Construction of A Recycled Bituminous Pavement Using Foamed Asphalt

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INTRODUCTION

Recycling is widely accepted as a feasible alternative to most of the rehabilitation or reconstruction methods. This is shown by the wide interest in recycling at conferences such as the Transportation Research Board meetings, the Asphalt Paving Technologists Conferences, the International Conferences on Concrete Pavements, etc. Recycling has obvious advantages regarding the saving of construction materials, energy and valuable resources when compared to some conventional methods such as overlaying or reconstruction with new material.

McKinney indicated at the Purdue Road School in 1979 that 94 percent of all paved roads utilize bituminous surfaces. The percentage of bituminous surfaced roads makes up approximately 83 percent of the total paved, hard-surface structures under the jurisdiction of the Indiana Department of Highways (10). It is therefore obvious that the recycling of bituminous pavements will be an alternative to be considered in a large number of maintenance projects.

A very important aspect of recycling is the savings in energy, especially liquid fuel. Halstead indicated at the Purdue Road School in 1979 that highway maintenance consumes a maximum of only 3 percent of the total energy used in the United States (8). Recycling alone will therefore not solve all the energy problems. Inferior construction practices may lead to excessive maintenance cost and energy usage. In other words, although recycling has certain advantages over conventional maintenance methods or new construction, the performance of the pavement also has to be taken into consideration. This might create a problem for the designer since recycling of bituminous pavements has been used extensively for only the last few years. The performance of recycled mixtures has been studied in laboratories and has been reported to give very good results (5,6,7). The only way to verify this is by actual field application. The positive laboratory results have not been completely verified, due to the relatively few recycled pavements that have been constructed and this short time in actual use (16). This does not mean that laboratory studies are not important, on the contrary, they give the basic information regarding the composition, the performance and the possible application of new methods or mixtures at a relatively low cost.

COLD RECYCLING WITH FOAMED ASPHALT

Recycling can be divided into two distinct areas based on the mixing procedure viz. cold and hot mixing. Cold recycling is used mainly to construct base courses. The binders traditionally used in the stabilizing of the cold recycled material were liquid asphalt cement and emulsified asphalt.

Another binder which shows promise as a stabilizer for virgin aggregate and recycled material is foamed asphalt. Foamed asphalt is the material obtained through the addition of a small amount of cold water (usually around 2 percent by weight of asphalt) to hot asphalt cement (usually at about 330 degrees F). This creates an asphalt foam. The expansion ratio is defined as the volume of the foamed asphalt to the volume of the asphalt cement. Unfortunately, the asphalt cement does not stay in the foamed state for very long. The half life is defined as the elapsed time (in seconds) from maximum expansion to the time it takes the foam to be reduced from the maximum volume to one-half of the maximum volume. The idea of foaming asphalt was introduced by Professor Csanyi of Iowa State University in the late 1950's (5). This method which produced foam by means of a steam generator was altered by Mobil of Australia in the late 1960's (8).

Foamed asphalt has been used with success to stabilize virgin aggregate and sands in base courses (1,9,11). To the author's knowledge there is no reported use of foamed asphalt as a binder in cold recycling in actual application.

Laboratory research at Purdue University on foamed asphalt and recycling (3,13,14) showed that foamed asphalt can be used in recycling. Foamed asphalt has the advantage over asphalt cement in that it can be used at a lower mixing temperature and over emulsified asphalt in that it does not need extensive curing. The strength of the foamed asphalt mixture relies very heavily on the coating of the fines to form a mastic. Research also provided the necessary information for the design of the foamed asphalt mixture.

As indicated earlier, research can provide information up to a point. Only field application can evaluate the construction procedure and the performance under actual traffic loads and environmental conditions.

The rest of this paper will discuss the construction of a recycled layer using foamed asphalt with the cold process in Indiana.

THE CONSTRUCTION OF THE RECYCLED PAVEMENT USING FOAMED ASPHALT

During 1980, the decision was made by the Indiana Department of Highways to construct an experimental section using foamed asphalt and emulsion as a binder in cold recycling. The road selected for this purpose was an 8.8 mile segment of SR 16 from the junction with SR 231 to the Jasper-White county line. Figure 1 shows the location of the road. This segment was divided into two approximately equal

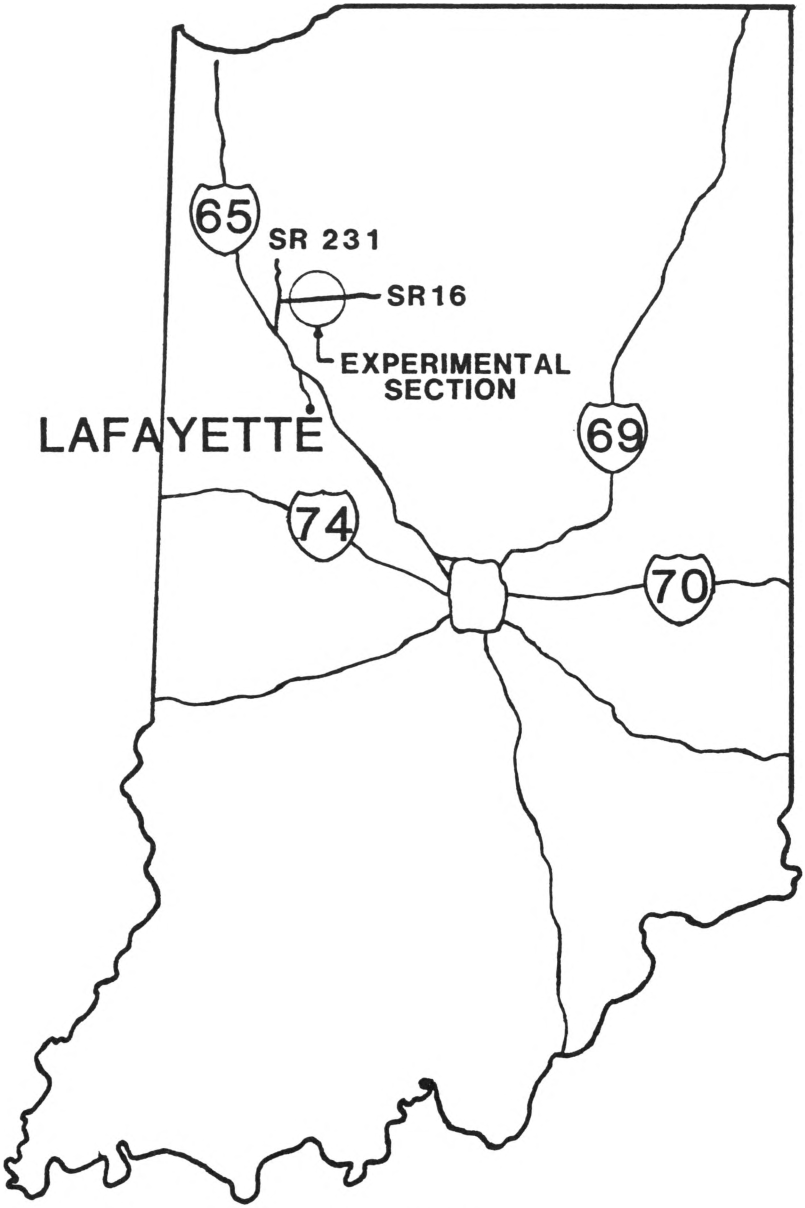

Fig. 1. Location of the Test Road

segments, one utilizing foamed asphalt as the binder and one using emulsion. The main objectives of this experimental section were to monitor and evaluate the construction procedures and the behavior of a recycled layer in field application. This was especially true for the construction of the foamed asphalt section, since foamed asphalt has not been previously used in Indiana. Conventional construction equipment had to be modified to be able to produce and mix foamed asphalt. As mentioned earlier the rest of the discussion will center around the construction of the foamed asphalt section.

The Conditions of the Initial Pavement

The initial pavement was 18-ft. wide. It showed a few longitudinal cracks, some rutting, some consolidation and extensive flushing. The longitudinal cracks appeared mostly along the wheelpath closest to the centerline. These cracks could have been caused by the lack of internal friction in the sandy subgrade (14) and/or excessive bending stresses in the wheelpath (15). None of these pavement defects caused serious performance problems. The flushing created an unsafe roadway in wet weather.

The traffic volume as determined in 1978 consisted of approximately 550 vpd in both directions with 18 percent trucks.

Original Construction Concept

The thought was to reconstruct the pavement using the pulverized in place pavement material mixed with additional aggregate and foamed asphalt as a base course. It was felt that cold in-place recycling could provide a low cost simple construction procedure.

In order to design the recycled mixture and to determine the thickness, tests were conducted on cores obtained from the initial pavement. Approximately 100 5-in. cores were taken over the 8.8 mile section.

At first 24 core samples from six sites were analyzed to determine the grading and the asphalt content. The results are given in Table 1. In a second investigation eight cores from four different locations were analyzed to determine the penetration and the kinematic viscosity of the asphalt concrete in the initial pavement. The results are given in Table 2. The average asphalt penetration was 41 pens. and the average kinematic viscosity 460 cSt. Both the penetration and the viscosity values had large variances. The average asphalt content was 6.1 percent, with a small variance.

Ten extra 4-in. cores were analyzed to determine the resilient modulus (Mr) at different temperatures and for the top and the bottom 2-1/2 in. There is no significant difference (at alpha = 0.05) between the Mr-values obtained from the top and the bottom 2-1/2 in. The average total thickness was 5.8 in. Visual inspection seemed to indicate that the top half had more asphalt than the bottom half. This was not verified through testing.

TABLE 1
RESULTS OF TESTS ON 24 CORE SAMPLES

	% Asphalt	3/4 in.	1/2 in.	3/8 in.	% Retained #4	#6	#200	Pass*
Avg.	6.10	0.83	8.56	16.90	34.50	9.12	25.11	4.39
S.D.	0.40	1.21	2.89	2.75	2.74	0.89	4.09	0.81
Range	5.06-6.79	0-4.18	4.19-14.72	11.46-21.5	27.39-39.14	7.67-11.14	18.93-37.10	2.39-5.76

*) % passing #200

TABLE 2
RESULTS OF TESTS ON 8 CORE SAMPLES

	Penetration (Pens)	Kinematic Viscosity (cST)	#8	#30	% Passing #40	#50	#100	#200
Avg.	41	459.9	28.3	15.1	13.4	11.9	8.6	5.5
S.D.	12.18	155.47	2.43	1.41	1.09	1.07	0.79	0.41
Range	28-63	195.2-651.4	25.8-33.3	13.4-17.9	11.9-15.0	10.1-12.5	7.3-9.5	4.6-5.9

Information obtained from the above tests, results from research at Purdue and practical experience were used to establish the material and construction requirements. The requirements are summarized in Table 3.

TABLE 3
CONSTRUCTION AND MATERIAL REQUIREMENTS

1. Foamed Asphalt:

   Asphalt concrete: AC-5
   Mixing temperature: 330°± 15°F
   Amount of water: 2% by weight of asphalt

   $$\text{Expansion ratio} = 10 = \frac{\text{volume of foamed asphalt}}{\text{volume of asphalt cement}}$$

   Half life = 20 seconds = time it takes for the volume of the foam to reduce from its maximum volume to one-half of the maximum volume
   Temperature during processing 50°F

2. Milled Material:

   Maximum size = 3 in.
   90 to 100 percent less than 1-1/2 in.
   Free moisture during mixing = 2.5 - 3.5%

3. Additional Aggregate:

   Grading: meeting section 903 of ISHC standard specifications
   Coarse aggregate: meet requirements of Class C aggregate
   Free moisture during mixing: 2.5 - 3.5%

4. Geometry of the Pavement:

   Minimum thickness of recycled base: 5 in.

5. Construction:

   The constructed section has to be open to two-way traffic during non-work periods and it must be graded and compacted.

The idea was to reconstruct the road to a width of 22-ft. by increasing the width by 2 ft. on each side. Excavations had to be made to a depth of 5 in. to extend the 5-in. base course. The excavated material was to be used on the shoulders. Some additional aggregate had to be added to maintain the 5-in. thickness of the base course. Figure 2 shows a cross section of proposed final pavement.

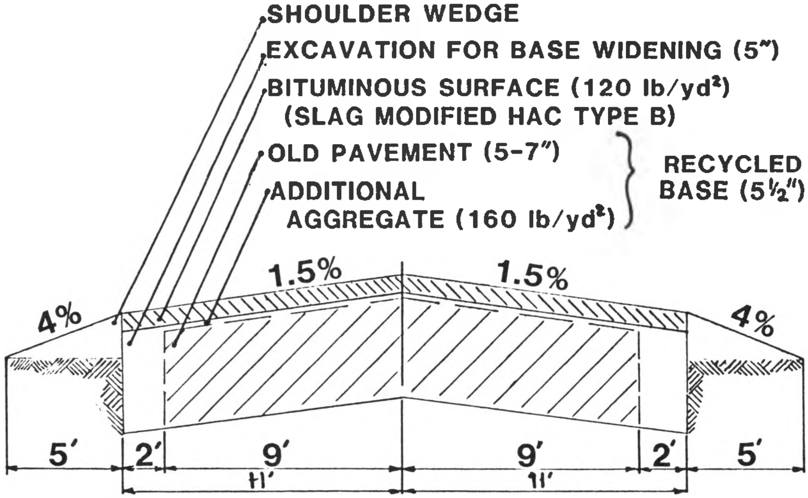

Fig. 2. Cross Section

A thickness of 5 in. of recycled base course and a 1-1/4 in. hot mix asphalt concrete surface seemed to be sufficient to carry the traffic on this road. No structural coefficients were available to be used in the design.

Cold in-place recycling was specified in the construction proposal. The initial pavement had to be ripped, milled, scarified or pulverized to a depth of 5 in. to such an extent that 100 percent of the material passed the 3-in. sieve and 90 to 100 percent the 1-1/2-in. sieve. After the excavations on the sides were made, the additional aggregate had to be placed on top of the reduced and shaped material at a rate of approximately 160 lb./sq. yd. The additional aggregate could be crushed stone, crushed blast furnace slag, natural or blast furnace slag, sand or a combination of these materials meeting a standard specification. A material complying to the specifications of the Indiana Department of Highways for a No. 53 crushed stone would be acceptable, as shown in Figure 3.

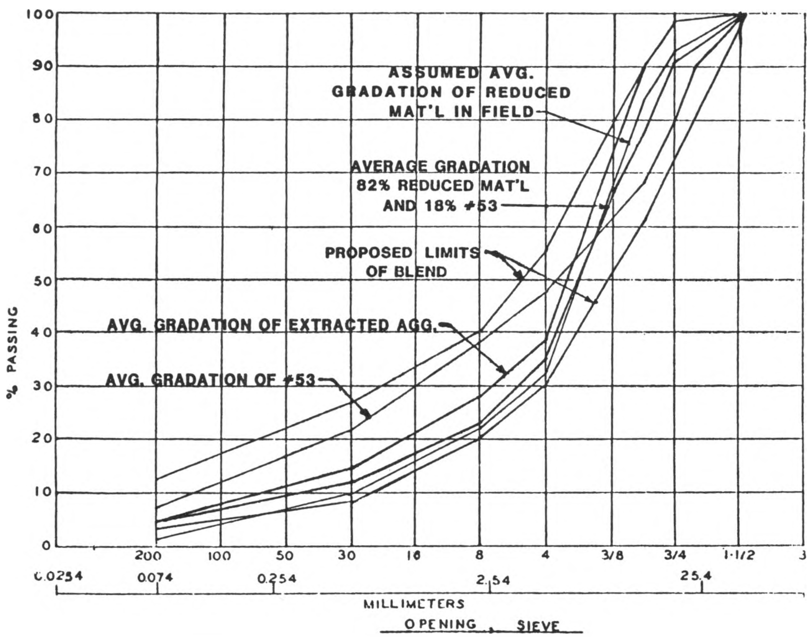

Fig. 3. Grading Analysis of Materials Used

The first application of foamed asphalt had to be applied directly to the additional aggregate at a rate of 0.75 gal./sq. yd. (4% by weight of aggregate) and simultaneously shallow mixed to a depth of not more than 0.5 in. below the additional aggregate layer. A second application of foamed asphalt had then to be applied at 1.0 gal./sq. yd. (1.5% by weight of material) and mixed to full depth. The hot mix surface at a rate of 20 lb./sq. yd. had to be placed on top of the recycled base (the specifications are summarized in Table 3).

The contractor was given 60 working days to finish the 8.8 mi. section. Adjustments to the proportions of the materials could be, and were, made if necessary.

Actual Construction

The construction of the foamed asphalt section started in August 1981. It was the first experience for the contractor with foamed asphalt.

The contractor got permission to mix the milled material and the additional aggregate at a central plant instead of in place. The main reasons for this were:

(1) the contractor had a mixing plant available approximately 10 mi. from the construction site.

(2) the milling machine had difficulty milling to a depth of 5 in. in one pass.
(3) the mixing control would be better at a central plant.

During trial runs at the central plant the proportion of the additional aggregate to be added was changed from 29 percent to approximately 33 percent by weight of reduced material or 25 percent by total weight of material. This small change did not seem to influence the quality of the mixture. No. 53 crused stone was to be used as additional aggregate. It was readily available to the contractor.

The centerline of the initial pavement was used as reference height. This meant that the transverse slope was measured from the centerline. The depth of the intended excavation of 5 in. on the sides of the pavement therefore varied since the initial pavement did not have a constant transverse slope.

The construction procedure was changed from cold in-place recycling to cold recycling at a central plant. Figure 4 displays a flow diagram of the actual construction procedure. The specifications given in Table 3 were still valid.

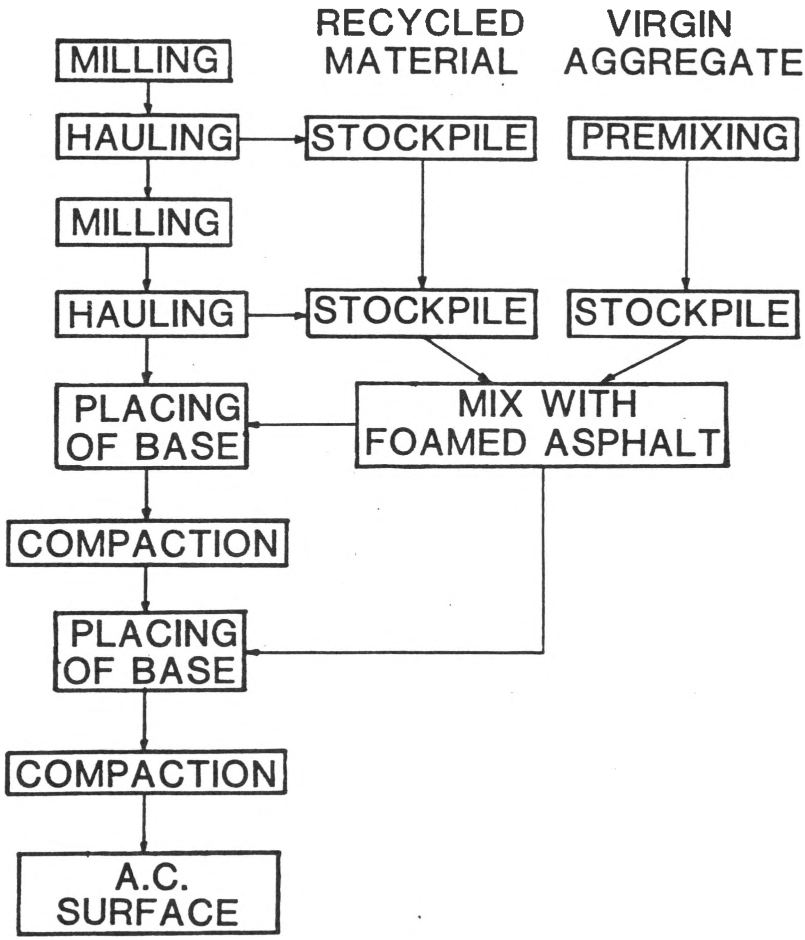

Fig. 4. Flow Diagram of the Actual Construction

Descrition of the Actual Construction Procedure

In order to keep the road open to traffic during non work periods the milling was done in two layers. First a layer of 2-1/2 in. was removed. The remaining 2-1/2 in. of initial pavement was sufficient to sustain traffic during construction. Approximately 8,000 to 10,000 linear feet of milling of this 9-ft. wide and 2-1½2 in. thick pavement layer could be done in a day. The milling was done to the width of a line (9 ft.) at a time. It was found that the milling was faster and fewer pieces larger than 3 in. were created during colder weather. The milling was therefore done mainly from early morning (6:30 am) to just after noon (2:30 pm). The milled material was hauled to the central plant and stockpiled.

During the first milling operation the additional aggregate (No. 53B) was mixed with 4 percent foamed asphalt (by weight of aggregate) and stockpiled. The mixing was done at the central plant with a modified twin-shaft pugmill. Figure 5 shows the process schematically.

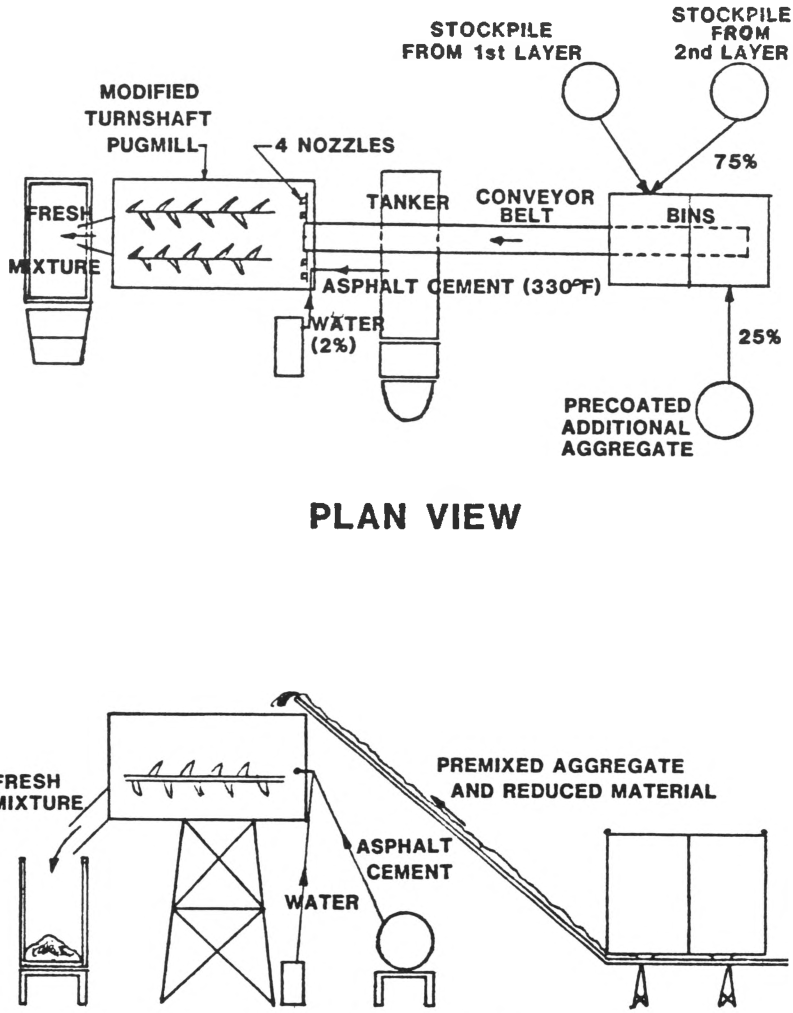

Fig. 5. Mixing Process

The mixing time was approximately 45 sec. This modified pugmill can produce up to 240 tons of a formed asphalt mixture per hour. The foamed asphalt coated the fines better than the coarse aggregate, as expected, since it relies on the mastic properties of the fines. The premixed stockpile had the color of wet aggregate and not asphalt coated aggregate.

The second milling operation followed the first one and removed an additional 2-1/2 in. of initial pavement. A thickness of 1 in. on average, of initial pavement was left on top of the underlying layers. This protected the subgrade and avoided problems with heavy construction equipment on places where very soft subgrades appeared.

The second milling operation was followed closely, at approximately 1000 ft., with the placement of the first 3 in. of the intended 5-1/2 in. of recycled base course. The placement was done by a conventional asphalt paver to a width of 11 ft., which is the lane width. The 2-ft. on the sides was cleared by a motor grader. Since the centerline height was taken as reference height and transverse slope had to be 1-1/2 percent no excavations (as originally specified) were made. The paver completed the portion that had been previously milled by the end of the construction day. This provided a graded, compacted and safe roadway during non work periods. Care was taken through the milling of a few inches at the side of the placed recycled material, to provide a good bond between the recycled material to be placed in the other lane and the existing recycled layer.

The mixture used in the paving operation was mixed in the two-shaft pugmill at the central plant. The reduced material was mixed with the premixed additional aggregate in the ratio of 3 to 1. The percentage of foamed asphalt added was 1-1/2 percent of the total mixture.

The compaction was started immediately after the placement of the first lift by two passes of a steel wheel roller. This was followed by two passes of a rubber wheel roller after a few hours and another two passes of the same roller at the end of the day. Nuclear density tests showed that 6 passes gave adequate compaction. Since the road was opened to traffic after a few hours, traffic and especially the heavy construction trucks traveling to and from the central plant caused extra compaction.

The placement of the second lift of 2-1/2 in. to reach a base thickness of 5-1/2 in. followed the first lift. It was placed and compacted in the same way as the first lift. An uncompacted placed layer of 4 in. compacted to a thickness of approximately 2-1/2 in. This is completely different from hot asphalt mixes.

Material from the first and second milling operation was stockpiled in separated piles. Material from both these stockpiles were used simultaneously in the mixing process to minimize the effect of possible unequal asphalt contents of the top and bottom of the initial bituminous pavement. The mixed material was generally transported directly from the pugmill to the paver to be placed. Only in a few cases, when some additional aggregate had to be coated, was the recycled mixture stored for a few days.

The placement of the second lift (top) of base coarse was followed after about three days with an AE-T tack coat of 0.05 gal./sq. yd. and the hot asphalt surface of 120 lb./sq. yd. A shoulder, using one size material obtained as a by-product from the production of crushed stone, completed the construction.

Control of the Foamed Asphalt Mixture

The properties of the foamed asphalt were checked before construction and it was found that a reasonable coating could be obtained by using a halflife of only 12 sec. and an expansion ratio of 10. These properties were checked frequently during construction.

It was never necessary to adjust the free moisture content of the material, since it was between 2.5 and 3.5 percent for most of the time.

Only a small amount of material larger than 3 in. was obtained through the milling operation. No effort was made to remove these pieces, since it was assumed that they would be broken down during the mixing.

Construction Problems

No serious problems occurred during construction. One of the minor problems was that milling during high pavement temperatures caused the milled material to stick together due to the high asphalt content. Another minor problem was that the larger pieces of reduced material were dragged along by the paver and the scars had to be corrected manually.

The biggest problem was ravelling. This was fortunately a problem only during the first few days of placement. It usually appeared on the outside few feet of the pavement. It occurred soon after placement and was initiated by the wheels of the heavy construction vehicles. The reasons for the ravelling appear to be a too low binder content, inadequate compaction for heavy vehicular use as well as a very soft or improperly prepared subgrade. The existence of some organic material e.g. grass could have prevented proper compaction. The ravelling was compacted by the traffic to distress pattern similar to rutting and was corrected by the placement of either the second lift of base course material or the surface. It was not necessary to remove these sections.

SOME IMPORTANT TEST RESULTS

The main thrust of the research at Purdue University on this project is to determine the structural coefficients of the foamed asphalt recycled layer. The material properties that are important in such a study are the resilient modulus, the Poisson's ratio and the tensile strength.

Samples of the mix were taken during construction and compacted in the laboratory at room temperature using the California kneading compaction method. Samples were taken at six different positions and at least six specimens prepared at each position. All six specimens were cured for 10 days in laboratory conditions (approximate 73° F). Three specimens were subjected to one hour vacuum saturation and left under water for 24 hours. The resilient modulus, Hveem-R value, Marshall stability and flow values were then determined at approximately 73° F for all six specimens using standard testing procedures. The resilient moduli were also determined for the three unsaturated specimens at 34° and 104° F.

Four-inch cores were also taken after construction at 18 different positions. Several were taken at each location to obtain a total of 35. The cores were cut into three segments; two 2-1/2-in. specimens representing the first and second lift and one 1-1/2-in. specimen representing the surface. These specimens were tested the same way as those prepared from the samples of the mix obtained in the field, except that only four were tested under vacuum saturation. It was difficult to get proper size specimens from the cores.

The resilient modulus (Mr) and Marshall stability values showed no statistical difference at alpha = 0.05 between the two lifts and the position on the pavements for both the laboratory samples and the cores. There is a difference between the Mr of the laboratory compacted samples and the cores, as shown in Figure 6. This is also true of

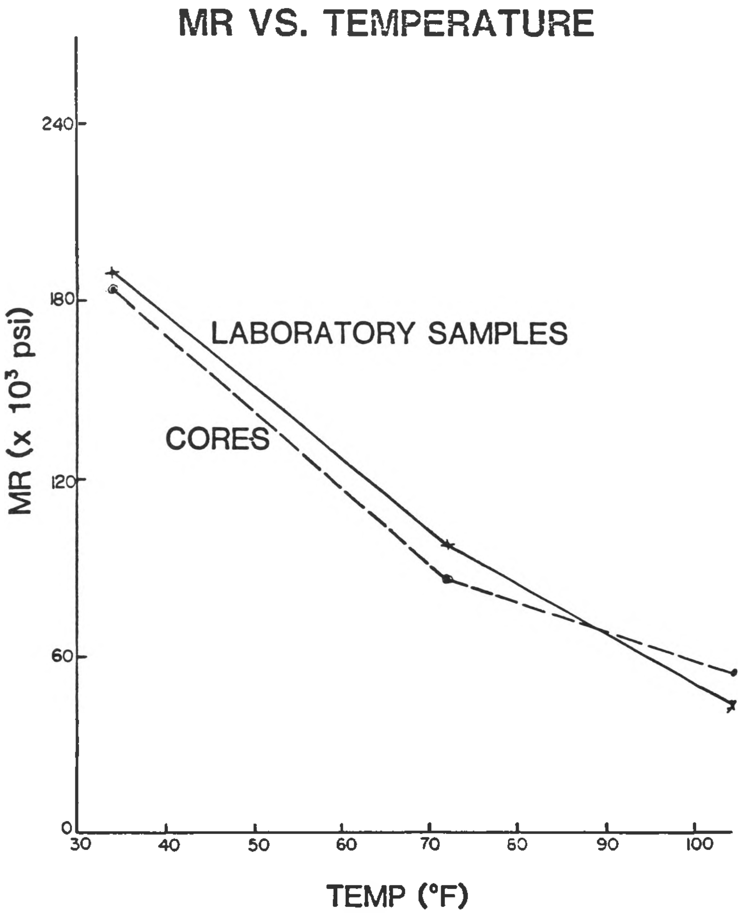

Fig. 6. Effect of Temperature on Resilient Modulus

the Marshall stability. The main reason for this is the difference between the densities of the laboratory samples and the cores. The average density of the samples is 147.5 pcf with a range from 143 to 149 and of the cores 138.6 pcf with a range from 132 to 150 pcf. It was also observed that the Mr (stiffness) decreases with the increase in temperature.

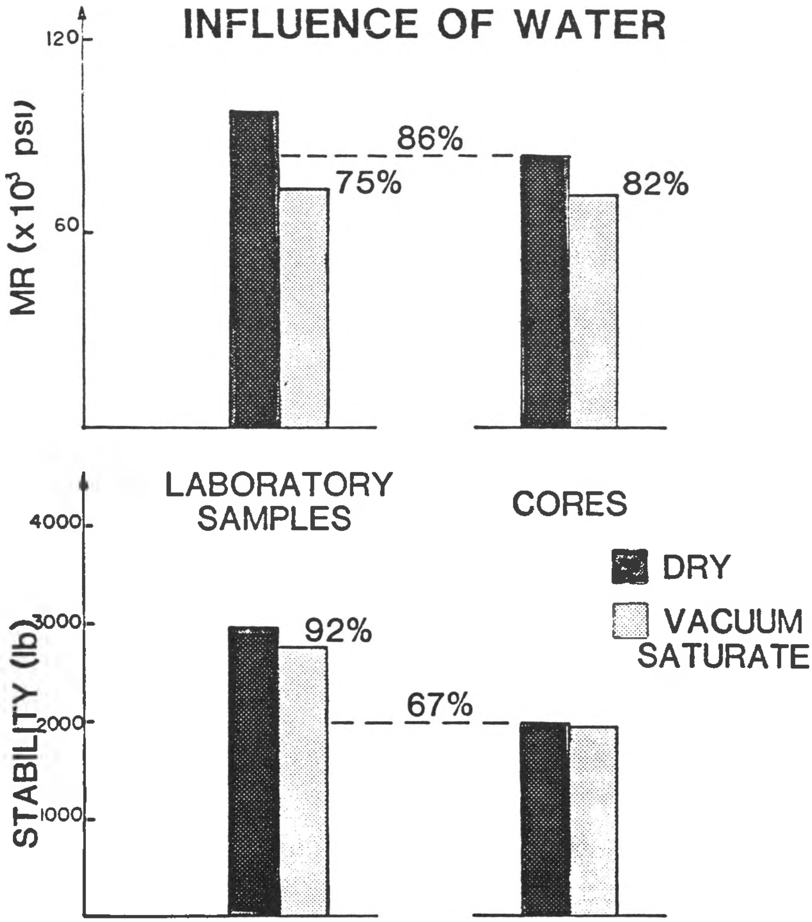

Fig. 7. Influence of Water on Resilient Modulus and Stability

Figure 7 depicts the influence of water on the resilient modulus and the Marshall stability. The resilient modulus is reduced significantly (at alpha = 0.05) with the introduction of water. The effect is less pronounced on the Marshall stability of the mixture, but still present. It is therefore important to keep water out of the foamed asphalt recycled layer through proper side drainage and surface protection.

Another very important factor in the stability of the mixture is the compaction moisture content. A definite optimum compaction moisture content exists. The effect of moisture content on the compacted unit weight for the laboratory compacted samples may be noted in Figure 8 where an optimum moisture content of 2.4 percent may be observed.

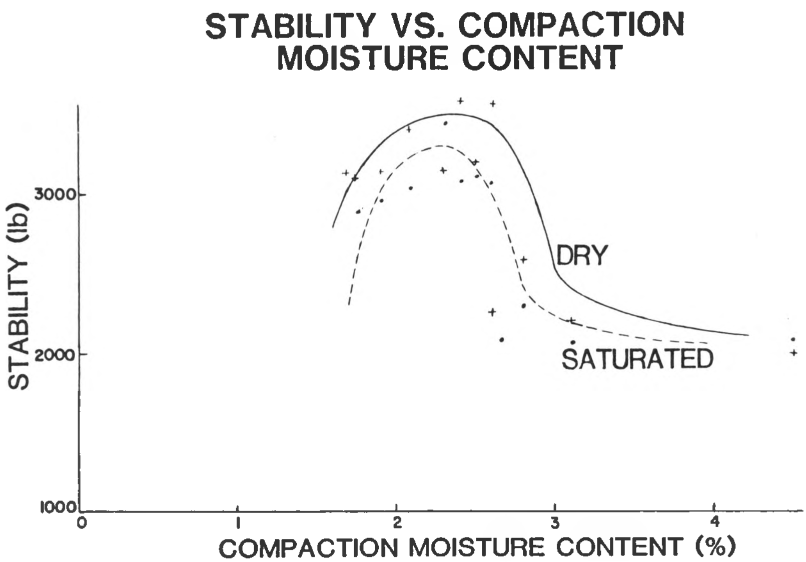

Fig. 8. Effect of Compaction Moisture Content on Stability

Curing time and method have a marked influence on the Mr (stiffness) and the tensile strength of the foamed asphalt recycled material as shown in Figures 9 and 10. Maximum curing is supposed to represent the condition of the pavement after some time in use under favorable conditions. This was simulated by air curing for 10 days and curing for 50 hours at 140° F. The 10 days air curing represent the condition of the pavement after a few weeks in use and the one day air curing immediately after construction. The results displayed in these figures were obtained by testing an extra 18 specimens compacted from a mixture sample taken during construction.

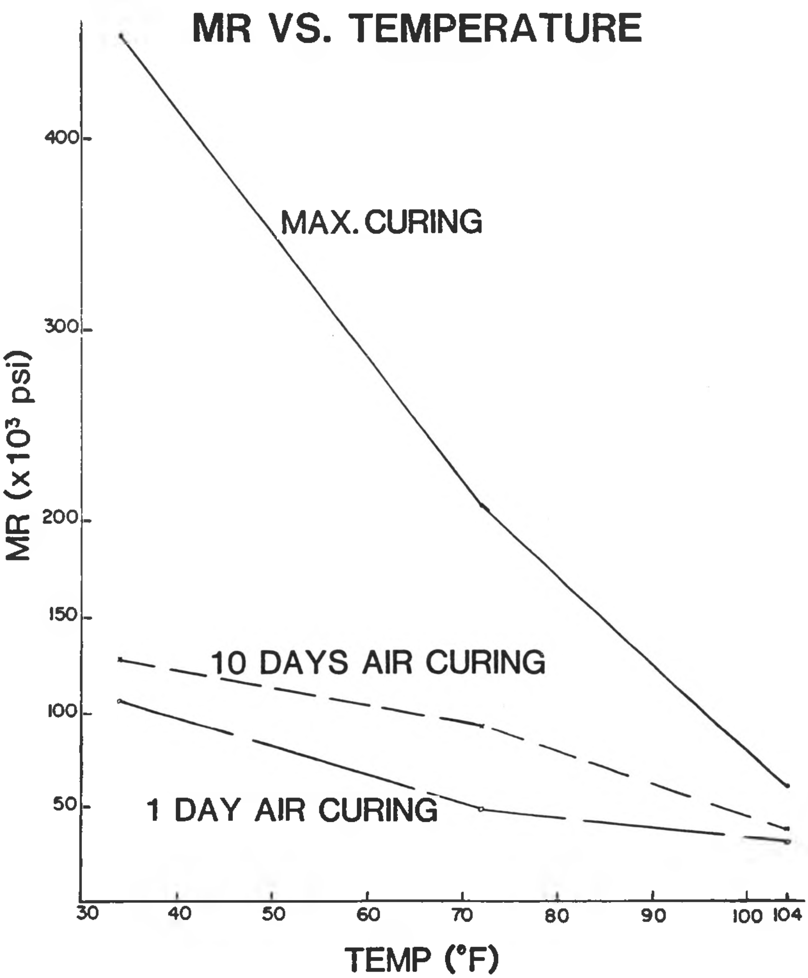

Fig. 9. Effect of Curing Time on Resilient Modulus

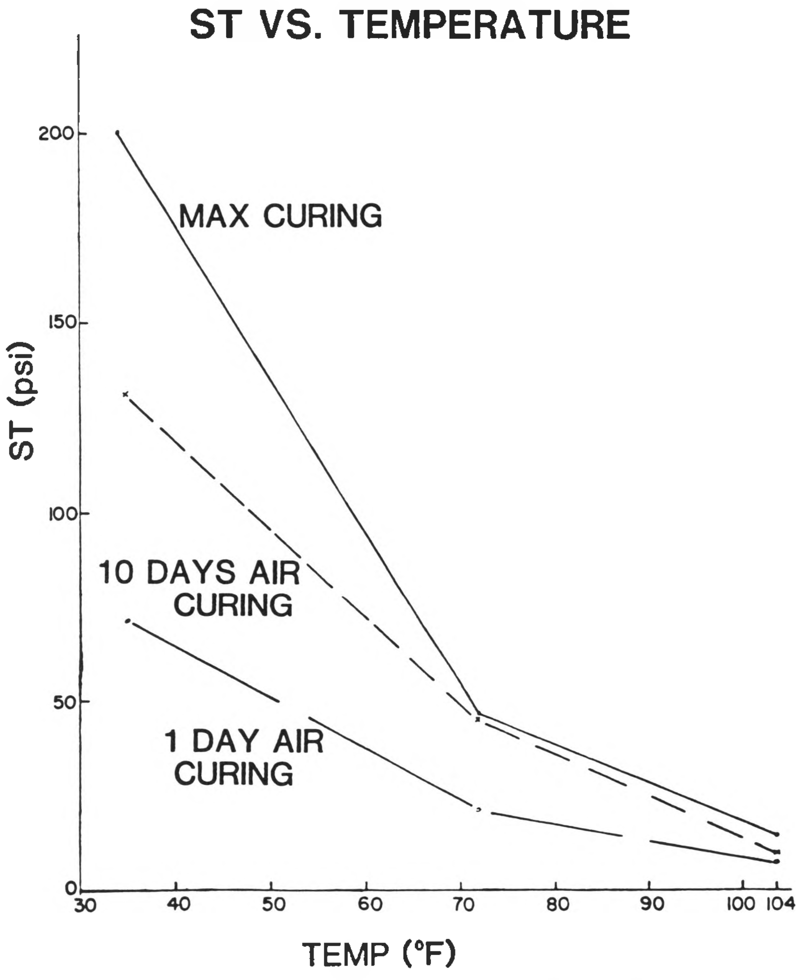

Fig. 10. Effect of Curing Time on Tensile Strength

Deflection measurements were taken with a Dynaflect before, during, and after construction. Figure 11 shows the Dynaflect maximum deflections before construction and during construction (on the foamed asphalt base course). The values have been adjusted for temperature.

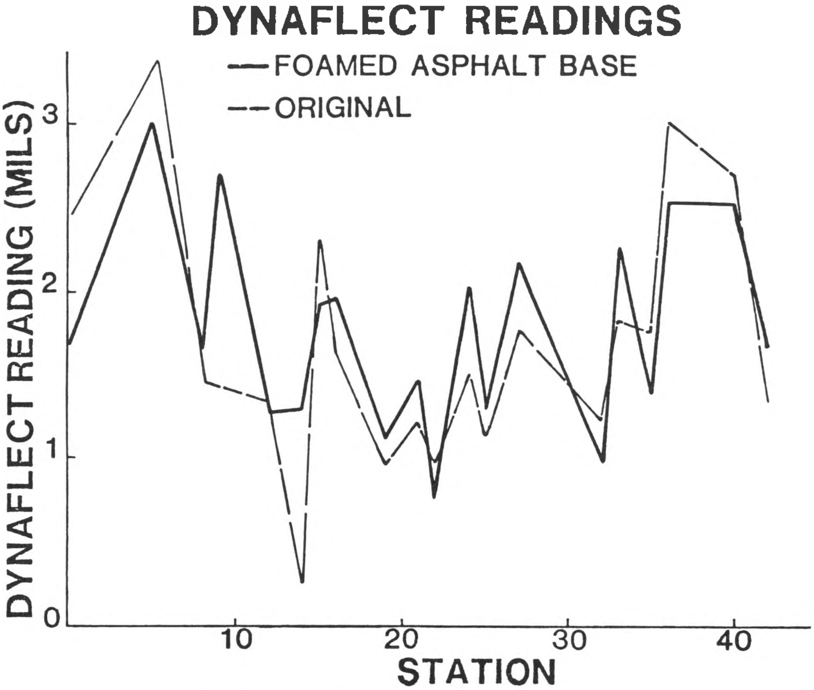

Fig. 11. Dynaflect Maximum Deflections

There is no significant difference between the deflections. This means that the newly constructed layer is at least as stiff as the initial pavement. The initial pavement was structurally sound. The laboratory study on the effect of the curing on the stiffness (Mr) indicates that the stiffness will increase and the deflections will therefore decrease. The deflection measurements were taken on the recycled foamed asphalt layer only a few days after construction.

CONCLUSIONS

Foamed asphalt seems to be an acceptable binder in cold recycling. No major equipment changes had to be made during construction to accommodate the foamed asphalt. The construction procedure could also be kept simple and progress maintained at an acceptable rate.

The pavement could be opened to traffic soon after construction and it performed well. Even the heavy construction vehicles had no detrimental effect on the recycled layer.

The importance of the correct moisture content during compaction and the detrimental effect of water on the recycled material must be kept in mind in design and construction.

The initial and short term performance of this foamed asphalt recycled layer seems to be satisfactory. Results from tests show that there is reason to believe that it will behave well in the future, but, as mentioned in the introduction, this can only be verified through monitoring the future and ultimate performance in actual use.

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REFERENCES

1. Abel, F., Base Stabilization with foamed asphalt. TRB presentation 1981.
2. Bavening, R. H. and Martin, C. L. Foamed Bitumen: Production and Application of Mixtures. Evaluation and Performance of Pavements. Proc. AAPT Vol. 45 (1976).
3. Brennen, et al. A Laboratory Investigation in the Use of Foamed Asphalt for Recycling Bituminous Pavements.
4. Castedo, H. and Shofstall, R. L. Stabilization of Three Typical Indiana Aggregates Using Foamed Asphalt. JHRP Interim Report.
5. Csanyi, L. H. Foamed Asphalt in Bituminous Paving Mixtures. TRR No. 160 (p. 108-122).
6. Epps, J. A. State-of-the-Art Cold Recycling. TRB No. 780 (p. 68).
7. Epps, J. A., Little, D. N., Holmgreen, R. J., Terrel, R. L., Ledbetter, W. B. Guidelines for Recycled Pavement Materials. NCHRP No. 224.
8. Holstead, W. J. Energy Concerns Relating to Highway Construction and Maintenance. Proc. Purdue Road School, 1979. p. 1.
9. McComb, R. W. Pueblo West, Colorado. Foamix Experience. TRB 1982 (meeting).
10. McKinney, J. L. Recycling of Bituminous Pavement. Proc. Purdue Road School, 1979, p. 12.

11. Mosey, J. and Welke, R. A. Use of In-Situ Foamed Asphalt in Michigan. TRB 1982 (meeting).
12. Tia, M., Wood L., Hancher, D. The Effect of Added Virgin Binders on the Properties of Cold Mix Recycled Asphat Paving Mixtures. AAPT 1981.
13. Tia, M. Characterization of Cold-Recycled Asphalt Mixtures. Ph.D. Thesis.
14. Yoder, E. J. and Witczak, M. Principles of Pavement Design, p. 631.
15. Asphalt Institute Information series No. 169 (IS-169). A Pavement Rating System for Low-Volume Asphalt Roads.
16. International Aspects of Recycling. Rural and Urban Roads. July 1981 (p. 22).