TRC 63

Research

USE OF PAVEMENT MILLINGS IN COLD MIXES

TRC-63

Prepared By
Arkansas State Highway and Transportation Department
Materials and Research Division
Research Section
In Cooperation With
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16. Abstract

Thirteen recycling agents were tested with ten stockpiles of asphalt concrete pavement millings for use in cold mix recycling. Six of the thirteen agents were emulsions and the rest were classified as rejuvinators. The aggregates in the ten stockpiles were limestone, novaculite, syenite, gravel, and sandstone. The physical properties of the asphalt cement in the pavement millings were investigated.

The recycling agents and pavement millings were tested by a modified marshall mix design procedure plus a visual rating system. Some mixes were tested for retaind strength by immersion-compression testing.

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Materials and Research Division

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FINAL REPORT

Transportation Research Project No. 63

July, 1984

GAINS, FINDINGS, AND CONCLUSIONS

The primary gains, findings, and conclusions of this study are as follows:

1. The asphalt content of the stockpiles vary over a wide range, prohibiting the use of one design formula.

2. The ductilities of the asphalt cement in these stockpiles are extremely varied.

3. The compacted mixes containing modifying agents are extremely moisture sensitive.

IMPLEMENTATION STATEMENT

The results of this investigation indicate that a modified Marshall procedure can be used to evaluate cold recycled mixes in the laboratory. All mixes tested in this study performed poorly. Therefore, use of this material on medium and high traffic roads is not recommended. The recycled mixes were so moisture sensitive that the application of a seal coat over roadways using a cold recycled mix is warranted.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The recycling of stockpiled pavement millings for use in cold mixes has received considerable attention in recent years because of the economic benefits involved with using a material that may normally be wasted. The Arkansas Highway and Transportation Department recognized the benefits of using this material as low volume road pavement material. The possible use of the pavement millings by the Department was limited to cold mix construction in this study.

The primary objective of this research was to develop a cold mix recycling design procedure that would be readily usable by all district maintenance crews. Ideally, the cold mix design should include the application of some type of modifier to improve the engineering properties of the material. The addition of binder and/or aggregate to improve the properties of the stockpiled material was not included in this research.

Thirteen modifying agents were tested with ten stockpiles of pavement millings to determine if acceptable mixes could be produced. The mixes were rated visually and tested for normal Marshall mix properties. Water sensitivity of these mixes was evaluated by vacuum saturation plus immersion compression testing.

REVIEW OF COLD RECYCLING MIX DESIGNS

Cold mix recycling may be defined as the reuse of existing pavement materials to produce an improved roadway without the addition of heat. Ideally, the laboratory mix design should be modified to simulate the actual field conditions, thereby giving an adequate indication of the actual behavior and performance of the mix in the field. For a mix design to accomplish such a task, the salvaged material must be analyzed and the mixing of this material with other aggregates and/or improving agents should be evaluated.

At the time this study was initiated there was no accepted procedure for the design of cold recycled asphalt mixtures. However, most of the literature reviewed shows that a general mix design method for cold mix recycling should consist of the following steps:

1. Evaluation of salvaged materials
2. Selection of modifier type and general amount
3. Preparation and testing of mixtures
4. Selection of optimum value of modifier
5. Final testing of mix with optimum modifier content.

Evaluation of Salvaged Materials

To begin an evaluation, a representative sample of the pavement material to be recycled should be obtained. Variations in pavement materials along the length of the recycled pavement should be noted. Each material may need to be evaluated separately. Extraction and Recovery of the asphalt and aggregate should be performed at each location sampled if material variability is expected. Aggregate recovered from recycled material should be tested for gradation. Asphalt content, penetration, and viscosity of the asphalt should be determined also.

Selection of Modifier Type and General Amount

Several researchers have reported that the asphalt demand of the recycled material can be estimated by the following equation:

$$P = \left[(4R+7S+12F)/100\right] \cdot 1.1$$

Where: P = Total % asphalt required in recycled mix (old asphalt + recycling agent)
R = Rock (retained on #8 seive)
S = Sand (passing #8 sieve; retained on #200)
F = Fines (passing #200 seive)

This equation was intended to give only approximate blending percentages. The use of this equation for selection of amount of modifier without further laboratory study was not recommended.

Many recycling agents or modifiers are available to restore the old asphalt characteristics to an acceptable level. It is generally believed that a modifier should serve to produce a mix that exhibits workability, stability, and durability. Therefore, an evaluation of the effect of the various modifiers on the properties of the asphalt cement may become necessary. The following tests may be useful in determining trial amounts of modifier needed in the recycled asphalt cement.

1. Ductility
2. Penetration
3. Viscosity

The most efficient means of testing a modifier with an aged asphalt involves the use of either an additive - penetration or an additive-viscosity curve. This curve can be produced by blending different percentages of modifier with the recycled asphalt and testing the blend for either penetration or viscosity. A curve can then be drawn to best fit the relationship between the added modifier percentage and penetration/viscosity. From this curve, the amount of modifier needed to produce a desired penetration/ viscosity can be easily found. The blended asphalt and modifier may be tested to determine the ductility of binder at the desired penetration/viscosity, or each blend used in the additive-penetration curve can be tested for ductility. These tests in conjunction with the estimated asphalt demand have been reported to give a good starting point in blending for the combined mix tests.

Preparation and Testing of Mixtures

Many different methods of mix preparation and testing have been studied. Several state agencies have reported that between 1% and 3% water should be added to the mix during testing to emulate the amount of moisture that may exist in the field when cold mix recycling is used. Others do not mention the use of water in the mix. Another difference in the procedure is the amount of reaction time needed for the modifier to react completely with the residual asphalt. Most mix designers have reported that some modifiers require a certain amount of reaction time before compaction. However, no time frame is given. Other designers have found no significant difference in strengths from prolonged reaction times. However, minimum reaction times of 24 hours or more have been reported by some to be necessary to produce the best results.

Most designers compact these laboratory mixes by standard Marshall procedure. However, the compaction is normally performed at room temperature. Some procedures allow for the specimens to set for an additional 24 hours in the molds at room temperature. The specimens are broken according to the Marshall method, however, the temperature of the sample at break has been reported to be 72°F or 140°F. There are good reasons for using both temperatures. At 72°F, the stability is found nearer to the field compaction temperature. However, the 140°F breaking temperature allows a comparison of strength to that of normal mixes. The designer may have a better "feel" for stability and flow values at standard Marshall temperature.

Selection of Optimum Value of Modifier

In addition to stability and flow, the percent air voids of the compacted mix is needed. It has been recommended that 3 different percentages of modifier be tested; one at the estimated optimum, one above optimum, and one below optimum. By using three points a method similar to a 3 point Marshall design can be used to select the final modifier amount.

Final Testing of Mix

In addition to the standard Marshall tests, a water sensitivity analysis has been recommended by some researchers. Immersion Compression, split tensile, or Lottman procedure may be used for this type of analysis. High retained strengths are not expected but the mix should have some retained strength. If the samples break apart during mositure conditioning, re-evaluation may be necessary.

It has been reported that resilient modulus may be the best single test to identify the effect of the modifier on the mixture. This test is considered sensitive to the properties of the binder and will help define the optimum consistency of the blended mix. Modulus values of 200,000 psi should be expected on recycled mixes using the apparatus developed by Schmidt at Chevron Research.

Comments

The mix design methods discussed in this chapter concerned only mixes that will not require any additional aggregate in the mix. Normally, the addition of new aggregate will be given consideration if the gradation of the salvaged material or its quality is unsatisfactory. New aggregate has been reported to: (1) satisfy gradation requirements; (2) improve skid resistance for surface courses; (3) improve stability, durability, and flexibility of the mix. If satisfactory mixes cannot be made with recycled aggregate alone, additional material may be needed.

TEST METHODS AND MATERIALS INVESTIGATED

Ten stockpiles of pavement millings from milling operations were sampled for this investigation. Twelve modifiers were tested for use in producing a mix that could be cold mixed and placed on the roadway for low volume road improvement. Of the twelve modifiers tested, 7 were emulsions and 5 were similar to cutback agents. The addition of other aggregates or asphalt cements was not considered in this research effort.

Materials Investigated

The stockpiles sampled for use in this study were located in different areas of the state. The exact locations are given in Table 1. Figure 1 shows the areas of the state these stockpiles were found. The aggregate type of the stockpiled material included gravel, limestone, syenite, and novaculite. The asphalts in the stockpiles were of different ages, grades, and sources. In general, the stockpiles of pavement millings varied widely from site to site.

A total of 12 modifiers were tested in this study. Six of the 12 were emulsions from Riffe Petroleum Co., and one emulsion was produced by Tosco Oil Co. Four of the remaining five were commercially available "rejuvenators". The remaining modifier tested was a MC-250 cutback. Table 2 lists the modifiers used in this research.

Sampling Procedure

Considerable effort was required to sample the stockpiles. The stockpiles were often crusted over, requiring the use of heavy equipment such as front end loaders to obtain a sample. In 8 of

Table 1

Location of Stockpiles

Sample (No.)	Location	Date Sampled
1	Jct S.H. 70 and U.S. 75	12-29-80
2	Jct S.H. 42 and I-55	12-29-80
3	Malvern, U.S. 67	12-19-80
4	Conway Maintenance Yard	12-18-80
5	North Little Rock	12-18-80
6	Magnolia, U.S. 79	12-17-80
7	Texarkana Maintenance Yard	12-17-80
8	Fort Smith, Hwy 22 and I-540	12-18-80
9	West Fork	12-18-80
10	Jefferson & Pul. Co. Lines	12-19-80

Figure 1. Distribution of stockpiles in Arkansas

Table 2

Modifiers Tested

Modifier Number	Description	Type
1	Riffe A	Emulsion
2	Riffe B	Emulsion
3	Riffe C	Emulsion
4	Riffe D	Emulsion
5	Riffe E	Emulsion
6	Riffe F	Emulsion
7	Nuflex 330	Rejuvenator
8	Nuflex 100	Rejuvenator
9	Paxole 857	Rejuvenator
10	Paxole 1009	Rejuvenator
11	MC 250	Cutback
12	Tosco AE 173-23	Emulsion

the 10 sites two samples were secured because of the varied appearance of the stockpiles at each site. Each sample was reduced to testing size in the laboratory by mechanical splitter and in accordance with AASHTO T248.

Testing of Salvaged Material

Samples from each stockpile were extracted to determine asphalt content and aggregate gradation by AASHTO test method T164. The asphalt cement was recovered in accordance with AASHTO T170 for further testing. The following physical properties of the asphalt cement were measured:

1. Penetration at 77°F
2. Absolute viscosity (140°F)
3. Kinematic viscosity (275°F)
4. Ductility (cm)

Sample Preparation and Testing

Samples were taken from each stockpile and mixed with the modifiers used in this study. The original percentage of modifier used with the recycle material was varied from 2 to 4 percent of the total weight of the mix. All mixing was performed at room temperature. After mixing, the samples were placed on brown paper and allowed to cure overnight. A rating panel of qualified members of the Materials and Research Division of the Arkansas Highway and Transportation Department was formed to examine these mixes.

The optimum modifier contents chosen were selected for further testing. These samples were mixed and molded by Standard Marshall procedure at room temperature. The compacted samples were allowed to cure overnight at room temperature, then divided into two groups. One group was tested for stability at room temperature while the other was tested in the Marshall apparatus at 140°F. A few selected samples were tested for retained stability by the immersion compression test.

TEST RESULTS AND DISCUSSION

The purpose of this study was to investigate the use of pavement millings to produce an asphalt mix acceptable for low volume roads. Modifiers were tested for improving the properties of the mixes and allowing adequate compaction. The mixes were compacted in the laboratory and tested for stability by the Marshall method. A number of samples were selected for determining the water sensitivity of the mixes using pavement millings and modifiers.

Evaluation of Pavement Millings

The pavement millings were tested for the following:

1. asphalt content
2. gradation of aggregates
3. physical properties of the asphalt cement

The aggregates of the stockpiles were from several different sources. The aggregate types of the stockpiles are shown in Table 3. These different types of aggregates are limestone, sandstone, syenite, novaculite, and gravel. The gradation of these aggregates are given in Table 4. Examination of the gradations show that the majority of the pavement milling stockpiles no longer meet specifications for a Type II surface mix. Only samples 3, 6, and 7 meet this specification. Six of the samples were slightly finer than normal Type II mixes. Only sample number 10 was coarser than the Type II specification limits. Figure 2 shows the Type II limits along with the coarsest and finest samples evaluated. The stockpiles of pavement millings were produced by using cold milling equipment on the pavement. Generally, only the top 1.5 to 2.0 inches of the pavement were milled. Since the majority of the material milled from the old pavement was the surface layer, it

Table 3

Aggregate Types of Stockpiles

Sample #	Aggregate
1	Limestone
2	Limestone
3	Novaculite
4	Sandstone
5	Syenite
6	Gravel
7	Gravel
8	Sandstone
9	Sandstone
10	Limestone

Table 4

Seive Analysis of Aggregates

Sample	Mixture Composition (Total % Retained) 3/4"	1/2"	3/8"	#4	#10	#40	#80	#200
1	0	1.7	5.8	23.9	47.5	72.7	83.6	89.0
2	0	0.5	4.6	19.1	41.0	68.1	81.2	88.4
3	0	2.6	9.1	32.9	55.3	68.5	86.9	92.5
4	1.5	6.9	14.5	35.3	52.5	72.4	84.7	90.2
5	0	1.7	4.0	20.2	42.4	66.7	81.3	89.4
6	0	1.2	7.0	29.8	48.5	69.1	85.2	92.7
7	0	8.4	17.3	36.0	51.3	72.3	88.6	93.3
8	0	0.2	5.1	27.9	48.6	67.1	78.7	88.4
9	0	2.1	5.0	20.0	41.3	64.0	77.0	85.5
10	5.4	15.8	26.7	47.7	62.8	75.1	83.4	92.0
Specification (Type 2 Surface)	0	3-15		25-45	45-60	68-80	80-92	90-96

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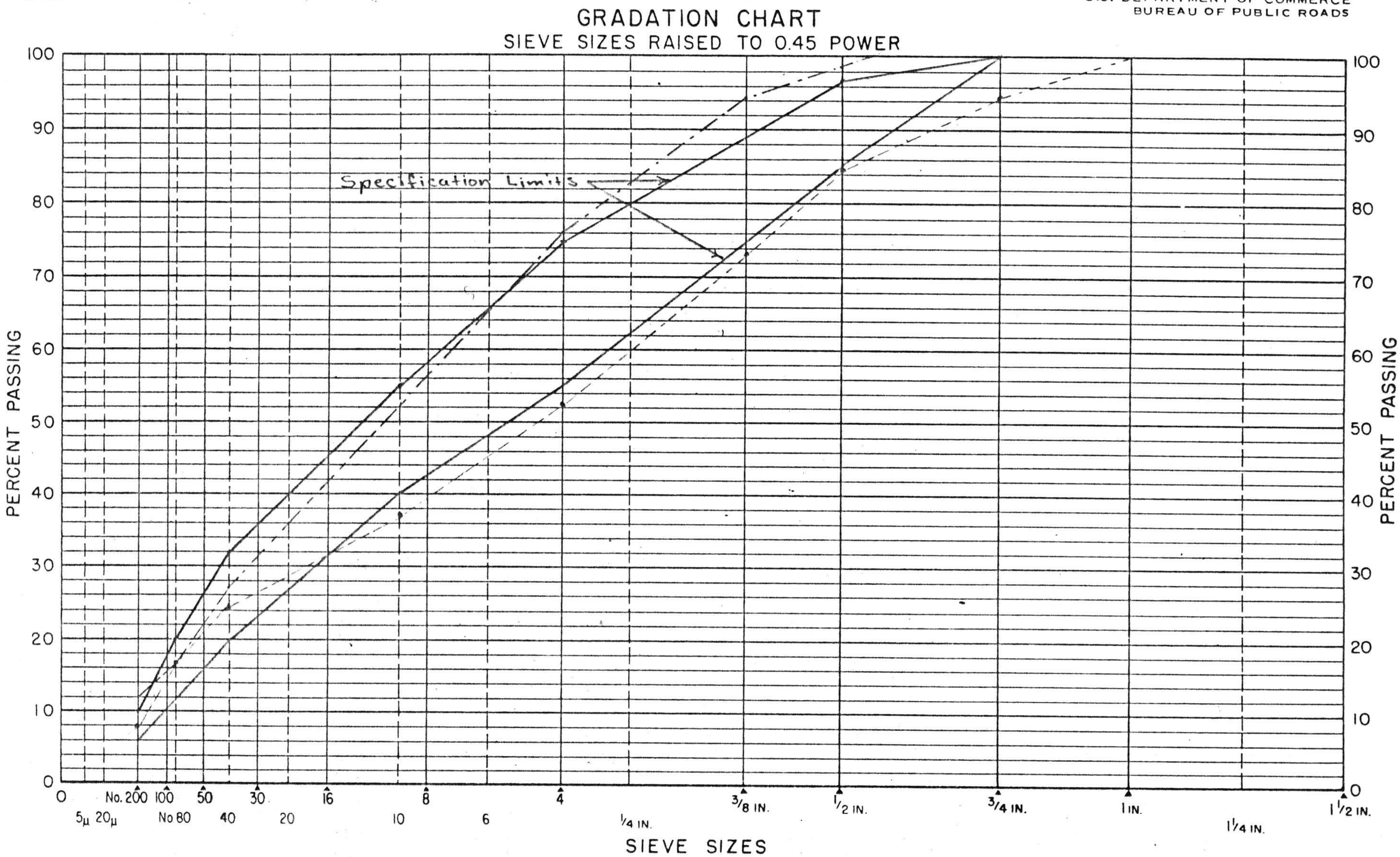

▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES	Identification of gradations: —·— Sample #10 Gradation - - Sample #1 Gradation	Sheet No. / Date

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Figure 2

was believed that the gradation of the material would be similar to that of the surface course. The reason for the generally finer gradation may be due to the action of the milling machine. The machine may chip and break enough aggregate particles to give the millings a slightly finer gradation. The reason for the coarser size of sample 10 is not known.

The asphalt content of each stockpile was determined by AASHTO T164. The asphalt contents of the stockpiles are shown in Table 5. The average asphalt content of the stockpiles was 5.4 percent. The range in asphalt content from these samples was 4.0 percent for sample number 10 to 6.6 percent for sample number 9. A standard deviation of 0.7 percent was found between samples. These results indicate that the asphalt contents of the stockpiles are varied. Therefore, the asphalt demand for the individual stockpiles may be varied also.

The results of the tests on the physical properties of the asphalt cement in each stockpile are given in Table 6. None of the results shown in this table were averaged because of the extreme variability between some of the test results from the same stockpile. This can be seen by examining the results of the ductility test. For example, the ductility of two samples tested in stockpile #1 vary widely, (76 cm and 19 cm). A variation of this magnitude would normally cause the samples to be retested. However, the penetration and 140^{O}F viscosity values are within acceptable limits with 32 and 30 for penetration, and 18,035 poises and 17,557 poises for absolute viscosity. Many stockpile samples had similar inconsistancies, while others did not show this trend. The reasons for this are unknown,

Table 5

Asphalt Content of Stockpiles

Sample No.	Location	Asphalt Content (%)
1	Jct. S.H. 70 and U.S. 75	5.4
2	Jct. S.H. 42 and I-55	5.2
3	Malvern	6.0
4	Conway	4.6
5	North Little Rock	6.0
6	Magnolia	6.0
7	Texarkana	4.9
8	Fort Smith	5.5
9	West Fork	6.3
10	Jefferson & Pulaski County	4.0

Table 6

Physical Properties of A.C.

Stockpile #	Penetration 77°F	Absolute Visc (140°F) Poises	Kenematic Visc (275°F) Centistokes	Ductility (cm)
1	32	18,035	1097	76
1	30	17,557	1194	19
2	28	13,958	1166	102+
2	26	14,411	1256	100+
3	46	11,460	899	100+
3	30	18,868	1129	26
4	24	33,675	1375	13
4	24	27,547	1299	13
5	42	8,530	895	100+
5	22	not run hard	2542	5
6	33	32,582	1732	19
7	39	11,524	880	57
7	38	14,774	981	57
8	33	7,473	691	95
8	35	9,252	850	73
8	24	42,147	1544	8
8	35	5,536	636	138+
9	27	22,681	1280	20.5
9	36	14,134	994	98
9	28	24,048	1215	19
10	39	20,060	1222	15
10	34	47,112	1964	6.8

however, these results seem to indicate that a direct relationship between ductility with penetration or viscosity does not exist. Inspection of the data from samples 7 and 10 illustrated this point. A penetration of 39 from sample 10 relates to a ductility of 15 cm while sample 7 with a penetration of 39 has a ductility of 57 cm.

Five of the ten stockpiles have very low ductilities; three have very high ductilities, while only two are in the medium range. The penetration ranges from 22 to 46. The range of the penetrations is considered small for asphalts of different ages. Furthermore, if a three stage rating similar to the ductility is used, all samples would be classified as hard. The absolute and kinematic viscosities show that most of the samples would be classified in the high viscosity range with some in the medium viscosity area and only two or three test results that could be in the low viscosity range. These results show that, in general, while penetration and viscosity between stockpiles are somewhat similar, the ductility of the asphalts may differ widely.

Mixing Tests

The first evaluation of the addition of modifier to pavement millings was by a rating panel. Four members of the Materials and Research Division rated the mix for cohesion, rich/dry appearance, and uniformity. The results of these tests are reported in the Appendix. The amount of modifier added to the mixes ranged from 2% to 4% of the total mix. The Tosco emulsion was not used in this phase of testing because it was not available until a later date. Results of this test show that the Riffe products were considered acceptable at low concentrations (2%), while the rejuvenators were rated as acceptable at high concentrations. The MC-250 was never rated as acceptable by the rating panel over the range of concentrations tested.

The results of this phase were unexpected. It was believed that the emulsions used in this test, because of their composition, would require higher concentrations in the mix to produce an acceptable material. However, the rejuvenators required an average of 2% higher concentrations to produce an acceptable mix.

Mix Design Tests

Several designs were mixed and tested for stability, flow, air voids, and retained stability at standard 50 blow Marshall compaction at room temperature. The mixes were tested for stability at two temperatures, 77°F and 140°F. These test results are shown in Table 7. The 140°F stability of these samples were found to be very low. The stabilities averaged approximately 220 lbs. The 75°F stabilities were larger with an average of 1800 lbs. However, it is not known if an 1800 lb. stability at 75°F is acceptable since the relationship between 75°F stability and 140°F stability is not known. The flow values show that the mixes are extremely weak. Even at 75°F, the flow averaged approximately 0.3 inches. These extremely low stabilities and high flows indicate that these mixes may be unacceptable if they are to be considered in the same range of structural coefficients for asphaltic materials.

The retained stabilities of the mixes tested were non existant. The samples simply broke apart during moisture conditioning. It is believed that the vacuum saturation phase caused the sample failures. The high air void content (10% or greater) probably contributed to this nonexistant retained strength. These results may show that

Table 7

Marshall Stability and Flow

Number	Modifier (Type)	Compaction Temp (^{o}F)	Break Temp (^{o}F)	Stability (lbs)	Flow (.01")	Retained Stab (lbs)
1	Riffe E	75	140	250	30	-
2	Nuflex 100	75	140	150	32	-
3	Paxole 857	75	140	225	30	-
4	MC250	75	140	250	30	-
5	Riffe E	75	75	625	25	*
6	AE 173-23	75	75	2000	35	*

* Samples were ruptured during moisture conditioning.

strength greater than a normal untreated base material may not be expected if moisture infiltrates the mix. Overall, these mix design tests indicate that if cold mixes are to be used in the field, a structural strength nearer to base material should be used.

CONCLUSIONS

Within the limitations of the laboratory test procedures and for the range of materials utilized in this investigation, the following conclusions are made.

1. The asphalt content of the stockpiles vary over a wide range.
2. The gradation of a stockpile after cold milling will normally be finer than the original mix.
3. The ductility of the asphalt contained in the stockpiles is extremely varied.
4. The material compacted at room temperature had such undesirable properties that its use in lieu of any treated layer is suspect.
5. The compacted mixes are extremely moisture sensitive.

RECOMMENDATIONS

1. The mixes tested should be investigated further to determine the effect of moisture during compaction.

2. The effect of reaction time on the density of the mixtures should be evaluated. This reaction time was not considered in this study.

3. The results of the compacted mixes are such that the use of new materials with these mixes to improve their properties should be investigated.

A P P E N D I X

Cold Mix Trial #1

2% rejuvenator (total wt basis)

West Fork Stockpile

1.	Riffe A	-	acceptable
2.	Riffe B	-	acceptable
3.	Riffe C	-	unacceptable - low cohesion properties
4.	Riffe D	-	unacceptable - low cohesion properties
5.	Riffe E	-	acceptable
6.	Riffe F	-	unacceptable - low cohesive properties
7.	Nuflex 330	-	unacceptable - appears rich with low cohesiveness
8.	Nuflex 100	-	unacceptable - rich appearance, no cohesion
9.	Paxole 857	-	unacceptable - low cohesion
10.	Paxole 1009	-	?
11.	MC-250	-	unacceptable - rich, low cohesion
12.	AE-173-23	-	not tested

Cold Mix Trial #2

3% rejuvenator West Fork Stockpile

Riffe A	-	undetermined	low cohesion
Riffe B	-	unacceptable	very low cohesion
Riffe C	-	unacceptable	no cohesion
Riffe D	-	unacceptable	no cohesion
Riffe E	-	unacceptable	no cohesion
Riffe F	-	unacceptable	no cohesion
Nuflex 330	-	undetermined	low cohesion
Nuflex 100	-	unacceptable	no cohesion, rich
Paxole 857	-	unacceptable	no cohesion, rich
Paxole 1009	-	unacceptable	no cohesion, rich
MC-250	-	unacceptable	no cohesion, very rich
AE 173-23	-	not tested	

Cold Mix Trial #3

4% rejuvenator West Fork Stockpile

All Riffe products	-	unacceptable	-	no cohesion
Nuflex 330	-	acceptable		
Nuflex 100	-	acceptable		
Paxole 857	-	acceptable		
Paxole 1009	-	acceptable		
MC-250	-	unacceptable	-	no cohesion
AE 173-23	-	not tested		

Cold Mix Trial #4

3% rejuvenator   Magnolia Stockpile

Riffe A	-	unacceptable	-	no cohesion
Riffe B	-	unacceptable	-	no cohesion
Riffe C	-	unacceptable	-	no cohesion
Riffe D	-	undetermined	-	low cohesion
Riffe E	-	"	-	" "
Riffe F	-	"	-	" "
Nuflex 330	-	"	-	" "
Nuflex 100	-	"	-	" "
Paxole 857	-	"	-	" "
Paxole 1009	-	"	-	" "
MC-250	-	"	-	" "

Cold Mix Trial #5

4% rejuvenator Magnolia Stockpile

Riffe A	-	unacceptable	No cohesion, rich
Riffe B	-	"	" " "
Riffe C	-	"	" " "
Riffe D	-	"	" " "
Riffe E	-	"	" " "
Riffe F	-	"	" " "
Nuflex 330	-	"	" " "
Nuflex 100	-	"	" " "
Paxole 857	-	"	" " "
Paxole 1009	-	"	" " "
MC-250	-	"	" " "
AE 173-23		Not tested	