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ABSTRACT

Mix design procedures for recycled asphalt pavements require the selection of virgin asphalt binder or recycling agent. This research project was undertaken to develop a procedure for selecting the performance grade (PG) of virgin asphalt binder based on the Superpave PG grading system. Blending charts, similar to the viscosity blending charts, were constructed and evaluated based on test parameters obtained from the dynamic shear rheometer (DSR). The criteria for selection was based on Superpave peflormance grading (PG) specification, for example, G*/sin**=1 kPa minimum for unconditioned asphalt binder, G*/sin**=2.2 kPa minimum for rolling thin film oven (RTFO) residue, and G*sin**=5 MPa maximum for RTFO and pressure aging vessel (PAV) residue. The criteria based on the fatigue parameter (G*sin**=5 MPa maximum for RTFO+PAV residue) was determined to be too liberal and, therefore, was not recommended. An alternative criteria based on the high temperature stiffhess (G*/sin**) was recommended.

KEYWORDS: hot mix asphalt concrete, reclaimed asphalt pavement, hot mix recycling, mix design, blending charts, Superpave, PG grade, asphalt binder, virgin asphalt

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INTRODUCTION

Several binder selection procedures were developed in the 1970s and 1980s for recycled hot mix asphalt (HMA) pavements. These procedures which primarily consist of selection of a virgin asphalt binder or recycling agent, have remained largely unchanged over the years. Most agencies use the viscosity blending chart to determine the viscosity of the virgin asphalt binder or the recycling agent to be used as a rejuvenator agent. However, many highway agencies have initiated programs to implement Superpave performance grading (PG) system for asphalt binder. This research project was undertaken to develop a procedure for selecting the performance grade (PG) of virgin asphalt binder based on the Superpave PG grading system. Only high and intermediate temperature properties of asphalt binders, measured by the dynamic shear rheometer (DSR), were considered in this study.

SUPERPAVE PERFORMANCE GRADING SYSTEM FOR ASPHALT BINDER

Superpave performance grading (PG) system [1, 2, 3] is basically designed to improve the peflormance of HMA pavements by selecting asphalt binder with physical properties that resist:

1. Tenderness during Iaydown by requiring the G*/sin* of unconditioned asphalt binder to be greater than 1.0 kpa (G* and sin* are complex modulus and phase angle, respectively),
2. Permanent deformation by requiring the G*/sin* (rutting factor) of rolling thin film oven (RTFO) residue to be greater than 2.2 kpa,
3. Fatigue cracking by requiring the G*sin* (fatigue factor) of rolling thin film oven and pressure aging vessel (RTFO+PAV) residue to be less than 5 MPa, and
4. Low temperature cracking by requiring the creep stiffness value (S) to be less than 300 MPa and slope value (m) to be greater than 0.300. If the creep stiffness is between 300 and 600 MPa, the direct tension requirement can be used in lieu of the creep stiffness requirement. The direct tension requirement is a 1.0% minimum failure strain.

Because these physical properties (such as G*/sin*, G*sin*, S, and m) are temperature dependent, any asphalt binder can meet the above physical properties at the appropriate test temperature. Therefore, Superpave performance grading system is actually based on some specified temperature with the required physical properties remaining constant for all PG grades. An example of Superpave PG grade is PG 64-22. A PG 64-22 asphalt binder meets the tenderness requirement (G*/sin* of unconditioned asphalt binder >1.0 kPa) and permanent deformation requirement (G*/sin* of RTFO residue >2.2 kPa) up to a high temperature value of 64°C. A PG 64-22 also meets the low temperature cracking requirement (S of RTFO+PAV residue < 300 MPa and m of RTFO+PAV residue > 0.300) down to a low temperature value of -22°C. In addition, a PG 64-22 is expected to perform adequately with respect to fatigue cracking between the service temperature of 64°C and -22°C by meeting the fatigue cracking requirement (G*sin* of RTFO+PAV residue < 5 MPa) down to an intermediate temperature value of 25°C.

Superpave Blending Charts

The Superpave asphalt binder PG system, therefore, is based on three temperature values (high, intermediate, and low) unique to the asphalt binder. Table 1 shows that two tests are needed to determine the high temperature value, one test is needed to determine the intermediate temperature value, and three tests are needed to determine the low temperature value of asphalt binder. This means that as many as six Superpave blending charts are needed to satis& six test parameters needed for Superpave PG grading of the binder blend containing mixture of virgin and aged asphalt binder (hereinafter called simply recycled asphalt binder). Low temperature performance or low temperature cracking is beyond the scope of this study because the relevant physical properties are not measured by the dynamic shear rheometer (DSR). Therefore, the number of Superpave blending charts being considered in this study was reduced to three.

These three Superpave blending charts can be used to determine the high and intermediate temperature values of the recycled asphalt binder. Two blending charts, hereinafter called high temperature sweep blending charts, are used to determine the high temperature value of recycled asphalt binder. The first high temperature sweep blending chart (hereinafter called high temperature sweep blending chart “G*/sin*= 1.0 kPa”) determines the temperature at which G*/sin* of the unconditioned recycled asphalt binder is 1.0 kPa. The second high temperature sweep blending chart (hereinafter called high temperature sweep blending chart “G*/sin*=2.2 kPa”) determines the temperature at which G*/sin* of RTFO residue of the recycled asphalt binder is 2.2 kPa. The high temperature value of the recycled asphalt binder is defined as the lower temperature value given by these two high temperature sweep blending charts (Table 1). The sole blending chart used to determine the intermediate temperature value of the recycled asphalt binder is called the intermediate temperature sweep blending chart “G* sin/*=5 MPa.” The intermediate temperature sweep blending chart determines the temperature at which G*sin* of RTFO+PAV residue of the recycled asphalt binder is 5 MPa.

Table 1. High, Intermediate, and Low Temperature Definitions

Temperature	No. of Tests	Definition
High	2	The lower temperature value of a) temperature at which G*/sin* of unaged binder= 1.0 kPa b) temperature at which G*/sin* of RTFO residue = 2.2 kPa
Intermediate	1	Temperature at which G*sin* of RTFO+PAV residue = 5 MPa
Low	3	The higher temperature value of a) temperature at which S = 300 MPa and m > 0.300 b) temperature at which S <300 MPa and m = 0.300 Or if 300 MPa < S <600 MPa and m >= 0.300 c) temperature at which failure strain = 1%

MATERIALS AND BLENDS USED

Virgin asphalt binders obtained from asphalt suppliers were PG 64-22, PG 58-22, and PG 52-28. PG 64-22 was PAV aged at 100°C and 2.07 MPa for 20 hours to produce aged asphalt cement, AACI. PG 64-22 was also PAV aged at 110°C and 2.07 MPa for 30 hours to produce aged asphalt cement, AACII. The third aged asphalt cement, AACIII, was recovered from a RAP (obtained from a HMA plant) by using the centrifuge extraction method (ASTM D 2172 Method A) and Rotovap procedure recommended by SHRP. The four recycled (blend of virgin and aged asphalt binders) asphalt binders used in this study were RAB-A, RAB-B, RAB-C, and RAB-D. RAB-A is a mixture of PG 58-22 and AACI. RAB-B is a mixture of PG 52-28 and AACII. RAB-C is a mixture of PG 58-22 and AACIII. RAB-D is a mixture of PG 52-28 and AACIII. The Superpave blending charts were constructed for each of the four recycled asphalt binders.

CONSTRUCTION OF SUPERPAVE TEMPERATURE SWEEP BLENDING CHARTS

Figure 1 shows the three Superpave blending charts for RAB-C. Example 1 of Figure 1 is the high temperature sweep blending chart "G*/sin*=l kPa." The temperatures (at which "G*/sin* of unconditioned RAB-C is 1 kPa) were determined by performing a temperature sweep at different percentages of virgin asphalt binder. These temperature values were plotted and an "iso-stifiess curve" was drawn. Any point on the "iso-stiffness curve" represents the possible combinations of temperature values and percent virgin asphalt binder in the recycled asphalt binder at which the G*/sin* of unconditioned RAB-C is 1 kPa. Similarly, temperature sweeps were performed to determine the temperatures at which G*/sin* of RTFO residue of RAB-C is 2.2 kPa for various percentages of virgin asphalt binder. The resulting data were used to construct the high temperature sweep blending chart "G*/sin*=2.2 kPa" (Example 2 of Figure 1). In like manner, temperatures at which G*sin* of RTFO+PAV residue of recycled asphalt binder is 5 MPa were used to construct the intermediate blending chart "G*sin*=5 Mpa" (Example 3 of Figure 1).

The Superpave blending chart determines the temperature values required for the recycled binder to have a specified stiffness, as opposed to the conventional viscosity blending chart which determines the viscosity (stiffness) of the recycled asphalt binder at a specified temperature. Therefore, temperature value is plotted on the Y-axis of temperature sweep blending chart as opposed to viscosity value in viscosity blending chart. The percentages of virgin (new) asphalt binder are plotted on the X-axis.

Applications of Superpave Temperature Sweep Blending Chart

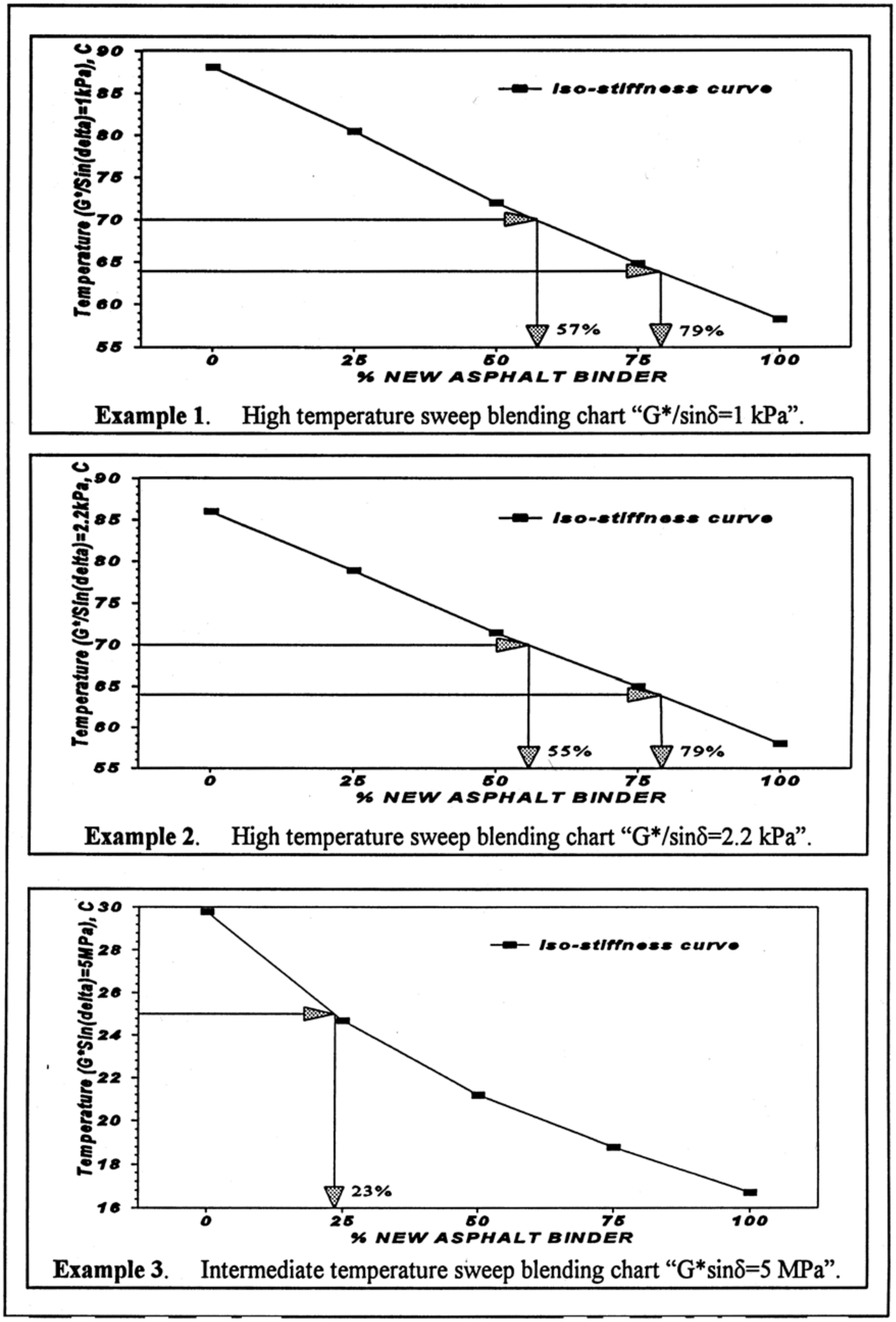
Superpave performance grading system is based on the high, intermediate, and low temperature of the asphalt binder. This means that each PG grade places its own specific requirement on the high, intermediate, and low temperature value of the recycled asphalt binder. For example, a PG 64-22 grade requires a high temperature value between 64 and 70°C and an intermediate temperature value of less than 25°C. This means that:

1. The temperature at which G*/sin* of the unconditioned recycled asphalt binder is 1 kPa must be between 64 and 70°C;
2. the temperature at which G*/sin* of the RTFO residue of recycled asphalt binder is 2.2 kPa must be between 64 and 70°C; and
3. the temperature at which G*sin* of RTFO+PAV residue of recycled asphalt binder is 5 MPa must be less than 25°C.

Example 1 of Figure 1 shows that between 57% and 79% of virgin asphalt binder are needed to satisfy (A). Example 2 of Figure 1 shows that between 55% and 79% of virgin asphalt binder are needed to satisfy (B). Example 3 of Figure 1 shows that at least 23% of virgin asphalt binder is needed to satisfy (C). Therefore, between 57% and 79% of virgin asphalt can be added in the recycled asphalt binder and the high and intermediate temperature of the recycled asphalt binder will still meet the requirement of PG 64-22.

EVALUATION OF TEMPERATURE SWEEP BLENDING CHARTS

It was observed that when the high temperature sweep blending charts are plotted on linear X-Y graph, the iso-stiflhess curve approaches a straight line [g]. Therefore, the high temperature sweep blending chart "G*/sin*=l kPa" can be constructed by plotting the two temperatures (at which G*/sin* of unconditioned virgin and aged asphalt binder is 1 kPa) on a linear X-Y graph and drawing a straight line between the two points. Similarly, the high temperature sweep blending chart "G*/sin*=2.2 kPa" can be constructed by plotting the two temperatures (at which G*/sin* of RTFO residue of virgin and aged asphalt binder is 2.2 kPa) on a linear X-Y graph and drawing a straight line between the two points. The iso-stiffness curve for the intermediate



Example 1. High temperature sweep blending chart "G*/sinδ=1 kPa".

Example 2. High temperature sweep blending chart "G*/sinδ=2.2 kPa".

Example 3. Intermediate temperature sweep blending chart "G*sinδ=5 MPa".

Figure 1. Example of Superpave Temperature Sweep Blending Charts for Recycled Asphalt Binder RAB-C

temperature sweep blending chart is not a straight line but curves gently downward (*4*). However, intermediate blending charts were constructed with the assumption that the iso-stiffness line is a straight line. This means that the intermediate temperature sweep blending chart "G*sin*=5 MPa" was constructed by plotting the two temperatures (at which G*sin* of RTFO+PAV residue of virgin and aged asphalt binder is 5 MPa) on a linear X-Y graph and drawing a straight line between the two points. It is noted that this was done solely for the purpose of analyzing the intermediate temperature sweep blending chart, and that intermediate temperature sweep blending chart constructed assuming that the iso-stiffness line is a straight line, will slightly underpredict the amount of virgin asphalt binder in the recycled asphalt binder blend (*4*).

These temperature sweep blending charts were evaluated for their effectiveness in determining how much virgin asphalt binder is needed such that the high and intermediate temperature value of the recycled asphalt binder meet the requirement of a specific PG grade.

Effect of Using Only One High Temperature Sweep Blending Chart

Table 2 shows that the amounts of virgin asphalt binder needed for the high temperature value of the recycled asphalt binders to be 64°C, as predicted by the high temperature sweep blending charts. According to Superpave, both high temperature sweep blending charts should be used. However, Table 2 shows that the amounts of virgin asphalt binder predicted by using only one high temperature sweep blending chart did not differ significantly from those predicted by both high temperature sweep blending charts. In all of the four recycled asphalt binders studied, the amount of virgin asphalt binder predicted did not differ by more than 5%. Therefore, only one blending chart can be used to determine the amount of virgin asphalt binder (or amount of RAP) that can be used in the recycled mix. High temperature sweep blending chart "G*/sin*=1.0 kPa" is recommended over high temperature sweep blending chart "G*/sin*=2.2 kPa" to avoid running the time-consuming RTFO tests.

Table 2. Effect of Using Only One High Temperature Sweep Blending Chart on the Maximum Amount of Virgin Asphalt Binder in the Recycled Mix

Recycled Asphalt Blend	Type of High Temperature Sweep Blending Chart Used			**Maximum Difference**
	G*/sin*=1 kPa	G*/sin*=2.2 kPa	Both	
RAB-A	70	72	70	**2**
RAB-B	68	73	68	**5**
RAB-C	79	81	79	**2**
RAB-D	73	69	69	**4**

Temperature Sweep Blending Chart Prediction Versus Field Experience With Recycled Mixes

High temperature sweep blending chart "G*/sin*=1.0 kPa" and intermediate temperature sweep blending chart "G*sin*=5 MPa" were constructed assuming iso-stiffness curve is a straight line. In additional to the blending charts for the four recycled asphalt binders (RAB-A, RAB-B, RAB-C, and RAB-D), the blending charts for four more recycled asphalt blends (RAB-1, RAB-2, RAB-3, and RAB-4) were also generated. This is made possible because the test properties of the virgin and aged asphalt binders needed to construct these blending charts are already available.

These blending charts were used to predict how much virgin asphalt binder can be added in each of the eight recycled asphalt blends without changing the PG grade (or how much RAP can be added in the recycled mix without changing the grade of the virgin asphalt binder). As an example, refer to recycled asphalt binder RAB-1, the shaded row of Table 3. The virgin asphalt binder is PG 64-22 and the aged asphalt binder is AACII. The high temperature values of the virgin and aged asphalt binder were determined to be 65°C and 86.5°C, respectively, and these values are plotted in Figure 2 on Y-axis. Figure 2 shows that as the percentages of virgin asphalt binder decreases from 100 to 77%, the high temperature value of the recycled asphalt binder increases from 65°C to 69.99°C (still qualified as a PG 64 grade). If the percentage of virgin asphalt is between 77% and 48%, the resulting recycled asphalt binder grade will be a PG 70. Therefore, for the high temperature grade of the recycled asphalt binder to be a PG 64, it must have a 77% minimum of virgin asphalt binder (or about 23%). Similarly, Figure 3 is a plot of the intermediate temperature sweep blending chart “G*sin*=5 MPa.” The intermediate temperature values of the virgin and aged asphalt binder are 22.5°C and 28.3°C, respectively. Figure 3 shows that if the percentage of virgin asphalt binder decreases born 100 to 57%, the intermediate temperature value of the recycled asphalt binder increases from 22.5°C to 25°C. If the percentage of virgin asphalt binder continues to decrease from 57%, the intermediate temperature value of the recycled asphalt binder will be greater than 25°C, which falls one grade below the PG 64-22. Therefore, the recycled asphalt binder must have a 57% minimum of virgin asphalt binder (or about 43% RAP) for the intermediate temperature grade of the recycled asphalt binder to remain at PG 64-22.

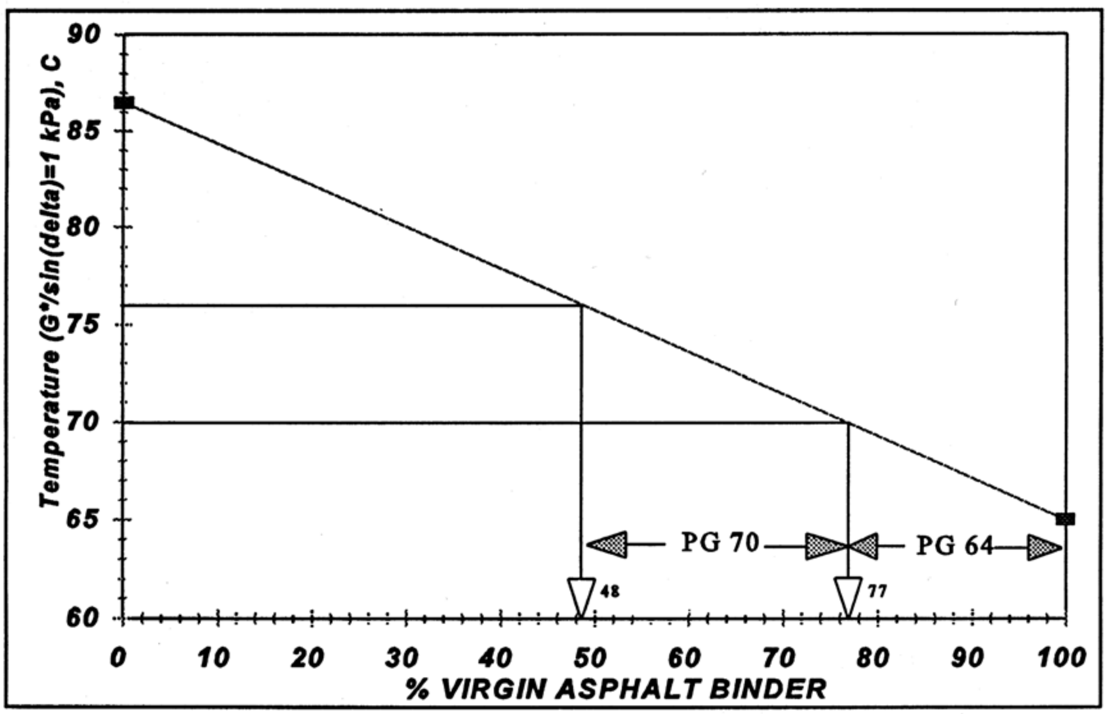


Figure 2. Example High Temperature Sweep Blending Chart “G*/sin*=1 kPa” (Assuming Iso-stiffness Curve Is a Straight Line)

RAB-1 with 77% minimum and 57% minimum percentages of virgin asphalt binder (as predicted by the high and intermediate temperature sweep blending charts) will satisfy the high and intermediate temperature requirements of a PG 64-22 grade. If between 100% and 77% virgin asphalt binder is used, RAB-1 will satisfy the high and intermediate temperature requirements of a PG 64-22. If between 77% and 57% virgin asphalt binder is used, RAB-1 will satisfy the high and intermediate temperature requirements of a PG 70-28. Although not exactly

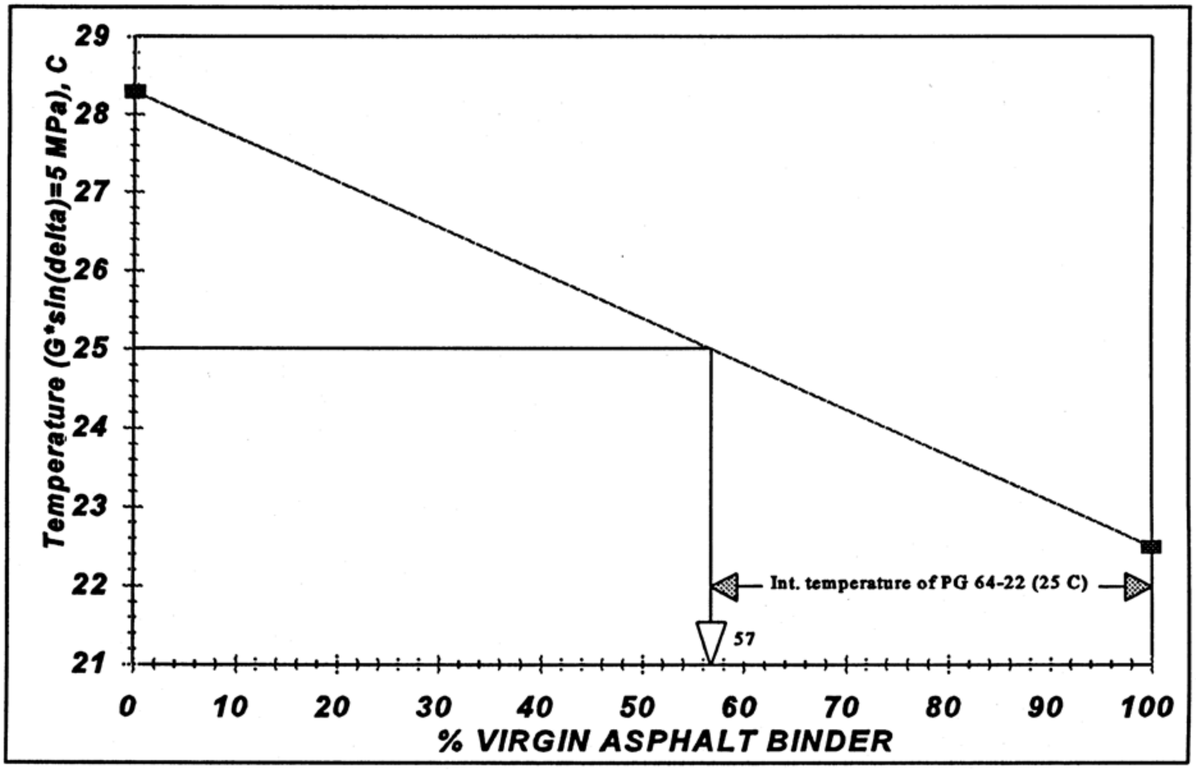


Figure 3. Example of Intermediate Temperature Sweep Blending Chart "G*sin*=5 Mpa" (Assuming iso-Stiffness Curve is a Straight Line)

the same, a PG 70-28 would still satisfy all the high and intermediate temperature requirements of a PG 64-22 grade.

Table 3 shows that the percentages of virgin asphalt binder predicted by the intermediate blending chart (which has a tendency to be higher than actual values) ranges born 35 to 81% (about 19 to 65% RAP) with an averaged value of 63% (about 37% RAP). These values are significantly higher than those typically used in the field in recycled HMA mixes. Field experience suggests that at least 80 to 85% virgin asphalt binder (about 15 to 2% maximum RAP) can be used successfully in the recycled mix without changing the grade of virgin asphalt binder to a softer grade. As a result, the intermediate temperature sweep blending chart based on the maximum G*sin* requirement of 5 MPa, becomes questionable and is not recommended for use at the present time. On the other hand, the high temperature sweep blending chart predicted percentages of virgin asphalt binder ranging from 71 to 89% (about 11 to 29% RAP) with an averaged value of 82% (about 18% RAP) which agrees with the field experience with recycled HMA mixes and, therefore, this blending chart is recommended.

The high temperature sweep blending charts were used to predict the percentages of virgin asphalt binder when the virgin asphalt binder is the same grade, one grade softer, and two grade softer. The predicted values are shown in Table 4. Table 4 shows that generally, if the recycled mix has more than 82% virgin asphalt binder (or less than 18% RAP), the PG grade of the virgin asphalt binder should remained unchanged. If the recycled mix has between 56 and 82% virgin asphalt binder (or between 18 and 44% RAP), the PG grade of the virgin asphalt binder should be one grade softer. If the recycled mix has between 32 and 56% virgin asphalt binder (or between 44 and 68% RAP), the PG grade of the virgin asphalt binder should be two grade softer. However, caution should be exercized when using a very soft asphalt binder in a recycled mix

Table 3. Percentages of Virgin Asphalt Binder Needed for the Recycled Asphalt Binder to be the Same PG Grade as the Virgin Asphalt Binder

Recycled Asphalt Binder	Virgin Asphalt Binder	Aged Asphalt Binder	High Temperature Sweep Blending Chart				Intermediate Temperature Sweep Blending Chart			
			High Temperature Values (°C)			**Virgin Binder Predicted (% min.)**	Int. Temperature Values (°C)			**Virgin Binder Predicted (% min.)**
			Virgin Binder	Aged Binder	Recycled Binder		Virgin Binder	Aged Binder	Recycled Binder	
RAB-1	PG 64-22	AACII	65	86.5	69.99	**77**	22.5	28.3	25	**57**
RAB-2	PG 64-22	AACIII	65	88	69.99	**79**	22.5	29.8	25	**65**
RAB-A	PG 58-22	AACI	59	76	63.99	**71**	16.7	24.9	22	**35**
RAB-3	PG 58-22	AACII	59	86.5	63.99	**82**	16.7	28.3	22	**54**
RAB-C	PG 58-22	AACIII	59	88	63.99	**82**	16.7	29.8	22	**60**
RAB-4	PG 52-28	AACI	54	76	57.99	**82**	12.9	24.9	16	**70**
RAB-B	PG 52-28	AACII	54	86.5	57.99	**89**	12.9	28.3	16	**79**
RAB-D	PG 52-28	AACIII	54	88	57.99	**89**	12.9	29.8	16	**81**

Table 4. Percentages of Virgin Asphalt Binder Predicted by High Temperature Sweep Blending Chart When the PG Grade of the Virgin Asphalt Binder is the Same, One, and Two Grade Softer

Recycled Asphalt Binder	Virgin Asphalt Binder	Aged Asphalt Binder	Percentages Virgin Asphalt Binder Predicted		
			Same Grade	One Grade	Two Grade
RAB-1	PG 64-22	AACII	77	49	21
RAB-2	PG 64-22	AACIII	79	52	26
RAB-A	PG 58-22	AACI	71	35	0
RAB-3	PG 58-22	AACII	82	60	38
RAB-C	PG 58-22	AACIII	82	62	41
RAB-4	PG 52-28	AACI	82	55	27
RAB-B	PG 52-28	AACII	89	69	51
RAB-D	PG 52-28	AACIII	89	70	53
	Averaged		82	56	32

containing high percentages of RAP, because all of the aged binder in the IWP may not be blended effectively with the virgin binder during construction.

Based on the general experience in the field with the viscosity-graded asphalt cements and the preceding, limited test data obtained in this research project with the Superpave PG asphalt binders, the following recommendations are made for proper selection of PG asphalt binder.

Tier 1: If the amount of RAP in the HMA mix is equal to or less than 15%, the selected PG grade of the virgin asphalt binder should be the same as the Superpave specified PG grade.

Tier 2: If the amount of RAP in the HMA mix is more than 15% but equal to or less than 25%, the selected PG grade of the virgin asphalt binder should be one grade below (both high and low temperature grade) the Superpave specified PG grade. For example, if the Superpave specified PG grade is PG 64-22 then a PG 58-28 asphalt binder should be selected. The use of specific grade blending chart (given later) to select the high temperature grade of the virgin asphalt binder is optional.

Tier 3: If the amount of RAP in the HMA mix is more than 25%, use the specific grade blending chart to select the high temperature grade of the virgin asphalt binder. The low temperature grade should beat least one grade lower than the binder grade specified by Superpave.

A discussion of the proposed specific grade blending chart follows. This blending chart may be revised in the future as more research is done.

RECOMMENDED BLENDING CHART TO SELECT THE PG GRADE OF VIRGIN ASPHALT BINDER

Based on the preceding discussion, the only recommended temperature sweep blending chart to select the PG grade of virgin asphalt binder is the high temperature sweep blending chart "G*/sin/*=1.0 kPa." However, the construction of high temperature sweep blending chart involves conducting temperature sweep on both aged asphalt binder in the RAP as well as virgin asphalt binders to determine the temperature at which G*/sin*=1.0 kPa. The inconvenience of running temperature sweep tests can be eliminated by constructing the following specific grade blending chart.

Specific Grade Blending Chart

Assume that a state highway agency (SHA) specifies a PG 64-22 asphalt binder in the state. The G*/sin* of a recycled asphalt binder at different percentages of virgin asphalt binder were measured at 64°C and plotted on the specific grade blending chart shown in Figure 4 with a 1.0 kPa stiffness line. Figure 4 shows that if the recycled asphalt binder has less than 73% virgin asphalt binder (or more than about 27% RAP), the stiffness of recycled asphalt binder will be greater than 1.0 kPa (or the high temperature value of recycled asphalt binder will be greater than 64°C), and thus it passes the high temperature requirement of a PG 64-22 grade. Therefore, Figure 4 can only be used to determine the maximum amount of virgin asphalt binder (or the minimum amount of RAP in the recycled mix) needed to obtain the specific grade, PG 64-22. If the SHA uses a PG 58-22 asphalt binder, the specific grade blending chart need to be constructed at 58°C.

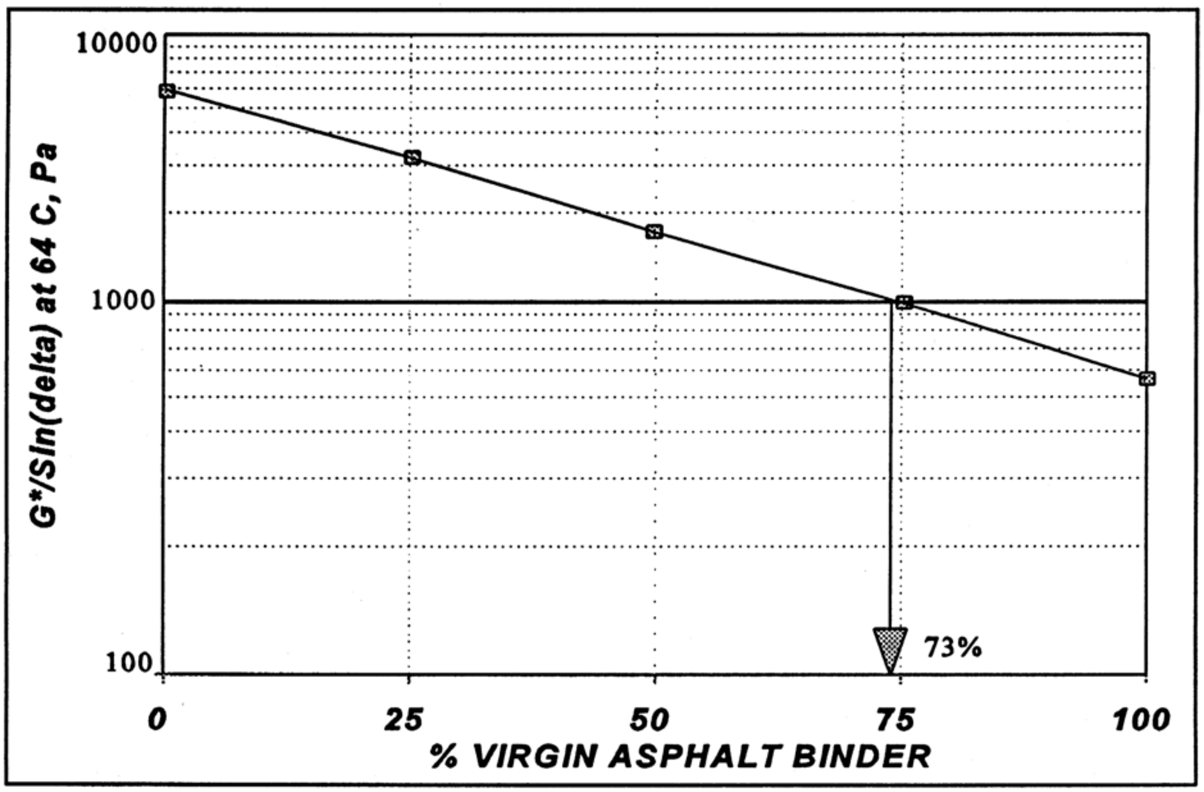


Figure 4. Example of Specific Grade Blending Chart at High Temperature Value of 64°C

The Y-axis of specific grade blending chart is in log-log scale (similar to viscosity and penetration blending chart). By plotting the stiffness, G*/sin*, on a log-log scale on the Y-axis versus % virgin asphalt binder on the X-axis, a near linear relationship or straight line is obtained (4). Therefore, the information needed to construct specific grade blending chart are the G*/sin* of unconditioned virgin and aged asphalt binders only at the specific test temperature.

Using Specific Grade Blending Chart

A recycled asphalt binder would always meet the G*/sin*=1.0 kPa minimum (for unconditioned asphalt binder) and G*/sin*=2.2 kPa minimum (for RTFO residue) requirement at any RAP content, provided the high temperature grade of the virgin asphalt binder and Superpave specified PG grade are the same. This is logical because the addition of RAP increases the G*/sin* values of unconditioned recycled asphalt binder and its RTFO residue, However, if the virgin asphalt binder is one or two grades below the specified PG grade, a procedure is required to determine the maximum amount of virgin asphalt binder (or minimum amount of RAP) to increase the high temperature stiffness of the recycled asphalt binder above the minimum values specified by Superpave. As shown earlier, this can be achieved by using one high temperature sweep blending chart only instead of two high temperature sweep blending charts. The recommended blending chart to determine the maximum amount of virgin asphalt binder (or the minimum amount of RAP) is the specific grade blending chart with the 1.0 IcPa stiffness line (Figure 5).

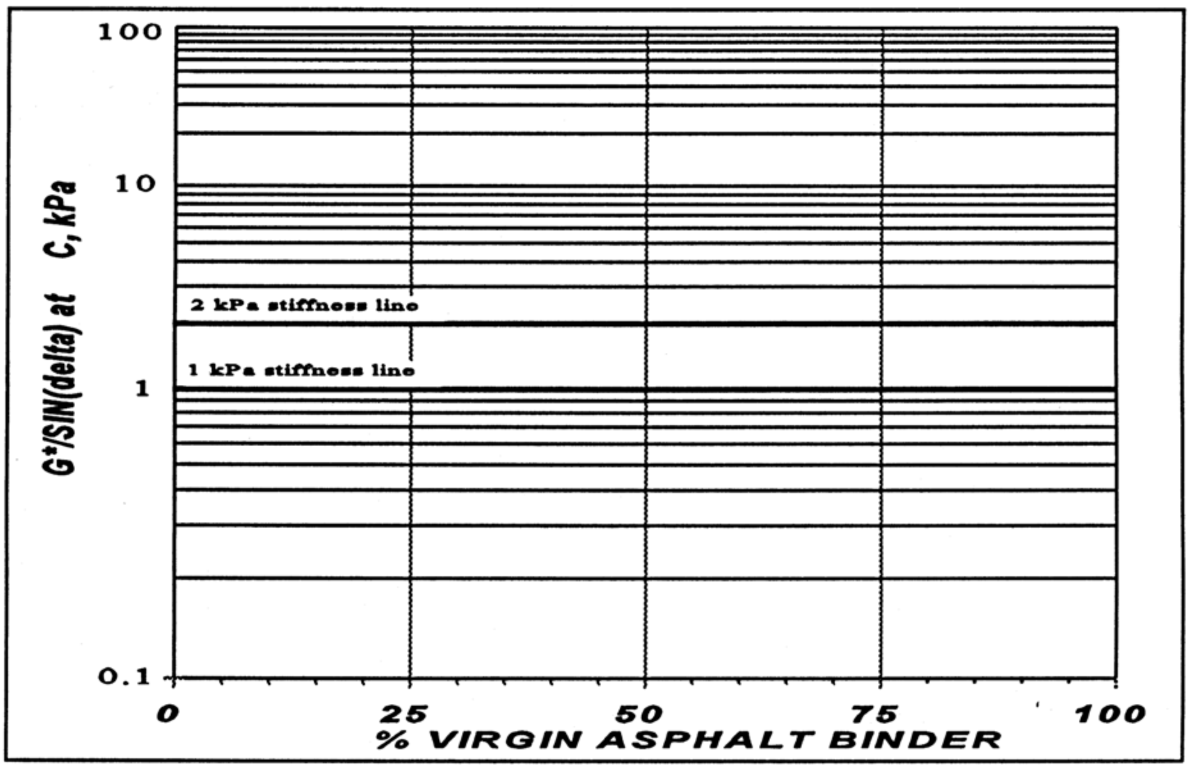


Figure 5. Recommended Specific Grade Blending Chart with 1.0 and 2.0 kPa Stiffness Lines

The procedure must also determine the minimum amount of virgin asphalt binder (or the maximum amount of RAP) so that the intermediate temperature stiffness does not exceed the "G*sin*=5 MPa maximum" specification for RTFO+PAV residue. The intermediate temperature sweep blending chart "G*sin*=5 MPa" should be used to ensure that the intermediate temperature stiffness (G*sin*) of the recycled asphalt blend does not exceed 5 MPa. However, as mentioned earlier, the intermediate temperature sweep blending chart predicted that an average of 37% of RAP can be included in the recycled mixes without changing the grade of the virgin asphalt binder. Historically, many states have successfully incorporated up to about 15 to 20% RAP only in the recycled mixes without changing the grade of the virgin asphalt binder.

The "G*sin*****=5 MPa maximum" specification (and thus intermediate temperature sweep blending chart), therefore, appears to be on the liberal side as established in this research project. Consequently, it is not recommended that the intermediate temperature sweep blending chart be used to select the PG grade of virgin asphalt binder or to determine the minimum amount of virgin asphalt binder (or maximum amount of RAP) in the recycled asphalt binder. Another procedure is therefore needed to (a) determine the minimum amount of virgin asphalt binder in the recycled asphalt binder, and (b) ensure that the recycled asphalt binder is not susceptible to fatigue cracking.

It is recommended that the specific grade blending chart which is used to determine the maximum amount of virgin asphalt binder (or minimum amount of RAP) also be used to determine the minimum amount of virgin asphalt binder (maximum amount of RAP) in the recycled asphalt binder. Routine test results on various unmodified PG asphalt cement binders have shown the value of G*/sin***** to be just above 1.0 kPa at the specified high temperatures. Usually the values are between 1.0 kPa to 1.5 kPa with an averaged value of 1.14 kPa (5). Therefore, it is recommended to use 2.0 kpa maximum value for G*/sin***** at high temperature to determine the minimum amount of unmodified virgin asphalt binder. Such a specific grade blending chart with this requirement is shown in Figure 5. Since G*sin*****=5 MPa criteria did not control the minimum amount of virgin asphalt binder as anticipated, the use of a 2.0 kPa stiffhess line will serve this purpose. (Note: The 1.0 kpa stiffhess line will serve to determine the maximum amount of virgin asphalt binder.) It should be noted that all tests on virgin and aged asphalt binders should be conducted at the high temperature for the PG grade specified. For example, if a state DOT uses PG 58-28 asphalt binder, all tests should be conducted at 58 'C to use the specific grade blending chart shown in Figure 5.

Examples of Using Recommended Specific Grade Blending Chart

Suppose a PG 64-28 was specified for a paving project. The G*/sin***** measured at 64°C of the unconditioned aged asphalt binder in the RAP and unmodified virgin asphalt binder (PG 64-28) were 100 kPa and 1.13 kPa, respectively. These values were plotted as point A and point B as shown in Figure 6. The line AB intersected the 2.0 kPa stiffness line at 85%. Therefore, the amount of the unmodified virgin asphalt binder PG 64-28 that can be added in the recycled mix will be 85 to 100% (or 0 to 15% RAP). Suppose an unmodified asphalt binder PG 58-34 was selected as the virgin asphalt binder. The G*/sin***** at measured at 64°C for the PG 58-34 was 0.65 kPa and plotted as point C in Figure 6. The line AC intersected the 1.0 kPa and 2.0 kPa stiffness lines at 72% and 89% respectively. Therefore, the amount of the unmodified virgin asphalt binder PG 58-34 that can be used in the recycled mix was 72 to 89% (or 11 to 28% RAP).

If a modified asphalt binder (such as a polymer modified binder) is used as a virgin asphalt binder, then it is recommended to test the modified virgin asphalt binder at the high temperature meant for the modified binder grade. For example, a state agency specifies a PG 64-28 grade for a paving project but the contractor chooses to use a PG 70-28 grade binder (most likely a polymer modified binder). In that case, the G*/sin***** of the modified asphalt binder was tested at 70°C and found to be 1.05 kpa. The G*/sin***** tested at 70°C of the aged asphalt binder in the RAP was found to be 50 kpa. These values are plotted in the specific grade blending chart for PG 70-28 as point A and point B (Figure 7). The amount of virgin asphalt binder that can be used in the recycled mix is between 83 to 100% (about 17% maximum RAP). It is also recommended that the resulting recycled asphalt binder be obtained by physically blending the appropriate amounts of aged and virgin asphalt binder. This blend should then be subjected to RTFO+PAV aging and tested for G*sin*****=5 MPa maximum requirement at the intermediate temperature of the specified PG grade. In this case, the intermediate temperature of specified grade of PG 64-22 is 25°C. Other examples of using the specific grade blending chart are given elsewhere (4).

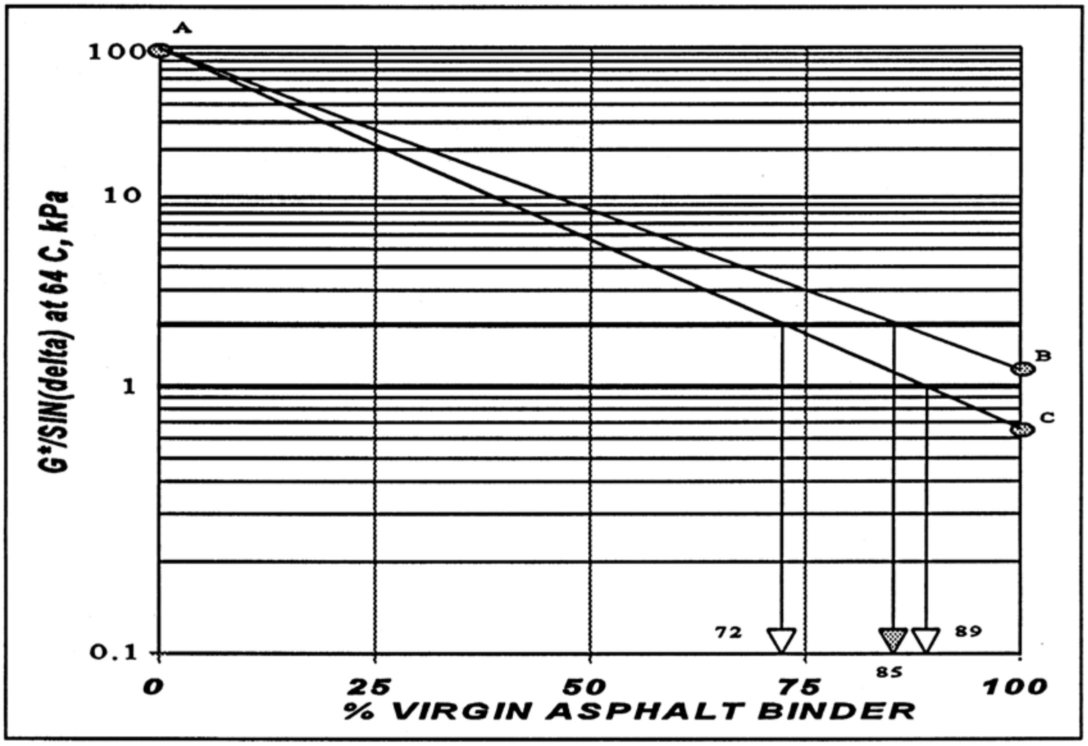


Figure 6. Graphical Method to Determine Minimum and Maximum Amount of Unmodified Virgin Asphalt Binder in the Recycled Asphalt Binder

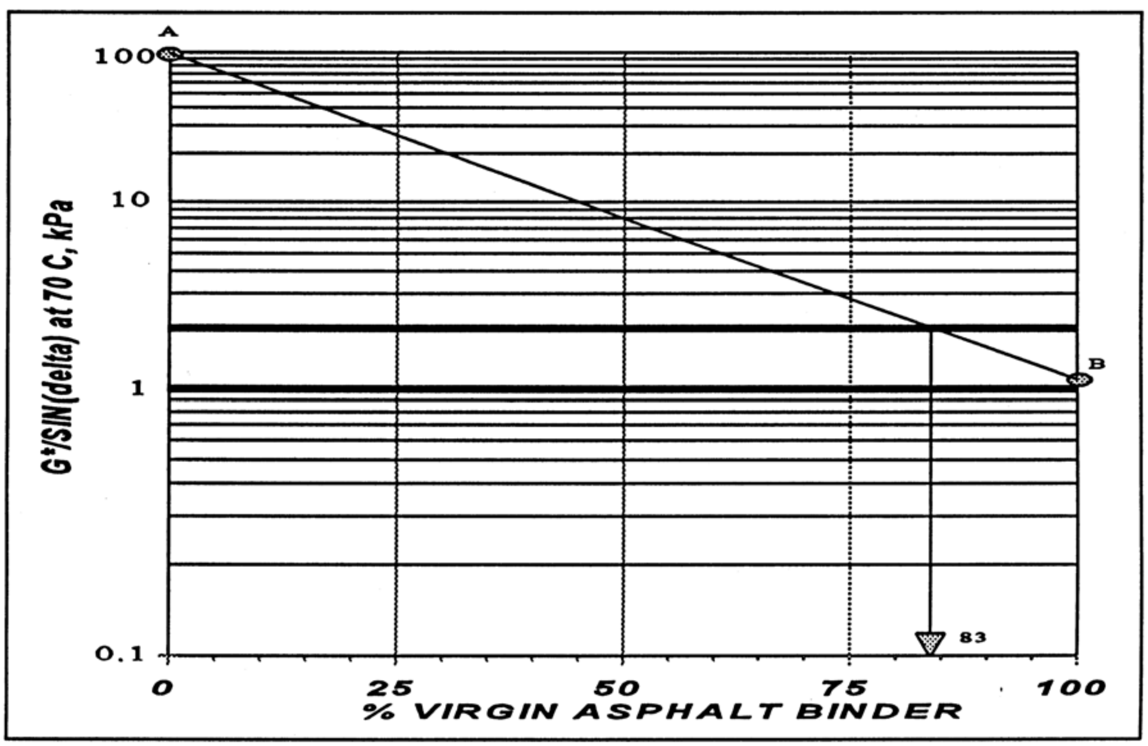


Figure 7. Graphical Method to Determine the Minimum and Maximum Amount of Modified Virgin Asphalt Binder in the Recycled Asphalt Binder

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn and recommendations made from this study:

1. High temperature value of the recycled asphalt binder petiormance grade can be determined by using only one high temperature sweep blending chart. High temperature sweep blending chart "G*/sin*=1.0 kpa" is recommended over high temperature sweep blending chart "G*/sin*=2.2 kPa" because it is easier to construct (no need to run RTFO test).
2. Although the intermediate temperature sweep blending chart "G*sin*=5 MPa" was expected to determine the maximum amount of RAP, it allowed unusually high percentages of M, which are inconsistent with the field experience with recycled HMA. It is recommended that the intermediate temperature sweep blending chart be not used at the present time. Further study of the Superpave binder specification for fatigue cracking is recommended, specifically with respect to temperature or stiffness criteria at intermediate temperature.
3. A three-tier system of selecting the PG grade of the virgin asphalt binder has been recommended for recycled mixes. The recommended blending chart to select the PG grade of virgin asphalt binder is the specific grade blending chart with 1.0 and 2.0 kpa stiffness lines. The 1.0 kPa stiffness line is used to determine the maximum amount of virgin asphalt binder (or minimum amount of RAP) in the recycled asphalt binder. The 2.0 kpa stiffness line is used to determine the minimum amount of virgin asphalt binder (or maximum amount of RAP) in the recycled binder due to the inability of G*/sin*=5 MPa criteria to do so). Recommendations have also been made concerning the selection of modified virgin asphalt binder.

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