larger and some allow sand mixtures with top size of ¼ in. (6.5 mm) or No. 4 (4.75 mm), these sizes are seldom actually used.

Large maximum-size aggregates are preferred when good stability is desired and when they can be used in the hole to be patched. This means that a ¾-in. (19-mm) aggregate must be used in a hole that is at least 1½ to 2 in. (38 to 50 mm) deep or deeper. When used in shallow holes, the large aggregate must be raked out of the mixture during finishing to have a smooth patch. In such instances, the contributions of the large aggregates to the stability of a mixture is lost.

When shallow holes are to be filled, small top-size aggregates should be used. Even finer mixtures are needed when the mixture must be feathered at the edges of the hole. For such thin edges, a sand mixture is preferred.

Ideally, two sizes of patching should be available, a large-size aggregate mixture to fill the deeper holes and a small-size aggregate mixture for shallow holes and feathered edges. This usually is not done because the maintenance forces want to handle only one patching mixture. The mixture normally used is a compromise, with an average top size of ⅜ in. (9.5 mm). This mixture is fairly stable, can be used satisfactorily in shallow holes, and can be feathered easily with little loss of large aggregates.

Shape and Surface Texture

Most agencies realize the important contribution of angular shape and rough surface texture for the stability of patching mixtures. Thus, crushed, coarse aggregates are usually specified. Rounded gravels are not allowed. The amount of crushed material required varies from 100 percent to 60 percent, depending upon the agency (e.g., Indiana requires 85 percent of the crushed gravel to have two or more mechanically fractured faces).

Shape and surface texture also influence the workability of the mixture. Angular, rough-surfaced aggregates will reduce the workability. Preferred patching mixtures often are composed of angular, rough-surfaced, coarse aggregate and rounded natural sands (as opposed to both crushed coarse and fine stone aggregates). In these mixtures, the angular, coarse aggregate contributes to the stability, while the smoother, rounded natural sands help to improve the workability.

Other Aggregate Characteristics

In asphalt concrete mixtures, the binder and aggregates must be compatible. For bituminous patching mixtures, stripping is a much greater problem, and more importance is placed on designing for compatibility.

If economically feasible, aggregates are selected that are compatible with the binder. Almost all agencies have compatibility tests that determine the ability of the binder to coat the aggregate or measure the ease with which water strips it (see Chapter Four). When satisfactory aggregates are not economically available, another binder may be used that is compatible with locally available aggregates. More likely, antistripping agents will be used, and no change will be made in the aggregate.

Highly absorptive aggregates have been used quite successfully with hot-mixed, hot-laid patching mixtures. However, when used in cold mixtures, these aggregates have a tendency to contain a high amount of moisture. This can contribute to stripping or drainage problems in the stockpile. In addition, these patching mixtures need a longer time to cure after being placed because the highly absorptive aggregates need more binder.

ADDITIVES

Additives are frequently used in bituminous patching material to increase resistance to stripping or to improve workability at low temperatures. Additives may be liquid or fine powder. Liquid additive is circulated with the binder until thoroughly mixed and then sprayed onto the aggregate in the mixer. Powders may be dissolved in the liquid binder before mixing with the aggregate, but normally they are mixed with the aggregate in the pugmill before the binder is sprayed into the mixing chamber. Sometimes the additive is put into the liquid binder at the refinery before shipping to the job.

Additives to Improve Water Resistance

Patching mixtures are subjected to extensive, vigorous water action. Thus, additives are often used to provide extra water resistance and increase the life of the patch. These additives are either hydrated lime or antistripping agents. The latter includes those made and marketed for improved coating and adhesion of the binder.

Antistripping agents are normally cationic, organic amines (amino acids), which are shipped in a liquid state. They may or may not be thermally stable. Heat stability is only important when the agents are put into the mixture through the binder at elevated temperatures. If the agents are not heat stable, they are lost during the hot-mixing and are not able to serve their purposes in the final mixture.

Amino acids can be quite corrosive. Thus, most specifications state that antistripping agents shall contain no ingredients injurious to the asphalt, to metal storage tanks, or to road machinery.

Few specifications control the makeup of antistripping agents to the degree, for instance, that the composition of a rapid-curing cutback is controlled. Antistripping agents are normally controlled by performance specifications. The antistripping agent, when added to the binder, must meet certain general requirements or specified test criteria (e.g., they shall coat wet, damp, or dry aggregates satisfactorily), or when subjected to coating, stripping, immersion/compression tests, etc., they shall meet minimum requirements. In addition, the antistripping agents must perform satisfactorily in the field. If after one or two winters of use, patching mixtures containing a particular antistripping agent strip, that agent may not be permitted in future mixtures.

Many different antistripping agents are marketed. Some products are available only in limited geographical areas, whereas others are available throughout the entire country. A tentative list of chemical antistripping agents approved by various state agencies is given in Appendix A. In addition to these approved antistripping agents, a number of agents have not been accepted or fully evaluated as yet.

Finely powdered hydrated lime and portland cement also are added to patching mixtures to promote adhesion. Both high calcium and dolomitic limes are satisfactory, but they must be hydrated. Quicklimes should not be used. Either ASTM C 6 or local specifications are used to control the amount of carbon dioxide, calcium, and magnesium oxide in the lime. Gradation requirements are usually specified. Almost any commercially produced hydrated lime is satisfactory as an antistripping agent, although Type N is usually used.

Hydrated lime and portland cement should be used only when asphalt cements or cutbacks are used as the binder. They should not be mixed with asphalt emulsions. The lime and cement are thermally stable and often used with hot mixtures. One word of caution: If more than about 1 percent of these powders is added to a mixture, the amount of binder may need to be increased. In such instances, the powders need to be considered as a mineral filler and the mixture redesigned accordingly. Hydrated lime may have other side effects. It may significantly increase the Marshall stability of some aggregate-binder mixtures and may tend to retard the rate of binder hardening after placing.

Additives to Improve Workability

Often maintenance groups are forced to use patching materials at temperatures well below freezing. Additives to increase workability can make the mixtures shovel and compact easily at temperatures as low as 0 F (−18 C).

Many additives and proprietary mixtures are sold on the basis of their workability at low temperature. Proprietary mixtures with low-temperature workability have been available for many years, and at least one has been on the market for more than 40 years.

In some instances, a producer may develop a low-temperature patching mixture by adding a petroleum distillate thinner to the bituminous binder. In some areas of Canada, for instance, a kerosene thinner is added in small quantities to a penetration grade asphalt cement. Petroleum naphtha that meets ASHTO Designation M 83 is also used as a thinner. These petroleum distillates will improve the workability of the patching mixture. They are not proprietary mixtures and can be produced and sold without restrictions.

Proprietary Materials

Many additives are proprietary agents and may have been patented. Their owners have exclusive right to their manufacture and use. The proprietary agent may be controlled just during manufacture and then sold to individual mixture producers. Or the entire patching mixture may be a proprietary mixture, with the additive, binder, and aggregate gradation all controlled. In these mixtures, locally available aggregates are usually used, whereas the binders may or may not be available in the area. Some firms ship bituminous binder containing additives and require it to be used with a specific gradation.

Usually patching mixtures made with proprietary agents are more expensive than nonadditive-bituminous mixtures. The additional cost varies considerably, from approximately \$0.50 per ton (\$0.55/Mg) of mixture, when some antistripping agents are used, to double the cost for a proprietary patching mixture. These mixtures should be evaluated in light of their performance and compared to the cost-performance of nonadditive patching mixtures. In some cases, the more expensive mixtures may be needed for certain characteristics and may give better results.

CHAPTER THREE

TESTS OF DESIRABLE PROPERTIES

The tests described in this chapter are used by various agencies for specifying, designing, or approving bituminous patching mixtures. If the test is common and frequently used, it is not described in detail. However, significant variations to common testing procedures, as well as tests that are used primarily for patching mixtures, are described herein.

STABILITY TESTS

Stability tests are seldom used to evaluate bituminous patching mixtures. Design procedures, especially those for cold-laid patching mixtures, often do not include stability criteria, and specifications do not require that patching mixtures meet a minimum stability value. In asphalt concrete mixtures, stability tests are used to predict shoving and rutting problems and also to select the appropriate amount of binder. But, they are rarely used for these purposes in patching mixtures. This is of considerable concern to many engineers.

Stability tests usually refer to the Hveem or the Marshall test. These tests are used to control hot-mixed, hot-laid and some cold-mixed patching materials. The criteria for patching mixtures with asphalt cement binders are typically: 35 minimum for Hveem stabilometer value and 1,700 lbs (7.6 kN) for Marshall stability. When other binders are used with hot-laid mixes, the stability requirements are either lowered or not used at all. Indiana requires a stabilometer value of at least 20 for its hot-laid asphalt emulsion WS bituminous patching mixture. Minneapolis, on the other hand, uses a varying Marshall stability criteria to control patching mixtures of different quality. High-quality patching mixtures used on heavily traveled streets must have a Marshall stability greater than 1,000 lbs (4.4 kN) and a flow between 10 and 18. For alleys, the allowable minimum stability is lowered to 800 lbs (3.6 kN) and the flow criterion is increased to 15.

The immersion-compression test, although used primarily to evaluate the resistance of a mixture to water action, is often used as an indication of stability. The unsoaked, unconfined compression test (ASTM Designation D 1074) result is a measure of stability used with hot-mixed, hot-laid patching mixtures.

When stability tests are required, they normally are used to control hot-mixed, hot-laid patching mixtures. The stability tests used with hot-laid patching mixtures and with hot-mixed asphalt concrete are the same. When the stability of cold-laid patching mixtures is measured, the same tests also are used. Usually the stability of stockpiled mixtures is not measured.

Stability tests are not universally used for several reasons. Often major emphasis is given to controlling other properties, such as stripping. Many engineers also feel stability tests are not suitable for indicating the performance of cold-laid patching mixtures, because current results seem quite sensitive to the proportion of water and volatiles. Even so, many other engineers do not feel the lack of stability requirements in design is justified. Either existing stability test procedures should be modified to effectively evaluate the patching mixtures, or new stability tests should be developed and used.

ADHESION TESTS

Adhesion tests can be grouped into one of three categories: coating tests, stripping tests, or immersion-compression tests. Rarely will both an immersion-compression test and a coating or stripping test be used on the same mixture. If a coating or stripping test is used, both may be required. For instance, Illinois and Michigan specify both coating and stripping tests for some of their patching mixtures. However, if only one of these tests is specified, it is the stripping test.

The use of adhesion tests to control bituminous patching mixtures is not universally accepted. Some agencies require them for only a few of their patching mixtures. Some do not require them at all. Other agencies use end-result/performance specifications for adhesion. In these instances, the field performance of the mixtures must be continuously evaluated.

Coating Test

The coating test is used to evaluate the ability of the binder (usually cutbacks) to satisfactorily cover wet aggregates. The aggregate is wetted before it is mixed with the binder and evaluated for the amount of coverage. The coated aggregate is not subjected to an extended soaking period. This is done only in the stripping test.

As an example, Illinois specifies two coating tests for asphalt additives (M-38-70). One uses wet siliceous Ottawa sand, and the other uses wet ⅜-in. (9.5-mm) topsize standard traprock. These aggregates are mixed with 5 percent binder. Immediately after mixing, the amount of aggregate surface coated with the binder is evaluated. For the wet Ottawa sand, 100 percent coverage is required, but only 95 percent of the wet traprock must be satisfactorily covered.

Stripping Test

In the stripping test, previously coated aggregates are immersed in water and allowed to soak for a period of time. Then the surface area of the aggregates still coated with bitumen is determined. This test is used with all types of bituminous binders.

Most testing procedures follow the standard ASTM test for "Coating and Stripping of Bitumen-Aggregate Mixtures" (ASTM Designation: D 1664) or modifications of it. Essentially, the ASTM test first requires wet or dry aggregate to be coated with a specific amount of bituminous material. After oven curing, the coated aggregate is remixed and covered immediately with distilled water at 77 F (25 C). The amount of surface area covered by the binder is evaluated after 16 to 18 hours.

When a more severe test is desired, the soaking time or temperature of the water is increased. For instance, Illinois specifications for asphalt additives (M-38-70) require soaking for 24 hours at 120 F ± 5 F (49 C ± 3 C). Another variation is to shake the mixture vigorously after the soaking period. An even more severe stripping test is to soak the coated aggregate in boiling water. For example, Pennsylvania, for its Type 3-P Hot-Mixed Bituminous Stockpiled Patching Materials (Section 485), places the cured mixture in boiling water for 3 minutes before evaluation.

The criterion that must be met to pass the stripping test varies with the severity of the test. ASTM specifies that at least 95 percent of the surface must remain coated. However, Pennsylvania, when using boiling water, requires only 90 percent coverage, whereas Illinois, in "Specifications for Bituminous Pre-Mix-Emulsified Asphalt HFE-300" (M-48-73), requires only 75 percent coating after 3 minutes of boiling.

Immersion-Compression Test

The immersion-compression test (ASTM Designation: D 1075), "Effect of Water on Cohesion of Compacted Bituminous Mixtures," is used by a few agencies. This is an unconfined compression test on compacted bituminous mixtures. It is used only on hot-mixed, hot-laid patching mixtures containing asphalt cements. The influence of water is evaluated by determining the strength reduction in specimens that have been immersed in water at 140 F (60 C) for 24 hours or at 120 F (49 C) for 4 days. This test often is used to determine if a hot-mixed, hot-laid patching mixture needs antistripping agents.

DURABILITY TESTS

Other than the coating and stripping tests, almost no tests are used to measure the durability of bituminous patching mixtures because most durability problems are related to the water-resistant property of the patching mixtures, and this property is measured by adhesion tests.

Pennsylvania uses a water absorption test to help evaluate the durability of its bituminous patching mixtures. Compacted bituminous specimens are placed in water and allowed to soak for a period of time. Then the percent gain in weight is determined. If small amounts of water are absorbed in a patching mixture, the detrimental effects of freezing and thawing should be reduced. An increase in resistance to freeze-thaw should result in more durable patching mixtures. Pennsylvania does not use the water absorption test in its specifications, but uses it in laboratory research to evaluate patching mixtures.

Before they are tested for other important properties, such as workability, Iowa subjects its loose mixtures to eight cycles of freezing and thawing. Thus, a weathering effect is produced instead of measuring some durability property of the patching mixtures. [Note this conditioning is used for reasons similar to those for heating asphalt concrete to 140 F (60 C) before testing.]

WORKABILITY TESTS

Few laboratory tests measure the workability of a bituminous patching mixture, and those used are fairly simple. To be tested, the mixture must be at a low temperature. Workability is then determined in a fairly straightforward, subjective manner.

Pennsylvania, for instance, evaluates the workability of patching mixtures by first cooling them to 20 F (−7 C) in the laboratory and observing the ease with which they can be broken up with an 8-in. (200-mm) spatula blade. Iowa uses a more detailed test for measuring workability. After exposing the mixture to eight cycles of freezing and thawing in a laboratory freezer, the workability is observed and the compactability is measured by the density of the patching mixture when compacted according to the standard Marshall method.

Only a few specifications include a laboratory test for controlling workability. Usually workability is controlled in an end-result specification. The specification may state only that the patching mixture shall "remain workable and capable of being shaped easily." Or a more detailed general statement may be used, such as:

> The mixture shall be capable of being unloaded from the truck by hand tools. It shall be readily compacted by hand tapping or power rolling at temperatures as low as 20 F immediately after preparation or over a period of at least six months in a stockpile. It shall be readily workable at all times in either hot or cold conditions (from the State of Indiana "WS Bituminous Patching Mixtures").

The exact workability condition of the mixture is then left up to the judgment of persons accepting the mixture.

A scientific test for measuring the workability of bituminous patching mixtures is needed. If one were available, it could be used for specifying workability characteristics and designing bituminous patching mixtures.

STORAGEABILITY TESTS

There are no satisfactory laboratory tests for measuring the storageability of bituminous patching mixtures. No tests have been developed for producing an accelerated storage condition in patching mixtures, nor is there agreement as to which physical properties should be measured.

The storageability of patching mixtures has been related to the workability of the mixture. This may or may not be justified. Usually, the workability is measured only in a mixture with lowered temperatures. The mixtures have not been subjected to long-term storage or accelerated "setting" conditions. Thus, the measurement is only an indirect indicator of storageability, and it is rarely used for this purpose.

Satisfactory storageability in a mixture usually is obtained through field experience. After a mixture has been used for several winters, its storageability is pretty well known. Storageability in these instances is determined subjectively, with people using various criteria and measuring techniques. There are disadvantages in measuring the storageability of patching mixtures in this manner. It is time-consuming and depends to a large extent upon the person doing the rating. However, this appears to be the best method to date.

A laboratory test is needed that can predict the storageability of a patching mixture. Consideration should be given to the effect of long-term storage upon the crusting and workability of the mixture and the possibility of the binder draining from a freshly stockpiled mixture. In addition, a rapid method needs to be developed for simulating the storage conditioning of a patching mixture.

TESTS FOR ADDITIVES

Because additives are used primarily to improve adhesion or workability, tests to evaluate them are the same as those used to check for those properties. It is difficult to evaluate the effects of additives with the existing laboratory tests. Final approval is usually not given until the additive has performed satisfactorily in the field. Proprietary patching mixtures are bought and used without comprehensive laboratory testing. However, if subsequently they behave poorly or do not provide significant improvements over regular patching mixtures, they are not approved for future use.

CHAPTER FOUR

DESIGN OF BITUMINOUS PATCHING MIXTURES

This chapter discusses various factors that have to be considered in the selection of appropriate aggregate and bituminous binders for different types of patching mixtures. Guidance also is given for choosing the proportion of the various materials needed and for adjustments that need to be made in a trial and error design procedure.

DESIGN OF HOT-LAID PATCHING MIXTURES

Dense-graded, hot-mixed, hot-laid patching materials are designed to be the highest type of bituminous patching mixtures produced. The same design procedures are used as in the design of regular dense-graded, hot-mixed asphalt concrete. The testing equipment and control criteria are the same, and usually the design laboratory will handle both types of mixtures the same.

Selection of Bituminous Binder

If the patching mixture is to be placed and compacted when hot, there is little need to be concerned about its storageability or workability. The consistency of the loose mixture is not controlled by the type of binder used but by the temperature, and it becomes stiff as the mixture cools. Thus, the ideal bituminous binder can be selected for hot-laid patching mixtures.

Because the objective is to design the highest type of patching mixture, hard residue asphalt cements are selected as the binder for hot-laid patching mixtures. Often the mixture producer will use the same asphalt cement as he uses to produce high type asphalt concrete during the construction season. Thus, AC-20 and AC-10 (60-70 and 85-100 penetration, respectively) are commonly selected. Some producers use a softer grade, such as AC-5 (120-150 penetration), especially in the late fall and early spring.

Liquid binders are sometimes selected for hot-laid patching mixtures. Hot asphalt emulsion patching mixtures are used by Indiana. Although patching mixtures containing the heaviest grades of slow-curing or medium-curing cutbacks have been used in the past, these binders are seldom used today in hot-laid patching mixtures.

Selection of Aggregates

There is general agreement on the type of aggregate to be used for hot-mixed, hot-laid bituminous patching mixtures. Almost all characteristics of the aggregate are chosen to provide high stability. This means aggregates are of the highest quality and best gradation (see Chapter Two).

Producers of hot-laid patching mixtures usually use the same aggregates and often the same dense gradation as are used in the production of normal asphalt concrete. The dense-graded aggregate provides a fairly impervious and durable mixture. Workability is not a major concern when selecting the gradation, because excellent workability is provided by the heat in the mixture at the time of placement.

If available, angular, rough surface-textured aggregates are chosen to help increase the stability of the patching mixture. The maximum size varies, but often it is ⅜ to ½ in. (9.5 to 12.5 mm) so that the mixture may be used for varying pothole depths. Usually aggregate selection is not affected by aggregate and binder incompatibility, because the aggregate is dry and hot when coated with the liquid asphalt cement. This insures, as it does in normal asphalt concrete production, a well-coated aggregate mixture that is highly resistant to stripping. In some instances, if there is concern about stripping, antistripping agents are added.

Selection of Optimum Quantity of Bitumen

The procedure for determining the bitumen content of hot-mixed, hot-laid patching mixtures containing asphalt cements is fairly straightforward. These mixtures are designed by the same procedures adopted for normal asphalt concrete design. Trial mixtures at various asphalt contents are compacted according to locally accepted methods, such as the Hveem or Marshall design procedures. Similar stability and void criteria are used to select the optimum asphalt content. For instance, typical stability criteria are 35 minimum for Hveem stabilometer value and 1,700 lbs (7.6 kN) for Marshall stability. Detailed procedures for designing the asphalt concrete, hot-laid patching mixtures are available from state and other materials laboratories.

DESIGN OF COLD-LAID PATCHING MIXTURES

Unlike hot-laid patching mixtures, no formal procedure has been developed and widely adopted for designing cold-laid patching mixtures. Successfully stockpiled patching mixtures have usually evolved over a period of time, with improvements being made in them gradually.

Selection of Bituminous Binder

It is not easy to select the appropriate binding material for a cold-laid patching mixture. Although the basic considerations are the same for all types of bituminous mixtures, there are additional and more difficult factors influencing the selection of the binder for patching mixtures.

Rate of Curing

Although a number of factors influence the time available between mixing and use of the patching mixture, the bituminous material has the most influence. The significance of this factor is illustrated by the large number of liquid bituminous materials available with different rates of curing. The importance of the curing rate is even exemplified in the names that have been selected for the liquid binders: rapid curing, medium setting, etc. If the mixture is to be used soon or immediately after mixing, a quick-curing binder is selected. If the mixture is to be stockpiled for a period of time, then a slower-curing binder is used.

Consistency

The ease of mixing the binder with the aggregate is influenced by the viscosity of the binder, which in turn is related to both the grade of binder used and the mixing temperature. Heating, of course, lowers the viscosity of asphalt cement binders to that needed for mixing, but in cold mixing, low viscosity must be produced by liquefiers. When the aggregate is easy to mix, heavier grades of liquid binder are selected, but when the aggregate is more difficult to mix or when a longer mixing time is needed (such as in a roadmix patching mixture), a lower, thinner grade of binder is selected.

Hardness of the Residue

The compacted patching mixture should have high cohesive strength in the pothole. This strength is related to the viscosity of the residue of the cured binder. When possible, binders are selected that have stiff residues of high viscosity.

One difficulty that is encountered in the selection of bituminous binders for patching mixtures is that often no single bituminous material has all the characteristics needed. This is especially noticeable when trying to select a binder that will produce good workability in a stockpiled mixture. Not only is a slow curing rate needed, but the binder residue needs to have high viscosity for a strong cohesive mixture. Such a bituminous material is not available.

Although all of these factors must be considered, the rate of curing is the most important because workability is of prime consideration. If need be, in stockpiled mixtures, cohesiveness is sacrificed for a more workable mixture.

In patching mixtures that are to be laid immediately after mixing or after a very short time in the stockpile, the quicker-curing binders, such as rapid-curing cutbacks, are selected. However, for long stockpile life, the slower, medium-curing and slow-curing cutbacks are used.

Some agencies prefer a different curing characteristic in their patching mixtures than can be obtained with normally specified asphalts. Thus, they produce their own binder by blending several asphalts. Often a low penetration asphalt cement is mixed with a small amount of slow-curing cutback. Asphalt cement also may be mixed with a petroleum distillate thinner to produce a longer-curing asphalt with a hard residue (see Chapter Two). These ready-made, long-curing binders are produced in central Canada and in some parts of the northern United States.

The gradation of the aggregate is also taken into account when selecting the binder. Many persons feel the main purpose of the binder in an open-graded mixture is to help waterproof the mixture; consequently, there is little need to be concerned about the consistency of the residue. However, others feel that because an open-graded mixture does not have the fines to fill the voids, the voids need to be filled with asphalt and, in order to have high cohesion in such a mixture, a low-penetration asphalt cement should be used. In these cases, a bituminous binder with a heavy residue is selected.

The type of binder needed in a stockpiled mixture varies at different times during the life of the mixture. This situation creates conflicting demands. During mixing and while in the stockpile, the mixture needs to retain good workability, which requires a low viscosity binder. After the mixture is placed in the pothole, a quick increase in viscosity is desired, so a higher viscosity binder will provide better cohesion and strength in the mixture. Either the workability is sacrificed for high cohesion, or the workability is developed through a low viscosity binder and the lower strength of the patching mixture is accepted. A few bituminous engineers have obtained both of these desirable characteristics. A very workable mixture is produced and stockpiled. Just before use, the mixture is put into a heated area or the stockpile room is heated and the volatiles are driven off. The workable, high viscosity, cohesive patching mixture is used while still warm. Another way to handle this conflict is to let the mixture cure and harden normally in the stockpile. Just before use, the mixture is processed through portable heating units. As more of these heating units are used, stiffer mixtures are being designed (see Chapter Five).

Selection of Aggregates

Greater consideration is given to the choice of aggregates for cold-laid bituminous patching mixtures than is commonly thought. The aggregate may be just as important and possibly even more important than the binder. Aggregates can control workability and stability as well as influence almost all other properties of the mixture. Aggregates with proper gradation, shape, and other characteristics should be very carefully chosen.

Workability and Stability

Although almost all characteristics of the aggregate influence workability and stability, gradation is perhaps most influential. For good workability, an intermediate-graded aggregate is often selected, whereas a dense-graded aggregate is more often chosen when stability is of major consideration. Workability is also improved by rounded aggregate, whereas angular aggregates improve stability.

Depth of the Hole to be Patched

The maximum size of the aggregate in a bituminous patching mixture should be no more than two-thirds to three-quarters of the minimum depth of the hole to be patched. A mixture with large-size aggregate is selected for deep potholes, whereas a small-size aggregate is chosen for mixtures to be used in thin or joint patches. Instead of using two different aggregate gradations, a nominal aggregate size such as ⅜ in. (9.5 mm) is chosen. This mixture can be used quite satisfactorily in both shallow and deep potholes. For shallow holes, a small amount of the larger aggregate is raked from the mixture.

Durability

Stripping and raveling often can be eliminated by changing the source or type of the aggregate. An aggregate is selected that is compatible with the bituminous binder.

Rate of Curing

The amount of air voids in a compacted mixture influences the rate of hardening. Large quantities of air voids will allow quick escape of volatiles, which will result in faster curing. More air voids exist in the more open, intermediate, and one-size graded aggregates than in the dense gradations. Thus, when fast escape of the volatiles is desired, the more open-graded mixture is selected. Dense-graded mixtures will cure slowly.

Intermediate-graded aggregates are used primarily for stockpiled patching mixtures. They are selected for workability. Some of the most widely used proprietary mixtures are intermediate-graded with medium to small top size. If a highly stable, though workable mixture is desired, much coarser, one-size aggregate is used.

Dense-graded aggregates are usually chosen for stockpiled mixtures when good stability is needed. This gradation provides greater resistance to water penetration as it has smaller amounts of unfilled voids, but it has potentially poor workability characteristics after being stockpiled. Workability can be improved by heating these mixtures just prior to use.

A different choice has to be made in selecting the shape of aggregates in cold-laid mixtures. For good workability, the very angular aggregates are avoided. Yet the good, angular, rough-surfaced aggregates are desired for better stability. Most agencies strike a happy medium between workability and stability by selecting an angular, coarse aggregate and a rounded natural sand as the fine aggregate.

Aggregates should be selected that are compatible with the binder. If the mixture is prone to strip, a change may be made in the aggregate source, the binder can be changed to one that is compatible, or the binder is made more compatible by adding antistripping agents or hydrated lime. When considering a new source, the cost of aggregate transport must be considered. Frequently, it is cheaper to add an antistripping agent to the mixture than to use an acceptable aggregate that has high transportation costs.

Highly absorptive aggregates are often avoided when the patching material is mixed cold. These aggregates can contain large amounts of moisture, which will increase the tendency for stripping. Also, then often create drainage problems in the stockpile and usually absorb more binder, which can result in a longer curing time for the patching mixture. Conversely, when high absorptive aggregates are used in hot-mixed patching mixtures, they usually are quite satisfactory.

Selection of Additives

The use of additives varies considerably. Some agencies require the automatic use of additives in all patching mixtures. One state, for instance, specifies for its bituminous premixtures: "cutback asphalts shall contain 2 percent approved antistripping additives."

Most specifications require additives be used when the patching mixtures do not meet a minimum specified criteria. In addition, some specifications allow the use of additives whenever the producer of the patching mixture wants to use them. Producers may wish to use additives to have a superior mixture for sales purposes. Usually, this is at the producer's expense, as the contracting agency will not pay for the additives.

The exact type of antistripping additive to be used in patching mixtures is usually left up to the producer. The additive used, though, must be selected from an approved list or must be tested and approved specifically.

Selection of Optimum Bitumen Quantity

There are no formal, step-by-step procedures for the design and selection of the bitumen content of cold-mixed, stockpiled patching mixtures. A trial and error procedure is used.

When a new, cold-laid patching mixture needs to be developed, the procedure has been as follows. First, the initial amount of bitumen content is estimated based upon the type and gradation of the aggregate and the type of binder. In some instances, trial batches with different proportions are made and stored. The workability and storageability are observed, and adjustments are made as needed in the mixture. Subsequently, the mixture is used in the field, and its performance is observed. If the mixture does not perform well after one or two winters' use, adjustments are made, and the new patching mixture is field-evaluated again.

When a patching mixture producer has to use an aggregate from a new source or with a different gradation, the bitumen content is guessed at, based upon the bitumen content previously used. This bitumen content may be checked with a few laboratory tests, such as stripping or adhesion tests. Performance is checked in the field before the final bitumen content is selected.

Although there seem to be no procedures for selecting the bitumen content for stockpiled patching mixtures, there are some general guides to adjustments needed when various changes are made in other materials in the mixture. The main adjustments are as follows:

- Gradation is changed. Mixture becomes more dense-graded as more sand is used—increase the bitumen content.
- Aggregate shape is changed to a more rounded aggregate in order to increase workability—decrease the bitumen content.
- More absorptive aggregates (such as slag) are used—increase bitumen content from 1 to 4 percent.
- Binder type is changed to one with a heavier grade of residue (such as 120-150 penetration instead of 200-300 penetration)—increase bitumen content by ⅓ to 1 percent.
- Materials are to be mixed hot and stockpiled immediately. Drainage of the bitumen usually controls—decrease bitumen content ½ to 1 percent from that used when materials are mixed cold.
- The workability of a cold-laid mixture needs to be increased—increase bitumen content 1 to 1½ percent.
- The curing time after compaction needs to be shortened—decrease bitumen content ½ to 1 percent.
- Mixture is to be used in cold weather and needs to be stickier—increase bitumen content ½ percent.
- Water absorption needs to be decreased—increase bitumen content ½ to 1 percent.
- Flushing that has occurred during the summer must be prevented—decrease bitumen content ½ percent.

Quantity of Additives

The percentage of chemical antistripping agents used is very small. Liquid antistripping agents are added in amounts of ½ and 2 percent by weight of the liquid binder. In one instance, 67 gallons of liquid antistripping agent were added to 6,000 gallons of liquid bituminous binder. Even the quantity of lime used is very small, no more than 2 percent of the total weight of the mixture.

An additional factor must be considered in determining the quantity of additives needed in a bituminous patching mixture. Liquid antistripping agents can be produced in various concentrations. No procedure exists to determine the concentration needed. The additive is shipped in the concentration the producer desires. The user must be careful, because the concentration can vary from one shipment to another and between antistripping agents from the same producer.

Procedures are rather straightforward for determining the percentage of cement, hydrated lime, or liquid antistripping additive of unknown concentration. Different samples of the patching mixtures are mixed with the binder containing various amounts of the additives. Usually the antistripping agent is varied from 0 to 2 percent in ½ percent increments. These mixtures then are evaluated according to established tests and criteria. The amount of liquid antistripping agent or lime is the lowest amount that will meet requirements for the tests. Because the quantity determined is for a specific concentration of the liquid additive, if the additive is changed, it may be necessary to use a different quantity. Incidentally, no test exists to determine if bituminous mixtures contain liquid antistripping agent.

CHAPTER FIVE

PRODUCTION, INSPECTION, AND STORAGE

PRODUCTION

General Considerations

The procedures for producing bituminous patching mixtures are essentially the same as for other bituminous mixtures. Because these practices are so well known, they are not covered in this synthesis. In a few areas, however, specialized equipment is used in the production of quality patching mixtures. This equipment will be discussed later.

By far, the bulk of the hot-mixed patching mixtures is produced by private contractors' plants. The mixture may be produced either under a low bid contract for a specified amount or sold by the truckload. In the latter case, the plant operator produces hot-laid material as needed or stockpiles a standard, cold-laid patching mixture in the yard. A few cities and several states produce hot-mixed patching mixtures in their own plants. These plants also are used for other purposes, such as the production of paving mixtures during the construction season.

After mixing, patching mixtures are handled in several different manners. Most hot-laid mixtures are used immediately. Hot-mixed, cold-laid mixtures may be stored in the plant's yard and used as needed, or the mixture may be hauled to a maintenance garage or an area close to the patching site. Many times the cost of hauling the mixture from the plant to another site is included in the contract price for producing the patching mixture.

Most hot-mixed patching mixtures for winter use are produced at the end of the summer construction season. Rarely does the operator want to fire up the plant in winter because of the excessive expense. Just before the plant is closed in the fall, enough mixture is produced to last through the winter. A few operators do fire up their plants for several days at a time during the winter months to produce mixture as needed. A much smaller quantity of mixture is produced at these times. Because the mixture is "fresher," it is more workable than mixture stockpiled from the end of the construction season and is preferred by maintenance personnel.

Cold-mixed patching materials are usually produced by the highway agency that will use them. Virginia, for instance, although contracting its summer patching, produces its own material for winter patching. Cold-mixed patching mixtures are produced essentially the same as cold-mixed paving materials. They are usually yard or road mixtures and, in rural areas, are often mixed on an abandoned section of paved road. Usually, they are mixed during the summer or early fall when the agency's forces have time. Rarely is road-mixed patching material produced during the cold winter months, but it is done.

Some bituminous mixtures used for patching today may not be materials specifically prepared for patching. More and more recycled bituminous mixtures are being used as patching material. The recycled materials usually have been removed from a pavement surface by a cold- or hot-planer or some other method before reconstruction or resurfacing. Recycled material is stockpiled, processed if need be, and used as a stockpiled patching mixture. Many recycled materials have the appropriate gradation and binder content and are used successfully without any processing. However, recycled bituminous material often has to be adjusted by adding new aggregate or additional liquid binder. Some agencies have produced a satisfactory patching mixture by adding a volatile, such as kerosene, to the recycled material prior to use.

Mixing

Hot-mixed bituminous patching mixtures are produced in stationary or portable plants—the same plants used for summer construction production. Although there is little difference in the equipment used, the normal sequence of production sometimes varies.

Minneapolis has two bituminous weigh cycles. Patching mixtures are produced that contain a mixture of AC 60-70 penetration (AC-20) asphalt cement and SC-250. The two bituminous materials are stored and heated separately. First, the asphalt cement is weighed and retained in the bucket. In the next cycle, the cutback is cumulatively weighed into the bucket already containing the asphalt cement. Both asphalt materials are introduced together into the aggregate in the pugmill.

Mixing is done by ordinary pugmill, traveling plant, or with a blade on a paved surface. The mixing time should be sufficient to produce a homogeneous mixture, well coated, and which, if stockpiled, may be handled without stripping.

The procedure of producing stockpiled patching mixtures varies in one way from the normal sequence of producing mixtures containing liquid asphalt. Usually after mixing, the material is aerated to eliminate the volatiles before it is compacted. In the production of patching mixtures that are to be stockpiled, the volatiles must be retained to prolong workability. Thus, little or no aeration of these mixtures takes place before they are stockpiled.

Special Equipment

Because good workability and long-lasting patches usually result from mixtures that are hot, portable equipment has been developed specifically to produce a hot patching mixture at the job during cold months. One type of equipment is essentially a small batch, hot-mix plant, whereas other types heat premixed patching materials that have been stockpiled.

The small batch plant is a towed unit containing a diesel fuel- or pressurized liquid gas-fired rotary dryer and a gasoline-powered pugmill. Aggregates are heated in the dryer. Subsequently, they are dumped into the pugmill and mixed with hot asphalt cement. This plant is actually a hot mix plant without any proportioning equipment. Its greatest advantage is that it can produce hot bituminous patching mixture at the job site during winter. However, extra time is required to fire up the towed unit and produce the hot patching mixture. Holes can be patched quicker with cold, stockpiled mixtures when the quality of the patching materials is of less concern.

The heater for stockpiled mixes is usually a towed unit consisting of a heater and a mixer. The heater is diesel- or liquid gas-fueled. The mixer just stirs up the heated material to produce a uniform mixture and is not suitable for mixing separately-introduced hot aggregate and liquid binder. Usually, stockpiled mixture is shoveled from a truck into the forward part of the unit. As the material is carried toward the rear, it is heated and thoroughly remixed. The warmed mixture is dumped on a low bed where it can be removed easily by shovel as workers need it. This unit provides hot, workable mixtures and can heat all types of liquid binder (stockpiled) patching mixtures. It requires less time and effort to produce a warm mixture than the small-batch plant unit and apparently is well-liked by maintenance personnel.

Several machines are now being developed to completely mechanize pothole patching. These machines also include a heating and mixing unit that provides hot, workable patching material.

Temperature

Temperature of bituminous patching material is a factor that must be considered at both the time of mixing and placing. During mixing, the temperature needed will vary depending upon the type of mixture being produced. Hot-mixed, hot-laid patching materials are heated to temperatures normal for hot-mix construction. The temperature of the mixture immediately after discharge from the pugmill will be 235 to 350 F (113 to 177 C) for dense-graded aggregates and 180 to 250 F (82 to 120 C) for intermediate-graded aggregates.

Liquid bituminous binders used in the preparation of hot-mixed, stockpiled patching mixtures usually are heated before mixing with the hot aggregate. Care is taken to prevent extra loss of volatiles at high temperature. Suggested temperatures of the mixtures are given in Table 6.

Although the aggregate for cold-mixed patching mixtures is not heated, the liquid binders are often warmed slightly. They should be heated no higher than needed to make them workable in preparation of the mixture. If possible, the temperature of cutbacks should be kept below the flash point for safety reasons.

The temperatures at the time of placing are quite another matter. If the mixture is hot-laid, it must be hot enough [at least 180 F (82 C)] so that it can be shoveled into place and compacted satisfactorily.

There is little difficulty placing cold mixture during warm weather. However, during cold weather several problems can occur. Each mixture usually has a minimum temperature at which it can be placed satisfactorily. This temperature depends upon the workability of the mixture, because the material becomes harder and more difficult to shovel as the temperature drops. Also, at low temperatures the cold mixture hardens and gains stability very slowly because additional time is needed for the volatiles to evaporate. Usually, cold mixtures should not be placed at temperatures below 20 F (−7 C). However, a few mixtures do have unusual low-temperature workability properties and can be used satisfactorily at temperatures down to 0 F (−18 C).

TABLE 6

DISCHARGE TEMPERATURE FOR HOT-MIXED, STOCKPILED PATCHING MIXTURES

Bituminous Material	Temperature of Mixture After Discharge from Pugmill C	F
MC & SC-250	55- 90	135-190
MC & SC-800	75-105	165-220
MC & SC-300	80-115	180-240
Emulsion	10- 75	50-170
RT-4	50- 95	120-200

INSPECTION AND SAMPLING

Inspection Prior To and During Production Mixing

Normally, hot-mixed patching materials are inspected and sampled during production, while cold-mixed patching materials are sampled at the stockpile. This inspection and sampling is essentially the same as for regular bituminous mixture production. The contracting agency usually retains the right to have access to and inspection of the plant during patching mixture production, as it does during regular construction with bituminous mixtures. If desired, the agency will check the proportions and characteristics of the materials, verify weights, and check the dryer, if used, and other equipment for proper performance. Some agencies require an appointed, qualified inspector to be at the plant during production.

Agencies that purchase relatively small amounts of patching materials, such as small cities, townships, etc., usually do not inspect the production of the patching mixtures they buy. They usually take the mixture from a stockpile that has been inspected and approved by the state agency or a public works department of a larger city. In such cases, the plant operator must report the tons of patching mixture sold to each agency.

When a producer decides to use different materials or when a patching mixture is first produced, a job mixture formula is needed. A few agencies will design the patching mixture and provide the producer with a tentative job mixture formula. In such instances, sometime prior to production of the mixture, individual samples of the various materials must be collected and sent to a laboratory to determine if they meet specifications.

Most contracting agencies leave the design of patching mixtures to the manufacturer. This is the case with proprietary patching mixtures. Samples of the proposed mixture are requested for testing prior to the letting of competitive bids. As an example, Iowa requires bidders on patching mixture contracts to submit samples of their patching mixtures four weeks before the lettings. If the sample does not meet specifications, the bidder is notified, so a new sample may be submitted prior to the letting date. The results of the testing are considered in making the awards.

Inspection at the Stockpile

Sampling of cold-mixed patching materials is usually done at the stockpile after the mixing is done. Then, based upon test results, the entire stockpile is accepted or rejected. This procedure is used because the entire stockpile is mixed at one time but is used gradually during the winter months.

A relatively small amount of patching mixture is produced throughout the winter by some operators who desire to have good, workable material on hand, even though it means firing up the plant frequently. Each freshly mixed batch must be sampled and tested. This can be as frequent as once a week during early winter and early spring.

There is some variation in the time required before the stockpiled material can be sampled. Usually, hot-mixed patching materials can be sampled as soon as they are stockpiled. Some specifications require that all materials be stockpiled at least 24 hours before sampling. Patching materials that have been stockpiled for a long time usually are retested. Pennsylvania, for instance, requires that all stockpiles, if still in existence, be resampled and tested 120 days after original approval.

When stockpiled material is rejected, the contractor is responsible for disposing of it and must insure that it is not sold to other governmental maintenance forces. In an emergency, the unacceptable pile may be used. Normally, the contractor will either use it or dispose of it if non-governmental buyers such as shopping centers, will accept it. If the rejected stockpile is in a maintenance yard, the contractor usually has two weeks to remove it from the site.

STORAGE

Changes in Patching Materials During Storage

As hydrocarbons or water evaporate from the stockpile, the viscosity of the mixture is increased and the workability is reduced. Patching mixtures stored for long periods of time will become stiff and hard to shovel. This phenomenon is so prevalent that most specifications try to limit the change in workability. For instance, Illinois specifies that patching mixtures ". . . shall be capable of being stockpiled over a period of at least six months without hardening and shall remain workable . . ."

As the volatiles evaporate, a crust is formed on the stockpile. The thickness of the crust can vary considerably, but usually it is about 1 in. (25 mm) thick after a few months. The crust tends to seal the surface and helps shed water. It is fairly stiff, but it is not very hard and usually can be broken quite easily with an end-loader. The hardened crust is rarely thrown away; when it is heated or mixed with the softer inside material, it usually can be used satisfactorily. The crust can provide a protective surface and delay curing if it completely envelops the stockpile. In one instance, a contractor used a five-year-old pile of patching mixture to pave an entrance road into a hot-mix plant. The crust broke up quite easily and was mixed with the other material in the stockpile. The paving material seemed to be performing satisfactorily after a couple of years.

Problems can develop in a stockpile when water enters the patching material. When it freezes, water will harden the stockpile. A frozen stockpile is troublesome to work. It is especially difficult to remove small quantities of the patching material with a shovel. A well-formed crust will help shed water, but when the crust is destroyed as patching material is removed, water will get into the stockpile and cause trouble.

Another problem is drainage of bituminous binder from freshly stockpiled, hot-mixed materials. Too much liquid binder may drain through the mixture and puddle on the base. This rarely occurs, though, when the correct amount of binder is used. The use of lower mixing temperatures also helps to reduce binder drainage from the aggregate.

Methods of Storing Patching Materials

Cold-laid patching materials must be stored until they are needed. Usually, they are stored in stockpiles to conserve space because storage in a truck or hopper, except for short periods of time, is not economically feasible. Several factors are usually considered in stockpiling patching mixtures.

Base

Stockpiles are placed on level bases where they can be reached by trucks. Bases are composed of portland cement concrete, asphalt concrete, or even the remains of a previous stockpile that has been well-compacted. The hard surface prevents dirt from being scooped up, contaminating the patching mixture. In many maintenance yards, though, the stockpile is placed directly on bare dirt. In these cases, workers should be very careful not to dig too deep and to always leave a thin layer of patching material on the ground.

Walls

Usually, patching mixtures are just dumped in a pile in the maintenance yard. No walls contain the material, and it slumps and spreads. These types of stockpiles will occupy a large space.

When space in the yard is tight, patching materials are placed in bins. The most preferred bins are open at opposite ends. Patching material can be removed from one end of the bin while more is added from the other end. Bins open only at one end present some difficulties. Once these bins have been charged, the old patching mixtures have to be completely removed before new mixtures can be added. Sometimes bins with one open end are built very wide so loaders can get to at least two sides of the pile. This construction reduces the effectiveness of the bin walls, and the bin occupies a considerable amount of space.

Protection

Although many stockpiles are formed in the open and are provided no protection from the weather, they increasingly are being covered to keep out snow and water. When patching materials are left in an open, unprotected area where they are subjected to rain and snow, their workability is reduced noticeably and their moisture content increases. Most agencies now require patching mixture to be protected from the time of mixing until used.

Protection is provided in several ways. The best protection is to store the patching mixture inside a building. This can be costly. Outside, stockpiles are often placed in an open shed with a solid roof, but usually open stockpiles are covered with just a tarp or plastic covering. When patching material is needed, a small section of the tarp is thrown back. After the patching material is removed, the tarp is drawn back to cover the mixture again. A few contractors make a special effort to cover stockpiles of fresh asphalt emulsion patching mixtures for a short period of time when they are concerned that rain might wash the asphalt emulsion off the aggregate.

Heated Stockpiles

The workability of patching mixtures can be improved not only by keeping water and snow off stockpiles, but also by keeping the mixtures warm. Mixtures are placed either inside a heated building or on a slab that is heated by hot oil circulating through pipes buried in the concrete. Solar heating of stockpiles is also being considered.

Height of Stockpile

The height to which patching material may be piled is limited by the type of equipment used to deliver the material to the stockpile—truck, front end loader, belt, etc. Often the height is of no concern, but Pennsylvania specifies that hot-mixed materials should not be stockpiled higher than 4 ft (1.2 m) for the first 48 hours to prevent drainage and stripping.

Stockpile Life

The term "stockpile life" refers to the time a patching mixture can be stored and still have satisfactory workability. For patching mixtures produced with cutback binders, stockpile life is a function of the curing rate of the volatiles from the patching material. The rate of curing, in turn, is dependent upon the type of volatiles used to thin the cutback and the conditions under which the material is stored. Cutbacks with thinners that volatize slowly, such as MC and SC, will have long stockpile lives. Any weather condition, such as heat, that tends to speed the rate of volatile evaporation will shorten the stockpile life.

The stockpile life of patching mixtures made with asphalt emulsions depends upon whether or not the emulsion has broken and the stiffness of the emulsion's residue. Emulsion patching mixtures that are cold-mixed usually are not broken when stockpiled. These mixtures must not be allowed to freeze. As soon as they freeze, they can no longer be used as a patching material. So long as they do not freeze, they will be workable. If the emulsion is broken, which may occur during hot mixing or in the stockpile, the life is dependent upon the stiffness of the emulsion residue. If the residue is relatively hard, as in MS, CMS, SS, and CSS, the mixture soon becomes unworkable. But if the residue is soft, such as in HFE 150 or 300, the stockpile life can be quite long.

Due to numerous materials and weather factors, the stockpile life of patching mixtures varies considerably. Patching mixtures produced with asphalt cement binders have very short stockpile lives unless they are heated. The lives of liquid binder patching mixtures range from very short to very long. In general, the lives of mixtures stored in the northern parts of the United States are as given in Table 7. Rarely are stockpiled patching mixtures made from MS, CMS, SS, and CSS asphalts unless the asphalt emulsion is modified. When modified, life is four to six weeks, provided the mixture is not allowed to freeze. The lives of liquid cutback patching materials are sometimes extended by adding petroleum distillates, such as diesel fuel, kerosene, etc., during mixing. (See Chapter Two for a discussion of binders that are modified to increase stockpile life.)

TABLE 7

APPROXIMATE LIFE OF STOCKPILED MIXTURES (NORTHERN U.S.)

Type of Binder	Approximate Stockpile Life
AC	Few hours
RC	Several weeks
MC	4 to 6 months
SC	At least 6 months
HFE	6 months
TARS	2 to 3 months

CHAPTER SIX

COST OF BITUMINOUS PATCHING MIXTURES

FACTORS INFLUENCING COST

Aside from the nominal cost of producing any bituminous mixture, such as the costs of the aggregates, bituminous binder, production, etc., several factors influence the costs of patching mixtures. In a particular locality, certain cost items favor one type of patching mixture over another. The exact magnitude of these differences varies from one place to another, and factors that produce a significant difference in one location are not important in another location. The major factors that may influence the difference in cost between two types of patching mixtures follow.

Type of Binder

The price of different types of binders varies considerably with factors unrelated to the cost of the residual asphalt cement. These costs are influenced by the availability and cost of the binders at the oil refinery and the transportation costs. The price of cutbacks can vary depending upon the cost of their volatile liquefiers, which in turn is related to the availability of crude oil. For asphalt emulsions, the emulsifying agent is a major cost item. These costs vary considerably and may favor asphalt emulsions in one area and cutbacks in another.

The costs of transporting binders from their place of production to the mixing site can be a major portion of the difference in cost between binders. Often asphalt cements and cutbacks have to be hauled long distances from a refinery. The volatiles in the cutbacks also have to be hauled from the refinery, whereas the water in emulsions is obtained locally. Once produced, asphalt emulsions usually are hauled shorter distances to the mixing plant than are cutbacks. Over all, the costs of hauling emulsions can be less than hauling cutbacks.

Aggregates

The difference in costs of aggregates normally depends on the type of gradation used in the patching mixture. Usually closely controlled, well-graded aggregates cost more than quarry-run stone. In some areas, the major price differential, though, is due to the additional cost of obtaining an aggregate that is compatible with the cutback or asphalt cement binder. Compatible aggregates may be available only after a long, expensive haul. In such instances, it may be cheaper to use a closer, less expensive aggregate and change the type of binder or add an antistripping agent.

Type of Mixing

Patching mixtures that are produced "hot" in a plant have greater production cost than those that are mixed "cold." This difference is due to the additional cost of heating the aggregate and proportioning the materials and to the greater amount of equipment and number of workers needed.

Transporting the Patching Mixture

Costs of hauling patching mixtures from mixing plants can be significant. The greater the distance the mixture must be moved, the larger the cost. Often a significant part of the additional cost of proprietary mixtures is due to hauling the entire mixture long distances. When these mixtures are produced closer to the job, the price often drops significantly. In addition, different prices are quoted if the mixture is to be picked up at the mixing plant or if it is to be delivered to a maintenance yard or storage site.

Availability

Production costs of some mixtures are influenced considerably by the time of the year. Hot-mix plants usually produce hot-mixed, hot-laid patching mixtures during warm weather and hot-mixed patching materials for stockpiling only in the fall before closing down for the winter. If hot-mix is produced during the winter, there are additional costs due to starting the plant up, the greater amount of fuel needed to heat and dry the aggregate, and the cost of bringing the workers back to the plant for a few days. Hot-mix, if available, usually is considerably more expensive in the winter than in the summer.

Additives

Additives increase the cost of a patching mixture. When additives are needed to improve the antistripping characteristics of the mixture or to improve workability, their cost must be included in the price of the patching mixture. The licensing or manufacturer's fee may double the cost for proprietary mixtures as compared to nonproprietary mixtures.

INITIAL COST OF PATCHING MIXTURES

A comparison of prices of similar mixtures in different parts of the country is difficult due to wide variations in specifications, the use of different types of patching mixtures, and the variation in factors that influence cost. Accordingly, the costs reported here are given in ranges that will cover the costs of similar patching mixtures. The average of these prices should not be used in an economic analysis of two or more different patching materials. The exact cost of the patching mixtures in the area should be used.

Considerable price data for patching mixtures have been collected by the Federal Highway Administration ("Unit Cost and Productivity Standards for Various Highways and Bridge Activities," June 1977). Analyses of these data indicate little difference in the cost of a particular patching mixture, regardles of location. In other words, the price range for a hot-mixed, medium-curing cutback patching material varies little between the southern, middle, and northern parts of the United States. Thus, prices given in Table 8 are not broken down by area of the country. In general, the costs of the patching mixtures given in Table 8 vary with the quality of the mixture. The highest types of patching mixtures are the most expensive. Proprietary mixtures are also more expensive because of licensing and manufacturer's fees and additional transportation costs when the entire mixture has to be shipped from a distant plant.

TABLE 8

RANGE IN INITIAL COST OF VARIOUS PATCHING MATERIALS

Type of Patching Material	Cost $/Ton ($/Mg)
Hot-mixed, hot-laid (asphalt concrete)	10-20 (11-22)
Hot-mixed, stockpiled	9-19 (10-21)
Cold-mixed, stockpiled	7-16 (8-18)
Mixes with antistripping additive	About .50 more (.55)
Proprietary mixes	25-50 (28-55)

A word of caution. The cost of patching mixtures as delivered to the job should not be used as the sole basis for selecting an appropriate patching material. The actual cost of the entire patching *operation*, which includes labor and equipment, should be considered, as well as the cost of the material. Because materials vary between 25 to 45 percent of the entire cost of the patching operations, other factors can significantly influence any economic analysis. For instance, the rate of replacing a patch influences the labor cost and consequently can have a substantial influence upon the overall cost of the patching operation. Analyses have indicated that high-quality, though expensive, patching materials that rarely need replacing may be more economical in the long run than cheaper patching material that needs replacing in a few months.

VARIATION IN COST AT ONE LOCATION

The cost data given in Table 8 vary over a large range, sometimes as much as 100 percent. Perhaps a more meaningful comparison of the initial cost of patching materials is given in Table 9, which gives costs in one location.

TABLE 9

COST OF PATCHING MATERIALS IN EASTCENTRAL ILLINOIS

Type of Patching Mixture	Cost $/Ton	($/Mg)
Hot-mixed, hot-laid (asphalt concrete)	19.50	(21.50)
Hot-mixed, stockpiled (using MC-250)	18.50	(20.40)
Hot-mixed, stockpiled (using MC-250 and anti-stripping agent)	19.05	(21.00)
Cold-plant mixed, stockpiled (using HFE-300)	14.75	(16.25)
Pav-Rite proprietary mix (using MC-250 and proprietary additive)	22.50	(24.80)

CHAPTER SEVEN

COMPOSITE BITUMINOUS PATCHING MIXTURES

In recent years, efforts have been made to improve bituminous patching materials through the development of composites that combine the bituminous patching mixture and other materials to increase the stability, accelerate the rate of hardening, and improve the longevity. These additives produce improvements in two different ways. One type of additive modifies the bituminous binder to produce a desirable chemical change. This modification may bring about a complete change in the structure of the binder, or it may be used to accelerate hardening. The other type of additive produces essentially no chemical changes but improves the physical characteristics of the mixture. Short, strong materials, such as fibers, are added to the mixture as reinforcements.

Several types of modifiers and reinforcements have been used with bituminous patching mixtures. In most instances, composite patching mixtures have not been used or been in service long enough to be properly evaluated. In all likelihood, some of these composites will not perform satisfactorily and other composites will be developed.

BITUMINOUS PATCHING MIXTURES WITH MODIFIERS

Sulfur

With the increasing cost of asphalt, sulfur, which is abundant, has been used to decrease the amount of asphalt needed in patching mixtures. Several composites have been developed that differ primarily by the amount of sulfur used. These processes are patented.

High-Sulfur/Asphalt Mixtures

One type of sulfur-asphalt patching mixture contains a very large amount of sulfur, as much as 60 to 75 percent by weight of binder. These mixtures may be produced by combining molten sulfur, asphalt, and aggregate in a pugmill. However, mixing is normally done through a patented process developed by the Division of Building Research of the National Research Council of Canada. In this process, the liquid sulfur is mixed with hot aggregate to form a colloidal dispersion, which upon cooling, produces a continuous, rigid sulfur skeleton filled with a continuous bituminous phase. In some instances, a small amount of reinforcement material may be added. These products are called "reinforced sulfur-asphalt composites."

High-sulfur/asphalt mixtures seem to act more like sulfur than a bituminous mixture. They are almost a liquid at 150 C (302 F) but harden as the temperature drops and become very stiff at normal and low temperatures. They do not need to be compacted or rolled, but are poured in the hole and struck off. They can take four to six hours to cool. They must be maintained at a temperature of 100 to 150 C (212 to 302 F) to be workable, which means a portable heater is necessary for any patching.

There are few reported data on the performance of high-sulfur/asphalt mixtures. They will need to be evaluated after they have been used and performance data are available.

Medium-Sulfur/Asphalt Mixtures

The most widely used sulfur-asphalt mixtures contain approximately 50 percent sulfur and 50 percent asphalt. They are produced in a manner similar to high-sulfur/asphalt mixtures as the liquid sulfur and liquid asphalts are mixed to produce a dispersion of the sulfur in the asphalt. Part of the sulfur appears to react with the asphalt. This binder mixture is used with conventional equipment to produce the bituminous mixture. Gulf Oil Canada Ltd. has patented this process.

Medium-sulfur/asphalt mixtures behave like a normal bituminous mixture. They can be laid with a finisher and have to be rolled in order to have high density. They have higher Marshall stability and lower Marshall flow values than the same mixtures without sulfur. They also seem to have improved water stripping resistance.

These mixtures have been used for high type paving applications in a number of places for four or five years. They have not been used specifically as patching materials, but there is no reason why they cannot be so used, provided the mixture is kept hot.

Portland Cements

Portland cements have been added to conventional cold-mixed, asphalt emulsion patching materials in order to accelerate hardening and improve the stiffness of the mixture. These mixtures also seem to have improved resistance to stripping.

Only a small amount of cement is added, but it can noticeably increase the cost of the patching material. Large amounts of cement can make the mixture brittle.

Although numerous laboratory studies have been done on these emulsion-cement mixtures, only Texas apparently has used them for patching materials. They had limited use, but apparently fair success.

BITUMINOUS PATCHING MIXTURES WITH REINFORCEMENTS

Rubber

Although rubber has been added to bituminous mixtures for normal construction, only recently has it been added as a reinforcement in patching materials. Both synthetic and natural rubbers have been used in amounts of 1.0 to 1.5 percent to improve the elastic properties of the mixture.

Rubber has been added to patching materials containing asphalt cement binders as well as to mixtures made with asphalt emulsions. These rubber-reinforced patching mixtures appear moderately successful.

Polyester Fibers

Delaware has improved the performance of its cold-mixed patching material by adding polyester fibers. The cold-mixed patching material is composed of an MC-250 with an antistripping additive mixed with an intermediate-graded aggregate. The polyester fibers are ¼ to ½ in. long (6 to 12 mm) and are added at the rate of 0.25 percent by weight of the mixture.

The patching mixtures with fibers are considerably more expensive. Polyester fibers add an additional $5.50 per ton ($6.10/Mg) to the basic price of the cold mixture. In addition, the asphalt content must be increased by 0.3 percent when the fibers are added. Delaware, however, feels the fibers significantly improve the behavior of patching mixtures and are well worth using.

Other Types of Reinforcements

In addition to organic fibers, inorganic fibers, such as asbestos, flake mica, and glass have been used as reinforcements. The Canadian Division of Building Research has used all of these reinforcements in patching mixtures and has included them in its patented patching mixtures.

Data from limited laboratory tests indicate the behavior is improved some when high-sulfur/asphalt patching mixtures contain these inorganic reinforcements. However, there are no field data to indicate the success of these reinforced patching mixtures in improving performance.

CHAPTER EIGHT

RESEARCH

CURRENT RESEARCH

Research directed toward improving the properties of bituminous patching materials has been conducted on a limited scale. In the U.S., less than 10 projects were reported in a recent three-year period. Most of these projects were funded with fairly small amounts of money and were directed toward improving a specific deficiency in a particular patching mixture. It is probable that more research has been conducted in this area but has not been reported due to the small size and funding of the projects.

In recent years, though, activity dealing with antistripping agents has increased. These investigations have been directed primarily toward the development of tests for acceptance and control of antistripping agents for patching mixtures.

Although the research work on the behavior of bituminous patching materials has been relatively small, interest in techniques for improving patching operations, including the development of new equipment, has increased. As an example, equipment is being developed to do essentially all of the patching operations, including the heating of a stockpiled bituminous mixture. There also has been considerable interest in the effective use of personnel and equipment in patching operations.

RESEARCH NEEDS

Although significant research on bituminous patching materials has been conducted, interest in the problems and deficiencies of these patching materials has increased and apparently will continue. The exact direction of future research is not known, but it probably will be toward improving the quality (water resistance, longevity, etc.) of the patching material and developing tests that will measure the various important properties of a patching mixture.

The following areas warrant special consideration:

- Collection of data on the longevity of bituminous patching mixtures.
- Development of a technique (and equipment) for simulating and accelerating storing conditions.
- Development of a test to measure workability.
- Development of a test to measure the amount of antistripping agent in an asphalt binder.
- Development of a practical design procedure for stockpiled bituminous mixtures that would have workability and storageability.
- Improvement of the gradation of aggregates for stockpiled patching mixtures for optimum stability and curing.
- Development of techniques for using nonhigh-float asphalt emulsions in patching mixtures or the modification of these emulsions so they can be used satisfactorily as binder in patching materials.
- Development of a patching mixture that will store well and also can be used satisfactorily under adverse winter conditions.
- Development of demonstration projects to compare the performance of different types of patching materials and techniques.

APPENDIX A

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APPENDIX B

PARTIAL LIST OF APPROVED CHEMICAL ANTISTRIPPING AGENTS

The antistripping agents included in the following list have been approved for use in bituminous mixtures in one or more states. Agents were not included if acceptance is pending. A list of antistripping agents that have been rejected is not included. It is possible that some acceptable agents are not included in the list because they were either unknown to the writer or have been developed or evaluated after the list was prepared. This list, then, is not a "status" report of all agents on the market.

A specific agent may be approved for use by a number of state agencies. For reference, only one agency is listed herein. Other states would have to be contacted to determine if they approve the agent.

Powdered antistripping agents, such as hydrated lime, cement, etc., are not included in this list.

	PRODUCT	APPROVING STATE	MANUFACTURER
1.	AAS-475	Louisiana	Dasch Oil & Chemical, Inc. Suite 223 Beck Bldg. Shreveport, La. 71101
2.	Crown-Rite	Illinois	Crown-Trygg Corp. P. O. Box 338, Route No. 6 Joliet, Ill. 60434
3.	CW-1	Iowa	Carter-Waters Corp. 2440 West Pennway Kansas City, Mo. 64108
4.	DeHydro-H86C	Alaska	Tretolite Co. of California 5515 Telegraph Rd. Los Angeles, Calif. 90040
5.	Edoco-7003	Alaska	Edoco Technical Products, Inc. 22039 S. Westward Ave. Long Beach, Calif. 90810
6.	Kerr-Mac	Iowa	Kerr-McGee Oil Industries 1812 Kermac Bldg. Kerr-McGee Center Oklahoma City, Okla. 73102
7.	Kling Beta X-22 Kling Beta LV Kling HS Beta-200 Kling HS Beta-1000 Kling Beta-W Kling Refinery Grade	Illinois Alaska Iowa Iowa Louisiana Louisiana	Lancaster Chemical Co. Broad and 13th Sts. Carlstadt, N.J. 07072
8.	Lubrizol-456	Iowa	The Lubrizol Corp. 29400 Lakeland Cleveland, Ohio
9.	No-Strip Super-Concentrate Acra-300 Acra-500	Illinois Iowa Iowa	Maquire Industries Inc. 122 E. 42nd St. New York, N.Y. 10017
10.	Pave-Bond Pave-192 Pave-Bond Special Pave-LP Pave Bond Anti-strip	Illinois Illinois Mississippi Louisiana Iowa	Cincinnati Malacron Chemical Co. Cincinnati, Ohio 44077 (or Painesville)
11.	Redicote 80-S Redicote 81-S Redicote 82-S	Illinois Illinois Louisiana	Armak Co. 8201 W. 47th St. McCook, Ill. 60525
12.	Rode-Rite	Illinois	Allied Chemical Corp. 10526 Cermak Rd. Westchester, Ill. 60153
13.	Sylvax UPM	Illinois	Sylvax Chemical Co. 342 Madison Ave. New York, N.Y. 10017
14.	TAPCO-206	North Carolina	Tap Co., Inc. 300 S. Benbow Rd. Greensboro, N.C. 27401
15.	TIZE	Illinois	Blacrete Corp. 8208 S. Kenwood Chicago, Ill. 60619
16.	Tyfo A-40 Tyfo A-42	Louisiana Louisiana	National Research and Chemical Co. 12520 Cerise Ave. Hawthorne, Calif. 90250

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