Modifier Influence in the Characterization of Hot-Mix Recycled Material

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The hot-mix recycling operation for bituminous mixes commonly uses a modifier to restore the aged asphalt cement to a condition that resembles a virgin asphalt cement. In the laboratory this is done on the extracted asphalt cement, thus assuring a thorough mixing. In the actual recycling operation, however, the modifier is added to the material during the mixing process and merely coats the salvaged asphalt concrete particles that are being recycled. It takes a certain amount of time for the modifier to combine with the old asphalt, but the exact nature of this time period and its influence on the structural behavior of the mix has not been reported. This paper investigates the influence of this diffusion process on material behavior and shows that the diffusion process exerts a large influence on the material properties required for long-term performance predictions in computer models such as VESYS. Immediately after sample preparation, the mix may have high stiffness and excellent resistance to rutting. For the material investigated in this paper, a week after preparation the stiffness had decreased by a factor of two, and the resistance to rutting had decreased accordingly. This behavior is explained from a conceptual consideration of the diffusion process and is physically verified by extracting the outer and inner layers of the modifier-asphalt cement combination prepared in a simulated recycling operation and by comparing their consistency. Consideration of this phenomenon has serious implications in characterization for long-term performance predictions and in evaluating the effects of various laboratory conditioning procedures.

Recycling operations have experienced a rapid growth in recent years. This growth has resulted from increased awareness of the potential for cost savings and material conservation. More importantly, the effort put forth by the equipment manufacturers has increased. The recent years have seen rapid advances in pulverizers, millers, and hot-mix plants that facilitate recycling operations. With the increase in recycling operations has come an increased awareness that the recycled material must be characterized in order to ensure a quality pavement. To accomplish this the Federal Highway Administration has funded (a) research to investigate the effect of rejuvenators on recycled binders (Texas A&M University), (b) a test procedure for examining the efficiency of the mixing process (University of Washington), (c) the design and characterization of recycled mixtures (University of Texas), (d) a study to compare the performance of recycled shoulders versus all-new construction (University of Illinois), and (e) a study to characterize and predict performance of recycled pavements (Resource International). These studies will help indicate whether the long-term performance of recycled pavements will be comparable to the performance of new construction. If the recycled pavements show excessive deterioration, the cost and energy savings obtained during construction may be lost through excessive maintenance. Initial indications are that a quality pavement is being constructed. However, these pavements have not been in service long enough to permit judgment of their long-term performance.

The present study undertaken at the University of Illinois--Design Properties of Recycled Shoulders: Performance Characteristics--has as its objective the one-on-one comparison of recycled and new construction. The economical method to generate these data involves the use of computer models for performance predictions and extensive characterization in the laboratory. The main computer model selected for these comparisons is VESYS-G (1). This model predicts fatigue cracking, rutting, roughness, and the serviceability index with time. Traffic loads, temperature, moisture conditions, and material property descriptions can be varied over the design life.

To obtain accurate comparisons with the VESYS program, extensive laboratory characterization is necessary. The necessary tests include

1. Fatigue: controlled stress, beam flexure;
2. Creep compliance: cylindrical compression;
3. Permanent deformation: cylindrical compression; and
4. Resilient modulus: indirect tensile, diametral loading.

Another damage mechanism not included in the VESYS analysis is thermal fatigue, which requires (a) creep compliance (tensile loading) and (b) thermal coefficient of contraction. Thermal fatigue is analyzed by a modified viscoelastic procedure (2).

REQUIREMENTS FOR PERFORMANCE COMPARISONS

To examine the performance of two asphalt-concrete materials in order to evaluate the influence of the recycling operation, the materials must be as similar as possible. The items that must receive consideration include (a) density and air voids, (b) gradation, (c) type of aggregate, (d) fluids content, and (e) viscosity of fluids (or penetration).

The common procedure for analyzing a recycled mixture involves (a) extraction of the asphalt cement, measurement of its properties, and selection of a proper amount and type of rejuvenator to restore the classification properties to a preselected level and (b) examination of the gradation of the aggregate after extraction of the asphalt cement in order to determine the amount and gradation of new aggregate that may be required.

In order to compare laboratory performance predictions for new construction and recycled materials, the voids, gradation, and aggregate type must be similar. These parameters, which represent variables that can be altered, can have a large influence on test results; they also indicate quality control in the recycling process. Fluids content and consistency must also be the same, for these two values represent the quantities that are most critically influenced by the recycling operation. The consistency of the recycled asphalt cement should be similar to that used in the samples that represent new construction and to the virgin asphalt cement added during the recycling operation in order to emphasize the influence of the recycling operation.

The procedures used for determining the amount of modifier and for mixing during the recycling operation represent the focal point for the most serious problem in characterizing a recycled material. This problem reduces to one question, How long after sample preparation should the specimens be allowed to cure before the data will be representative of the pavement over its design life? The necessity for this question arises from the fact that the modifier does not instantaneously combine with the old asphalt cement that coats the salvaged material. A diffusion process takes place over a period of time during which this combination occurs.

THE DIFFUSION PHENOMENON

In order to determine the amount of modifier required, the asphalt is extracted from the salvaged material and thoroughly fluxed with various percentages of the modifier. The classification properties are then measured on this rejuvenated asphalt cement. These test results are used to select the amount of modifier needed to match classification data of a virgin asphalt cement (penetration at 25°C or viscosity at 60°C).

In a typical hot-mix recycling project, the modifier is added during the mixing process along with the virgin asphalt cement and new aggregate. The actual addition process varies with the recycling technique being used, but the general process involves addition of modifier during mixing. During this procedure the modifier is attracted to the virgin asphalt cement and to the old asphalt cement surrounding the aggregate. Both materials will begin to soften at different rates because of the different affinities exerted on the modifier by the virgin asphalt cement and the old oxidized asphalt cement.

This presents a very complicated picture indeed. To simplify the discussion, the remainder of this paper will be concerned with a mixture containing 100 percent recycled material (no virgin materials added). The process that begins when the modifier is added in the recycling operation can be outlined as follows:

1. The modifier forms a very low-viscosity layer that surrounds the aggregate, which is coated with very high-viscosity aged asphalt cement (time step 0).
2. The modifier begins to penetrate into the aged asphalt cement layer, thereby decreasing the amount of raw modifier that coats the particles and softening the old asphalt cement (time step 1).
3. No raw modifier remains, and the penetration continues; the viscosity of the inner layer is lowered, and gradually the viscosity of the outer layer is increased (time step 2).
4. Equilibrium is approached over the majority of the shell of asphalt cement except right at the interface, which may remain at a higher viscosity level (time steps 3 and 4).

These phases and time steps are depicted schematically in a plot that illustrates the variation in viscosity with time (Figure 1). This penetration is a diffusion of the modifier or select components of the modifier into the aged asphalt.

The gradual softening, or rejuvenating, of the asphalt in a mixture once it has been compacted is a major problem in the characterization of a recycled material. The time between mixing and testing of the samples may be critical because of the softening effect. The structural parameters may or may not be sufficiently developed to provide any resistance to the wheel loads during the initial portion of the recycled pavement's life, when it will be softening because of the diffusion process. Thus, it is necessary to characterize the material by its long-term parameters as well as its short-term parameters. In order to examine the importance of this diffusion process in material characterization and in performance predictions, a testing program was set up to examine the property changes following sample preparation.

SAMPLE PREPARATION

The material used in this study was removed from a city street in Champaign, Illinois, in June 1976 by using a Roto-Mill made by the CMI Company of Oklahoma City. The material had been in service for 12-15 years and had developed a rough ride surface (as a result of transverse cracking), a low skid resistance, and a poor drainage profile. The surface, a hot-mix asphaltic concrete, was milled to a 1.9-cm depth, left open to traffic for approximately four months, and overlaid with a 2.5-cm overlay. The material removed from the roadway was stockpiled by the city of Champaign and used as a cold-weather patching material.

The material removed from the roadway was less than 2.5 cm in size because of the abrasive action of the Roto-Mill. The oversized material was crushed to pass the 1.25-cm sieve. Approximately 6000 g of asphalt cement were extracted and recovered from the salvaged material. The aggregate and fines were saved for later use in preparation of the rejuvenated samples. The properties of the asphalt cement were

Item	Value
Viscosity at 60°C	4490 Pa•s
Penetration at 25°C	2.6 mm
Penetration at 4°C	2.2 mm
Softening point	63°C
Asphalt content	5.3 % (total weight basis)
Specific gravity	1.198

The salvaged pavement aggregate had a specific gravity of 2.71 (bulk). The aggregate gradation (wet sieve on recovered samples), which very closely followed an Illinois CA-12 specification, was as follows:

Sieve Size	Percent Passing	Sieve Size	Percent Passing
12.5 mm	100	850 μm	34
9.5 mm	81	425 μm	23
6.3 mm	78	150 μm	13
4.75 mm	68	75 μm	9
2.00 mm	58		

In order to study the influence of the modifier alone, a standard modifier (Paxole 1009) was chosen. Various percentages of the modifier were mixed with the reclaimed asphalt cement. The results of viscosity testing are presented in Figure 2 as a plot of viscosity at 60°C versus the percentage of the modifier. A 20 percent modifier by weight of asphalt cement was selected to produce a viscosity of 100 Pa•s at 60°C, corresponding to an AR-1000. The properties of this rejuvenated combination are given below.

Item	Value
Viscosity at 60°C	99.4 Pa•s
Penetration at 25°C	11.2 mm
Penetration at 4°C	3.7 mm
Softening point	44°C
Specific gravity	1.164

The amount of modifier (Paxole 1009) in the rejuvenated asphalt cement was 20 percent (by weight of asphalt); its viscosity at 60°C was 234 mm^2/s, and its specific gravity was 1.028. The properties are not dissimilar to those of a virgin asphalt cement. In the mixing process used for laboratory preparation, this asphalt-modifier combination hardened to an approximate viscosity of 240 Pa•s at 60°C.

Rejuvenated Samples

The 6000-g quantity of extracted asphalt cement was

Figure 1. Schematic of modifier coating an aggregate particle during recycling to illustrate viscosity variation.

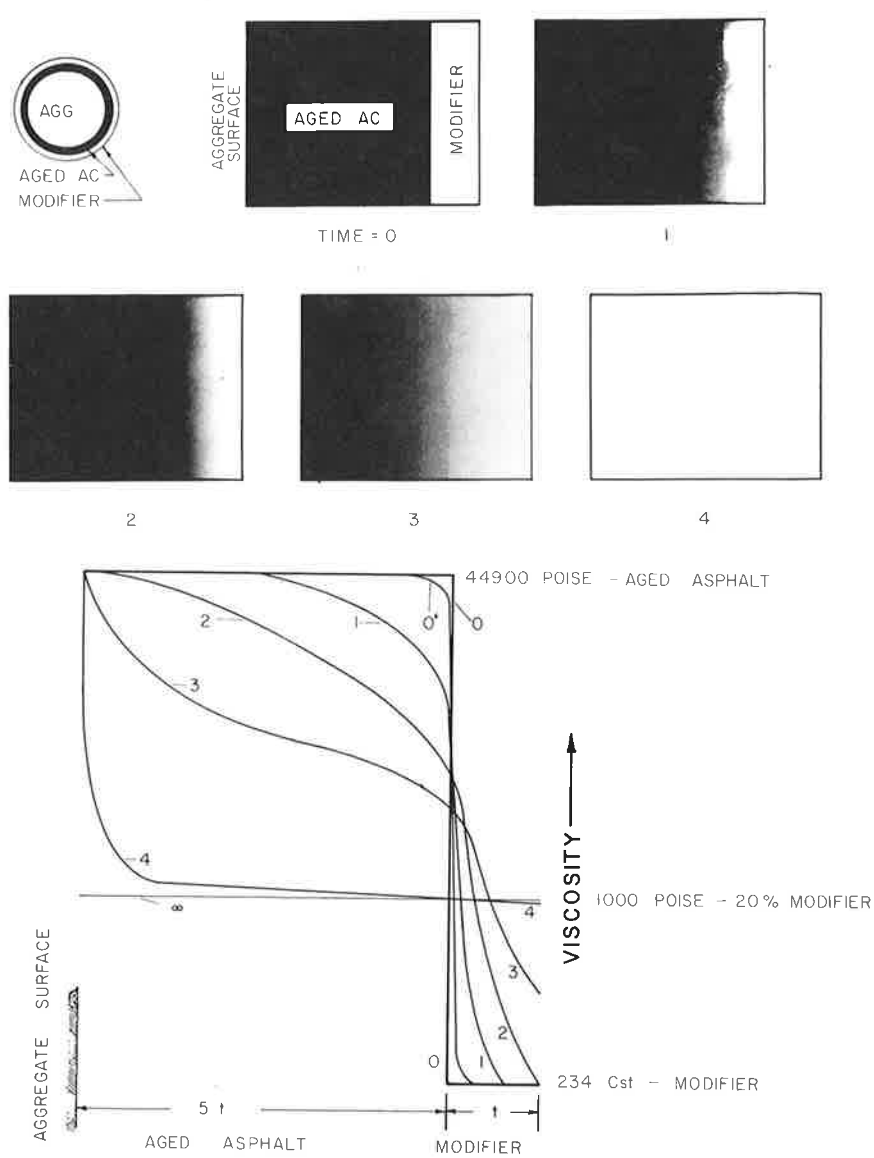
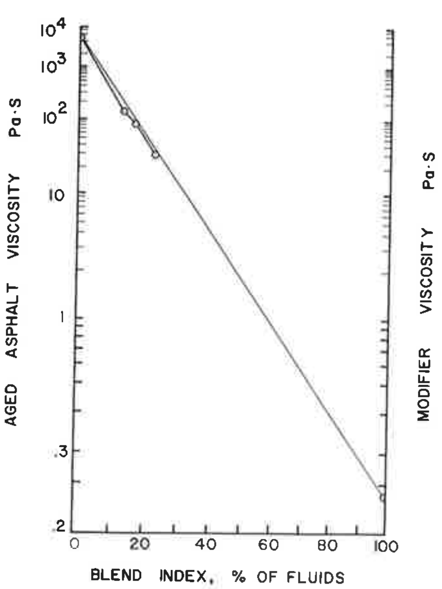


Figure 2. Viscosity of rejuvenated asphalt cement as a function of percentage of modifier.



fluxed with 20 percent modifier. This rejuvenated combination was then used as a normal asphalt cement. It was added to the recovered aggregate from which it was originally removed, and six Marshall samples were formed by using 75 blows per side. Six cylindrical samples (5.08 x 10.16 cm) were also formed by using double-ended static compaction. The analysis of the rejuvenated samples, including bulk specific gravity of mixture (Gmb) and coefficient of variation (CV), is given below.

Property	Marshall Samples	Cylindrical Samples
Gmb	2.414	2.401
σ	0.0091	0.0094
CV (%)	0.38	0.39
Air voids (%)	3.4	3.9

The fluids content represents the original asphalt cement, 5.3 percent by weight of aggregate, plus the 20 percent modifier. These samples represent a rejuvenated material with which samples formed by the recycling process may be compared. All subsequent samples were constructed by using double-ended static compaction to match the density of these samples as closely as possible.

Recycled Samples

The salvaged material was heated to 116°C, and 11.2 g of the modifier were mixed with 1056 g of the salvaged material. These percentages match those used in the rejuvenated samples. The recycled material was then compacted to a predetermined height to produce the desired density for 16 Marshall samples. The same procedure was followed in preparing four cylindrical samples. The resultant analyses are shown below.

Property	Marshall Samples	Cylindrical Samples
Gmb	2.368	2.343
σ	0.024	0.014
CV (%)	1.03	0.060
Air voids (%)	5.3	6.3

The samples were tested at various times after preparation to illustrate the influence produced by the diffusion process of the modifier into the asphalt cement in the recycled samples.

TEST RESULTS

The complete test sequence necessary for a VESYS characterization has been detailed earlier. We did not feel that the entire series of tests was necessary for studying the effects of diffusion. Resilient modulus in diametral loading on Marshall samples, creep compliance and permanent deformation tests on cylindrical samples, and Marshall stability were deemed sufficient, since they are all influenced to a large degree by the type and amount of asphalt cement present.

Resilient Modulus

The resilient modulus values for the rejuvenated samples showed no variation with time after compaction, as expected. The relatively low value of 358 540 kPa does not indicate a poor-quality material but, rather, reflects the influence of a low-viscosity material tested at a relatively high temperature (25-27°C). The fluids content of 6.3 percent by total weight is also above what normally would be used and would be reduced by adding new aggregate.

The resilient modulus values for the recycled samples showed a rather dramatic variation with time (Figure 3). The day following preparation the modulus is high. With time it decreases and finally increases again. There is a critical period when the resilient modulus is at a low value.

Creep Compliance Results

The creep compliance tests showed essentially no variation with time (Figure 4). The recycled samples show the same value for creep compliance as do the rejuvenated samples. The lack of variation with time in the compliance curves indicates that diffusion, if it is occurring, has a minimal influence on creep compliance. The explanation of this phenomenon is given below in the discussion of the implications of the test data collected.

Permanent Deformation Results

The permanent deformation data are developed from the incremental-static procedure outlined in the

Figure 3. Variation in resilient modulus as a function of time.

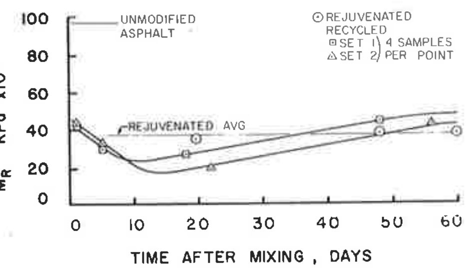


Figure 4. Creep compliance data for rejuvenated and recycled samples.

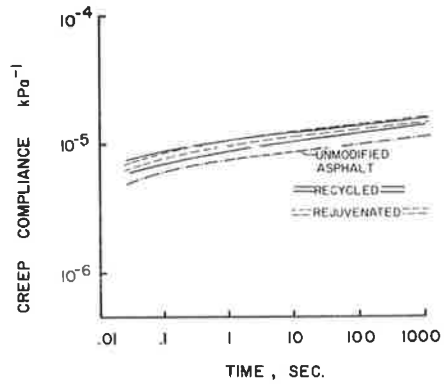
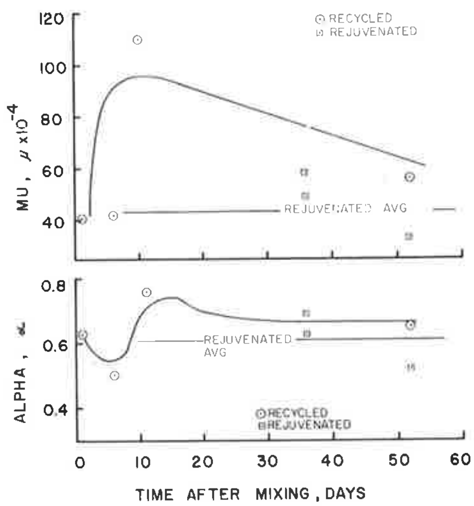


Figure 5. Variation in μ and α with time.



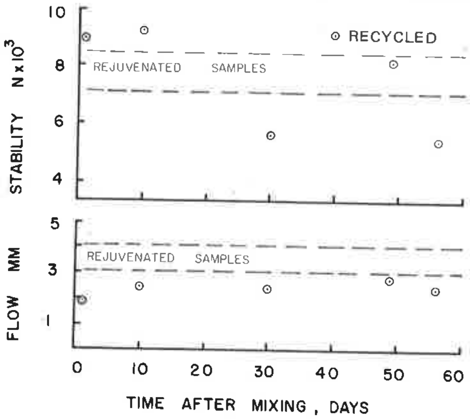
VESYS User's Manual (3). Although they are not based on as many samples as the resilient modulus data, a trend may be inferred from the time variation of μ and α, the values used in the rutting subsystem of VESYS (Figure 5). The rejuvenated sample values again show little variation with time. The recycled samples again show a softening followed by a hardening.

Briefly, permanent deformation is characterized by the following equation in the VESYS program:

$$F = \mu N^{-\alpha} \quad (1)$$

where

Figure 6. Variation in Marshall stability and flow with time.



F = fraction of total deformation that becomes permanent deformation,
N = number of wheel loads, and
μ,α = coefficients determined from test data.

In general, as μ increases and α decreases, the accumulation of permanent deformation increases. The data indicate that increased permanent deformation may be accumulated over the initial short-term portion of the pavement's life. The interpretation of these data will assist in explaining the influence of the proposed diffusion model on material characterization.

Marshall Test Results

The Marshall stability and flow values for the rejuvenated and recycled samples are presented in Figure 6. Test values for the rejuvenated samples fell within the range indicated by dashed lines on Figure 6. Little can be inferred from these data because of the inherent insensitivity of the Marshall test. It is important to note, however, that the stability and flow values are acceptable, even though no attempt was made to obtain a suitable mix from the Marshall standpoint. It is unlikely this mix would perform satisfactorily as a normal pavement mix, however, because of the other performance parameters.

INTERPRETATION OF TEST RESULTS

The test data support a softening effect caused by the diffusion of the modifier into an old asphalt cement. This is most apparent in the resilient modulus test, which is measured entirely in tension. The creep compliance, a compressive test, showed no interpretable variation with time, whereas the permanent deformation characteristics, which rely on a rebound to place the asphalt films in tension, showed variation similar to that of the resilient modulus. The following discussion explains the test data in terms of the diffusion process discussed earlier.

1. The modifier is mixed with the salvaged material (as shown in Figure 7a) and compacted to a predetermined density.
2. Compaction forces the old asphalt-coated aggregate into intimate contact, high viscosity in contact with high viscosity and even aggregate in contact with aggregate, as shown in Figure 7b.
3. The modifier begins diffusing into the old asphalt cement. This produces an enlarging layer of lower-viscosity material. The asphalt in the recessed contact areas begins to soften only slightly because of the distances the modifier must penetrate. This is illustrated in Figure 7c.
4. As the modifier continues to diffuse, it reaches a balance point at which all the raw modifier is gone and the driving potential for diffusion is reduced. At this point, the outer layer is at its softest consistency, and stiffness measurements may be at their lowest values.
5. With the decrease in the driving force, the diffusion process slows down appreciably. An imbalance of viscosities still exists between the inner and outer layers. At this time the viscosity of the inner layer begins to decrease and the outer layer's viscosity begins to increase as a result of the continuing diffusion. Stiffness measurements begin to show an increase at this point.
6. The long-term equilibrium point might be similar to that depicted in Figure 7d. The viscosity will have stabilized, slightly lower on the surface and slightly higher at the aggregate interface compared with the totally rejuvenated value determined on extracted asphalt. Because of distance effects, the modifier could be expected to take a very long time to penetrate to the contact areas. Thus, stiffness measurements may be slightly higher for a recycled sample than for a rejuvenated sample.

This explanation of the proposed diffusion model accurately models the test data measured on recycled samples. At stage 2, when stiff asphalt is in contact with stiff asphalt, the recycled samples are stiffer than the rejuvenated samples are. At stage 3, a larger volume of the asphalt cement has been softened and, when put in tension, it deforms more than at stage 2. In compression, however, old asphalt cement is still being forced into old asphalt cement, and compression testing produces nearly the same results that it did in the previous stages. However, there is less old asphalt that resists deformation under the load, and when the load is released there will be less rebound and more permanent deformation. At stage 5, the outer layer begins to increase its viscosity and the sample will stiffen, which was observed in all tests except the creep compliance test. Some softening in the creep compliance may occur, but this trend may be masked by data scatter. At stage 6, the "long-term equilibrium point," the average viscosity may be similar to that of the rejuvenated material. However, because the viscosity of the inner recesses will still be higher, the recycled data should be stiffer. After a sufficiently long time, the recycled data should asymptotically approach the rejuvenated values.

PHYSICAL VALIDATION

Although the test data substantiate the proposed diffusion model quite well, a physical verification was attempted. This process involved mixing a recycled sample with the modifier in the same manner that was used to prepare the recycled samples. The proper amount of modifier (11.2 g) was added to 1056 g of the salvaged material. The sample was mixed at 116°C and allowed to cure, uncompacted, for a specified time. Three samples were used for each determination.

At predetermined time intervals, an incremental extraction process was initiated. The recycled mix was immersed in trichloroethelyne and left to sit for 3 min, and the solution was decanted. The solution for each of three samples was combined, and the asphalt cement was recovered by using the Abson method. The remaining mixes were washed with the

Figure 7. Schematic of diffusion in a compacted sample.

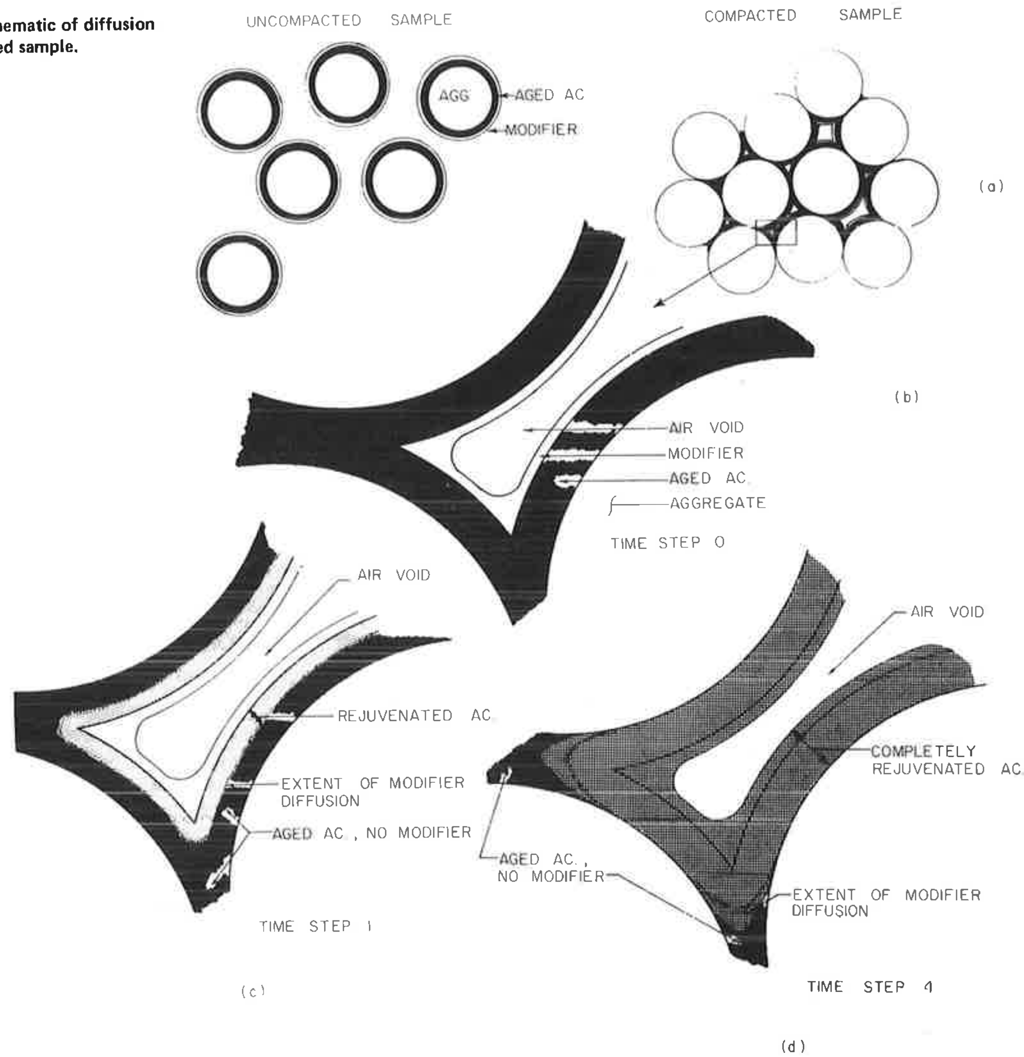
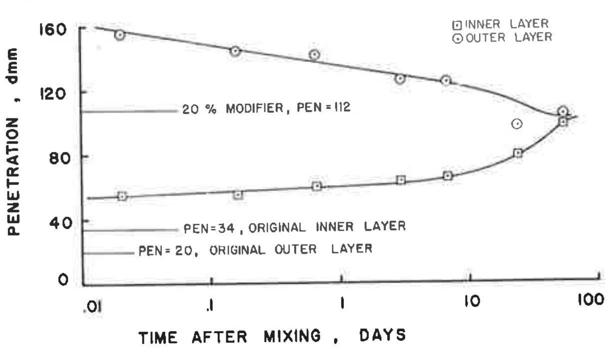


Figure 8. Penetration of the outer and inner layers as a function of time.



solvent to remove all of the remaining asphalt cement. The asphalt cement in these washings was also recovered. This procedure provided two samples of asphalt cement: The first sample represented the outer layer, and the second represented the inner layer. The consistency of each layer should vary with time if the diffusion process was acting as hypothesized. This procedure was used by Zearley of Iowa to determine whether a soft asphalt cement would penetrate an aged asphalt cement after two years of service (4).

The data from these extractions clearly indicate that the outer and inner layers are not of the same consistency for an appreciable time following mixing. The penetration at 25°C for each layer is plotted as a function of time after mixing (Figure 8). The data clearly show the outer and inner layers to be approaching the same consistency, indicated by the penetration value of the rejuvenated sample. The long-term consistency is stiffer than that of the rejuvenated asphalt cement and indicates the hardening produced in the laboratory mixing procedure.

DISCUSSION

The data developed in this study pose some serious problems for anyone attempting to characterize a recycled bituminous mix that contains a modifier. The recognition and acceptance of the diffusion process that occurs over an extended time period compared with normal time frames for material testing imply that the handling of the samples as well as the time between mixing and testing is critical. Different modifiers in different concentrations may diffuse at different rates. The composition of the old asphalt cement could also affect the diffusion rate of the modifier.

Studies that have cured a recycled mixture for a given period in a specified manner (5) are open to skepticism about the results and how well such results indicate the performance of that material over the long term. A process of artificial aging by placing the sample in an oven for a specified time is meaningless if the process is undertaken before diffusion is complete: The material undergoing aging will be the modifier, not the combination of modifier and old asphalt cement. It is this combination that will age over the extended life of the actual pavement, so it is this combination that must be aged in the laboratory. The same argument holds for accelerated moisture and freeze-thaw conditioning. To be indicative of long-term performance of the mixture, the conditioning must not begin until the diffusion process is completed.

Therefore, studies that have sampled recycled paving mixtures at some time after placement and compared the results of the characterization tests with similar materials compacted in the laboratory may not be comparing similar sets of data (6). Even though the results may indicate an acceptable mix, it cannot be stated that these results might not have changed appreciably if the samples had been tested several days before or after the date of their actual testing. Further, if samples are used in tests that require an extended period of time for completion (such as fatigue testing), the results cannot be interpreted in a meaningful manner. For one thing, the tests on each sample will run for different lengths of time, depending on physical test inputs such as load or strain magnitude. It is also unlikely that each sample test will begin at the same time after sample preparation.

The main point is that by no stretch of the imagination can data taken on a sample that is in the transition phase of the diffusion process be used for long-term performance predictions. During this transition phase, the material is highly bimodular because of the viscosity variation with thickness. The compression modulus will be high, and the tensile modulus will be low. The fact that previous testing on recycled mixes has indicated good mixes, even though some of the data might have been collected during the transition phase, is testament to the fact that a well-planned recycling operation can produce an excellent mix.

In an actual recycling operation that employs any of the commonly used recycling equipment, the problem of time dependency may be accentuated even further. In the actual recycling operation, virgin asphalt cement is added at the same time as the new aggregate and the modifier. The modifier will then diffuse at different rates into each asphalt, since their diffusivity coefficients will be different. This could remove modifier from the old asphalt and excessively soften the virgin asphalt. It would take much longer for this system to diffuse to a uniform-viscosity asphalt cement than it would take the simple asphalt-modifier system investigated in this paper. The considerations are exactly the same, however, and the material must be characterized after the diffusion process is complete in order for long-term performance predictions to be meaningful.

The structural properties of the pavement during the diffusion process must be investigated to make certain that the pavement will not fail during the time that the mix is at its softest. Any accumulation of damage during this diffusion period should be predicted so that it can be combined with the long-term performance. If the mix becomes too tender, it may accumulate excessive rutting and roughness when it is exposed to traffic; it then may have to be redesigned or the pavement closed to traffic for a period immediately after construction.

It must be recognized that the data discussed in this paper were developed on a recycled mix prepared from 100 percent salvaged material. No new aggregate or asphalt cement was used. Therefore, these data may represent the most severe condition for softening produced by the diffusion process. When a relatively large amount of new aggregate, typically 30 to 50 percent, is used in an actual recycling process, the dramatic softening will be reduced somewhat. Because the economics of recycling commonly dictate using the lowest amount of new material possible, the diffusion process will still be present to some extent. It is this extent that must be determined.

RECOMMENDATIONS

The diffusion process must be recognized and accounted for in the laboratory characterization for field performance predictions of recycled pavements that use a modifier. These considerations must encompass the following.

1. Diffusion effects must be examined for all modifier-asphalt combinations during the mix-design stage of the recycling project in order to assess the structural effects that the diffusion process will produce. If these effects will lead to serious structural problems, the mix should be redesigned. The most common redesign would include increasing the amount of new aggregate in the mix, which reduces the influence of the modifier.
2. If redesign of the mix is not practical because of economic factors, the influence of the diffusion process should be lessened by cold mixing the modifier with the salvaged pavement after crushing. The material could be stockpiled for a sufficient time to allow the diffusion process to pass the critical period. Material handling problems should be considered, since the modifier may accelerate the congealing of material in the stockpile.
3. For research purposes, recycled materials should be tested throughout their initial life period after construction. These data should be developed whenever recycling procedures are being investigated and a modifier is being used. These tests should be made to quantify this behavior with as many material combinations as possible.

ACKNOWLEDGMENT

This report was prepared as a part of the Illinois Cooperative Highway Research Program's project on Design Properties of Recycled Shoulders: Performance Characteristics, conducted by the Department of Civil Engineering in the Engineering Experiment Station, University of Illinois at Urbana-Champaign, in cooperation with the Illinois Department of Transportation and the Federal Highway Administration, U.S. Department of Transportation. The contents of this report reflect our views, and we are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Abridgment

Evaluation of Selected Recycling Modifiers

RICHARD J. HOLMGREEN, JR., AND JON A. EPPS

A study was undertaken to establish guidelines for use of modifiers in recycling pavement materials for use by the field engineer. Several modifiers were subjected to physical laboratory tests both alone and in blends with aged asphalts. The results indicated that an aged asphalt could be reconstituted but would not necessarily meet all specifications for a virgin asphalt of the same grade. Indications for modifiers blended with asphalts from Woodburn, Oregon; Rye Grass, Washington; and Abilene, Texas, are that the recycled binders should perform satisfactorily.

Materials used to alter properties of asphalt cements have been called softening agents, reclaiming agents, modifiers, recycling agents, fluxing oils, extender oils, bromatic oils, etc. Suppliers of these oils market their products under such names as Cyclogen, Dutrex, Paxole, Reclaimite, and RejuvAcote (1). The term "modifier" will be used to designate this type of material in the report and originates from the American Society for Testing and Materials Subcommittee on Modifier Agents for Bitumen in Pavements and Paving Mixtures. The general definition of modifier is "a material that when added to asphalt cement will alter the physical-chemical properties of the resulting binder". A more specific definition has been developed by the Pacific Coast User-Producer Group for the term "recycling agent"; their Specification Committee defines a recycling agent as "a hydrocarbon product with physical characteristics selected to restore aged asphalt to requirements of current asphalt specifications". It should be noted that soft asphalt cements as well as specialty products can be classified as recycling modifiers or agents.

The purpose of the modifier in asphalt-pavement recycling is to (a) restore the recycled or "old" asphalt characteristics to a consistency level appropriate for construction purposes and for the end use of the mixture, (b) restore the recycled asphalt to its optimal chemical characteristics for durability, (c) provide sufficient additional binder to coat any new aggregate that is added to the recycled mixing, and (d) provide sufficient additional binder to satisfy mixture design requirements.

Methods must therefore be developed to permit the engineer to define the type and amount of modifier to use for a particular asphalt-pavement recycling operation. Findings of a study performed at the Texas Transportation Institute for the National Cooperative Highway Research Program aimed at aiding the engineer in the field are reviewed below.

MODIFIER PROPERTIES

Modifier properties of interest to the engineer are those that can be used for specification purposes to ensure that the modifier will perform the following functions:

1. Be easy to disperse in recycled mixture (2),
2. Alter viscosity of old recycled asphalt cement to the desired level (2-4),
3. Be compatible with the old recycled asphalt to ensure that syneresis (exudation of maltenes from asphalts) will not occur (3),
4. Have the ability to redisperse the asphaltenes in the old recycled asphalt (4),
5. Improve the life expectancy of the recycled asphalt mixture (2-4),
6. Be uniform in properties from batch to batch (2), and
7. Be resistant to smoking and flashing if used in hot-mix operations (2,3,5).

In an effort to classify the modifiers, four possible properties emerged that had enough information on each modifier to use as a classification test. The four tests were viscosity at 77°F (25°C) and at 140°F (60°C), the percentage loss from the thin-film oven test, (TFOT), and viscosity at 140°F on the thin-film oven residue. Since asphalts are graded by viscosity at 140°F either before or after the TFOT, these two tests were considered more significant than the thin-film oven loss and viscosity at 77°F. Also, the design procedure requires the input of viscosity at 140°F of both old asphalt and modifier. Since the old binder was to be reconstituted to an AC-10 grade asphalt, for the purposes of this program, viscosity at 140°F before the TFOT was chosen as the classifying test.