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The opinions, findings, and conclusions expressed in this paper are mine and not necessarily those of the sponsoring agencies.

REFERENCES

1. N.K. Vaswani. Pavement Design and Performance Study: Phase B--Deflection Study. Virginia Highway Research Council, Charlottesville, Interim Rept. 3, Feb. 1971.
2. Road and Bridge Specifications. Virginia Department of Highways and Transportation, Charlottesville, Jan. 1, 1978.
3. J.H. Dillard and G.W. Maupin, Jr. Use of Sprinkle Treatment to Provide Skid-Resistant Pavments. Proc., AAPT, Vol. 40, 1971.

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# Rational Approach to Design of Bituminous Stockpile Patching Mixtures

PRITHVI S. KANDHAL AND DALE B. MELLOTT

**Although a considerable amount of maintenance expenditure is spent on bituminous patching, the performance of conventional cold stockpile patching materials has been generally unsatisfactory. No concerted effort has been made to design these mixtures on a rational basis. The challenges of designing these mixtures are reviewed, and some new concepts vital for the survival of these mixtures in the adverse environment of potholes are presented. These concepts among others include the use of finer and predominantly one-sized gradation for the aggregate and the maximum dust content (minus 200 fraction) of two percent in the mixture. A formulation based on these concepts has been developed and used in the field during the past three years. The data obtained from the field and laboratory evaluation of the suggested formulation are reported. Laboratory test data indicate the effect of dust content on the workability of these mixtures. Attempts were made to quantify the workability of the mixtures by using a cement concrete penetrometer. However, the results were inconsistent and merely show a trend of higher penetrometer readings for mixtures with poor workability.**

After severe winters, potholes are certain to appear. Several estimates of the extent of the pothole problem have been attempted. According to a CBS Evening News broadcast of February 21, 1978, in 1977 there were an estimated 160 million potholes produced in nearly 4 million miles of roads and streets in the United States, which cost nearly $1 billion to repair. The most comprehensive damage estimates so far come from The Roads Information Program (TRIP), whose researchers estimated in a February 28, 1979, news release that 93 million potholes dotted roads around the country in 1979. According to TRIP, 5 million tons of asphalt mix, costing $256 million, was required just to fill the craters.

Pennsylvania's 72 418 km (45 000 miles) of state-administered highways constitutes the fourth largest such system in the United States. A value engineering study (1) conducted by the Pennsylvania Department of Transportation (PennDOT) for the Federal Highway Administration (FHWA) during the 1975-1976 fiscal year indicated that this vast network required a maintenance expenditure of $145 million, of which $25.8 million or 17.8 percent was required for bituminous patching. The cost for bituminous patching material alone was $5.7 million, or 22.1 percent of the total patching allotment. The remaining 77.9 percent covered the costs for equipment and labor. This study indicated that PennDOT should be providing a more permanent patch and reducing the number of repeat trips to the same area. To realize this goal, the need for using proper patching techniques cannot be overemphasized. O'Brien (2) has reported the annual costs per ton of patching material in place for five different patching techniques, taking into consideration the life of the patch. The annual cost per ton of the material was determined to be $307.68 when it was simply dumped in the pothole in one lift and hit with a shovel versus $61.41 when it was placed properly (proper placement includes shaping the area, removing loose debris, applying a tack coat, shoveling in the material, leveling with a lute, and compacting with a pug roller).

Many proprietary patching products have been promoted by various manufacturers. These mixtures are usually tailor-made with one stone type under strictly controlled conditions and supplied in 55-gal drums. The cost of such materials ranges from $100 to $500/ton, which makes their use prohibitive from the economic standpoint.

There is a need to develop a stockpile patching mixture that is economical, capable of withstanding some abuse in placement, and reasonably durable. It may be more cost effective to design mixtures for better durability. Information assembled from numerous sources, including a large number of highway and transportation departments (3), indicates the lack of a rational design procedure.

## CHALLENGES OF MIX DESIGN

It is difficult to design stockpile patching mixtures because the properties required in stockpiling and handling and after the material is placed in the pothole are contradictory. Some of these contradictory requirements are as follows:

1. Aggregate gradation--For good mixture workability, an open gradation is desired. After the mix is placed, however, a denser gradation is needed to improve durability.
2. Aggregate shape--To obtain good workability, angular aggregate shape should be avoided. However, once the mix is in place, a high degree of angularity is desirable for better stability.
3. Binder viscosity--Lower binder viscosity is

desired for storageability and workability, but after placement higher viscosity is desirable as soon as possible for better cohesion of the mixture.

4. Binder content--Greater residual bitumen content in the mixture is needed to obtain thicker films on the aggregate for stickiness and durability, but there is a possible binder drainage problem in the stockpile just after stockpiling while the mix is hot.

Use of highly absorptive aggregates can also pose problems. High moisture content in such aggregates often causes stripping and/or drainage problems in the stockpile. Selective absorption of the lighter fractions of the bituminous binder by such aggregates leaves a bituminous film that has undesirable characteristics and is significantly different from the original bituminous binder used.

It is not possible to use conventional methods of mix design generally used for hot asphaltic concrete, such as the Marshall and Hveem methods. Not only are the specimen preparation and testing difficult, but also the desired design criteria for the stockpile patching mixtures are unknown.

## NEW CONCEPTS

In the past, the use of larger-sized aggregate [12.5-19.0 mm (0.5-0.75 in)] in the stockpile mixture has been promoted to obtain higher stability. Such a mixture can be successful if the patching technique is ideal (for example, making edges vertical, cleaning, applying tack coat, and compacting adequately). However, ideal patching techniques are not always used and mixtures that contain larger aggregate start to ravel under traffic, which results in premature failure of the patch. Another concept is to disregard the stability and make the mixture finer and more pliable so that it will be more tolerant of abuse during placement and perform under traffic. This finer mix, if placed less than 76 mm (3 in) deep in one lift in a confined area, should be stable. For deeper and/or larger holes, the mixture has to be compacted in layers.

The cohesive and adhesive qualities of a mix depend mainly on the composition of the mortar (bituminous binder plus fines). If there are excessive fines or dust [material passing a 0.075-mm (no. 200) sieve] in the mixture, the mortar will be lean, less tacky, and friable. It is no coincidence that most of the expensive commercial patching products are made from clean stone. Several extraction tests run on such products have revealed that the fines (the minus 200 fraction) are usually less than 1 percent. In the absence of excessive fines, mixtures are very tacky; therefore, tack coating of the pothole will not be required. Many of PennDOT's conventional stockpile patching mixtures have not performed satisfactorily because of excessive fines. Such mixes are dull and friable and lack cohesive and adhesive qualities.

## PENNSYLVANIA'S IMPROVED FORMULATION

### Mixture Characteristics

In view of the challenges of mix design and new concepts, the characteristics discussed below appeared desirable for a satisfactory and economical stockpile patching mixture.

### Finer and Predominantly One-Sized Gradation

A gradation consisting of 100 percent passing the 9.5- or 4.75-mm (0.375-in or no. 4) sieve has the following advantages:

1. The mix is pliable and workable.
2. Due to increased surface area, more bituminous binder can be incorporated into the mix to improve the durability.
3. The mix remains pliable for a prolonged period of time and continues to densify easily under traffic and will continue to adapt to the changing geometry of the pothole. This characteristic enhances its chances of survival.

Normally, a finer dense gradation will not have good workability. However, if it is made of predominantly one-sized aggregate [100 percent passing the 9.5- or 4.75-mm sieve and mostly retained on the 1.18-mm (no. 16) sieve], the following advantages result: (a) the workability of the mixture is increased significantly, and (b) the mixture can cure effectively.

### Clean Aggregate

As discussed earlier, it is very important to keep the dust content (minus 200 fraction) in the mixture as low as possible to impart tackiness. This would significantly improve the adhesive and cohesive properties of the mixture.

### Angular Aggregate Shape

Angular aggregate shape is desirable for better stability. Since a finer and predominantly one-sized gradation is used, the effect of aggregate angularity on the workability of the mix is minimal. Angular crushed-stone aggregate is an ideal material.

### Use of Least Absorptive Aggregate

Highly absorbent aggregates should be avoided. The aggregate water absorption should be limited to approximately 1 percent.

### Adequate Binder Content

It has been determined that at least 4.5 percent residual bituminous binder is required in a stockpile patching mixture made from an aggregate whose water absorption is less than 1 percent. If the aggregate absorbs water in excess of 1 percent, the residual binder content should be increased a similar amount. For example, an aggregate that absorbs 1.5 percent water should have 5.0 percent mimimum residual bituminous binder. The factor limiting the maximum amount of the bituminous binder is drainage in the stockpile just after manufacture. The drainage can be minimized or eliminated by using lower mix temperatures and limiting the stockpile height to 1.2 m (4 ft) during the first 48 h.

### Proper Type and Amount of Antistripping Agent

The antistripping agent is a very important part of the formulation of the stockpile mixture. A mixture should retain its coating in the stockpile under adverse weather conditions, during handling, and in the pothole after placement. A stockpile patching mixture, which is more pervious than a densely graded hot mix, has to withstand by far the most severe weather and traffic effects. It has to survive in conditions that led to the creation of the pothole in the first place (such as poor base, inadequate drainage, and deteriorated adjacent pavement). Rain or melting snow provides water. The pneumatic tires of vehicles provide high pressures. This combination can emulsify the bituminous binder or displace it from the aggregate. If sufficient stripping occurs as a result of this action, the traffic will dislodge the aggregate particles.

There are many commercially available antistripping agents in the market for use with the medium-curing (MC) cutback asphalts. Extensive testing in the PennDOT Bituminous Laboratory shows that there is no single additive that will work with all aggregate types. Therefore, it is essential that the type of antistripping agent and its amount be selected after testing with the aggregate that is actually being used in the mix. PennDOT requires its bituminous suppliers to conduct the wet coating test, static immersion test, and stripping test with the job aggregate.

## Specifications

The salient features of Pennsylvania's stockpile patching material specifications are discussed below.

### Description

The material shall consist of plant-mixed stockpile patching bituminous mixture composed of mineral aggregate coated with bituminous material. The material shall be capable of being stocked for at least six months without stripping and shall be workable at all times.

The material is intended for patching holes up to 76 mm (3 in) deep. For holes deeper than 76 mm, the material will be compacted in layers, each layer not exceeding 76 mm.

### Bituminous Materials

The listed bituminous materials shall meet the applicable requirements of PennDOT Bulletin 25 (Specification for Bituminous Materials):

| Class of Material | Type of Material |
|---|---|
| MC-250 | Cut-back petroleum asphalt |
| MC-800 | Cut-back petroleum asphalt |
| ME-250 | Emulsified cut-back asphalt |
| ME-800 | Emulsified cut-back asphalt |
| E-10 | Emulsified asphalt (high-float residue) |
| E-12 | Cationic emulsified asphalt |
| RT-4 | Coal tar |
| RT-6 | Coal tar |

Materials MC-250, ME-250, and RT-4 shall be used between November 1 and March 1; materials MC-800, ME-800, and RT-6 shall be used between March 1 and October 31; and materials E-10 and E-12 may be used throughout the year.

Materials MC-250, MC-800, ME-250, and ME-800 shall be treated with antistripping agents to meet the requirements of the wet coating test, the static immersion test, and the stripping test performed with the job aggregate. Materials E-10 and E-12 shall pass the dry and wet stone-coating test on the job aggregate.

The contractor shall furnish the sample of the job aggregate to the bituminous supplier for the coating and stripping tests specified in PennDOT Bulletin 25 and obtain a certificate that the bituminous material has been treated to suit the job aggregate. This certificate shall be produced when required by the engineer.

### Composition of Mixture

The contractor shall furnish the mixed material within the gradation limits specified below (1 mm = 0.039 in):

| Sieve Size (mm) | Percent Passing Specified | Preferred |
|---|---|---|
| 9.5 | 100 | 100 |
| 4.75 | 40-100 | 85-100 |
| 2.36 | 15-40 | 10-40 |
| 1.18 | - | 0-10 |
| 0.075 | 0-2 | 0-2 |

The quantity of bituminous material in the mix shall be such that the minimum requirements on the percentage of residue specified below are met:

| Aggregate Type | Water Absorption (%) | Binder Residue (%) |
|---|---|---|
| Stone and gravel | <1.0 | 4.5 |
| Stone and gravel | 1.1 to 1.5 | 5.0 |
| Stone and gravel | 1.6 to 2.0 | 5.5 |
| Stone and gravel | 2.1 to 2.5 | 6.0 |

As far as possible, aggregate with less than 1.0 percent water absorption should be used. Exceptional cases where the minimum requirements of the preceding table are difficult to meet shall be referred to the Materials and Testing Division for approval.

### Preparation of Mixtures

All mineral aggregates and bituminous material shall be proportioned by weight or by volume. The mixture shall be such that it may be stocked, handled, placed, and finished without stripping of the bituminous material from the aggregate. To help prevent stripping, the mixed material shall be stocked no higher than 1.2 m (4 ft) for the first 48 h.

The mineral aggregate shall be clean and surface dry before mixing. The temperatures of the bituminous material, the aggregate, and the resulting mixture shall be maintained as follows [t°C = (t°F - 32)/1.8]:

| Material | Temperature Range (°C) Aggregate | Bituminous Material | Mixture |
|---|---|---|---|
| MC-250 | 4-66 | 57-82 | - |
| MC-800 | 4-66 | 74-96 | - |
| ME-250 | 4-66 | 79 max | - |
| ME-800 | 4-66 | 79 max | - |
| E-10 and E-12 | Appropriate for specified mix temperature | 60-79 | 88-121 |
| RT-4-C | 38-93 | 54-66 | 38-88 |
| RT-6-C | 38-93 | 54-79 | 38-88 |

When E-10 or E-12 emulsified asphalt is used, the temperature requirements on the aggregate and the mixture can be waived by the engineer if it is demonstrated that the mix can be prepared with unheated aggregate without any coating or stripping problems, during production and stockpiling. To help prevent drainage of bituminous binder in the stockpile, the mixing temperature shall be held as low as practicable within the ranges specified above.

The following two tests on the mixture, freshly prepared or taken from the stockpile, shall be performed by the contractor in the presence of a PennDOT representative before the samples are sent to the Materials and Testing Division for testing:

1. Water-resistance test--Fifty grams of mixture, whether freshly prepared or taken from the stockpile, shall be heated at 121°C (250°F) in a laboratory oven for 1 h, cooled at 93°C (200°F) in laboratory air, and then placed in 400 mL of boiling distilled water in a 600-mL glass beaker and stirred

Figure 1. Potholes filled with improved formulation (3 PX) and Sylvax (SX).

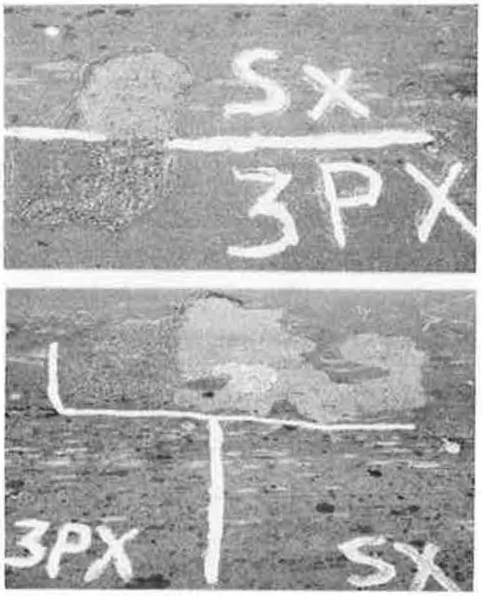
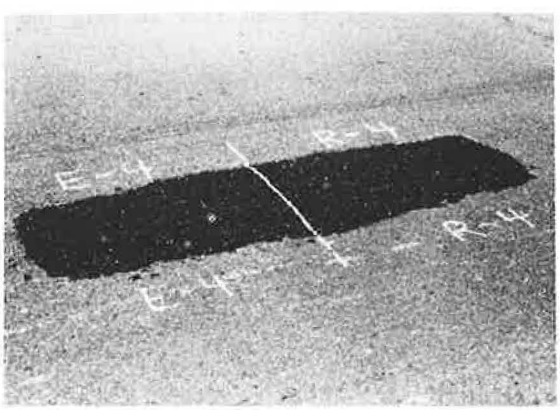



Figure 2. Trucks carrying different mixtures for comparative field evaluations.

Figure 3. Different mixes laid side by side in one patch.



with a glass rod at the rate of 1 revolution/s for 3 min. The water shall be decanted, and the mix shall be spread on an absorbent paper for visual observation of the coating. The aggregate shall be at least 90 percent coated with a bituminous film.

2. Workability test--Approximately 2.3 kg (5 lb) of the mixture shall be cooled to -6.7°C (20°F) in the laboratory. After cooling, the mixtures shall be capable of being broken up readily with a spatula that has a blade length of approximately 203 mm (8 in). This test shall be performed when the mixture is produced or used between November 1 and March 1. If the mixture is not workable at -6.7°C, it shall be rejected and the composition of the mixture shall be properly modified (for example, by increasing the percentage of bitumen residue or by gradation changes).

FIELD EVALUATIONS

The experimental (improved formulation) stockpile patching mixture discussed above was used in April 1977 at two locations: (a) US-22, Lebanon County, Stations 10-50; and (b) the road in front of the PennDOT Testing Laboratory, which carries city traffic. The improved formulation was used along with Sylvax UPM, supplied by Sylvax Chemical Corporation, Great Neck, New York. Sylvax UPM, a proprietary patching material, was determined to be significantly better than the standard cold mixes in field tests conducted by Public Technology, Inc. (4).

Both materials were placed in wet potholes without any preparation. Most of the evaluations conducted in March 1980 indicate that both materials are performing equally well. These patches are shown in Figure 1.

More field installations of these two stockpile patching mixtures were completed during the first two weeks of March 1978 on the various legislative routes and state and U.S. routes given below:

| County | Route | Location |
|---|---|---|
| Cumberland | LR-34, US-11 | North of Carlisle |
| Dauphin | LR-1, PA-147 | South of Halifax |
| | US-22,4; PA-225 | South of Halifax |
| | LR-769, I-83 | John Harris Bridge |
| Indiana | LR-54, US-422 | East of Indiana |
| | LR-63, US-119 | North of Indiana |
| Allegheny | LR-247, PA-51 | South of Pittsburgh |
| | US-22,70 | Liberty Bridge, Pittsburgh |

The weather generally met the criteria established for cold-weather patching with temperatures that ranged from -6° to 2°C (22°-35°F) with occasional snow flurries. The potholes filled ranged in size from about 0.05 to 3.72 $m^2$ (0.5-40 $ft^2$), and from 25.4 to 101.6 mm (1-4 in) deep. Many were wet, and some had ice in the bottom of the hole that was not removed. A total of 42 control patches and 251 Sylvax UPM patches were observed for performance. Most patches were observed regularly and photographed on each occasion to determine the extent of failures as they might occur. The observations were made after 1, 7, and 14 days, and 1, 2, and 6 months. Two of the locations have been observed after one year.

Again, as observed in the 1977 trials, most patches performed well, regardless of the technique or material used. No significant differences could be noted after the last observation. Failures have occurred in the areas surrounding many of the test patches, and additional patches have been placed. Figures 2 and 3 show the field installation of the patches in this comparative study.

LABORATORY EVALUATION OF FIELD MIXTURES

Encouraged by the initial successful results of the improved formulation for the stockpile patching mixture, six engineering districts in Pennsylvania were selected for wide-scale field trials during the

**Table 1. Mix test data: good workability.**

| Item | District | Gradation (percent passing) 9.5 mm | 4.75 mm | 2.36 mm | 0.075 mm | Residue Asphalt (%) | Penetrometer Reading (N) | Marshall Test at -6.7°C Stability (N) | Flow (mm) |
|---|---|---|---|---|---|---|---|---|---|
| Sample | | | | | | | | | |
| 6444 | 4 | 100 | 72 | 27 | 2 | 5.0 | 489 | 3020 | 1.62 |
| 6451 | 9 | 100 | 58 | 26 | 1 | 4.0 | 445 | 5284 | 1.88 |
| 6783 | 8 | 100 | 62 | 28 | 2 | 3.5 | 623 | 4653 | 1.88 |
| 6872 | 8 | 100 | 79 | 23 | 2 | 5.2 | 578 | 1793 | 2.68 |
| 6887 | 10 | 100 | 69 | 27 | 1 | 5.6 | 445 | 4110 | 2.75 |
| 6888 | 8 | 100 | 70 | 26 | 2 | 4.3 | 534 | 5698 | 1.88 |
| 6906 | 9 | 100 | 50 | 27 | 2 | 4.7 | 267 | 1966 | 2.1 |
| 79-24 | 2 | 100 | 52 | 25 | 2 | 4.2 | 534 | 5623 | 2.25 |
| 13145 F | 8 | 100 | 65 | 26 | 2 | 4.4 | 356 | - | - |
| Mean | | 100 | 64 | 26 | 1.78 | 4.54 | 476 | 4017 | 2.12 |
| Standard deviation | | - | 9.6 | 1.4 | 0.44 | 0.65 | 111 | 1584 | 0.40 |
| 95 percent confidence limit | | | | | | | | | |
| Low | | 100 | 45 | 23 | 0.9 | 3.2 | 254 | 850 | 1.32 |
| High | | 100 | 83 | 29 | 2.7 | 5.8 | 698 | 7184 | 2.92 |

Note: 1 mm = 0.039 in; 1 N = 0.225 lbf.

**Table 2. Mix test data: fair workability.**

| Item | District | Gradation (percent passing) 9.5 mm | 4.75 mm | 2.36 mm | 0.075 mm | Residue Asphalt (%) | Penetrometer Reading (N) | Marshall Test at -6.7°C Stability (N) | Flow (mm) |
|---|---|---|---|---|---|---|---|---|---|
| Sample | | | | | | | | | |
| 6302 | 4 | 100 | 51 | 27 | 3 | 5.3 | 801 | 5578 | 2.38 |
| 6445 | 4 | 100 | 75 | 26 | 3 | 5.1 | 578 | 4341 | 1.62 |
| 6763 | 2 | 100 | 54 | 24 | 2 | 3.8 | 311 | 4070 | 1.62 |
| 6847 | 2 | 100 | 51 | 18 | 2 | 4.1 | 623 | 1922 | 3.25 |
| 6848 | 2 | 100 | 51 | 16 | 3 | 4.6 | 445 | 3879 | 3.15 |
| 6917 | 2 | 100 | 52 | 24 | 2 | 3.9 | 445 | 2304 | 1.35 |
| 6918 | 2 | 100 | 48 | 16 | 2 | 3.7 | 1068 | 1294 | 1.38 |
| 13145 C | 8 | 100 | 52 | 27 | 2 | 3.9 | 623 | 4301 | 1.50 |
| 123 | 9 | 100 | 74 | 24 | 3 | 4.2 | 756 | 4422 | 4.50 |
| Mean | | 100 | 56 | 22 | 2.44 | 4.29 | 627 | 3567 | 2.30 |
| Standard deviation | | - | 10.3 | 4.5 | 0.53 | 0.58 | 227 | 1401 | 1.10 |
| 95 percent confidence limit | | | | | | | | | |
| Low | | 100 | 35 | 13 | 1.4 | 3.1 | 173 | 765 | 0.10 |
| High | | 100 | 77 | 31 | 3.5 | 5.4 | 1081 | 6370 | 4.50 |

Note: 1 mm = 0.039 in; 1 N = 0.225 lbf.

1978-1979 winter. Whereas some producers met the specification requirements (cited earlier), others were either excessive in the 0.075-mm (minus 200) fraction or deficient in residual bitumen content. A laboratory evaluation of these accepted and rejected field mixtures was conducted in 1979. The following tests were conducted:

1. Extraction analysis--Aggregate gradation and residual binder content were determined.
2. Subjective workability test--The mix was cooled to -6.7°C (20°F) and its capability of being broken up readily with a spatula that had a blade length of approximately 203 mm (8 in) was observed. The workability was noted as good, fair, or poor.
3. Penetrometer test--An attempt was made to quantify the workability. The mix was placed in a Marshall mold and compacted at ambient temperatures by using two blows of a Marshall hammer to level the mix and to obtain consistency in packing. A concrete penetrometer (Soil Test CT-421) was used to measure the maximum force required to penetrate the surface. This penetrometer has a range from 0 to 3114 N (0-700 lb) and is graduated in 89-N (20-lbf) increments.
4. Marshall test--After the penetrometer test, the mix was compacted with 50 blows on both sides of the specimen. Since it was not possible to extract the specimen from the mold and test at ambient temperatures without damage, the specimen in the mold was cooled to -6.7°C (20°F), extracted, and tested for Marshall stability and flow at this low temperature.

The mix test data obtained by use of the above procedures are given in Tables 1-3, grouped by subjective workability rating. At the present time, the subjective workability test is the only reliable tool available to evaluate the mix. Figure 4 shows the effect of dust content (minus 200 fraction) and residual bitumen content on the mix workability at -6.7°C. Specification limits for a stone mixture (water absorption less than 1 percent) are shown by dotted lines on this figure and represent a minimum residual bitumen content of 4.5 percent (4.0 percent based on extraction) and a maximum of 2 percent minus 200 fraction (2.4 is rounded off to 2). The effect of the minus 200 fraction on the mix workability (or stiffness) is clearly evident. At dust content levels of 3 and 4 percent, even the increased bitumen content does not appear to help workability. This laboratory evaluation of the mixtures produced in various bituminous concrete plants lends support to the development of the new formulation.

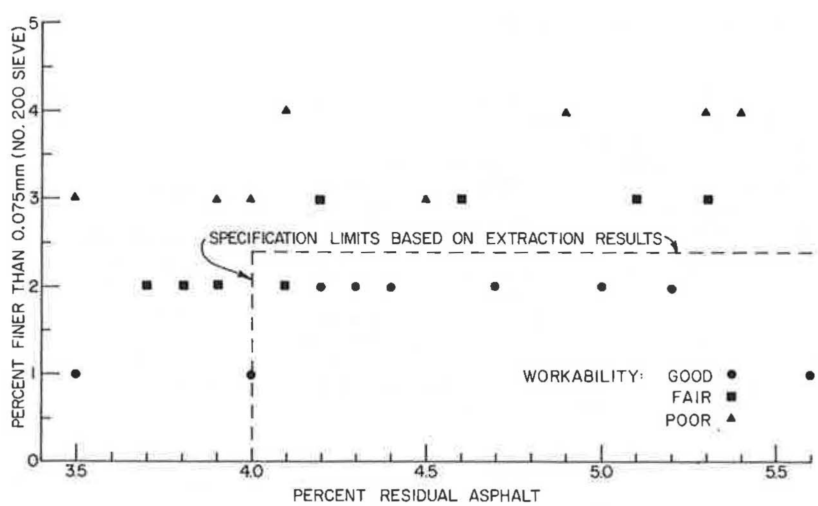
Penetrometer test data (Tables 1-3) indicate a general trend toward higher readings for the mix-

**Table 3. Mix test data: poor workability.**

| Item | District | Gradation (percent passing) 9.5 mm | 4.75 mm | 2.36 mm | 0.075 mm | Residue Asphalt (%) | Penetrometer Reading (N) | Marshall Test at -6.7°C Stability (N) | Flow (mm) |
|---|---|---|---|---|---|---|---|---|---|
| Sample | | | | | | | | | |
| 6441 | 2 | 100 | 56 | 25 | 3 | 4.5 | 712 | 4 225 | 1.88 |
| 6446 | 4 | 100 | 73 | 27 | 4 | 5.4 | 890 | 4 724 | 2.00 |
| 6627 | 2 | 100 | 67 | 24 | 4 | 4.1 | 534 | 5 587 | 1.88 |
| 6768 | 2 | 100 | 54 | 25 | 3 | 3.9 | 1334 | 5 080 | 2.50 |
| 6927 | 9 | 100 | 70 | 22 | 3 | 4.0 | 934 | 8 727 | 2.12 |
| 6932 | 2 | 100 | 58 | 27 | 4 | 4.9 | 1601 | 9 043 | 2.00 |
| 6933 | 2 | 100 | 55 | 27 | 4 | 5.3 | 1112 | 9 768 | 1.75 |
| 6922 | 9 | 100 | 51 | 24 | 3 | 3.5 | 801 | 3 790 | 2.38 |
| Mean | | 100 | 60 | 25 | 3.50 | 4.45 | 988 | 6 370 | 2.05 |
| Standard deviation | | - | 8.3 | 1.8 | 0.53 | 0.69 | 347 | 2 406 | 0.25 |
| 95 percent confidence limit | | | | | | | | | |
| Low | | 100 | 43 | 21 | 2.4 | 3.1 | 294 | 1 557 | 1.55 |
| High | | 100 | 77 | 29 | 4.6 | 5.8 | 1681 | 11 183 | 2.55 |

Note: 1 mm = 0.039 in; 1 N = 0.225 lbf.

**Figure 4. Mix workability at -6.7°C (20°F).**




tures as workability decreases. But the data are inconsistent, and this test has failed to quantify the workability parameter. The configuration of aggregate particles at the spot tested seems to obscure the test data. A vane-shear type of device, to measure the maximum torque, is probably more appropriate.

Marshall test data (Tables 1-3) generally indicate higher Marshall stabilities for the mixtures with poor workability. Again, this test is not sensitive enough to evaluate the stockpile patching mixtures. The mixtures with good workability densify readily during the Marshall compaction and thus can also give higher stability values. The mixtures with poor workability can also give higher stability values on account of higher dust content and/or deficient bitumen content.

## FIELD PROBLEMS

The improved formulation was used by six Pennsylvania engineering districts in the 1978-1979 winter and by all 11 engineering districts in the 1979-1980 winter. Mix handling and performance have been generally satisfactory. In some instances, failures were reported, such as partial or complete loss of mix from the pothole and shoving of the mix in the pothole. The following mix characteristics and/or placement techniques are believed to be the probable causes of these failures:

1. Stripping of asphalt binder from the aggregate due to inadequate and/or improper type of antistripping agent in the binder;
2. Deficient binder content, which caused the mix to ravel, or excessive binder content, which caused the mix to shove (excessive binder will result at the bottom of the stockpile if the mix has drained);
3. Rounded or subrounded gravel particles (lack of aggregate angularity to provide good interlocking);
4. Excessive use of tack coat;
5. Potholes deeper than 76 mm (3 in) not compacted in layers; and
6. Excessive fines in the mix.

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REFERENCES

1. W. Bortree and D. Mellott. Value Engineering Studies: Bituminous Patching. Pennsylvania Department of Transportation, Harrisburg, Oct. 1976.
2. L. O'Brien. Value Engineering in Pothole Patching. Rural and Urban Roads, Oct. 1976.
3. Bituminous Patching Mixtures. TRB, Synthesis of Highway Practice 64, Sept. 1979.
4. Field Test Evaluation Program: Sylvax UPM. Public Technology, Inc., Washington, DC, 1977.

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# Asphalt Mixtures: Comparative Analysis of Characterization for Design

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**Direct relations among manifestations of pavement distress, materials evaluation, and techniques of asphalt mix design are desirable in the design of asphalt mixtures. Static and repeated-load testing, which estimate properties that have direct relations with distress, were used to evaluate asphalt mixtures designed and prepared by using the Texas blackbase design procedure. Three mixtures containing three different aggregate types and a range of asphalt contents were tested and evaluated at three test temperatures. Optimum asphalt contents were determined for various engineering material properties, including tensile strength, fatigue life, static modulus of elasticity, and permanent deformation. The differences between design asphalt contents and the values derived from experimental tests were often quite significant, depending on test temperature and material type. The asphalt contents obtained by the Texas procedure were found to be generally higher than the optimum values identified for distress-related material properties. Optimum asphalt contents for static tensile properties were generally less than those for repeated-load properties.**

The performance of asphalt pavements is frequently characterized by the presence or absence of fracture, distortion, or disintegration. These various distresses may manifest themselves through thermal or shrinkage cracking, fatigue cracking, permanent deformation or rutting, stripping, raveling, or other phenomena (1).

Direct relations among distress, materials evaluation, and mix-design techniques are obviously desirable. This investigation was designed to evaluate testing procedures that produce properties that can be directly related to distress through a comparison with a currently used mix-design procedure. The resulting data and analyses produced, in effect, an evaluation of a typical mix-design procedure that indicates how well this procedure could normally be expected to relate to pavement distress. The procedure was the blackbase mix-design procedure used by the state of Texas (2,3), which includes techniques for selecting the optimum asphalt content for both laboratory and field mixtures of blackbase that have maximum aggregate sizes of 45 mm (1.75 in).

## SELECTED TEST METHODS

The tests selected for this evaluation were the static and repeated-load indirect tensile tests, which are documented elsewhere (4-8) and are currently used by several agencies. Both forms of the indirect tensile test measure the tensile properties of pavement materials that directly relate to the common tensile failure and provide information on tensile strength, modulus of elasticity, and Poisson's ratio for both static and repeated loads, fatigue characteristics, and permanent deformation characteristics of pavement materials.

## EXPERIMENTAL PROGRAM

The basic experimental approach was to compare the engineering properties of blackbase mixtures at various asphalt contents with the properties of mixtures at the design asphalt content obtained by using the current Texas design procedure. The engineering properties were determined at 10°, 24°, and 38°C (50°, 75°, and 100°F). Three asphalt mixtures currently used in the construction of actual pavements by the Texas State Department of Highways and Public Transportation (TSDHPT) were tested by using the static and repeated-load indirect tensile tests and the unconfined compression test.

### Materials

The three basic aggregate combinations used in this investigation were obtained from Eagle Lake, Lubbock, and Lufkin, Texas. Each of these aggregates has been used in pavements and has performed satisfactorily; generally, however, when mixtures that contained these aggregates were tested in unconfined compression by TSDHPT, only the Lubbock mixture satisfied the specified strength requirements.

The Eagle Lake aggregate combination was a mixture of four different aggregates that might generally be described as a smooth, angular, nonporous, crushed river gravel. The asphalt cement mixed with the Eagle Lake aggregate was an AC-20 produced by the Exxon refinery in Baytown, Texas, the same as that used for an actual blackbase construction.

The Lubbock aggregate was a rough, subangular, porous crushed limestone (caliche). The asphalt cement used with this material was an AC-10 produced by the Cosden Oil refinery in Big Spring, Texas.

The Lufkin aggregate was a combination of two pit sands, mixed in equal proportions to obtain the desired gradation. The asphalt cement was an AC-20 produced by the Texaco refinery in Port Neches, Texas.

### Specimen Preparation

All specimens were mixed and compacted according to Texas test method Tex-126-E except that the mixing