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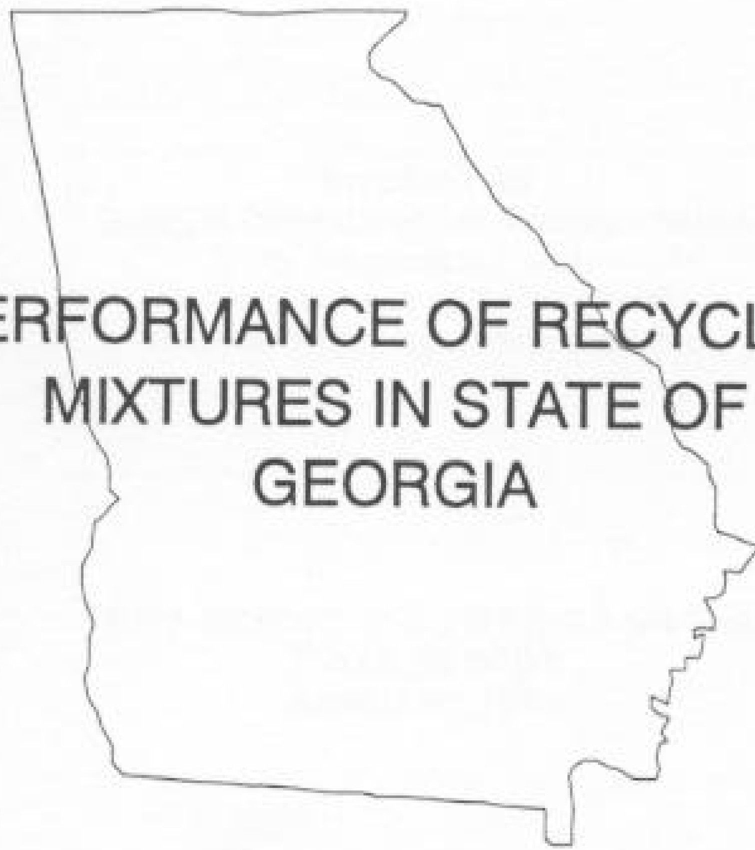

PERFORMANCE OF RECYCLED MIXTURES IN STATE OF GEORGIA

OFFICE OF MATERIALS & RESEARCH
RESEARCH AND DEVELOPMENT BRANCH

PERFORMANCE OF RECYCLED MIXTURES IN STATE OF GEORGIA

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16. Abstract

The Georgia Department of Transportation (GDOT) has been constructing recycled asphalt pavements routinely for about four years. This research project was undertaken to evaluate the performance of recycled pavements in comparison to virgin (control) asphalt pavements.

Five projects, each consisting of a recycled section and a control section, were subjected to detailed evaluation. In-situ mix properties (such as percent air voids, resilient modulus and indirect tensile strength), recovered asphalt binder properties (such as penetration, viscosity, $G^*/\sin\delta$ and $G^*\sin\delta$), and laboratory recompacted mix properties (such as Gyratory Stability Index and confined, dynamic creep modulus) were measured. A paired t-test statistical analysis indicated no significant differences between these properties of virgin and recycled mix pavements which have been in service from 1 1/2 to 3 1/2 years.

Ten additional virgin mix pavements and 13 additional recycled pavements were also evaluated as two independent groups. No statistically differences were found between the recovered asphalt properties (penetration and viscosity) of these virgin and recyled pavements in service.

The current GDOT recycling specifications and mix design procedures appear to be satisfactory based on the results of this study.

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INTRODUCTION

Hot mix recycling of asphalt pavements is increasingly being used as one of the major rehabilitation methods by various highway agencies all over the United States. Besides general savings in costs and energy expended, it also saves our natural resources and environment.

The Georgia Department of Transportation (DOT) has been constructing recycled hot mix asphalt (HMA) pavements routinely for about four years. It was felt necessary to evaluate the performance of these recycled pavements in comparison to virgin HMA pavements constructed during the same period. This would determine whether the recycled HMA pavements have performed similar to the virgin HMA pavements. It would also provide information for adjusting specification and mix design method for recycled mixtures, if needed.

The hot mix recycling process involves adding a specified amount of reclaimed asphalt pavement (RAP) to virgin aggregates and mixing with virgin asphalt cement. When a substantial amount of RAP is used in recycling, softer (lower viscosity or higher penetration) virgin asphalt cement is used as compared to that used in conventional virgin HMA mixtures to compensate for the hard asphalt cement in the RAP. However, if the asphalt cement used is too soft, the HMA mix may be tender initially and this may cause premature rutting of the HMA pavement. Because of this concern for rutting, most of the recycled pavements in Georgia have been constructed using AC-20 asphalt cement (rather than a much softer AC-10 asphalt cement) whereas virgin HMA pavements are generally constructed using AC-30 asphalt cement. However, if the virgin asphalt cement is not soft enough, the resulting binder in the recycled mix may be too hard and this could lead to premature ravelling and/or cracking of the HMA pavement. This research project was undertaken to compare the relative performance of virgin and recycled HMA pavements in Georgia and to recommend specification and mix design modifications for recycled mixtures if needed.

OBJECTIVES

The objectives of this project are summarized below:

1. Evaluate the performance of the in-place recycled and virgin (control) HMA pavements both visually as well as in the laboratory,
2. Compare the performance of recycled HMA with that of virgin (control) HMA,
3. Determine whether the recycled HMA mixes age faster than virgin mixes,
4. Recommend mix designs and quality control procedures to improve the performance of recycled pavements, and
5. Review GDOT's present recycling specifications and recommend changes where necessary.

REVIEW OF LITERATURE

Hot mix recycling has been defined as a process in which reclaimed asphalt pavement materials (RAP), reclaimed aggregate materials (RAM) or both are combined with new aggregates and asphalt cement or recycling agents in a central plant (1). These materials are blended in proportions needed to meet the required standard specification for conventional mixes.

The definitions of some of the common terms used in this report are as follows (1), Reclaimed Asphalt Pavement (RAP)

RAP is the removed and/or processed pavement material containing asphalt and aggregate.

Reclaimed Aggregate Material (RAM)

RAM is the removed and/or processed pavement material containing no reusable binding agent.

Recycled Mixture

Recycled mixture is the final mixture of reclaimed asphalt pavement, new asphalt cement, recycling agent if necessary, RAM or new aggregates.

RAP Binder

RAP binder is the aged asphalt cement present in the RAP material.

Virgin/Control Mixture

Virgin or control mixture is the conventional hot mix asphalt mixture placed adjacent to a recycled mixture for comparison.

Research carried out by Little and Epps (2), Little et al (3), Brown (4), Meyers et al (5), and Kandhal et al (6) has indicated that the structural performance of recycled mixes is equal and in some instances better than that of the conventional mixes.

The properties of the recycled mixture are believed to be mainly influenced by the aged RAP binder properties and the amount of RAP in the mixture. Kiggundu et al (7) showed that mixtures prepared from the recycled binder blends generally age at a slower rate than virgin mixtures. This may be due to the fact that the RAP binder has already undergone oxidation which tends to retard the rate of hardening (5, 7). Such a condition is believed to improve the temperature susceptibility characteristics of the recycled mix (7). Kiggundu and

Newman (8) have indicated that the recycled mixtures withstood the action of water better than the virgin mixtures. Dunning and Mendenhall (9) have also shown that the durability of recycled asphalt concrete mixtures is greater than that of the conventional mixtures.

The aging or the hardening of asphalt cement is mainly caused by oxidation due to prolonged exposure of the pavement to air. The process of oxidation basically increases the concentration of the asphaltenes in the asphalt cement thereby increasing the polarity of the asphalt molecules (8). The increased polarity results in higher viscosity and stiffness of the aged binder. If the rate of oxidation is very high, the asphalt binder becomes very stiff and the pavement may develop premature cracking. Addition of soft asphalt cement or recycling agent to an aged RAP decreases the stiffness of the binder in the RAP.

Brown (4) recommended the use of low viscosity asphalt cements instead of recycling agents to modify the RAP binder properties. Recycled mixtures prepared by using recycling agents were found to be more temperature susceptible as compared to those prepared using softer asphalt cements.

The amount of the RAP used in a recycled mixture depends on the type of hot mix plant being used for preparing the mix and also on environmental considerations. The specified maximum permissible amounts of RAP vary from state to state. The Georgia Department of Transportation limits the amount of RAP to 40 percent of the total recycled mixture for continuous type plants and to 25 percent for batch type plants (10). According to the specification the RAP binder when blended with virgin asphalt cement should give a viscosity between 6,000 poises to 16,000 poises after the thin film oven test.

This review of literature was also conducted to determine typical ranges of asphalt cement properties (such as penetration at 25°C and viscosity at 60°C) for virgin as well as recycled pavements, which have been in service for at least two years. Unfortunately, there

TABLE 1. Typical viscosity and penetration data for aged asphalt cement

No. of projects Studied	Age of the Mix (years)	Mix type	Viscosity @ 140 F (poises)	Penetration @ 77 F (0.1 mm)	Researchers & References
2	----	RAP Binder*	20,500 - 44,000	9 - 12	Little & Epps (2)
3	----	RAP Binder	38,100 - 400,000+	4 -28	Brown (4)
3	----	Aged Mix**	9,800 - 75,600	18 - 59***	Brown (4)
3	20+	RAP Binder	56,800-172,795	6 - 22	Kiggundu et al. (7)
2	----	RAP Binder	51,203 - 197,316	10 - 19	Kiggundu et al. (8)
4	2 1/2	Aged Mix	10,000 - 29,000	29 - 35	Kandhal (11)
6	2 1/2	Aged Mix	5,000 - 11,000	----	Kandhal (12)
4	----	Aged Mix	----	13 - 18	Kari (13)
10	----	RAP Binder	4,090 - 400,000+	9 - 37	Escobar (14)
4	2 1/2	Weathered Mix****	8,000 - 170,000	10 - 35	G. R. Kemp (15)
1	----	RAP Binder	28,519 - 147,187	6 - 16	Whitcomb (16)
2	1	Aged Mix	10,806 - 13,400	35 - 39	Chari (17)

* RAP binder refers to recovered asphalt cement from RAP stockpile.
** Aged mix refers to mix from a conventional pavement after a certain duration of service
*** Asphalt cement recovered from blended mix after fatigue test
**** Recycled mix blended in laboratory and weathered at different sites for 4 years for all projects
---- Not available

is very little information on the aged binder properties of in-service recycled pavements. Since this study involves properties of aged binder in virgin and recycled pavements in Georgia, such data would be useful for comparative purposes. Some data for aged binders were, however, collected and are summarized in Table 1 with references. The presented data show a large range for viscosity and penetration values of the asphalt cement due the presence of so many variables such as type of mix (RAP, laboratory aged mix or recycled mix) and age.

The study (6) conducted in 1989 by the National Center for Asphalt Technology to develop guidelines for hot-mix recycling in Georgia involved evaluating aged asphalt binder properties from RAP stockpiles at five locations in the State. The results from this project are summarized in Table 2. The RAP stockpiles normally contain material milled from pavements which are relatively old (usually more than 10 years). Therefore, the values represent very old pavements as compared to 2-3 year old pavements evaluated in this study. However, the data in Tables 1 and 2 can serve as relative background information.

SAMPLING AND TESTING PLAN

This study was divided into two tasks. Task 1 involved identifying existing field projects which have used both recycled and virgin (control) mixes on the same project and conducting a detailed comparative evaluation. Task 2 consisted of evaluating at least 10 recycled HMA pavements and at least 10 virgin mix pavements constructed independently throughout the state during the last 2-3 years. The properties of the binders recovered from the mixtures of the above projects formed a database for comparative purposes.

The work for each task involved collecting construction data of all the projects, visual evaluation of the in-place pavements, and extensive laboratory testing of the field cores taken from each project.

TABLE 2. Typical Properties of asphalt cement recovered from RAP stockpiles

RAP Stockpile Location	Viscosity @ 140 F (poises) Range	Average	Penetration @ 77 F (0.1 mm) Range	Average
Newton County	18,541 - 78,744	48,390	18 - 25	20
Forest Park	39,123 - 198,213	111,361	9 -24	16
Resaca Asphalt Plant	10,331 - 63,542	28,608	21 -41	29
Bryan County	61,840 - 409,720	289,668	5 - 19	9
Lowndes County	8,130 - 20,456	16,262	31 - 49	36

Task 1

This task consisted of identifying projects that had both recycled as well as virgin (control) sections on the same project in order to evaluate and compare the performance and properties of the recycled section relative to those of the control section.

Selection of Projects

Only five existing field projects could be identified for this task, which had both recycled and virgin HMA mixtures on the same project in the wearing course. The selection of these projects assured that the recycled and the virgin sections used the same virgin aggregates in the mixtures, were produced by the same HMA plant, were placed and compacted by the same equipment and crew, and were subjected to the same traffic and environment during service.

These five projects are located in Coffee, Ware, Chatham, Emanuel and Columbia/Richmond counties as shown in Figure 1.

Project Details

The project details of both the recycled and the control (virgin) wearing course mixtures for the five projects were obtained from the Georgia DOT. Table 3 gives site number, county, section type, age, percentage RAP, virgin asphalt cement properties (grade, viscosity and penetration), and mix properties (asphalt content and the air void content of the mat when constructed). Additional details of the projects including the properties of the recovered asphalt cement from the RAP and recycled mixtures, are given in Tables A1 through A3 of Appendix "A". As shown in the Table 3, Georgia DOT also uses AC-20 Special (designated as AC-20S) which is required to have a penetration range of 60 to 80. Georgia DOT's asphalt specification are given in Appendix "C".

Test Plan

The recycled and the control sections for all five projects were visited. A representative 150 m (500 ft) long test area was selected in each section for detailed evaluation. The pavement was visually evaluated for surface distress such as rutting, ravelling and weathering, alligator (fatigue) cracking, and transverse cracking. The Strategic Highway Research Program (SHRP)'s Pavement Distress Identification Manual (18) was used to identify the distress type and its severity (low, moderate and high) based on the pictures given in the manual. A copy of the pavement evaluation sheet and SHRP guidelines are given in Appendix "B". Rut depths were measured across the lane using a straight edge. The total number and the cumulative length of the cracks was also determined.

A total of eight 101-mm (4-inch) diameter cores and four 152-mm (6-inch) diameter cores were obtained from each 150-m (500-ft) representative section from the outside wheel track as shown in Figure 2. Cores were obtained at an interval of 30-m (100-ft). This was done to obtain an average evaluation of the pavement section when tested in the laboratory. Typical pavement coring operations can be seen in Figures 3 and 4.

Laboratory tests were conducted on the field cores according to the flow chart shown in Figure 5. All the field cores were sawed to recover only the recycled or the control (virgin) wearing course portion of the pavement. It was noticed that the thickness of the layer in question varied from 20 mm (0.8 inch) to about 38 mm (1.5 inches). Since the total amount of mix material from sawed 101 mm (4-inch) cores obtained from each section was limited, it was necessary to save the tested samples from the indirect tensile test also for extraction of the asphalt cement from the mix. Also, the mix tested for the Rice specific gravity was air dried and used in the recompaction of the mix for the same reason.

The mix from the 152-mm (6-inch) diameter cores was reheated to 133 °C (300 °F) and

FIGURE 1. Project location map (Task 1)

TABLE 3 Project construction details (Task 1)

Site No.	County	Section	Age yrs	RAP %	Virgin Asphalt Cement Properties: Grade	Viscosity 140 F	Pen. 77 F	Mix Properties: Asphalt Content (%)	% Air Voids (mat)
18C	Coffee	Virgin	1.50	0	AC-30	2988	***	6.0	9.0
18R	Coffee	Recycled	1.50	15	AC-30	2988	***	5.7	9.3
22C	Ware	Virgin	1.75	0	AC-30	2703	***	6.0	6.6
22R	Ware	Recycled	1.75	10	AC-20S	1912	***	5.7	6.9
23C	Chatham	Virgin	1.50	0	AC-30	2807	***	***	***
23R	Chatham	Recycled	1.50	25	AC-20	1990	***	5.4	6.5
25C	Emanuel	Virgin	2.25	0	AC-30	2965	***	5.8	7.9
25R	Emanuel	Recycled	2.25	20	AC-20	2055	***	5.7	7.4
28C	Columbia/ Richmond	Virgin	1.50	0	AC-30	3047	***	6.0	8.3
28R	Columbia/ Richmond	Recycled	1.50	20	AC-30	3046	***	5.8	7.8

*** Data not available

recompacted in the laboratory using the U.S. Corps of Engineers Gyratory Test Machine (GTM). This was done to evaluate the rutting potential and shear properties of the recycled and the control mixes. Properties such as gyratory stability index (GSI), gyratory elasto-plastic index (GEPI), and roller pressure, which are discussed later, were determined as the mix was compacted. Air void contents of the compacted specimens were also obtained. Confined, dynamic creep tests were performed on the recompacted specimens at 60°C (140°F), 138 kPa (20 psi) confining pressure and 828 kPa (120 psi) vertical pressure. Dynamic loading was applied for a duration of one hour and then the specimen was allowed to recover for 30 minutes.

The extraction of the aged asphalt cement from the HMA mixtures was accomplished by the ASTM D2172 (Method A) procedure. The asphalt cement from the solution was recovered using the Rotovapor apparatus as recommended by the SHRP program. The recovered asphalt cement was tested for viscosity at 60°C (140°F) and penetration at 25°C (77°F). Also, the complex shear modulus (G*) and the phase angle (δ) of the recovered asphalt binder were determined using a dynamic shear rheometer (DSR) according to the AASHTO Performance Graded Binder Specification (MP1) for the State of Georgia. Test temperatures of 64°C (148°F) and 22°C (72°F) were used to determine the potential for rutting and fatigue cracking, respectively, as contributed by the binder.

The following tests were conducted on the 101-mm (4-inch) diameter field cores.

- Thickness determination
- Bulk specific gravity (to determine in-situ air voids)
- Resilient modulus at 25°C (77°F), and
- Indirect tensile test at 25°C (77°F)

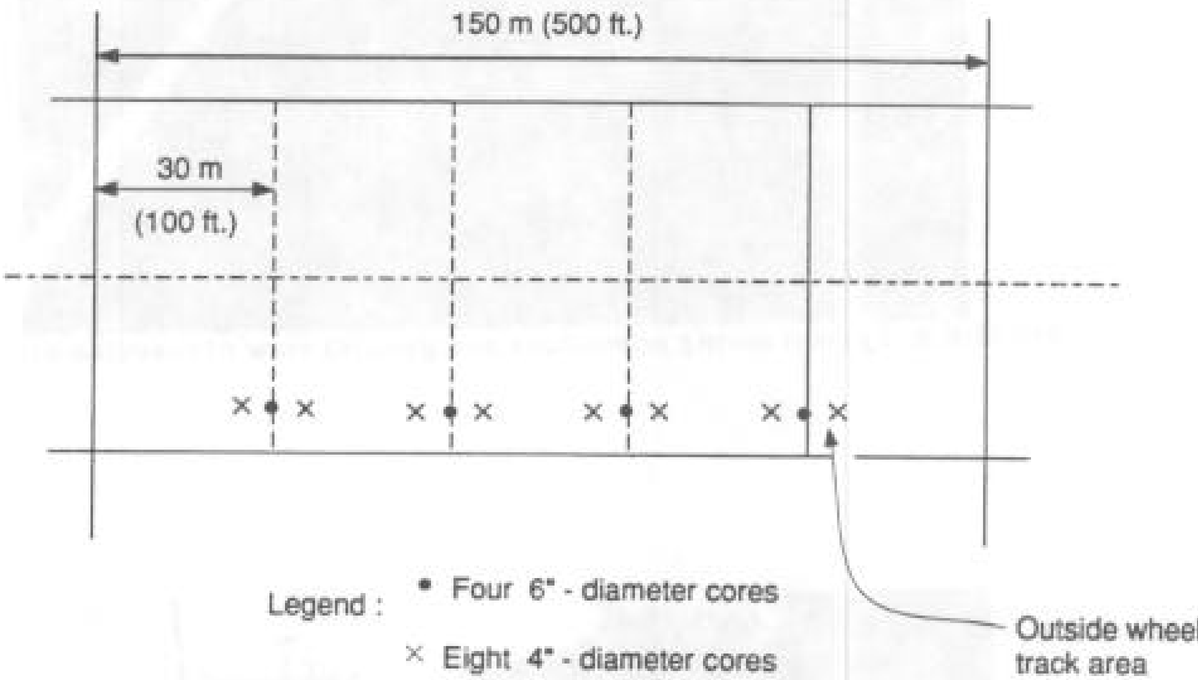
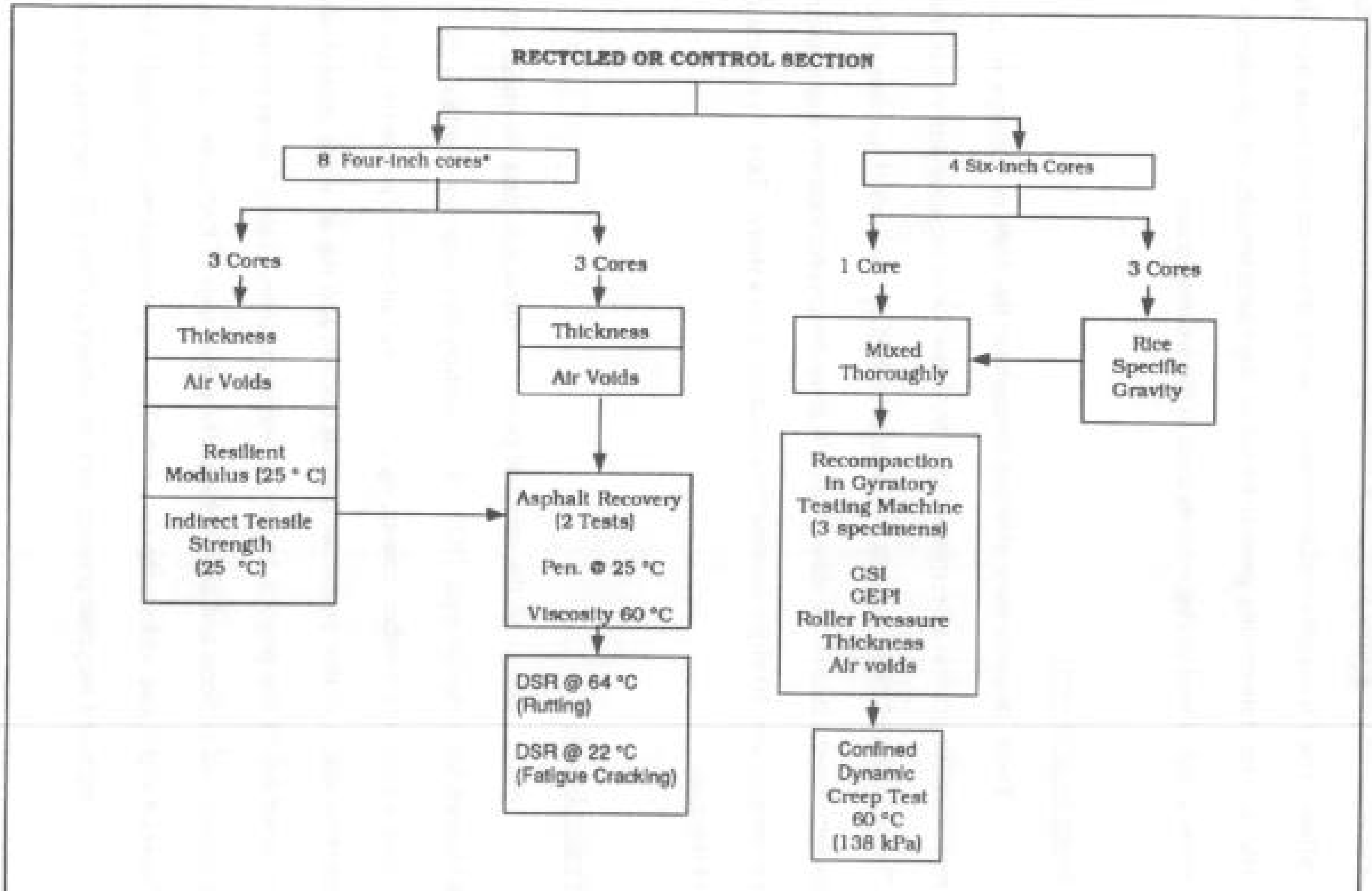


FIGURE 2. Core sampling plan (Task 1)

FIGURE 3. Typical coring operations and general view of recycled Site no. 3

FIGURE 4. Typical coring operations and general view of recycled Site no. 1



* Two extra cores taken to obtain at-least six good cores with truly vertical edges for testing.

FIGURE 5. Core testing plan (Task 1)

Task 2

This task consisted of 13 projects involving only the recycled wearing courses and 10 projects involving only virgin mix wearing courses constructed generally during the same period. The results obtained from these projects combined with those from Task 1 formed a database for determining general trends in the characteristics and performance of recycled mixes as compared to virgin mixes used in the wearing courses.

Selection of Projects

These projects were selected throughout the State of Georgia in order to obtain a representative general assessment of the performance of recycled and virgin HMA pavements. The selection of these projects was also governed by the limited number of hot mix recycled projects constructed in the state. Figure 6 gives the project location map showing 13 recycled pavements and 10 virgin pavements evaluated in this study. Task 1 projects are also shown in the map.

Project Details

As in Task 1, all the relevant project construction data for these 23 projects were obtained from the Georgia DOT. Construction data was not available for project no. 10. Table 4 gives site number, county, age, virgin asphalt cement properties (grade, viscosity and penetration), and mix properties (asphalt content and the air voids content of the mat when constructed) for the projects containing virgin mixtures. Table 5 gives similar information for the recycled projects and also includes the percentage of RAP used. It should be noted that Tables 4 and 5 also include the data from Task 1 to enhance the data base. Additional details of the virgin and recycled projects such as project and mix ID numbers, maximum aggregate

FIGURE 6. Project location map (Task 2)

TABLE 4. Project construction details (Task 2 - Virgin mixes)

					Virgin Asphalt Cement Properties			Mix Properties	
Site No.	County	Section	Age (years)	RAP %	Grade	Viscosity (poises)	Pen. 77 F	Asphalt Content	% Air Voids
2	Murray	Virgin	2.50	0	AC-20S	1729	***	5.7	6.4
4	Walker	Virgin	2.50	0	AC-30	3085	***	5.8	6.8
5	Floyd	Virgin	1.75	0	AC-30	1870	72	5.2	7.6
6	Bartow	Virgin	2.00	0	AC-30	3113	***	5.5	6.2
7	Bartow	Virgin	3.50	0	AC-30	2858	***	6.0	7.5
8	Cherokee	Virgin	3.50	0	AC-30	2773	***	6.3	7.2
10	Fulton	Virgin	3.75	0	AC-30	3092	72	***	***
13	Quitman	Virgin	4.75	0	AC-30	3137	65	5.7	7.0
14	Quitman/ Randolph	Virgin	4.00	0	AC-30	2911	64	5.7	7.1
18C	Coffee	Virgin	1.50	0	AC-30	2988	***	6.0	9.0
22C	Ware	Virgin	1.75	0	AC-30	2703	***	6.0	6.6
23C	Chatham	Virgin	1.50	0	AC-30	2807	***	***	***
25C	Emanuel	Virgin	2.25	0	AC-30	2965	***	5.8	7.9
27	Jenkins	Virgin	2.00	0	AC-30	2897	***	5.8	6.5
28C	Columbia/ Richmond	Virgin	1.50	0	AC-30	3047	***	6.0	8.3

*** Data not available

TABLE 5. Project construction details (Task 2 - Recycled mixes)

Site No.	County	Section	Age (years)	RAP %	Virgin Asphalt Cement Properties: Grade	Viscosity (poises)	Pen. 77 F	Mix Properties: Asphalt Content	% Air Voids
1	Murray	Recycled	1.25	25	AC-20S	2018	***	5.9	7.6
3	Catoosa	Recycled	2.75	10	AC-20	2155	***	5.5	7.8
9	Walton	Recycled	2.25	15	AC-20S	2141	***	5.6	7.4
11	Fulton	Recycled	3.50	40	AC-10	1179	98	5.6	8.2
12	Dekalb	Recycled	5.00	20	AC-20S	1939	67	5.3	6.8
15	Worth	Recycled	3.50	40	AC-10	1179	123	5.7-6.0	6.0
16	Brooks	Recycled	3.00	25	AC-20	1895	82	5.5	6.4
17	Irwin	Recycled	3.00	25	AC-20	2114	84	5.3	7.6
18R	Coffee	Recycled	1.50	15	AC-30	2988	***	5.7	9.3
19	Coffee	Recycled	2.25	25	AC-20	2063	86	6.0	7.1
20	Benhill/Erwin	Recycled	2.00	25	AC-20	1998	93	5.5	7.8
21	Benhill	Recycled	2.25	25	AC-20	2063	86	6.0	7.4
22R	Ware	Recycled	1.75	10	AC-20S	1912	***	5.7	6.9
23R	Chatham	Recycled	1.50	25	AC-20	1990	***	5.4	6.5
24	Chatham	Recycled	1.50	25	AC-20	1982	***	5.1	5.7
25R	Emanuel	Recycled	2.25	20	AC-20	2055	***	5.7	7.4
26	Emanuel	Recycled	2.00	30	AC-20	2075	***	6.0-6.3	7.5
28R	Columbia/ Richmond	Recycled	1.50	20	AC-30	3046	***	5.8	7.8

*** Data not available

size, and theoretical maximum density (TMD) are given in Tables A2 and A3 of Appendix "A".

Test Plan

Visual evaluation of all projects in Task 2 was performed as in Task 1. Surface distresses like rutting and cracking were measured and quantified. Four 152-mm (6-inch) were obtained at an interval of about 30 m (100 ft) from the representative test area for further laboratory testing. The cores were obtained from the outside wheel track area.

Laboratory tests were conducted on the field cores according to the flow chart shown in Figure 7. The field cores were sawed to separate the top recycled or the virgin mix layer for the purpose of this study. The thickness and density of the cores were measured. In-situ air voids were determined using the theoretical maximum density (TMD) values obtained from the project construction records.

Asphalt cement was extracted and recovered from the cores following the procedures mentioned in Task 1. Penetration at 25°C (77°F) and viscosity at 60°C (140°F) of the recovered asphalt cements were then determined. The results obtained from Task 2 were augmented by those from Task 1 in the analysis of the data.

TEST DATA

A brief discussion of the tests conducted and the results obtained is given below.

Task 1

As mentioned earlier, visual evaluation of the recycled and the control sections was carried out at the beginning of the project. A summary of the observations made during the pavement evaluation is presented in Table 6. These results have been analyzed and quantified

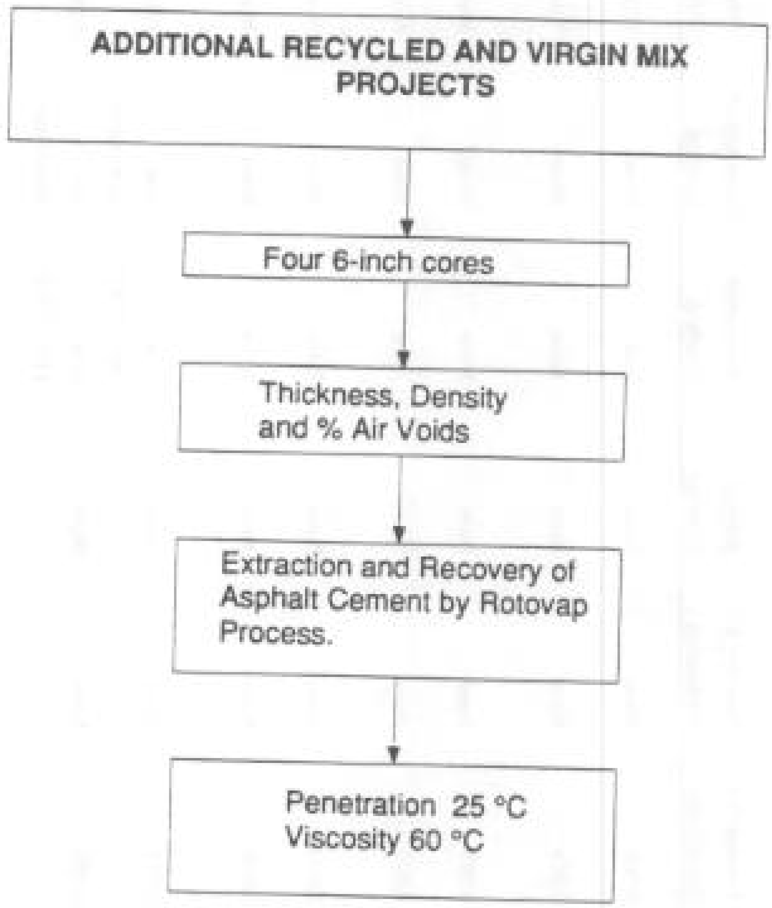


FIGURE 7. Core testing plan (Task 2)

TABLE 6. Pavement surface evaluation (Task 1)

Site No.	County	Mix Type	Average Rut Depth (Inch)	Ravelling & Weathering	Alligator Cracking	Transverse Cracking	Longitudinal Cracking	Other Surface Distress
18C	Coffee	Virgin	0.069	None	None	Low (5-48 ft.)*	None	WBL has more transverse cracks
18R	Coffee	Recycled	0.069	None	None	None	None	None
22C	Ware	Virgin	0.069	None	None	None	None	None
22R	Ware	Recycled	0.063	None	None	None	None	None
23C	Chatham	Virgin	0.044	None	None	None	None	None
23R	Chatham	Recycled	0.066	None	None	None	None	None
25C	Emanuel	Virgin	0.009	None	None	Low (23-276 ft.)*	Low (continuous)	Map cracking
25R	Emanuel	Recycled	0.063	None	None	Low (17-222 ft.)*	Low (continuous)	Long. refl. crack
28C	Columbia/ Richmond	Virgin	0.013	None	None	None	None	None
28R	Columbia/ Richmond	Recycled	0.078	None	None	Low (hairline) (5-60 ft.)*	None	Open Surface Texture

* The first and the second values in parenthesis indicate the number of cracks and the total length of all cracks, respectively in the test section

TABLE 7. In-situ mix properties (Task 1)

Site No.	% Air Voids In-Situ N=6		Indirect Tensile Strength @ 77 F (psi) N=5		Deformation @ Failure (0.01 inch) N=3		Resilient Modulus @ 77 F (psi) N=3	
	Control	Recycled	Control	Recycled	Control	Recycled	Control	Recycled
18	7.6 (0.45)*	8.2 (0.81)	256 (15)	231 (21)	7.8	9.0	1087692	952517
22	9.4 (0.70)	7.5 (0.89)	150 (4)	142 (9)	9.7	9.8	716193	610073
23	3.6 (0.80)	4.9 (0.52)	169 (18)	161 (17)	9.2	9.6	698035	685162
25	6.2 (1.07)	5.3 (0.70)	219 (24)	195 (15)	8.2	9.0	1201282	830669
28	8.3 (1.34)	6.5 (0.99)	217 (10)	207 (9)	8.8	9.9	1029613	1379549

* The values in parenthesis are standard deviations

later to compare the relative performance of recycled and control sections.

Laboratory tests were conducted on the cores obtained from the project sites according to the testing plan shown in Figure 5.

In-situ Mix Properties

Table 7 gives the test data obtained on the field cores from the five projects (both recycled and control sections). The test data includes air voids content, resilient modulus at 25°C (77°F), indirect tensile strength and deformation at failure at 25°C (77°F).

Recompacted Mix Properties

The mix obtained from the field cores was heated and recompacted in the GTM as mentioned earlier. Based on NCAT's experience, a vertical pressure of 828 kPa (120 psi) and 1° initial gyration angle was used. The compaction is achieved by applying a combination of shearing stress and constant vertical pressure equal to the anticipated tire pressure. The common gyratory indices and shear properties used in this study are briefly explained below.

Gyrograph

The gyrograph is a recording of shear strain experienced by the asphalt mixture during the compaction process (Figure 8)

Gyratory angle

The gyratory angle is an indication of the magnitude of the gyratory shear strain. It is expressed in the form of the width of the recording band in the gyrograph. Three gyratory angles used in the calculations are as follows:

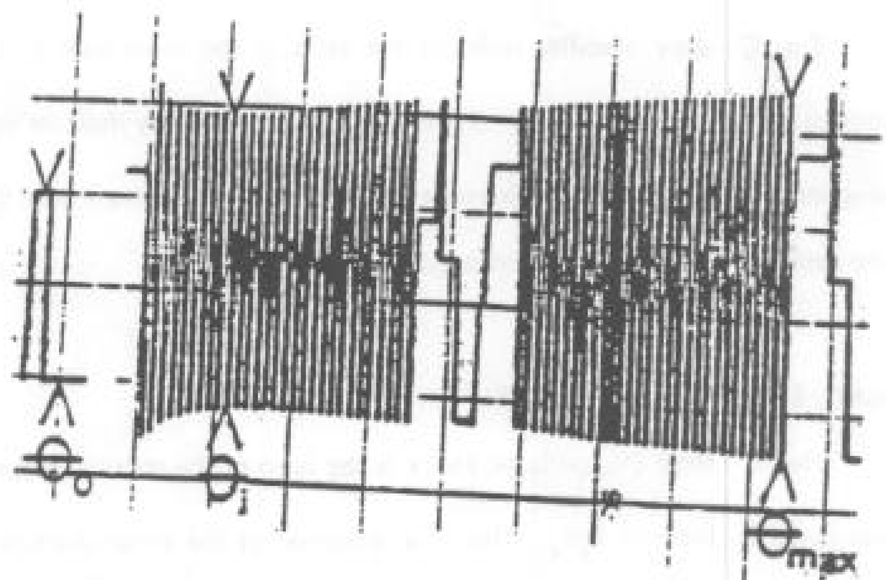


FIGURE 8. A gyrograph showing θ_0, θ_{min}, and θ_{max}

Initial gyratory angle which is the machine setting = θ_0

Minimum gyratory angle or shear strain = θi

(Minimum gyrograph band width)

Maximum gyratory angle or shear strain = θ_{max}

(Maximum gyrograph band width)

Gyratory Stability Index (GSI)

The Gyratory Stability Index is the ratio of the maximum gyratory angle to the minimum gyratory angle or θ_{max}/θ_i. GSI values in excess of unity indicate increase in plasticity during densification. This results from a progressive transfer of stress from the aggregate phase to the asphalt phase during the compaction process.

Gyratory Elasto-Plastic Index (GEPI)

The Gyratory Elasto-Plastic Index is the ratio of the minimum gyratory angle to the initial gyratory angle or θ_i/θ_0. This is a reflection of the shear strain experienced by the specimen and as such is an indication of the internal friction which is mostly contributed by the aggregate structure.

Roller Pressure

This is a measure of the pressure developed due to the resistance to deformation of the compacted specimen. The more resistance the sample offers to deformation, the higher will be the roller pressure. The roller pressure generally reduces in the compaction process as the gyrograph shows widening of the band width. This indicates that the mix is plastic. The final

TABLE 8. Recompacted mix properties (Task 1)

Site No.	% Air Voids		GEPI ϴmin/ϴinitial		GSI ϴmax/ϴmin N=3		Roller Pressure (psi) N=3	
	Control	Recycled	Control	Recycled	Control	Recycled	Control	Recycled
18	4.0	3.1	1.1	1.2	1.1	1.0	10.3	6.0
22	4.3	3.8	1.2	1.3	1.0	1.0	8.7	6.5
23	1.7	2.2	1.1	1.3	1.3	1.3	6.0	5.0
25	5.4	3.1	1.1	1.3	1.0	1.0	7.7	6.0
28	5.2	3.3	1.1	1.3	1.1	1.1	9.3	6.0

TABLE 9. Creep test data (Task 1)

Site No.	Section	% Air Voids (Recompacted)	Creep Modulus @ 140 F (psi)	Permanent Strain @ 140 F (in/in)
18C	Control	4.0	10478	0.017
18R	Recycled	3.1	6383	0.022
22C	Control	4.3	5706	0.025
22R	Recycled	3.8	9692	0.013
23C	Control	1.7	4253	0.036
23R	Recycled	2.2	7483	0.017
25C	Control	5.4	6824	0.021
25R	Recycled	3.1	9144	0.019
28C	Control	5.2	6295	0.020
28R	Recycled	3.3	15058	0.011

roller pressure for the test specimen was documented in this study.

Table 8 gives the average recompacted mix properties such as air void content, GEPI, GSI and roller pressure. Individual specimen test values including the bulk specific gravity, thickness and theoretical maximum specific gravity are given in Table A3 of Appendix "A". Table 9 gives the average test data obtained from the confined, dynamic creep tests.

Recovered Asphalt Binder Properties

Extraction of the asphalt cement from the field cores was carried out using ASTM standard D 2172-92 (Test method A) employing the centrifuge method. The recovery of asphalt cement from the solution involved distillation of the Trichloroethylene solvent using a Rotovapor apparatus. Since one of the objectives of this study was to compare the aging characteristics of recovered asphalt cement from the control and the recycled sections, it was important to eliminate all the traces of the solvent during the distillation process without exposing the asphalt cement to excess heat.

The recovered asphalt cement was tested for penetration at 25°C (77°F) (ASTM D 5) and absolute viscosity at 60°C (140°F) by Vacuum Capillary Viscometer (ASTM D 2171). The results from these tests are summarized in Table 10. Two samples were tested from each section and, therefore, the test data reported is the average of two tests.

Since the main concern of this project is performance, it was decided to determine the rheological properties of the recovered binder using performance based SHRP binder tests such as the dynamic shear rheometer (DSR). This testing was carried out as per the SHRP asphalt binder specification proposed for the State of Georgia. The viscoelastic behavior of the recovered asphalt cement was characterized by measuring the Complex Shear Modulus (G^*) and the Phase Angle (δ) of the asphalt cement. G^* is the ratio of the maximum shear stiffness

(τ_{max}) to maximum shear strain (γ_{max}). The time lag between the applied stress and the resulting strain is the phase angle δ.

According to SHRP specifications, rutting potential or the permanent deformation of the mix is controlled by limiting the rutting factor G*/Sinδ at high test temperatures to values greater than 2.2 kPa after RTFOT aging. For this study, the specification test temperature for the state of Georgia for rutting was assumed to be 64°C (148°F) from the SHRP temperature zone chart (as shown in Figure 9). Higher rutting factors at 64°C (148°F), indicate better rutting performance.

Fatigue cracking normally occurs at low to moderate temperatures. According to the SHRP specifications, it is controlled by limiting the fatigue cracking factor G* Sinδ of the recovered asphalt binder to values less than 5000 kPa at the test temperature. The test temperature for fatigue cracking in Georgia was assumed to be 22°C (72°F). The five pavement sections in Task 1 have been in service from 1 1/2 to 3 1/2 years averaging about 2 years. The recovered asphalt binder is therefore expected to be softer than the corresponding Pressure Aging Vessel (PAV) residue which simulates 5 to 10 years in service. However, the fatigue factor can be used in this study for comparing the fatigue behavior of the control and recycled sections. The ability to dissipate or relax stress is desirable in order to resist fatigue cracking. This can be achieved effectively if the asphalt binder has the tendency to flow into the surrounding area when loaded or stressed i.e. if the asphalt binder is not excessively stiff. Hence lower fatigue cracking factors indicate better ability for the asphalt binder to dissipate stress.

The dynamic shear rheometer testing procedure involves subjecting a circular layer of asphalt binder bounded by two parallel plates to oscillations under a constant stress and

TABLE 10. Recovered asphalt cement properties (Task 1)

Site No.	Section	% Air Voids In-situ	Penetration @ 25 C (0.1 mm)	Viscosity @ 60 C (poises)	G*/Sin(delta) @ 64 C (kPa)	G* Sin(delta) @ 22 C (kPa)
18C	Control	7.6	15	55810	20.8	2078
18R	Recycled	8.2	15	55370	21.9	2012
22C	Control	9.4	24	33092	12.1	781
22R	Recycled	7.5	23	36773	11.9	655
23C	Control	3.6	24	34677	12.3	1030
23R	Recycled	4.9	24	33002	10.3	721
25C	Control	6.2	17	103440	28.1	1789
25R	Recycled	5.3	20	59341	16.1	1341
28C	Control	8.3	21	46272	16.0	1102
28R	Recycled	6.5	19	49907	16.9	1712

FIGURE 9. SHRP temperature zone chart for the State of Georgia

monitoring the resulting strain. The dimensions of the spindle and the thickness of the asphalt layer between the two plates depends on the test temperature. For test temperatures over 52°C (126°F), a large spindle of 25-mm (1-inch) diameter is used with a corresponding layer thickness of 1 mm (0.04 inch). Similarly, for low test temperature between 7°C to 34°C (45°F to 94°F), a small spindle of 8-mm (1/4-inch) diameter is used with a corresponding asphalt layer thickness of 2 mm (0.08 inch). Temperature control of the specimen is accomplished by means of a circulating water bath. The oscillation speed for all the tests was maintained at 1.5 Hz. A summary of the results obtained from the tests is presented in Table 10.

Task 2

The projects selected in Task 2 consisted of pavements throughout Georgia which were constructed using either the recycled mix or the virgin mix. Visual pavement surface evaluation of these pavements was conducted in the beginning of the project. The observations are summarized in Tables 11 and 12 for virgin (control) mixes and recycled mixes, respectively. Most of the virgin and recycled pavements do not exhibit any distress at this time. For example, recycled Site no. 3 (Fig. 3), recycled Site no. 1 (Fig. 4), and virgin Site no. 4 (Figure 10) do not show any distress. Figures 11 and 12 show some ravelling in virgin Site no. 5, which is associated with segregation of the surface mix. Figures 13 and 14 show some alligator (fatigue) cracking in the recycled Site no. 11. Figure 15 shows some typical transverse cracking in virgin Site no. 13.

Bulk specific gravity of the cores was determined to calculate the air void content. As in Task 1, asphalt cement was recovered from the field cores. Penetration and viscosity of the recovered asphalt binder were determined. The corresponding penetration and viscosity values from Task 1 were combined with Task 2 values to increase the database for analysis.

A summary of the above properties is presented in Table 13 for virgin mix pavements and in Table 14 for recycled mix pavements.

ANALYSIS OF TEST DATA

The results obtained from the projects in Task 1 as well as Task 2 were analyzed with respect to the objectives of this study. Visual observations were quantified on a rating scale from 0 to 6 as indicated below.

Pavement Distress

Ratings	Rutting (inches)	Ravelling	Cracking (Alligator, Transverse and longitudinal)
0	0.00- 0.10	None	None
2	0.11 - 0.20	Slight	Slight
4	0.21 - 0.30	Moderate	Moderate
6	> 0.31	High	High

Intermediate ratings such as 1 implies a pavement distress condition from none to slight. From the above rating scale, it is obvious that a pavement section with a low rating value has given a high performance during the service period.

Task 1

As mentioned earlier, five project sites (Nos. 18, 22, 23, 25 and 28) were selected to determine the relative performance of the recycled and the control (virgin) mix. The percentage of RAP ranged from 10 to 25 in the recycled mixes. Three grades of asphalt cements: AC-20, AC-20S, and AC-30, were used in these five projects.

TABLE 11. Pavement surface evaluation (Virgin mixes - Task 2)

Site No.	County	Mix Type	Average Rut Depth (Inch)	Ravelling & Weathering	Alligator Cracking	Transverse Cracking	Longitudinal Cracking	Other Surface Distress
2	Murray	Virgin	0.115	None	None	None	None	None
4	Walker	Virgin	0.172	None	None	None	None	None
5	Floyd	Virgin	0.094	Low (20 - 30% S.A)*	None	None	None	Segregation of mix
6	Bartow	Virgin	0.138	None	None	None	None	Bleeding @ Stn. 400 + 20
7	Bartow	Virgin	0.134	None	None	None	None	None
8	Cherokee	Virgin	0.075	None	None	Low (10 -130 ft.)**	None	None
10	Fulton	Virgin	0.044	None	None	Low (14 - 150 ft.)**	Moderate (Wheel path)	None
13	Quitman	Virgin	0.150	None	None	Low (38 - 456 ft.)**	Low	Thin long. crack in wheel path
14	Randolph	Virgin	0.071	None	None	Low (12 - 128 ft.)**	Low	Long. crack in wheel path
18C	Coffee	Virgin	0.069	None	None	Low (5 - 48 ft.)**	None	WBL has more transverse Cracks
22C	Ware	Virgin	0.069	None	None	None	None	None
23C	Chatham	Virgin	0.044	None	None	None	None	None
25C	Emanuel	Virgin	0.009	None	None	Low (23 - 276 ft.)**	Low (Continous)	Map cracking
27	Jenkins	Virgin	0.019	None	None	None	None	None
28C	Columbia/ Richmond	Virgin	0.013	None	None	None	None	None

* S.A = Surface area

** Values in paranthesis are the number of cracks and the total length of all cracks, respectively

TABLE 12. Pavement surface evaluation (Recycled mixes - Task 2)

Site No.	County	Mix Type	Average Rut Depth (inch)	Ravelling & Weathering	Alligator Cracking	Transverse Cracking	Longitudinal Cracking	Other Surface Distress
1	Murray	Recycled	0.191	None	None	None	None	None
3	Catoosa	Recycled	0.188	None	None	None	None	Centerline Jnt. opening
9	Walton	Recycled	0.128	Low (Wheel path)	None	Low (13 -144 ft.)**	None	Map cracking
11	Fulton	Recycled	0.084	None	High (40% S.A)*	Low (12-138 ft.)**	None	Primary fatigue cracking
12	Dekalb	Recycled	0.275	Low (Wheel path)	None	None	None	One Long. Crack (Stn. 375-500)
15	Worth	Recycled	0.088	None	None	None	None	None
16	Worth	Recycled	0.018	None	None	None	None	None
17	Irwin	Recycled	0.118	None	None	None	None	None
18R	Coffee	Recycled	0.069	None	None	None	None	None
19	Coffee	Recycled	0.088	None	None	None	Low (Intermittent)	None
20	Benhill	Recycled	0.000	None	None	None	None	None
21	Benhill	Recycled	0.025	None	None	None	None	None
22R	Ware	Recycled	0.063	None	None	None	None	None
23R	Chatham	Recycled	0.066	None	None	None	None	None
24	Chatham	Recycled	0.550	None	None	Low (6 - 62 ft.)**	Low (1 long. crack)	Ruts due to shoving
25R	Emanuel	Recycled	0.063	None	None	Low (17 - 222 ft.)**	Low (continuous crack)	Long. refl. crack (10')
26	Emanuel	Recycled	0.031	None	None	None	None	None
28R	Columbia/ Richmond	Recycled	0.078	None	None	Low (hairline) (5-60 ft.)**	None	Open surface texture

* S.A = Surface area

** Values in paranthesis are the number of cracks and the total length of all cracks, respectively

FIGURE 10. General view of virgin Site no. 4.

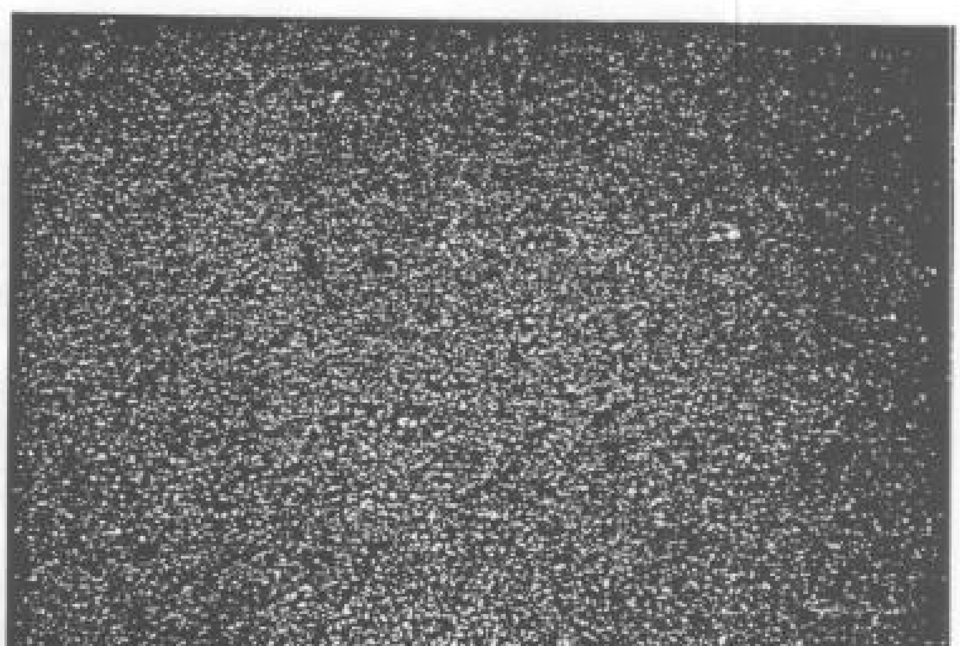


FIGURE 11. Segregation related ravelling in virgin Site no. 5.

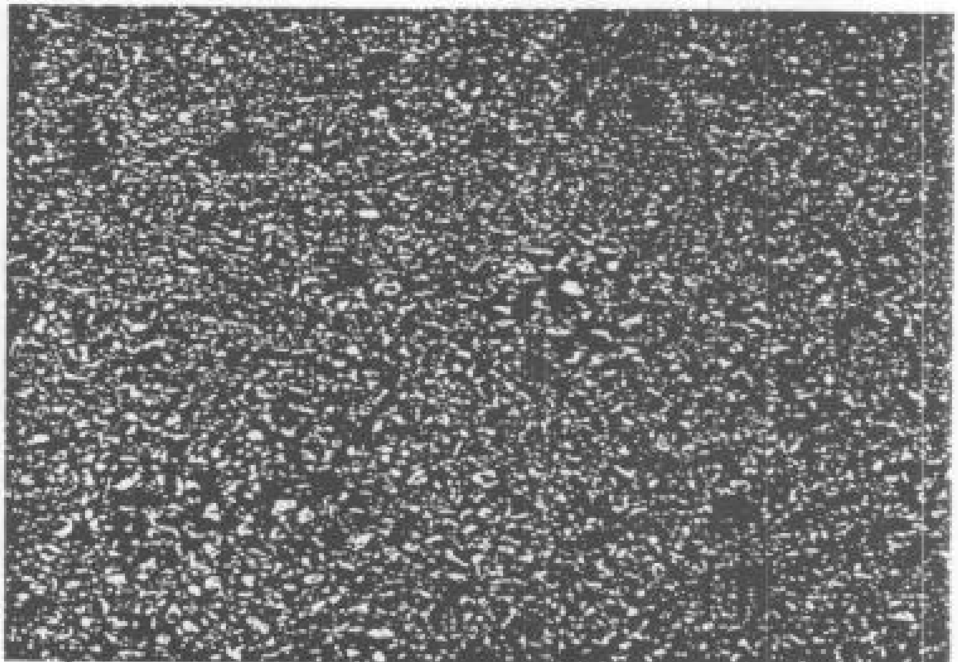


FIGURE 12. Close-up of ravelling in virgin Site no. 5.

FIGURE 13. Alligator cracking in recycled Site no. 11.

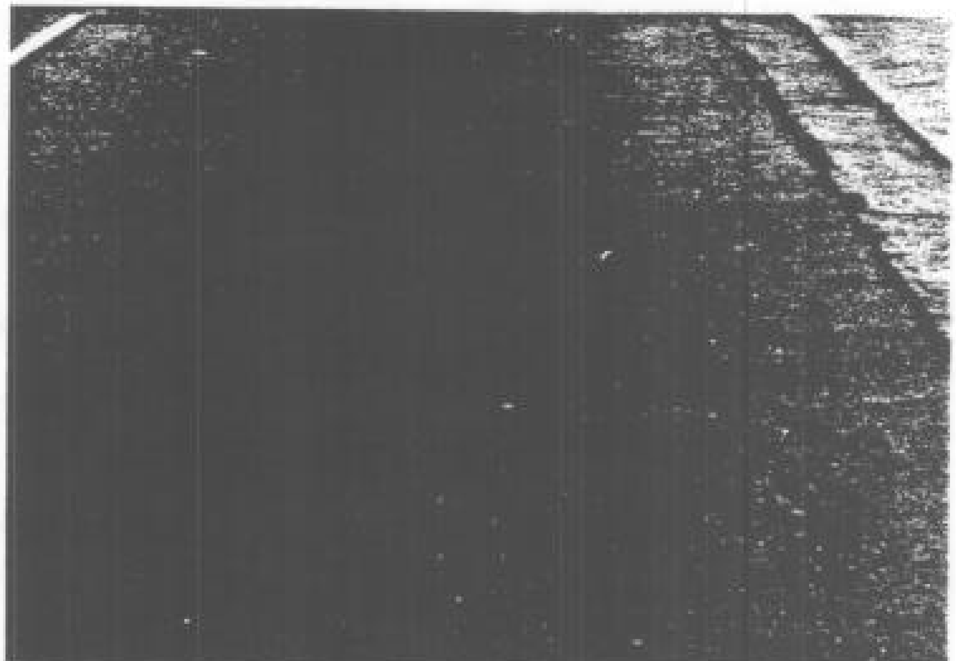


FIGURE 14. Close-up of alligator cracking in recycled Site no. 11.

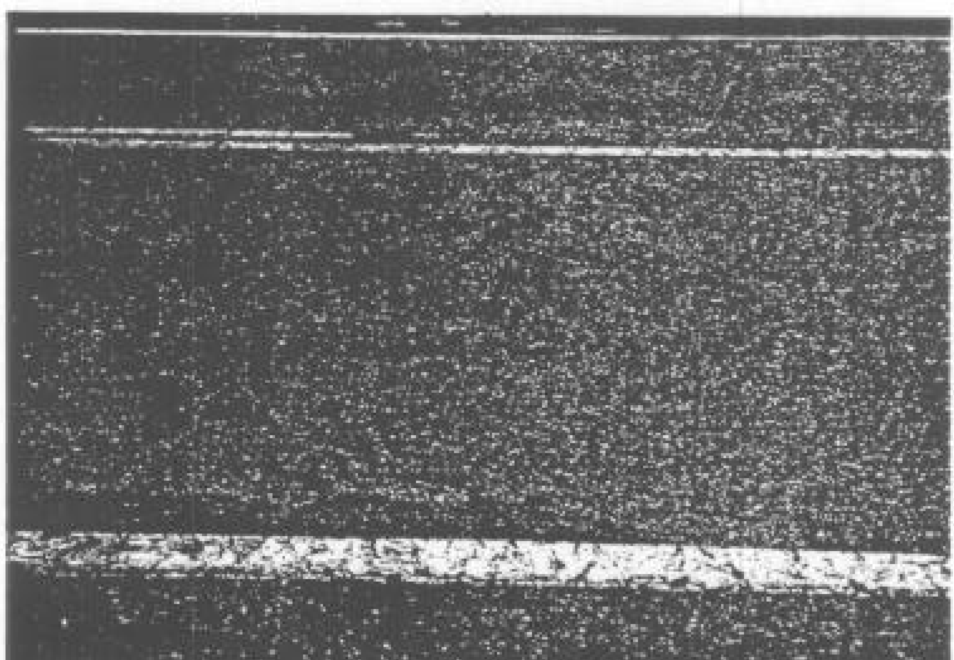


FIGURE 15. Typical transverse cracking in virgin Site no. 13.

TABLE 13. Air voids content and recovered asphalt properties of virgin mixes (Task 2)

Site No.	Age (Years)	AC Grade	Air Voids %	Penetration (0.1 mm)	Viscosity (Poises)
2	2.50	AC-20S	3.8	17	24,038
4	2.50	AC-30	7.7	16	69,182
5	1.75	AC-30	4.3	19	27,675
6	2.00	AC-30	7.3	15	62,589
7	3.50	AC-30	0.9	25	22,309
8	3.50	AC-30	4.5	19	47,347
10	3.75	AC-30	***	19	36,771
13	4.75	AC-30	7.0	15	186,092
14	4.00	AC-30	5.0	14	284,226
18C	1.50	AC-30	7.6	15	55,810
22C	1.75	AC-30	9.4	24	33,092
23C	1.50	AC-30	3.6	24	34,677
25C	2.25	AC-30	6.2	17	103,440
27	2.00	AC-30	5.3	15	62,945
28C	1.50	AC-30	8.3	21	46,272
Average			5.8	18	73,098
Std. Dev			2.3	4	71,524
Minimum value			0.9	14	22,309
Maximum value			9.4	25	284,226
Avg - 2 Std. dev			1.2	11	-69,951
Avg + 2 Std. dev			10.3	26	216,146

TABLE 14. Air voids content and recovered asphalt properties of recycled mixes (Task 2)

Site No.	Age (Years)	AC Grade	% RAP	Air Voids %	Penetration (0.1 mm)	Viscosity (Poises)
1	1.25	AC-20S	25	8.4	16	47,244
3	2.75	AC-20	10	6.4	12	73,611
9	2.25	AC-20S	15	6.4	17	71,015
11	3.50	AC-10	40	3.5	16	88,813
12	5.00	AC-20S	20	2.8	22	17,627
15	3.50	AC-10	40	3.3	21	39,998
16	3.00	AC-20	25	7.2	16	144,707
17	3.00	AC-20	25	6.1	19	39,245
18R	1.50	AC-30	15	8.2	15	55,370
19	2.25	AC-20	25	4.3	22	25,502
20	2.00	AC-20	25	7.5	13	110,724
21	2.25	AC-20	25	11.9	16	86,436
22R	1.75	AC-20S	10	7.5	23	36,773
23R	1.50	AC-20	25	4.9	24	33,002
24	1.50	AC-20	25	3.8	33	16,607
25R	2.25	AC-20	20	5.3	20	59,341
26	2.00	AC-20	30	9.1	19	51,614
28R	1.50	AC-30	20	6.5	19	49,907
Average				6.3	19	58,197
Std. Dev				2.3	5	33,299
Minimum value				2.8	12	16,607
Maximum value				11.9	33	144,707
Avg - 2 Std. dev				1.6	9	-08,401
Avg + 2 Std. dev				11.0	29	124,794

Statistical Analysis

A paired t-test is appropriate for analyzing the test data in Task 1 to determine if there is a significant difference between the test values obtained in recycled and control section. Task 1 consists of 5 pairs (projects), each pair consisting of one recycled and one control section. Average test values were used in the analysis.

Paired t-test is used to eliminate subject to subject variability for the purpose of detecting differences in means in a population or between two populations. The criteria for using paired t-test analysis is that the samples under consideration should form a couple wherein, only the treatments differ but all the other variables are considered constant. In this study, the type of mixes, that is recycled and control mixes, are assumed to be the applied treatment. The differences between the pairs form a sample of values, which is used to determine whether the properties of the recycled mixes differ significantly from those of the virgin mixes. The paired comparison t-test was used to analyze mean of differences at 5 percent level of significance.

Visual Evaluation

Pavement surface evaluation of control and recycled sections was reported in Table 6. The extent of distress was quantified and is reported in Table 15. From Tables 6 and 15 it is obvious that no significant rutting, ravelling and alligator cracking has occurred in all the sites. Rutting occurs when the HMA mix is too soft. Alligator (fatigue) cracking can occur if the HMA mix is too stiff or brittle. A moderate amount of transverse cracking was observed in both recycled and virgin sections on Site 25. The overall pavement surface evaluation and rating indicates that both recycled and control sections are performing equally well after the average service life of about two years. It would be interesting to revisit these test sections in

TABLE 15. Pavement surface evaluation rating (Task 1)

Site No.	County	Mix Type	Rutting	Ravelling & Weathering	Alligator Cracking	Transverse Cracking	Longitudinal Cracking	Cumulative Rating
18C	Coffee	Virgin	0	0	0	2	0	2
18R	Coffee	Recycled	0	0	0	0	0	0
22C	Ware	Virgin	0	0	0	0	0	0
22R	Ware	Recycled	0	0	0	0	0	0
23C	Chatham	Virgin	0	0	0	0	0	0
23R	Chatham	Recycled	0	0	0	0	0	0
25C	Emanuel	Virgin	0	0	0	4	2	6
25R	Emanuel	Recycled	0	0	0	4	2	6
28C	Columbia/ Richmond	Virgin	0	0	0	0	0	0
28R	Columbia/ Richmond	Recycled	0	0	0	2	0	2

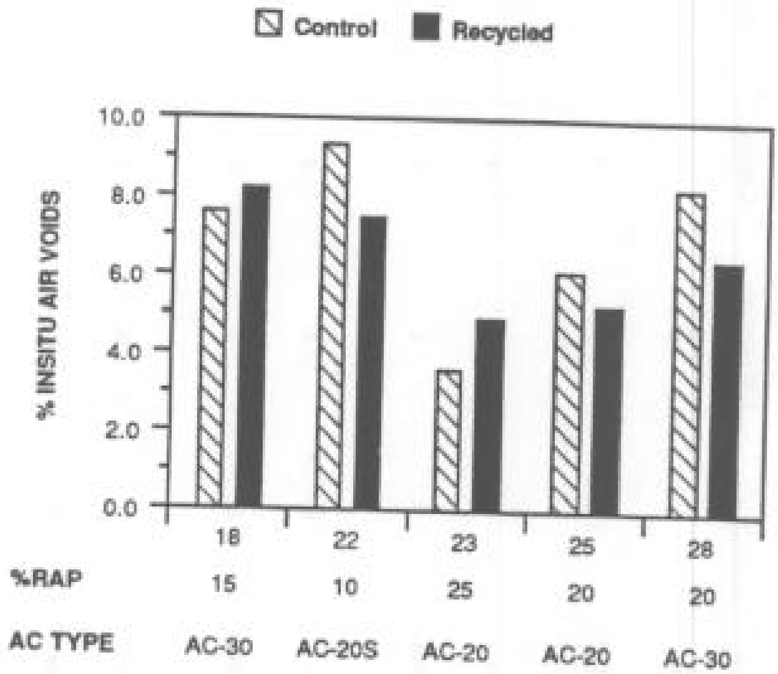


FIGURE 16. In-situ air voids (Task 1)

the future to ascertain their relative performance.

In-situ Air Voids

In-situ air voids data is reported in Table 7. A histogram showing the average percentage of total air voids present in the field cores is shown in Figure 16. Recycled sections in Sites 22, 25 and 28 have lower air voids compared to the corresponding control sections, whereas control sections in Sites 18 and 23 have lower air voids compared to the corresponding recycled sections. The paired t-test analysis as reported in Table 16 indicates no significant difference between the air voids in recycled and control sections. Average air voids in the five projects are 7.0 and 6.5 percent, respectively, in control and recycled sections. Air voids significantly affect the rate of aging of asphalt binders in HMA pavements. High air voids accelerate the aging process. It is encouraging to know that the recycled sections do not have air voids higher than those in the control sections.

Recovered Asphalt Binder Properties

Asphalt cement was recovered from the field cores and tested to determine conventional binder properties such as penetration at 25°C (77°F) and viscosity at 60°C (140°F), and SHRP recommended test properties such as $G^*/\sin\delta$ at 64°C (148°F) and $G^* \sin\delta$ at 22°C (72°F). Table 10 contains all asphalt binder test data which have been analyzed as follows.

It should be realized that the recovered asphalt binder properties are affected by the amount of RAP used, properties of the aged asphalt binder in the RAP, properties of the virgin asphalt binder used, air void content at the time of construction, and subsequent densification under traffic. However, the properties of the aged binder in the RAP and in the recycled mix at the time of production, and the penetration of virgin asphalt cements are not available.

Therefore, variations in recovered binder properties cannot be explained fully.

Penetration

The penetration histogram shown in Figure 17 indicates comparable penetration values for control and recycled sections in Sites 18, 22 and 23. The recycled section has a higher penetration value in Site 25 and a lower penetration value in Site 28 compared to the corresponding control sections. The paired t-test (Table 16) indicates no significant difference between the penetration of control and recycled sections. Among the five recycled sections, AC-20 or AC-20S asphalt cements have generally resulted in relatively higher penetration values compared to AC-30 asphalt cements (Figure 17). Site 25 and 28 used the same amount of RAP (20 percent) but different grades of asphalt cements. Site 28 with AC-30 gave a lower penetration value than Site 25 with AC-20 asphalt cement. Site 18 has the lowest penetration of all the sites because this pavement is the oldest (3 1/2 years) compared to the remaining pavements which range in age from 1 1/2 to 2 1/4 years.

Viscosity

The viscosity histogram shown in Figure 17 indicates comparable viscosity values for control and recycled sections in all sites except Site 25. Generally, the viscosity values are consistent with the penetration values. Except Site 25, the use of AC-30 asphalt cement generally resulted in relatively higher viscosity values compared to AC-20 or AC-20S asphalt cements. The paired t-test (Table 16) indicates no significant difference between the viscosity of the control and the recycled sections.

TABLE 16. Paired t-test results (Task 1)

Property	Average of 5 Projects: Control	Average of 5 Projects: Recycled	t calc*	Are Differences Significant at 5 % Level?
A. In-Situ Mix				
Air Voids (%)	7.0	6.5	0.818	No
Resilient Modulus @ 77 F (psi)	947,000	892,000	0.469	No
Indirect Tensile Strength @ 77 F (psi)	202	187	3.994	Yes
B. Recompacted Mix				
Air Voids (%)	4.1	3.1	2.022	No
GSI	1.1	1.1	2.181	No
GEPI	1.1	1.3	7.467	Yes
Roller Pressure (psi)	8.4	5.9	4.192	Yes
Creep Modulus (psi)	6,710	9,550	1.378	No
C. Recovered Asphalt				
Penetration @ 77 F (0.1 mm)	20	20	0.047	No
Viscosity @ 140 F (poises)	54,658	46,879	0.850	No
G* / Sin(delta) (kPa) @ 148 F	17.9	15.4	1.012	No
G* Sin(delta) (kPa) @ 72 F	1,356	1,288	0.371	No

* t critical = 2.776 for 5 number of observations (sample size) at 5 % level of significance

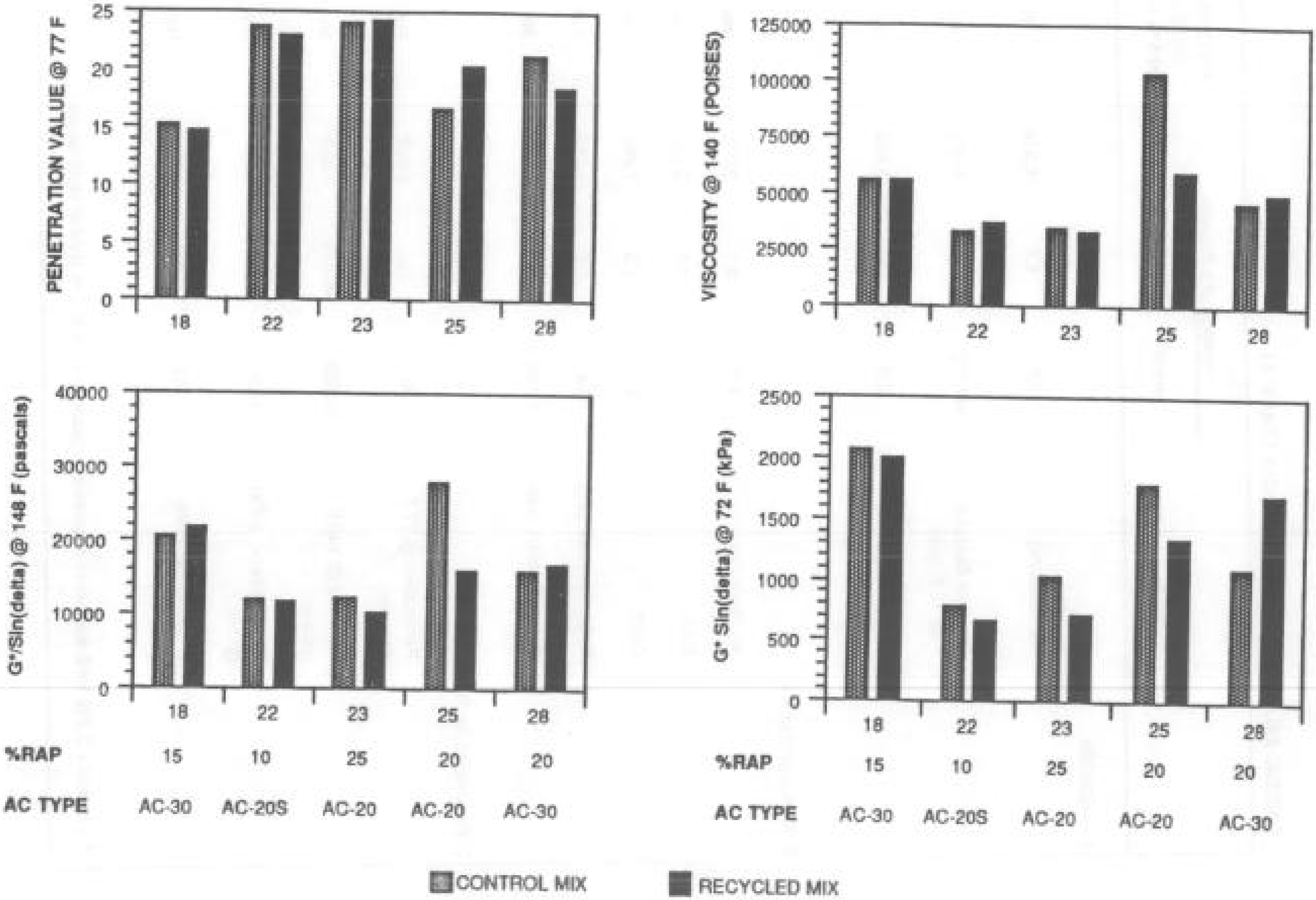


FIGURE 17. Recovered asphalt binder properties (Task 1)

G*/Sinδ (Rutting Factor)

Complex shear modulus G* and the phase angle δ of the recovered asphalt binder were determined using the dynamic shear rheometer (DSR) as mentioned earlier. Rutting characteristics of the asphalt binder is explained by the rutting factor G*/Sinδ. Performance based SHRP binder specification specifies a minimum value of 2.2 kPa for the rutting factor when the DSR test is conducted on the RTFO residue at 64°C (148°F). It is important to note that the test was performed on the recovered asphalt cement from pavements ranging from 1 1/2 to 3 1/2 years old. However, the test would still give an indication of the rutting potential of the mix in Georgia climate and also is a measure of aging of the binder. As mentioned earlier, the higher the rutting factor, the more the binder resists rutting.

The G*/sinδ histogram shown in Figure 17 shows comparable values for control and recycled sections in all sites except Site 25. The paired t-test (Table 16) indicates no significant difference between the G*/sinδ values of the control and the recycled sections. This means the binders are equally resistant to rutting. It is interesting to note that G*/sinδ histogram and the viscosity histogram have similar trends. Both tests were conducted at high temperatures: DSR at 64°C (148°F) and viscosity at 60°C (140°F). The viscous component of the complex shear modulus G*, therefore, appears to be dominant in the recovered asphalt cements.

G* Sinδ (Fatigue Cracking Factor)

The potential for fatigue cracking is explained by the fatigue cracking factor G* Sinδ which is specified at a maximum of 5000 kPa for a pressure aging vessel (PAV) residue in the performance based SHRP binder specifications. The PAV residue is supposed to simulate the binder aging after 5-10 years of service. Although the pavement projects selected are less than five years old, this test was conducted to get a general and relative indication of cracking potential of the mixes. The DSR test was conducted at 22°C (72°F) to represent the Georgia climate as much as possible.

The G* sinδ histogram shown in Figure 17 indicates that all values are well below 5000 kPa as expected. The paired t-test (Table 16) indicates no significant difference between the G* sinδ values of control and recycled sections. This means they are equally resistant to fatigue cracking. The G* sinδ histogram is consistent with the penetration histogram (Figure 17) because both tests are conducted at very close temperatures. Again, the use of AC-30 asphalt cement (Sites 18 and 28) generally gave high G* sinδ values (more prone to fatigue cracking) compared to AC-20 or AC-20S asphalt cements. Site 18 has the highest G* sinδ value because this pavement is the oldest (3 1/2 years) of all five projects.

<u>In-situ Mix Properties</u>

In-situ mix properties were obtained from field cores. Table 7 gives the in-situ properties such as air voids, resilient modulus and indirect tensile strength.

Resilient Modulus

The resilient modulus histogram shown in Figure 18 indicates comparable values for control and recycled sections in all Sites except 25 and 28. The recycled section has higher resilient modulus in Site 28 and lower resilient modulus in Site 25 compared to corresponding control sections. However, the paired t-test indicates no significant difference between the control and recycled sections when all five projects are considered in statistical analysis (Table 16). Since the resilient modulus is an indicator of the mix strength under dynamic loading,

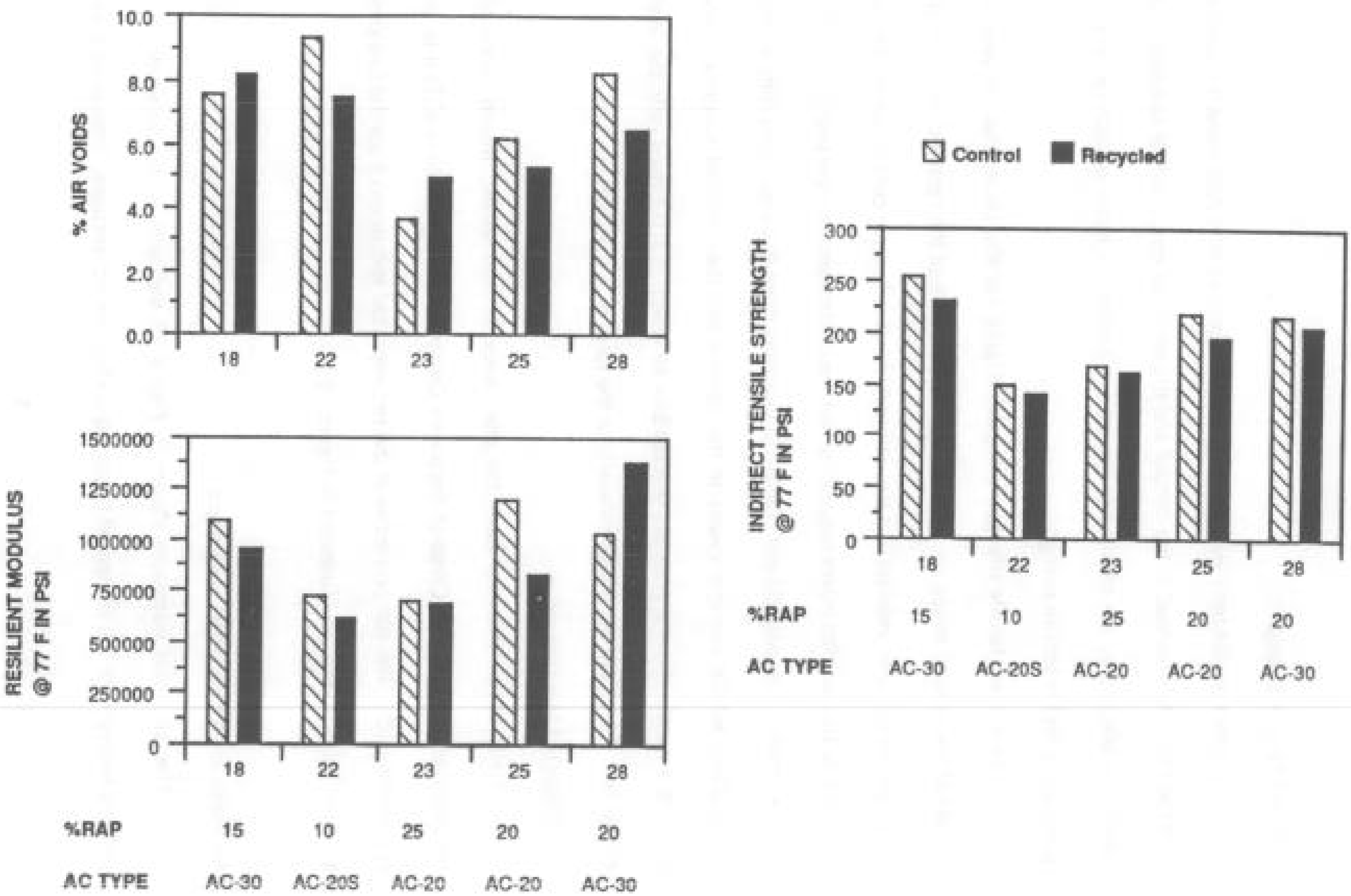


FIGURE 18. In-situ mix properties (1)

both control and recycled sections appear to have comparable structural strengths.

Indirect Tensile Strength

Indirect tensile tests were run on the core specimens to determine the tensile strength and the cracking potential of the control and the recycled mix. Tensile strength of the mix is primarily affected by the stiffness of the asphalt binder. A stiffer asphalt cement in the mix produces a higher tensile strength.

The indirect tensile strength histogram (Figure 18) also shows that the tensile strength values of the control mixes are slightly higher than those of the recycled mixes in all the five sites. The results also indicate that the deformation at failure for control specimens was lower than that for the recycled mixes suggesting that the control sections are prone to crack at lower tensile strains. The paired t-test (Table 16) indicates there is a significant difference between the indirect tensile strength values of the control and the recycled sections. Since these projects are only about 2 years old (except Site 18 which is 3 1/2 years old), the implications of this test, if any, are not evident visually in the form of some distress.

Recompacted Mix Properties

Field cores obtained from the sites were broken down, mixed thoroughly, and recompacted by the U.S. Corps of Engineers Gyratory Testing Machine (GTM) to give three specimens each. The test properties of the recompacted specimens from the five projects are given in Table 8, and are illustrated in Figure 19.

Air Voids in Recompacted Specimens

The air voids histogram shown in Figure 19 indicates lower air voids in recycled sections (except Site 23) compared to corresponding control sections. However, if all five

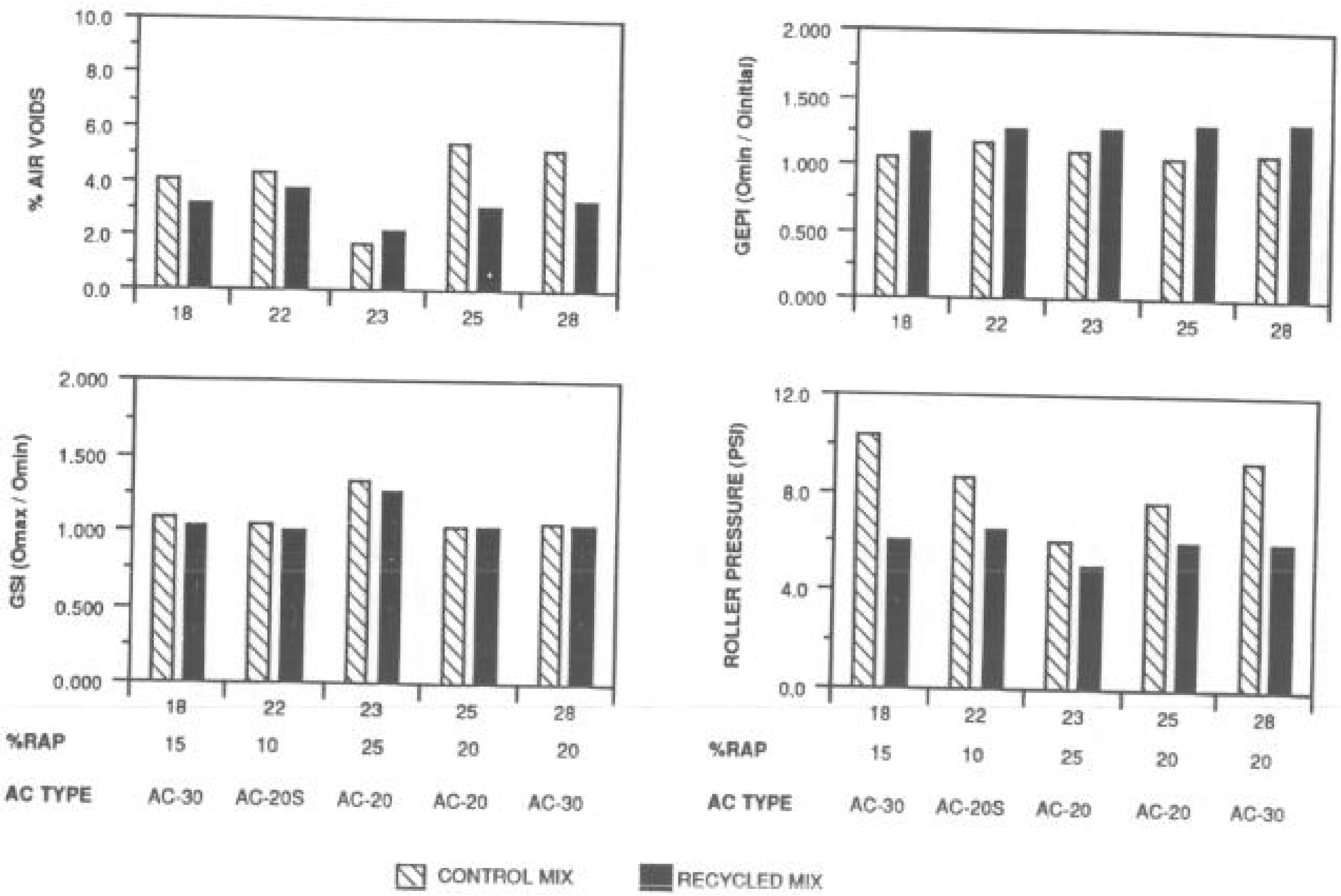


FIGURE 19. Recompacted mix properties (Task 1)

projects are considered, the paired t-test (Table 16) indicates no statistically significant difference between the control and recycled sections. Both control and recycled mixes in Site 23 compacted to very low air voids contents of 1.7 and 2.2 percent, respectively. This indicates a potential for rutting in the future if the site is subjected to heavy traffic loads. Site 23 has the lowest in-situ air voids (Figure 16) at the present time. Apparently it has not rutted because the in-situ air voids are more than 3.5 percent at the present time.

Gyratory Stability Index (GSI)

The GSI is a measure of the stability of the mix. GSI in excess of 1.00 indicates an increase in plasticity. The GSI histogram shown in Figure 19 indicates that the GSI values of the control and recycled mixes are comparable. The paired t-test (Table 16) also indicates no statistically significant difference between the control and recycled mixes. As reported earlier, no site has developed any significant amount of rutting at the present time. GSI values of Site 23 appear to be high and therefore, there is a potential for rutting. The recompacted air voids were also low for site 23 (Figure 19). However, the in-situ air voids are still above 3.5 percent.

Gyratory Elasto-Plastic Index (GEPI)

GEPI is a measure of internal friction present in the mix. GEPI values near one are found in fresh stable HMA mix with low shear strain. The GEPI histogram shown in Figure 19 indicates consistently higher values for recycled mixes compared to control mixes. This means the recycled mixes have less internal friction compared to control mixes. This could be attributed to the fact that 100 percent virgin aggregate particles have more interlocking effect than the recycled mix which contains a mixture of virgin aggregate particles and RAP particles. The RAP particles are usually not as angular as virgin aggregate particles due to the milling operation. Also, the RAP particles are already coated with asphalt binder and therefore, may not have a rough surface texture. The paired t-test (Table 16) indicates that the GEPI values of control and recycled mixes are statistically significantly different.

Roller Pressure

The roller pressure values measured during the GTM compaction procedure are shown in the histogram in Figure 19. It is evident from the histogram that the recycled mixes have lower roller pressure compared to control mixes in all cases. The paired t-test also indicates that the difference is statistically significant.

The roller pressure is a measure of resistance to deformation of the mix. A higher roller pressure indicates greater resistance of the mix against deformation. Site 23 has the potential for rutting in the future if subjected to heavy traffic. This site also had low compacted air voids and a high GSI value as discussed earlier.

Creep Modulus

Table 9 contains the confined, dynamic creep modulus data obtained with 138 kPa (20 psi) confining pressure and 828 kPa (120 psi) normal pressure. The creep histogram shown in Figure 20 indicates higher creep modulus (higher resistance to permanent deformation) for recycled mixes compared to control mixes in all sites except Site 18. However, the paired t-test (Table 16) shows that the differences are not statistically significant. The creep modulus data are unlike GEPI and GSI data which showed that the recycled mixes have lower resistance to permanent deformation compared to control mixes.

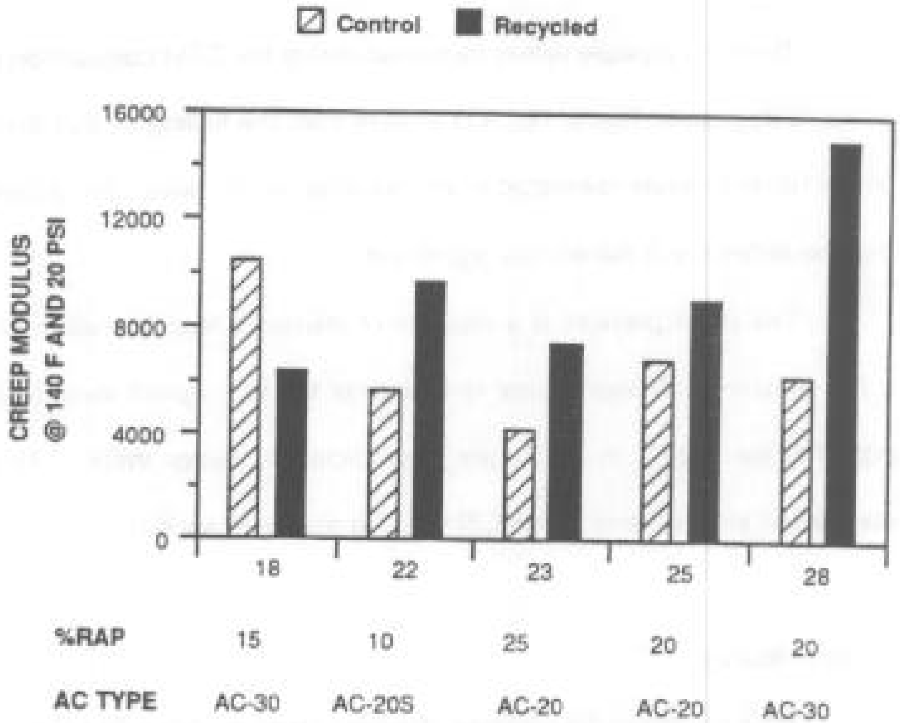


FIGURE 20. Creep modulus values (Task 1)

TABLE 17. Specific recycled projects details (Task 2)

Virgin Asphalt Grade	No. of Projects	Specified Penetration	Supplied Penetration	% RAP Used	Age of Pavement (years)
AC - 10	2	80+	98 - 123	40	3.50
AC - 20	10	60+	82 - 93	10 - 30	1.5 - 3.0
AC - 20S	4	60 - 80	67 - 84	10 - 25	1.25 - 5.0
AC - 30	2	60 +	-----	15 - 20	2.0 - 3.5

TABLE 18. Pavement surface evaluation ratings (Virgin mixes - Task 2)

Site No.	County	Mix Type	Rutting	Ravelling & Weathering	Alligator Cracking	Transverse Cracking	Longitudinal Cracking	Cumulative Rating
2	Murray	Virgin	2	0	0	0	0	2
4	Walker	Virgin	2	0	0	0	0	2
5	Floyd	Virgin	0	2	0	0	0	2
6	Bartow	Virgin	2	0	0	0	0	2
7	Bartow	Virgin	2	0	0	0	0	2
8	Cherokee	Virgin	0	0	0	2	0	2
10	Fulton	Virgin	0	0	0	2	4	6
13	Quitman	Virgin	2	0	0	6	0	8
14	Randolph	Virgin	0	0	0	2	2	4
18C	Coffee	Virgin	0	0	0	2	0	2
22C	Ware	Virgin	0	0	0	0	0	0
23C	Chatham	Virgin	0	0	0	0	0	0
25C	Emanuel	Virgin	0	0	0	4	2	6
27	Jenkins	Virgin	0	0	0	0	0	0
28C	Columbia/ Richmond	Virgin	0	0	0	0	0	0
		Average	0.67	0.13	0.00	1.20	0.53	2.53

TABLE 19. Pavement surface evaluation ratings (Recycled mixes - Task 2)

Site No.	County	Mix Type	Rutting	Ravelling & Weathering	Alligator Cracking	Transverse Cracking	Longitudinal Cracking	Cumulative Rating
1	Murray	Recycled	2	0	0	0	0	2
3	Catoosa	Recycled	2	0	0	0	0	2
9	Walton	Recycled	2	2	0	2	0	6
11	Fulton	Recycled	0	0	6	2	0	8
12	Dekalb	Recycled	4	2	0	0	0	6
15	Worth	Recycled	0	0	0	0	0	0
16	Worth	Recycled	0	0	0	0	0	0
17	Irwin	Recycled	2	0	0	0	0	2
18R	Coffee	Recycled	0	0	0	0	0	0
19	Coffee	Recycled	0	0	0	0	2	2
20	Benhill	Recycled	0	0	0	0	0	0
21	Benhill	Recycled	0	0	0	0	0	0
22R	Ware	Recycled	0	0	0	0	0	0
23R	Chatham	Recycled	0	0	0	0	0	0
24	Chatham	Recycled	6	0	0	2	2	10
25R	Emanuel	Recycled	0	0	0	4	2	6
26	Emanuel	Recycled	0	0	0	0	0	0
28R	Columbia/ Richmond	Recycled	0	0	0	2	0	2
		Average	1.00	0.22	0.33	0.67	0.33	2.56

Task 2

The Task 2 part of the study involved the evaluation of 15 independent virgin mix pavements and 18 independent recycled mix pavements to obtain a test database for comparison. These projects are located throughout the State of Georgia. It should be realized that many variables (such as the percentage and properties of RAP used, grade of the virgin asphalt cement, and age of the pavement) are involved in the 18 recycled mix projects as shown in Table 17. The most common asphalt cement grade used was AC-20 (10 projects) followed by AC-20S (4 projects). AC-10 and AC-30 grades were used on two projects each. The percentage of the RAP varied from 10 to 40 percent with 25 percent as the most common (8 projects). Because of these variables, the recovered asphalt cement properties are expected to vary significantly.

Visual Evaluation

Pavement surface evaluation ratings of virgin mix pavements and recycled mix pavements are given in Tables 18 and 19, respectively, based on the observations reported in Tables 11 and 12 as discussed earlier. The average cumulative performance ratings of virgin mix pavements and recycled mix pavements are 2.53 and 2.56, respectively. Therefore, there is no significant overall difference in the performance of virgin and recycled pavements at the time of inspection (January/February 1993). Slight ravelling was observed on two recycled pavements: Site 9 (15 percent RAP + AC-20S asphalt cement) and Site 12 (20 percent RAP + AC-20S asphalt cement). Some alligator (fatigue) cracking was observed on Site 11 which used 40 percent RAP and AC-10 asphalt cement (see Figures 13 and 14)

Statistical Analysis

The test data (air voids, penetration or viscosity) obtained in Task 2 can be treated as two independent groups (virgin mixes and recycled mixes) of unequal sizes (15 virgin and 18 recycled mixes). One of the objectives of this study is to determine if the characteristics of the recycled mixes are significantly different from those of the virgin mixes. This can be accomplished by performing statistical analysis using the Independent Samples t-test, for testing the equality of means of percent air voids, penetration and viscosity data at 5 percent level of significance. It is assumed that the sample means are reasonable estimates of their respective population means. Table 20 gives the results of the statistical analysis.

In-situ Mix Properties

The air voids histogram given in Figure 21 shows the minimum, average and maximum values of air voids in virgin and recycled pavements. The average in-situ air voids in virgin and recycled pavements are 5.8 and 6.3 percent, respectively. The t-test analysis (Table 20) indicates no statistically significant difference between the air voids of virgin and recycled pavements at the time of core sampling.

Recovered Asphalt Binder Properties

Penetration

The penetration histogram showing the minimum, average and maximum values of penetration in virgin and recycled pavements is also given in Figure 21. The average penetration values of virgin and recycled pavements are 18 and 19, respectively. The t-test analysis (Table 20) indicates no statistically significant difference between the penetration value of the two pavement types.

TABLE 20. Testing equality of means by t-test (Task 2)

Property	Sample Size		Average		Standard Deviation		t calc	t critical	Are Differences Significant at 5 % Level ?
	Virgin	Recycled	Virgin	Recycled	Virgin	Recycled			
In-Situ Air Voids (%)	14	18	5.8	6.3	2.27	2.34	0.62	2.040	No
Penetration at 77 F (0.1 mm)	15	18	18.3	19.1	3.7	5.0	0.51	2.037	No
Viscosity at 140 F (poises)	15	18	73,100	58,200	71,500	33,300	0.79	2.037	No

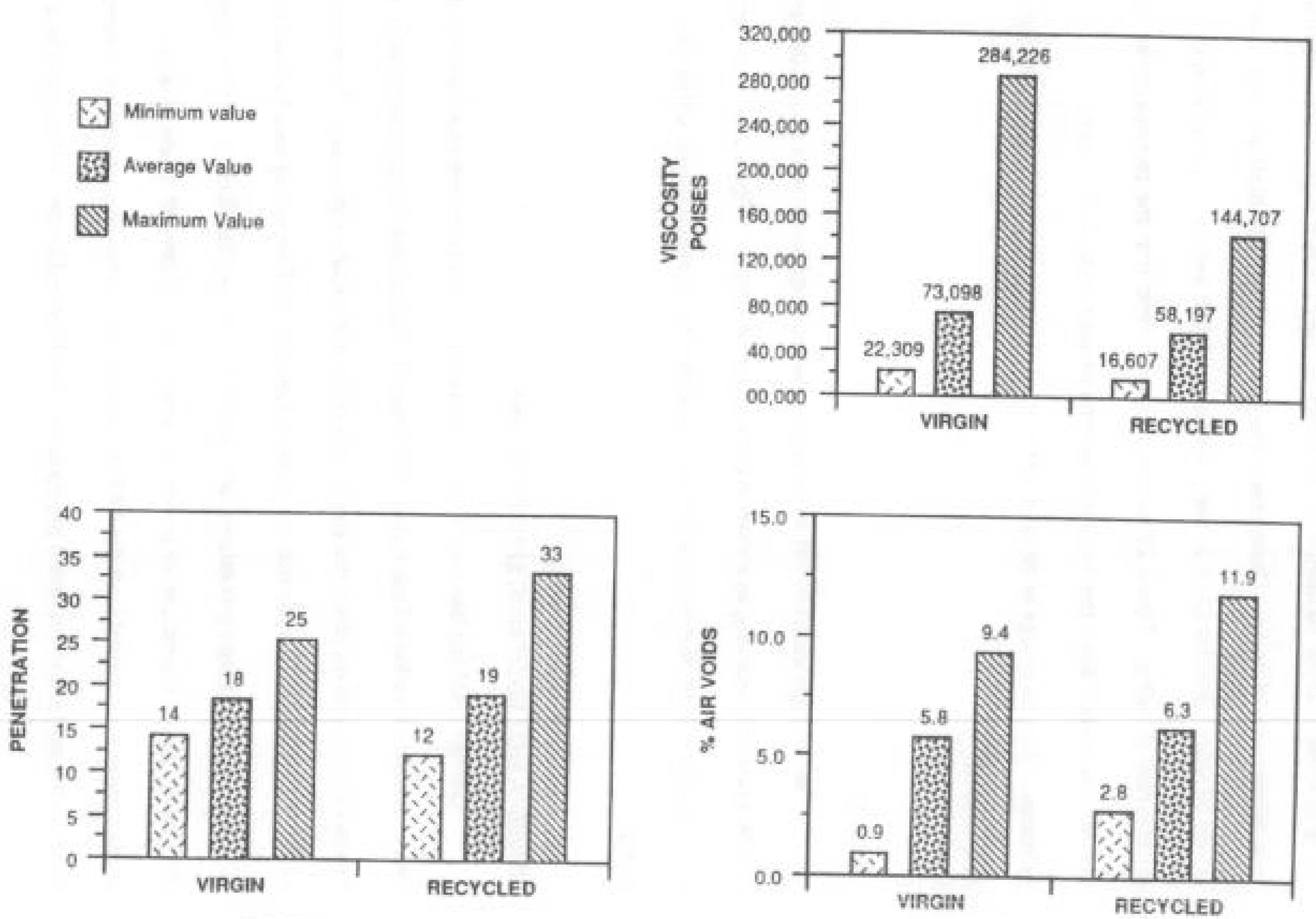


FIGURE 21. histograms of % air voids, penetration and viscosity (Task 2)

The percentage of voids in a HMA pavement has been known to influence the rate of aging of asphalt binder substantially. A higher air void content in the HMA pavement results in a greater rate of aging. Quite often, the effect of relatively high air voids can mask the effects of other variables (such as the percentage of RAP and the virgin asphalt cement grade) on the rate of aging. Figure 22 shows a general trend that the penetration of the asphalt cement recovered from the recycled pavements decreases as the percentage of air voids increases. The percentage of air voids at the time of construction has more pronounced effect as expected.

Viscosity

The average viscosity values of virgin and recycled pavements are 73,098 poises and 58,196 poises, respectively, as shown in the viscosity histogram (Figure 21). The t-test analysis indicates there is no significant difference between the viscosity values of the two pavement types.

GEORGIA DOT RECYCLING SPECIFICATIONS

Georgia DOT has been constructing recycled HMA pavements routinely for about four years. The data from both Task 1 and Task 2 have indicated that the difference between virgin mix pavements and recycled mix pavements is not statistically significant. Therefore, it could be concluded from this study that the existing Georgia DOT recycling specification (Appendix "C"), recycled mix design procedures, and quality control are satisfactory. At the present time, the Department's procedure to select the virgin asphalt cement grade is as follows. The asphalt cement recovered from the RAP is blended with virgin asphalt cement (intended to be used on the project) in proposed proportions. The blended binder is then aged in a thin film

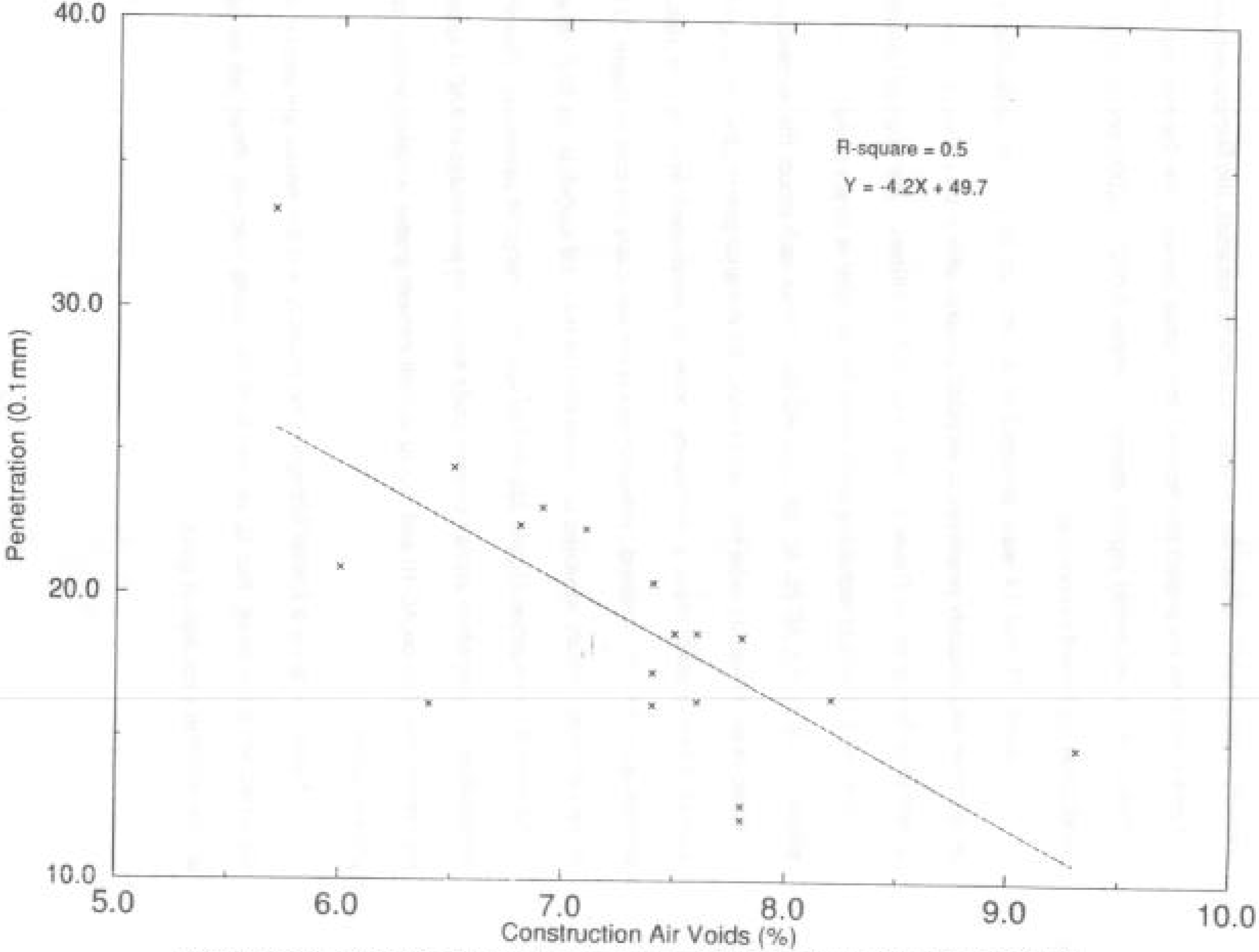


FIGURE 22. Effect of air voids on recovered asphalt penetration (Task 2)

oven (TFO). The TFO residue is then tested for viscosity at 60°C (140°F). If the measured viscosity falls between 6,000 poises and 16,000 poises then the grade of the virgin asphalt cement is acceptable. When the recycled mix production starts, the Department samples the recycled mix from the project and recovers the asphalt cement from the recycled mix. If the viscosity of the recovered asphalt cement is within 6,000 - 16,000 poises range, the mix production is allowed to continue.

Figures 23 and 24 were prepared in an attempt to give an indication of of the penetration and viscosity properties of recycled projects after 1 1/4 - 5 years in service. The penetration histogram in Figure 23 was prepared as follows. The recycled projects were arranged in 4 groups in increasing order (from left to right) of virgin asphalt cement viscosity grades such as AC-10, AC-20, AC-20S, and AC-30. Within each group, the percentage of RAP is placed in an increasing order from left to right. By this arrangement, the histogram for each asphalt group should show a decreasing order of penetration from left to right as the percentage of RAP is increased. However this is not obviously the case in Figure 23 because of the following primary variables: (a) penetration of the aged asphalt in the RAP, (b) air voids at the time of construction (Figure 22), and (c) age of the recycled pavement. Therefore, it is not possible to judge which asphalt cement grade and/or the percentage of RAP is appropriate. Moreover, the data on AC-10 and AC-30 asphalt cement grades is rather limited (only two projects each).

Figure 24 gives a similar histogram for viscosity and the results are similar to those discussed for penetration, that is, no trends of increasing viscosity (from left to right) are apparent within each asphalt group.

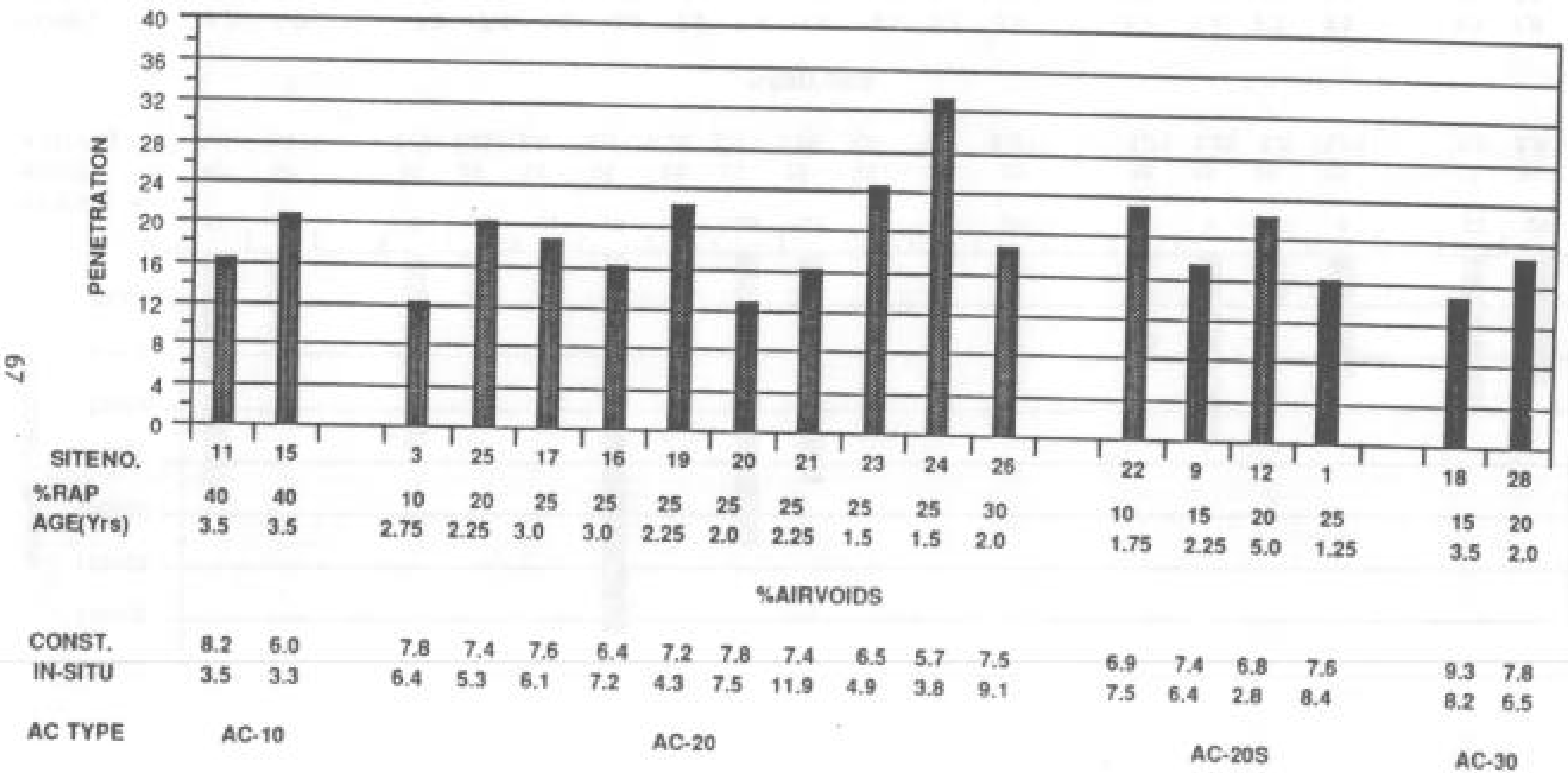
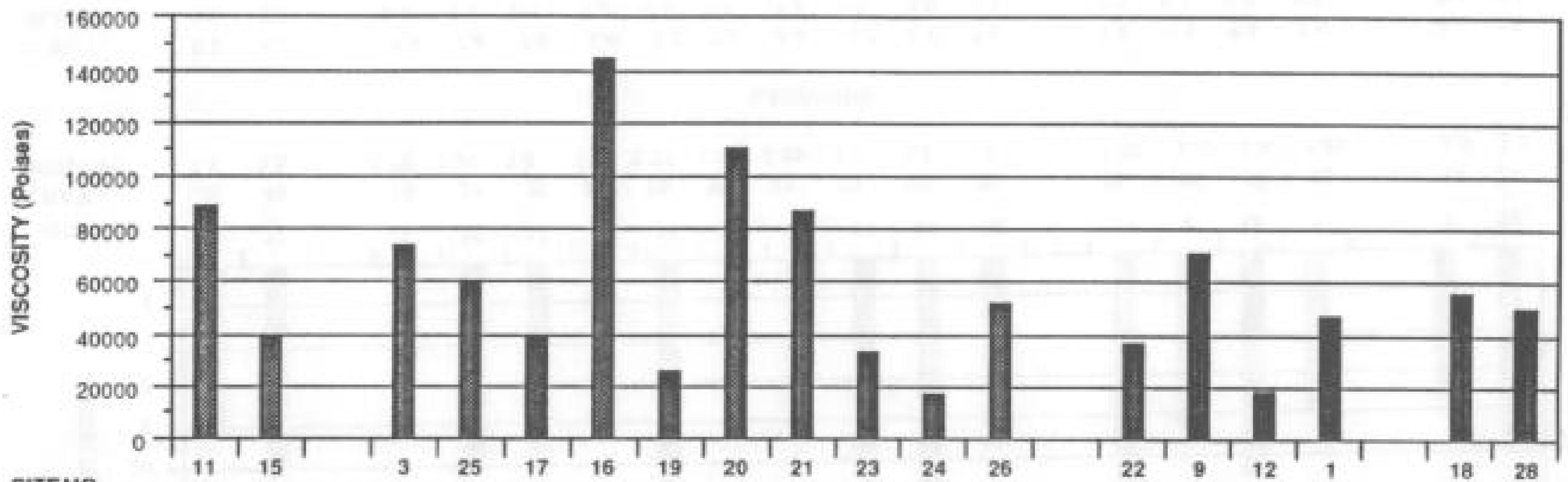


FIGURE 23. Effect of asphalt cement grade and percentage of RAP on recovered penetration (Task 2)



SITE NO.	11	15	3	25	17	16	19	20	21	23	24	26	22	9	12	1	18	28
%RAP	40	40	10	20	25	25	25	25	25	25	25	30	10	15	20	25	15	20
AGE(Yrs)	3.5	3.5	2.75	2.25	3.0	3.0	2.25	2.0	2.25	1.5	1.5	2.0	1.75	2.25	5.0	1.25	3.5	2.0
%AIRVOIDS																		
CONST.	8.2	6.0	7.8	7.4	7.6	6.4	7.2	7.8	7.4	6.5	5.7	7.5	6.9	7.4	6.8	7.6	9.3	7.8
IN-SITU	3.5	3.3	6.4	5.3	6.1	7.2	4.3	7.5	11.9	4.9	3.8	9.1	7.5	6.4	2.8	8.4	8.2	6.5
AC TYPE	AC-10		AC-20										AC-20S				AC-30	

FIGURE 24. Effect of asphalt cement grade and percentage of RAP on recovered viscosity (Task 2)

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from this study.

1. Both virgin and recycled sections of the five projects in Task 1 are performing satisfactorily after 1 1/2 to 3 1/2 years in service with no significant rutting, ravelling & weathering, and fatigue cracking.

2. The differences between the following properties of virgin and recycled sections of Task 1 projects were found to be not statistically significant at a 5 percent level of significance based on paired t-test.

   (a) In-situ mix properties such as percent air voids, resilient modulus at 25°C (77°F), and indirect tensile strength at 25°C (77°F).

   (b) Aged asphalt binder properties such as penetration at 25°C (77°F), viscosity at 60°C (140°F), SHRP rutting factor $G^*/\sin\delta$ at 64°C (148°F), and SHRP fatigue cracking factor $G^* \sin\delta$ at 22°C (72°F).

   (c) Recompacted mix properties such as percent air voids, Gyratory Stability Index (GSI), and confined dynamic creep modulus at 60°C (140°F).

3. The differences between the Gyratory Elasto-Plastic Index (GEPI) and the roller pressure values of virgin and recycled sections of Task 1 projects were found to be statistically significant at a 5 percent level of significance.

4. Task 2 pavements were treated as two independent groups (virgin mixes and recycled mixes) of unequal sizes (15 virgin and 18 recycled mixes) for statistical analysis. Independent Samples t-test was used for testing the equality of means of percent air

voids, penetration and viscosity of the two groups. No statistically significant difference was found in these three properties of virgin and recycled pavements at a 5 percent level of significance.

5. There was no significant overall difference in the performance of virgin and recycled pavements based on visual inspection.

6. Based on the evaluation of Task 1 and Task 2 pavements, it can be concluded that the recycled pavements are generally performing as well as the virgin pavements at the present time in Georgia. Therefore, it can be implied that the existing Georgia DOT recycling specifications, recycled mix design procedures and quality control are satisfactory. The specification to achieve a viscosity of 6,000 to 16,000 poises for the blend (RAP binder + virgin binder) appears reasonable based on the present data.

The following recommendations are made based solely on the experience of the researchers:

1. Consider allowing up to 10 or 15 percent RAP in all courses without changing to a softer asphalt cement grade. For example, if AC-30 grade is used in a 100 percent virgin mix, it should be allowed when the percentage of RAP is limited to 10 or 15 percent. This change will substantially save the Department's time and effort in analyzing the RAP properties without significantly affecting the overall quality of the recycled mix. The time and effort saved can be devoted to the design and control of other projects using higher percentages of RAP. The mix design should be developed for all recycled mixtures regardless od the amount of RAP.

2. The Department's procedure of physically blending the aged asphalt cement (recovered from the RAP) with the virgin asphalt cement, subjecting the blend to thin film oven (TFO) test and then testing the TFOT residue for viscosity is a good method but very time consuming. It is recommended to try the blending chart given in Figure 25. The RAP asphalt cement viscosity is plotted on the left vertical axis and the TFO viscosity of the virgin asphalt cement (already known from the asphalt supplier or Department testing) is plotted on the right vertical axis. The two points are connected with a straight line. A vertical line is then drawn corresponding to the percent of virgin asphalt in the binder blend (X-axis). The intersection of this vertical line with the previously drawn line gives the blend viscosity on the Y-axis. Since the aged asphalt in the RAP does not significantly increase in viscosity in the TFO test, the proposed simple method should give results not only on the conservative side but also reasonably close to those obtained by the Department's current procedure. Moreover, the proposed method can give the blend viscosity for any desired blend (that is, desired percentage of RAP) without physically blending the aged and virgin asphalt cements again. An example of this procedure is given in Appendix "D".

3. Georgia DOT's asphalt cement specifications (Appendix "C") appear to be suitable for virgin as well as recycled mixes. The minimum penetration of 60 should be maintained for AC-20, AC-20S and AC-30 asphalt cement to minimize premature fatigue cracking. Typical test values (both means and range) of asphalt cements supplied to the department during 1993 (Appendix "C") appear to be satisfactory.

4. If more than 10 percent RAP is used in recycling, the department should obtain

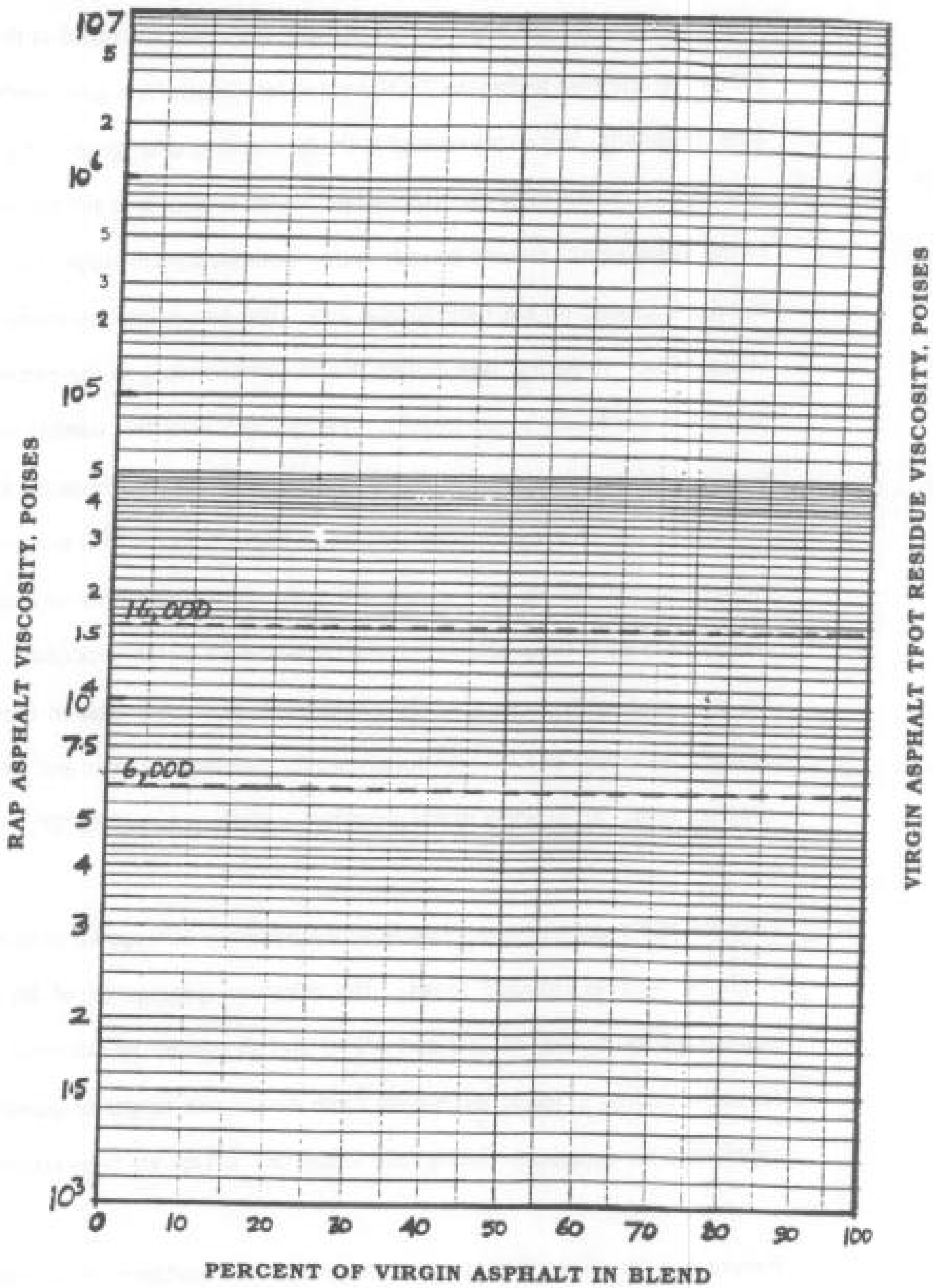


FIGURE 25. Blending chart

samples of the recycled mix from the projects on a random basis, to determine if the recovered asphalt cement viscosity is between 6,000 poises to 16,000 poises. Conventional QC/QA tests should be conducted more often.

5. Some selected virgin and recycled pavements (especially those included in Task 1) should be reevaluated after another 2-3 years service. This should include pavement surface evaluation and determination of aged asphalt properties of the same representative section used in this study.

ACKNOWLEDGMENTS

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APPENDICES

APPENDIX "A"

TABLE A1. Project construction details (Task 1)

Site No.	County	Section	Age yrs	RAP %	Virgin Asphalt Cement: Grade	Virgin Asphalt Cement: Viscosity 140 F	Virgin Asphalt Cement: Pen. 77 F	Mix Properties: Maximum Agg. Size	Mix Properties: % Asphalt Content	Mix Properties: % Air Voids	TMD gm/cc	Project details: Mix I.D. No.	Project details: Project I.D. No.
18C	Coffee	Virgin	1.50	0	AC-30	2988	***	1/2"	6.0	9.0	2.4215	099X035H2	SAMA-32 (65) 01
18R	Coffee	Recycled	1.50	15	AC-30	2988	***	1/2"	5.7	9.3	2.4103	099X151035H1	SAMA-32 (65) 01
22C	Ware	Virgin	1.75	0	AC-30	2703	***	1/2"	6.0	6.6	2.4295	121X052H1	SAMA-4 (115) 01
22R	Ware	Recycled	1.75	10	AC-20S	1912	***	1/2"	5.7	6.9	2.4359	121X151X052H1	SAMA-4 (115) 01
23C	Chatham	Virgin	1.50	0	AC-30	2807	***	***	***	***	2.4220	***	SAMA-204 SP (4) 02
23R	Chatham	Recycled	1.50	25	AC-20	1990	***	1/2"	5.4	6.5	2.4455	052X151F3	SAMA-204 SP (4) 02
25C	Emanuel	Virgin	2.25	0	AC-30	2965	***	1/2"	5.8	7.9	2.4183	081-F4	FR-38-1 (35) CT2
25R	Emanuel	Recycled	2.25	20	AC-20	2055	***	3/4"	5.7	7.4	2.4376	081X151F1-P0	FR-38-1 (35) CT2
28C	Richmond	Virgin	1.50	0	AC-30	3047	***	1/2"	6.0	8.3	2.4375	041X104F6	SAMA-104 (16) 01
28R	Richmond	Recycled	1.50	20	AC-30	3046	***	1/2"	5.8	7.8	2.4391	041X151X104F1	FR-75-1-24-01

*** Data not available

TABLE A2. Project Construction Details (Task 2.- Virgin Mixes)

					Virgin Asphalt Cement			Mix Properties						Project details
Site No.	County	Section	Age yrs	RAP %	Grade	Viscosity 140 F	Pen. 77 F	Maximum Agg. Size	% Asphalt Content	Bulk sp. Gravity	% Air Voids	TMD gm/cc	Mix I.D. No.	Project I.D No.
2	Murray	Virgin	2.50	0	AC-20S	1729	***	3/4"	5.7	2.3475	6.4	2.5080	010X046F2	FR-18-1(54) CT 1
4	Walker	Virgin	2.50	0	AC-30	3085	***	1/2"	5.8	2.2449	6.8	2.4087	047-F2	SAMAFR-184-1 (5) CT1
5	Floyd	Virgin	1.75	0	AC-30	1870	72.30	3/4"	5.2	2.2493	7.6	2.4343	010-E1	FR-12-1 (62) CT2
6	Bartow	Virgin	2.00	0	AC-30	3113	***	3/4"	5.5	2.4141	6.2	2.5737	046-E2	MAFR-19-1 (12)
7	Bartow	Virgin	3.50	0	AC-30	2858	***	1/2"	6.0	2.3184	7.5	2.5064	C010X046F1	FR-18-1 (49) CT1
8	Cherokee	Virgin	3.50	0	AC-30	2773	***	1/2"	6.3	2.3111	7.2	2.4904	102X046F099H1	SAMA-20 (112)
10	Fulton	Virgin	3.75	0	AC-30	3092	72.00	***	***	***	***	***	***	SAMA-42 (69)
13	Quitman	Virgin	4.75	0	AC-30	3137	65.25	1/2"	5.7	2.2997	7.0	2.4728	044-F2	FR-30-1 (10) CT2 *
14	Quitman /Randolph	Virgin	4.00	0	AC-30	2911	64.00	1/2"	5.7	2.2972	7.1	2.4728	044-F2	FR-30-1 (17) CT2 *
18C	Coffee	Virgin	1.50	0	AC-30	2988	***	1/2"	6.0	2.2035	9.0	2.4215	099X035H2	SAMA-32 (65) 01
22C	Ware	Virgin	1.75	0	AC-30	2703	***	1/2"	6.0	2.2691	6.6	2.4295	121X052H1	SAMA-4 (115) 01
23C	Chatham	Virgin	1.50	0	AC-30	2807	***	***	***	***	***	2.4220	***	SAMA-204 SP (4) 02
25C	Emanuel	Virgin	2.25	0	AC-30	2965	***	1/2"	5.8	2.2272	7.9	2.4183	081-F4	FR-38-1 (35) CT2
27	Jenkins	Virgin	2.00	0	AC-30	2897	***	1/2"	5.8	2.2611	6.5	2.4183	081-F4	FR-15-1 (52) 01
28C	Columbia/ Richmond	Virgin	1.50	0	AC-30	3047	***	1/2"	6.0	2.2352	8.3	2.4375	041X104F6	SAMA-104 (16) 01

*** Data not available

TABLE A3. Project Construction Details (Task 2.- Recycled Mixes)

Site No.	County	Section	Age yrs	RAP %	Virgin Asphalt Cement: Grade	Virgin Asphalt Cement: Viscosity 140 F	Virgin Asphalt Cement: Pen. 77 F	Mix Properties: Maximum Agg. Size	Mix Properties: % Asphalt Content	Mix Properties: Bulk sp. Gravity	Mix Properties: % Air Voids	Mix Properties: TMD gm/cc	Project details: Mix I.D. No.	Project details: Project I.D No.	Asphalt Cement Properties: Avg Viscosity RAP	Asphalt Cement Properties: Avg Viscosity Blend	Asphalt Cement Properties: Pen. Value RAP	Asphalt Cement Properties: Pen. Value Blend
1	Murray	Recycled	1.25	25	AC-20S	2018	***	1/2"	5.9	2.2685	7.6	2.4551	047X151X046+F1	MLP-61(49) 01	41424	15061	27	31
3	Catoosa	Recycled	2.75	10	AC-20	2155	***	3/4"	5.5	2.1765	7.8	2.3606	018X151030+F1	SR-820 (8) CT1 & SR -821 (5) CT 1	414831	5417	10	44
9	Walton	Recycled	2.25	15	AC-20S	2141	***	1/2"	5.6	2.2497	7.4	2.4295	C068X151F1	FR-61-1 (96)	111628	6993	23	48
11	Fulton	Recycled	3.50	40	AC-10	1179	98.00	1/2"	5.6	2.2450	8.2	2.4455	15X15XF1P0	SAMA-42-SP (2)	***	***	18348	29
12	Dekalb	Recycled	5.00	20	AC-20S	1939	67.00	3/4"	5.3	2.2747	6.8	2.4407	Mix type E	FR-37-2 (50)	***	***	***	***
15	Worth	Recycled	3.50	40	AC-10	1179	123.00	1/2"	5.7-6.0	2.3093	6.0	2.4567	044X151F2-P0	FR-26-2 (76)	***	21310	***	***
16	Brooks	Recycled	3.00	25	AC-20	1895	82.00	3/4"	5.5	2.3063	6.4	2.4639	017X151F134H1	FR-206-1 (1) CT1	99029	15633	14	37
17	Irwin	Recycled	3.00	25	AC-20	2114	84.30	3/4"	5.3	2.2592	7.6	2.4450	099X151X035F1	FR-38-1 (20) CT1	325022	7478	16	42
18R	Coffee	Recycled	1.50	15	AC-30	2988	***	1/2"	5.7	2.1861	9.3	2.4103	099X151035H1	SAMA-32 (65) 01	70214	6321	16	50
19	Coffee	Recycled	2.25	25	AC-20	2063	86.00	3/4"	6.0	2.2525	7.1	2.4247	099X151H1	FR 79-1 (29) CT1	99029	***	14	***
20	Benhill/Erwin	Recycled	2.00	25	AC-20	1998	93.00	3/4"	5.5	2.2548	7.8	2.4455	099X151X035F1	SR 2718 (2) CT1	325022	***	16	***
21	Benhill	Recycled	2.25	25	AC-20	2063	86.00	3/4"	6.0	2.2453	7.4	2.4247	099X155H1	SAMAFR-137-1 (4) CT1	99029	***	14	***
22R	Ware	Recycled	1.75	10	AC-20S	1912	***	1/2"	5.7	2.2878	6.9	2.4359	121X151X052H1	SAMA-4 (115) 01	305305	6348	11	54
23R	Chatham	Recycled	1.50	25	AC-20	1990	***	1/2"	5.4	2.2866	6.5	2.4455	052X151F3	SAMA-204 SP (4) 02	54253	6066	29	43
24	Chatham	Recycled	1.50	25	AC-20	1962	***	3/4"	5.1	2.3197	5.7	2.4599	052X151E1	SAMA-26 (117) 02	54253	32898	29	31
25R	Emanuel	Recycled	2.25	20	AC-20	2055	***	3/4"	5.7	2.2571	7.4	2.4375	081X151F1-P0	FR-38-1 (35) CT2	54253	11490	29	39
26	Emanuel	Recycled	2.00	30	AC-20	2075	***	3/4"	6.0-6.3	2.2502	7.5	2.4327	081X151H3	SR-622 (8) 01	131379	10350	17	42
28R	Columbia/ Richmond	Recycled	1.50	20	AC-30	3048	***	1/2"	5.8	2.2489	7.8	2.4391	041X151X104F1	FR-78-1-24-01	70340	10812	18	42

*** Data not available

TABLE A4. Paired t-test for equality of means of mix properties (Task 1)

SITE NO.	IN-SITU % AIR VOIDS			INDIRECT TENSILE STRENGTH @ 77 F IN PSI			RESILIENT MODULUS @ 77 F IN PSI		
	N=8			N=5			N=3		
	Control	Recycled	Difference	Control	Recycled	Difference	Control	Recycled	Difference
18	7.5921	8.2006	-0.6085	255.72	230.57	25.15	1.08E+06	9.53E+05	1.35E+05
22	9.3529	7.4918	1.8611	150.12	141.57	8.56	7.16E+05	6.10E+05	1.06E+05
23	3.6234	4.9263	-1.3030	169.40	161.24	8.16	6.98E+05	6.85E+05	1.28E+04
25	6.1628	5.2947	0.8682	219.15	195.12	24.04	1.20E+06	8.31E+05	3.71E+05
28	8.2651	6.4739	1.7912	217.31	207.22	10.09	1.03E+06	1.38E+06	-3.50E+05
AVERAGE	6.9992	6.4774	0.5218	202.34	187.14	15.20	9.47E+05	8.92E+05	5.50E+04
STD.DEV	2.2130	1.3967	1.4259	42.33	35.71	8.62	2.27E+05	3.03E+05	2.62E+05
DOF (NU) = 4									
Tcrit, 0.05(2),4 =		2.7760			2.7760			2.7760	
Tcal =		0.8183			3.9441			0.4693	
R:|Tcal|>Tcrit	Means are not significantly different			Means are significantly different			Means are not significantly different		

TABLE A4. (contd.) Paired t-test for equality of means of mix properties (Task 1)

SITE NO.	% AIR VOIDS			GEPI (Omin / Oinitial)			GSI (Omax / Omin)		
	Control	Recycled	Difference	Control	Recycled	Difference	Control	Recycled	Difference
18	4.0259	3.1292	0.8967	1.050	1.233	-0.1833	1.095	1.028	0.0670
22	4.2678	3.7538	0.5140	1.167	1.275	-0.1083	1.043	1.000	0.0430
23	1.6809	2.1964	-0.5155	1.100	1.267	-0.1667	1.342	1.264	0.0780
25	5.4054	3.0658	2.3396	1.050	1.300	-0.2500	1.027	1.039	-0.0118
28	5.1662	3.3099	1.8563	1.083	1.317	-0.2333	1.060	1.051	0.0092
AVERAGE	4.1092	3.0910	1.0182	1.0900	1.2783	-0.1883	1.1133	1.0762	0.0371
STD.DEV	1.4770	0.5678	1.1258	0.0480	0.0321	0.0564	0.1303	0.1066	0.0380
DOF (NU) = 4									
Tcrit, 0.05(2),4 =		2.7760			2.7760			2.7760	
Tcal =		2.0224			-7.4673			2.1811	

R:|Tcal|>Tcrit Means are not significantly different — Means are significantly different — Means are not significantly different

TABLE A4. (contd.) Paired t-test for equality of means of mix properties (Task 1)

SITE NO.	ROLLER PRESSURE PSI			CREEP MODULUS @ 140 F AND 20 PSI N=3		
	Control	Recycled	Difference	Control	Recycled	Difference
18	10.333	6.000	4.3333	10478	6383	4.10E+03
22	8.667	6.500	2.1667	5706	9692	-3.99E+03
23	6.000	5.000	1.0000	4253	7483	-3.23E+03
25	7.667	6.000	1.6667	6824	9144	-2.32E+03
28	9.333	6.000	3.3333	6295	15058	-8.76E+03
AVERAGE	8.4000	5.9000	2.5000	6.71E+03	9.55E+03	-2.84E+03
STD.DEV	1.6566	0.5477	1.3333	2.31E+03	3.35E+03	4.61E+03
DOF (NU) = 4						
Tcrit, 0.05(2),4 =			2.7760			2.7760
Tcal =			4.1926			-1.3785
R:|Tcal|>Tcrit		Means are significantly different			Means are not significantly different	

TABLE A4. (contd.) Paired t-test analysis of recovered AC properties (Task 1)

SITE NO.	PENETRATION VALUE @ 77 F		
	Control Section	Recycled Section	Difference
18	15.25	14.75	0.5000
22	23.75	23.00	0.7500
23	24.13	24.38	-0.2500
25	16.75	20.38	-3.6250
28	21.38	18.50	2.8750
AVERAGE	20.25	20.20	0.0500
STD.DEV	4.06	3.80	2.3595

DOF (NU) = 4
Tcrit, 0.05(2),4 = 2.7760
Tcal = 0.0474

R:|Tcal|>Tcrit Difference of means are not significant

SITE NO.	VISCOSITY @ 140 F (POISES)		
	Control Section	Recycled Section	Difference
18	55810.40	55370.07	440.32
22	33091.71	36773.36	-3681.65
23	34676.56	33001.62	1674.94
25	103439.69	59340.57	44099.12
28	46272.32	49907.21	-3634.89
AVERAGE	54658.13	46878.57	7779.57
STD.DEV	28790.90	11524.59	20444.37

DOF (NU) = 4
Tcrit, 0.05(2),4 = 2.78
Tcal = 0.8509

R:|Tcal|>Tcrit Difference of means are not significant

TABLE A4. (contd.) Paired t-test analysis of recovered AC propertie

SITE NO. G*/Sin(delta) AT 64 C (pascals)

SITE NO.	Control Section	Recycled Section	Difference
18	20780.02	21872.55	-1092.53
22	12130.25	11896.31	233.95
23	12313.65	10252.44	2061.21
25	28089.70	16136.85	11952.85
28	16046.89	16874.07	-827.18
AVERAGE	17872.10	15406.44	2465.66
STD.DEV	6709.17	4565.71	5446.43

DOF (NU) = 4
Tcrit, 0.05(2),4 = 2.78
Tcal = 1.0123

R:|Tcal|>Tcrit Difference of means are not significant

SITE NO. G* Sin(delta) AT 22 (kPa)

SITE NO.	Control Section	Recycled Section	Difference
18	2077.85	2011.74	66.11
22	781.44	655.20	126.24
23	1029.51	720.95	308.56
25	1788.56	1340.75	447.82
28	1101.57	1711.54	-609.97
AVERAGE	1355.78	1288.04	67.75
STD.DEV	549.92	597.48	407.79

DOF (NU) = 4
Tcrit, 0.05(2),4 = 2.78
Tcal = 0.3715

R:|Tcal|>Tcrit Difference of means are not significant

TABLE A5. Independent t-test for equality of means (Task 2)

	% AIR VOIDS		PENETRATION		VISCOSITY	
	VIRGIN SECTION	RECYCLED SECTION	VIRGIN SECTION	RECYCLED SECTION	VIRGIN SECTION	RECYCLED SECTION
	3.76	8.36	16.50	16.25	24038	47244
	7.75	6.41	16.38	12.13	69182	73611
	4.32	6.38	18.88	17.25	27675	71015
	7.28	3.48	15.38	16.38	62589	88813
	0.93	2.78	25.25	22.38	22309	17627
	4.46	3.33	18.75	20.88	47347	39998
	7.02	7.21	18.50	16.13	36771	144707
	5.02	6.13	15.13	18.63	186092	39245
	7.59	8.20	14.13	14.75	284226	55370
	9.35	4.30	15.00	22.25	55810	25502
	3.62	7.52	23.75	12.63	33092	110724
	6.16	11.89	24.13	16.13	34677	86436
	5.28	7.49	16.75	23.00	103440	36773
	8.27	4.93	15.00	24.38	62945	33002
		3.80	21.38	33.38	46272	16607
		5.29		20.38		59341
		9.13		18.63		51614
		6.47		18.50		49907
AVERAGE	5.77	6.28	18.33	19.11	73098	58197
STD. DEV	2.27	2.34	3.68	4.97	71524	33299
VARIANCE	5.16	5.49	13.51	24.66	5.12E+09	1.10E+09
SAMPLE SIZE	14	18	15	18	15	18
DOF	13	17	14	17	14	17
POOLED DOF	30		31		31	
POOLED VARIANCE	5.34		19.62		2.92E+09	
Tcrit,0.05(2) =	2.04		2.04		2.04	
Tcalc	-0.62		-0.51		0.79	
R: |Tcalc| > Tcrit	The means are not significantly different		The means are not significantly different		The means are not significantly different	

APPENDIX "B"

1. Pavement Evaluation Sheet.
2. Description and Severity of Pavement Distress.

Performance of Recycled Mixtures in State of Georgia
PAVEMENT EVALUATION SHEET

Project (Route): **County:**

Location:

Mix Type (circle one): **Recycled** **Virgin**

Core Identifications:

Select a 500' long representative section on each job for coring. Visually rate the pavement surface condition as follows:

1. RUT DEPTHS (Obtain 4 measurements near core locations):

   (a) (b) (c) (d) ($\bar{x}$) =

2. RAVELLING AND WEATHERING

   Severity Levels: (None) (Low) (Moderate) (High)

   % Surface Area =

3. ALLIGATOR (FATIGUE) CRACKING

   Severity Levels: (None) (Low) (Moderate) (High)

   % Surface Area =

4. TRANSVERSE CRACKING

Severity Levels:	(None)	(Low)	(Moderate)	(High)
Number		( )	( )	( )
Linear feet		( )	( )	( )

   Are these reflection cracks? (Yes) (No)

5. OTHER SURFACE DISTRESS (SUCH AS BLEEDING) AND EXTENT

Rated by ______________________

Date ______________________

13. Raveling and Weathering

Description

Wearing aw-; of the pavement surface caused by the dislodging of aggregate particles (raveling) and loss of asphalt binder (weathering).

Severity Levels

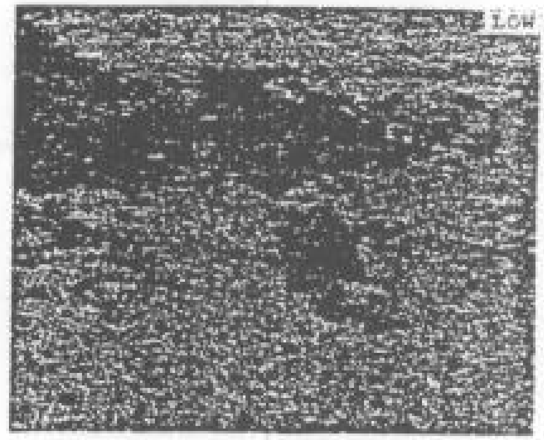
Low - Wearing away of the aggregate or binder has started but has not progressed significantly.

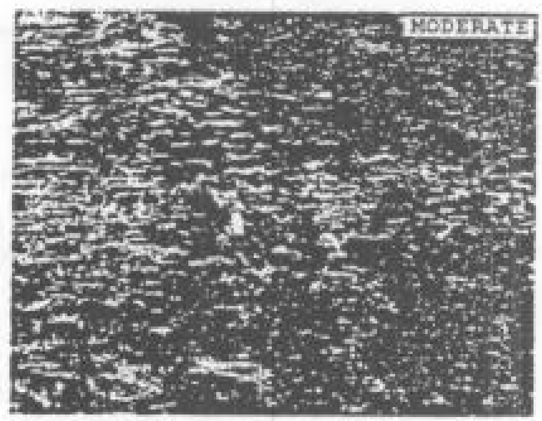
Moderate - Aggregate and/or binder has worn away and the surface texture is becoming rough and pitted; loose particles generally exist.

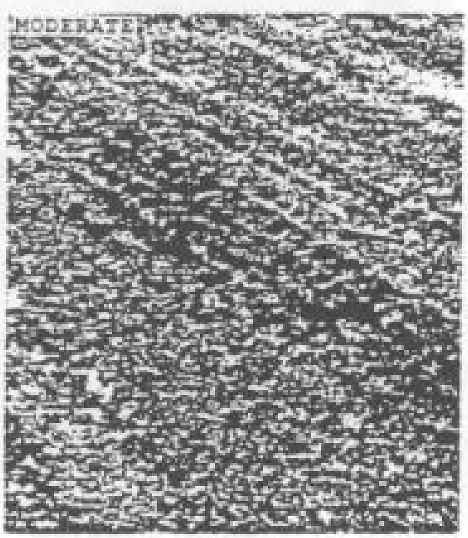
High - Aggregate and/or binder has worn away and the surface texture is very rough and pitted.

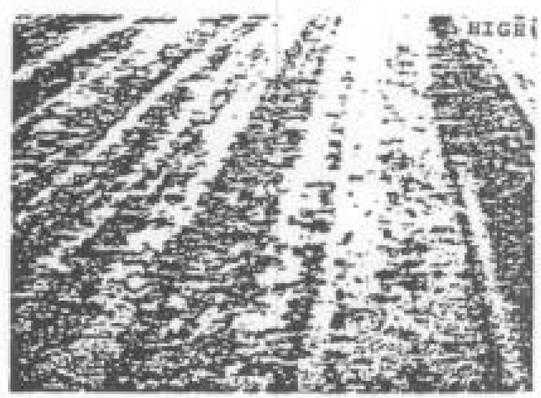
How to Measure

Square feet of surface area at each severity level.









1. Alligator (Fatigue) Cracking

Description

- Series of interconnected cracks.
- Many-sided, sharp-angled pieces, usually less than 1' on longest side.
- Chicken wire/alligator pattern.
- Occurs only in areas subjected to repeated traffic loadings (usually in wheelpaths).
- Initially appears as longitudinal cracks.

Severity Levels

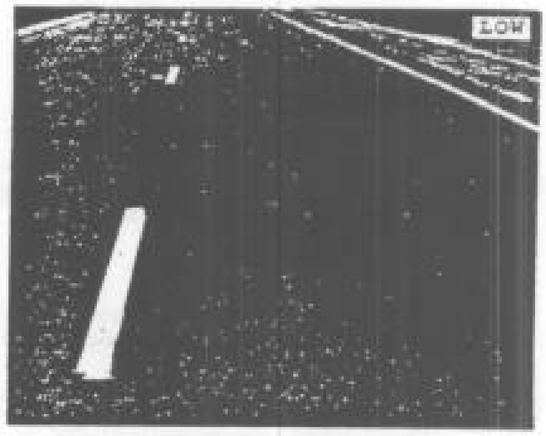
Low - Longitudinal disconnected hairline cracks running parallel to each other; may be a single crack in wheelpath; cracks not spalled.

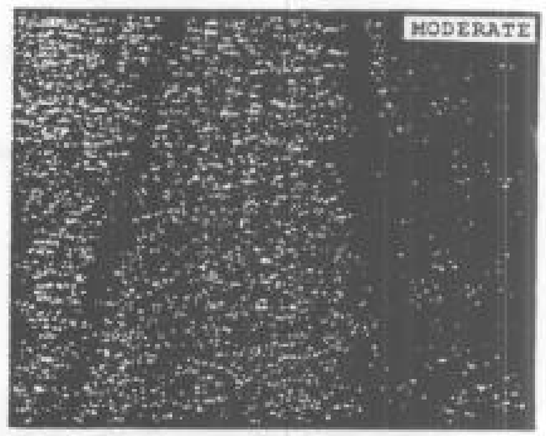
Moderate - A pattern of articulated pieces formed by cracks that may be lightly spalled; cracks may be sealed.

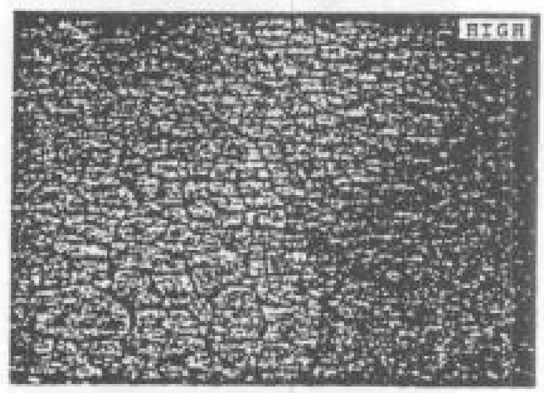
High - Pieces more severely spalled at edges and loosened until the pieces rock under traffic; pumping may exist.

How to Measure

- Square feet of surface area at each severity level.
- If different severity levels existing within an area cannot be distinguished, rate entire area at highest severity present.







6. **Transverse Cracking**

Description

Cracks relatively perpendicular to pavement centerline.

Severity Levels

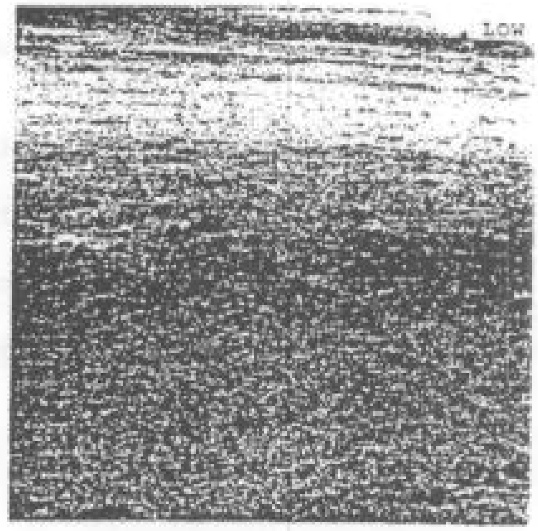
Low - Cracks with low severity or no spalling; mean unsealed crack width of 1/4" or less; sealant material in good condition.

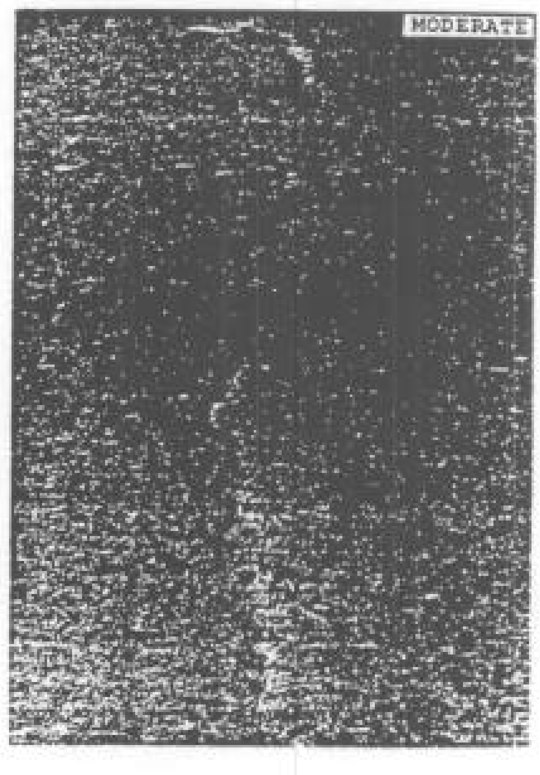
Moderate - Cracks with moderate severity spalling; mean unsealed crack width of greater than 1/4"; sealant material in bad condition; low severity random cracking near the crack.

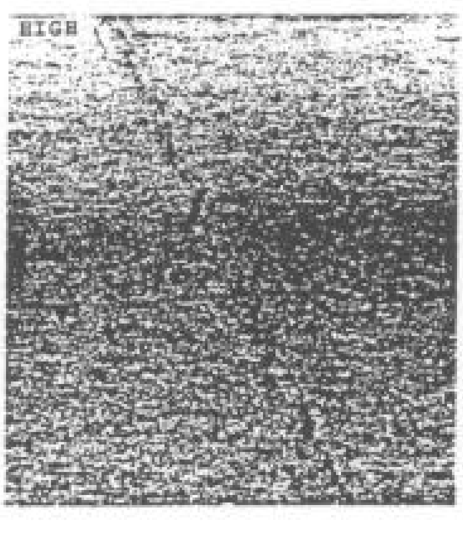
High - Cracks with high severity spalling; moderate or high severity random cracking near the crack.

How to Measure

Number and linear feet of transverse cracks at each severity level.







APPENDIX "C"

1. Section 402 - Hot Mix Recycled Asphaltic Concrete (Georgia DOT Specifications, 1993)
2. Georgia DOT Specifications for Asphalt Cements.
3. Typical Test Values of Asphalt Cements in Georgia during 1993.

SECTION 402—HOT MIX RECYCLED ASPHALTIC CONCRETE

402.01 DESCRIPTION: This work shall consist of producing and placing a hot mix recycled asphaltic concrete which incorporates Reclaimed Asphalt Pavement (RAP), virgin aggregate, hydrated lime, and neat asphalt cement.

Hot mix recycled asphaltic concrete production and placement, along with all materials, equipment and acceptance plans, except as specifically noted or modified herein, shall be in accordance with Section 400 – Hot Mix Asphaltic Concrete Construction.

402.02 MATERIALS:

A. RAP MATERIAL: The RAP materials will be from the existing roadway, from the Contractor's RAP stockpile which has been approved by the Department, or from a stockpile belonging to the Department. If RAP materials belonging to the Department are used, the location of any such stockpiles shall be as indicated on the Plans.

The amount of RAP used in the recycled mixtures for mainline and/or ramps (where applicable) may range from 0 - 40 percent dependent upon the amount of RAP available and Contractor's production facilities, and provided the mixture meets all Specification requirements as outlined in Section 828 – Hot Mix Asphaltic Concrete Mixtures. The maximum ratio of RAP material to the recycled mixture shall be 40 percent for continuous mix type plants and 25 percent for batch type plants. If the amount of RAP material available is not sufficient to provide the permissible limit, the Contractor may supplement with RAP material from a stockpile which has been approved by the Department. The amount of RAP to be used in recycled mixtures for any other areas shown on the Plans (i.e., paved shoulders, local service roads, subbase for PCC pavements, etc.) will be at the contractor's discretion limited only by the amount that will yield satisfactory mixture properties as outlined in Section 828.

Asphaltic Concrete removed from an existing roadway by the Contractor shall become the property of the Contractor unless specified otherwise on the Plans. If the Department elects to retain any portion of the RAP material, the amount shall be so designated on the Plans, and the RAP shall be stockpiled at the location specified on the Plans.

Where the RAP is removed from a stockpile belonging to the Department, the amount furnished to the Contractor shall be limited to an amount required to produce a 40 percent recycled mixture, unless otherwise specified. The actual amount of RAP allowed in the recycled mixtures shall be governed by the above outlined stipulations. Any such RAP furnished to the Contractor, which is not used in the Work, will remain the property of the Contractor.

The Contractor shall notify the Engineer prior to removing any RAP material from a designated stockpile belonging to the Department and shall provide the Engineer with certified weight tickets of materials removed from the stockpile.

The Laboratory will determine the projected composition of the RAP from the project to be milled and will calculate theoretical aggregate blends prior to the work being let to contract. The Laboratory may be contracted to obtain the theoretical blends. Representative materials shall be obtained from the Contractor's stockpile(s) for the final mix design.

Representative samples of the virgin aggregates along with the gradation of each and a proposed blend shall be submitted no later than fifteen days prior to the planned beginning date for the production of the recycled mixture.

Stockpiles shall be separated and a sign satisfactory to the Engineer shall be erected on each stockpile to identify the source(s). Stockpiles shall be kept separated by project sources and also separated by Group I and Group II aggregate types. If RAP material from different project sources should become intermixed in a stockpile, those materials shall be used only where approved by the Laboratory. The Department also reserves the right to reject, by visual inspection, any stockpiles that are not kept clean and free of foreign materials.

The Department may also require that additional quality control tests be performed to determine the consistency of the RAP stockpile as well as quality of the RAP aggregate. For this purpose the Contractor shall conduct extraction/gradation tests at the minimum of three tests from each individual source. Such aggregate shall meet the quality standards as established in Section 800 of the Standard Specifications.

The Contractor shall furnish to the Laboratory an affidavit attesting to the sources of any stockpiled materials belonging to him to be used on a State project. The information which shall be included in the letter is the State project number and location from which the material was removed, the approximate dates when the removal took place, the mix types removed and estimated quantity of each in stockpiles, and any other information that may be available about the stockpiled material such as percentage of local sand in the RAP. If stockpiles containing RAP from different project sources have been mixed or Group I and Group II aggregates have been mixed, specific approval must be obtained from the Laboratory to use that stockpile. Any stockpile containing RAP from other than State projects such as LARP and County Contracts will also require specific approval from the Laboratory for use on a stockpile approved basis only.

Where applicable, the amount of local sand allowed in the recycled mixes shall be as stipulated in Section 828 for the affected project. The amount of local sand in the RAP material will be considered when determining the percentage of local sand in the total mix. When a Blend I mix is specified, any Group I materials in the RAP will be considered when determining the Group I portion allowed in the total mix as specified in Sub-Section 828.07.

All RAP material to be used in the recycled mixture shall be processed as necessary so that 100% will pass the 2 inch sieve. Additional crushing and sizing may also be required if the RAP aggregate exceeds the maximum sieve size for a particular mix type as established in Section 828.

B. ASPHALT CEMENT: The grade of asphalt cement that shall be used in the recycled mixture will be determined by the Department through Laboratory evaluation and shall meet the requirements of the appropriate Specifications. When blended with asphalt cement recovered from the RAP material and after tests on residue from Thin Film Oven Tests, the asphalt cement shall have a viscosity of 6,000-16,000 poises or as approved by the Engineer.

If, during construction, it is determined by the Engineer that the grade of asphalt cement so selected is not performing satisfactorily, the Department reserves the right to change, without a change in the Contract Unit Price, the grade of asphalt cement being used in the mixture. Asphalt cement shall be recovered from the recycled mixture to verify that the viscosity specified above is being met.

C. RECYCLED MIXTURE: The recycled mixture shall be a homogenous mixture of RAP material, virgin aggregate, hydrated lime, and neat asphalt cement. The mixture shall conform to an approved mixture design meeting the requirements outlined in Section 828 except the hydrated lime shall be added at a rate of 1.0 percent of the virgin aggregate portion plus 0.5 percent of the aggregate in the RAP portion of the mixture.

402.03 EQUIPMENT; A hot mix plant, with such modifications as necessary to process recycled material, and approved by the Engineer, shall be used for the recycling process. The plant used shall be designed, equipped, and operated in such a manner that the proportioning, heating, and mixing will yield a uniform final mixture within the Job Mix Formula tolerances.

The RAP material shall be proportioned by a separate cold feed bin and the material shall meet the size requirements specified in Sub-Section 402.02 above. The ratio of the RAP to virgin aggregate shall be controlled gravimetrically. Electronic belt weighing devices shall be provided to monitor the flow of RAP and the flow of virgin aggregate. Plants may consist of an interlocking system of feeders and conveyors synchronizing the flow of RAP material with the flow of virgin aggregate. The electronic controls shall be capable of tracking the flow rates indicated by the belt weighing devices and developing the necessary signal to automatically maintain the desired ratio at varying production rates. The RAP feeder bins, conveyor system and any auxiliary bins, if used, shall be designed to avoid segregation and sticking of the RAP material.

In lieu of the above belt weighing system, batch type plants may be equipped to weigh the RAP portion of the batch in a weigh hopper prior to incorporation into the pugmill.

The Contractor shall furnish a detailed description of the recycling methods at the Preconstruction Conference. This shall include, but not be limited to, the type of plant to be used and how the RAP material will be incorporated into the processed recycled mixture.

402.04 MEASUREMENT: The Recycled Asphaltic Concrete mixture, complete in-place and accepted, will be measured in tons. The actual weight will be determined by recorded weights, if an approved recording device is used, or by weighing each loaded vehicle on an approved motor truck scale as the material is hauled to the roadway.

402.05 PAYMENT: The Work performed and materials furnished as prescribed by this Specification will be paid for at the Contract Unit Price per ton. This payment shall be full compensation for providing all materials, for all hauling and necessary crushing, for all processing, placing, rolling and finishing of the recycled mixture, and for all labor, tools, equipment and incidentals necessary to complete the Work, including hauling and stockpiling of any surplus RAP material.

Payment will be made under:

Item No. 402.	Reycled Asphaltic Concrete Type, Group Blend, Including Bituminous Materials and and Hydrated Lime	per Ton
Item No. 402.	_________Inch Recycled Asphaltic Concrete Type, Group-Blend, Including Bituminous Materials and Hydrated Lime	per Square Yard
Item No. 402.	Recycled Asphaltic Concrete Patching Including Bituminous Materials and Hydrated Lime	per Ton
Item No. 402.	Recycled Asphaltic Concrete Leveling Including Bituminous Materials and Hydrated Lime	per Ton

SECTION 820—ASPHALT CEMENT

820.01 ASPHALT CEMENT: This Section covers asphalt cements which have been prepared from crude petroleum by suitable methods. The asphalt cements shall be homogenous, free from water and shall not foam when heated to 347°F. Blending of asphalt cements to produce a specified viscosity grade shall result in a uniform, homogenous blend with no separation.

A. PROPERTIES: The various grades of asphalt cement shall meet the requirements for the respective grades as shown in Table 820.01.

TABLE 820.01 PROPERTIES FOR PETROLEUM ASPHALT CEMENTS

	VISCOSITY GRADE									
	AC-10		AC-15		AC-20		AC-30		AC-40	
	Min.	Max.	Min.	Max.	Min.	Max.	Min	Max.	Min.	Max.
Viscosity, 140°F (60°C) Poises	1000 ±	200	1500 ±	300	2000 ±	400	3000 ±	600	4000 ±	800
Viscosity, 275°F (135°C) CS	240	-	240	-	300	-	350	-	350	-
Penetration at 77°F (25° C) 100 g., 5 sec.	80	-	60	-	60	-	60	-	40	-
Flash Point, COC, °F	425	-	425	-	450	-	450	-	450	-
Solubility in Trichloroethylene, %	99.0	-	99.0	-	99.0	-	99.0	-	99.0	-
Tests on Residue from Thin-Film Oven Test:										
Loss on Heat (%)	-	-	-	0.5	-	0.5	-	0.5	-	0.5
Viscosity, 140°F (60°C) Poises	-	4000	-	6000	-	8000	-	12000	-	16000
Ductility at 77°F, (25°C) 5 cm per min., CM	100	-	100	-	80	-	60		50	-

Note: Viscosity grade AC-20 having a penetration at 77°F not exceeding 80 dmm; and an initial viscosity at 77°F not less than 2.3 million poises by AASHTO: T-202, or not less than 2.5 million poises by ASTM: D-3205, may be used in lieu of AC-30. These asphalts will be designated as AC-20 Special. The method in ASTM: D-3205 using the medium cone shall be the referee method.

Where AASHTO: T0202 is used, The Asphalt Institute vacuum capillary viscometer size 800R shall be used.

B. TESTS: Methods of tests shall be in accordance with the following:

Viscosity at 275° F. (135°C.)	AASHTO: T 201
Viscosity at 140°F. (60°C.)	AASHTO: T 202
Penetration	AASHTO: T 49
Flash Point	AASHTO: T 48
Ductility	AASHTO: T 51
Thin-Film Oven Test	AASHTO: T 179
Solubility	AASHTO: T44

Typical Test Values of Asphalt Cements in Georgia during 1993.

Supplies	TYPICAL TEST VALUES			
	Viscosity @ 140 F		Penetration @ 77 F	
	Mean	Range	Mean	Range
Coastal AC-30 (From Chickasaw)	2850	2500 - 3100	65	62 - 70
Citgo AC-30 (From Savannah)	2900	2750 - 3250	67	61 - 71
Shell AC-20 Special (From Wood River)	1900	1750 - 2100	67	62 - 74
Coastal AC-20 (From Chickasaw)	2165	2100 - 2300	76	70 - 90
Citgo AC-20 (From Savannah)	2100	1900 - 2200	78	70 - 90
Shell AC-10 (From Wood River)	900	850 - 1100	105	95 - 120

APPENDIX "D"

Example of the proposed blending chart.

Example of the proposed blending chart

Consider a case where,

a. Viscosity of the RAP binder measured = 30,000 poises
(plot on left Y-axis as point a)

b. Viscosity of the virgin asphalt cement (TFOT residue) = 5,000 poises
(plot on right Y-axis as point b)

c. The optimum asphalt content of the recycled mix = 6.0%

d. The percentage RAP used in the recycled mix = 20%

e. The asphalt content present in the RAP = 5.0%

∴ The % asphalt binder content contributed by the RAP mix

= (20/100) X 5.0 = 1.0%

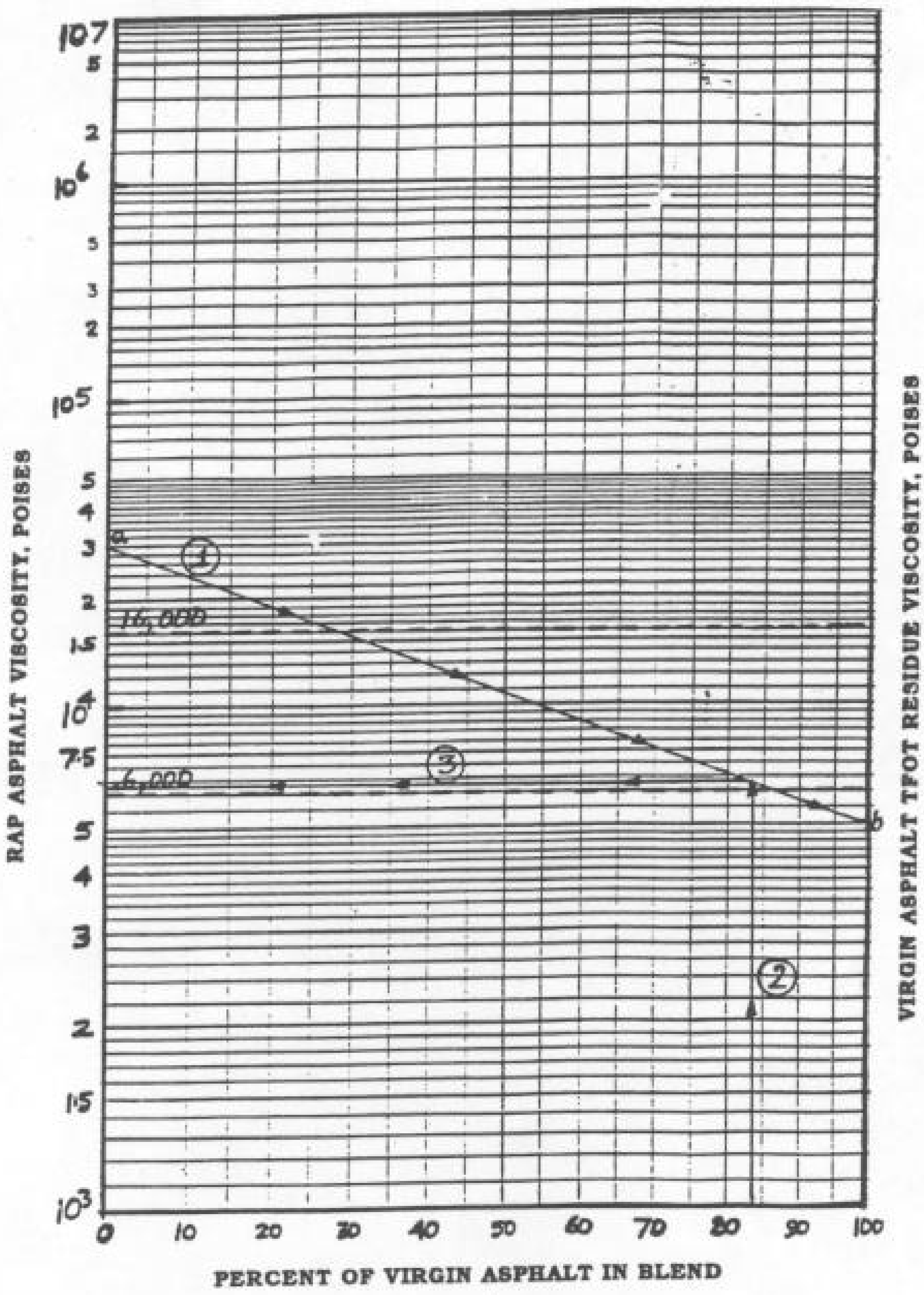
∴ The % virgin asphalt needed in the recycled mix = 6.0 - 1.0 = 5.0%

∴ The percentage of virgin asphalt cement present in the final blend

= (5/6) X 100 = 83.33 %

1. Connect the points a and b (see line 1 figure in page 103)
2. Draw a vertical line from from the X-axis at 83.3 %
(denoted by the vertical solid line 2)
3. Draw a horizontal line (represented by line 3) at the point of the intersection of the above two lines.
4. The value of the viscosity on the Y-axis indicated by this horizontal line represents the final blend viscosity.

For the above problem the final blend viscosity was determined as 6,200 poises.



10^7
5
2
10^6
5
3
2
10^5
5
4
3
2
1.5
10^4
7.5
5
4
3
2
1.5
10^3
16,000
6,000
a
b
1
2
3
0
10
20
30
40
50
60
70
80
90
100
RAP ASPHALT VISCOSITY, POISES
VIRGIN ASPHALT TFOT RESIDUE VISCOSITY, POISES
PERCENT OF VIRGIN ASPHALT IN BLEND