# Evaluation of Reclaimed Asphalt Pavement and Virgin PG Binder Blends

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**ABSTRACT**

With the switch to Performance Graded Asphalt Cements (PGAC) from the traditional penetration and viscosity grading in Ontario, the use of Reclaimed Asphalt Pavement (RAP) has decreased dramatically. Currently, hot mix contractors tend to use only 20 percent RAP or less in their mixes. This is due to the directive from the Ministry of Transportation of Ontario (MTO) that allows contractors to use up to 20 percent RAP in their mixes without the need to change the grade of virgin asphalt cement. The MTO would like to increase the percentage of RAP in all parts of the Province, however very little research has been completed to guide the selection of PGAC for use with recycled mixes. The objective of this laboratory study was to determine how the various grades of PGAC react when combined with different percentages of RAP with respect to the final performance grade of the blend.

Two RAP sources and ten virgin PGAC binders were investigated. The virgin binders were blended with the recovered RAP binders in various percentages and tested according to the American Association of State Highway and Transportation Officials (AASHTO) M320 specification. Based on the results obtained, various conclusions and recommendations are presented.

**RÉSUMÉ**

Avec le transfert en Ontario de la traditionnelle pénétration et viscosité au bitume selon la performance PGAC, l'utilisation du matériau bitumineux à recycler (RAP) a diminué dramatiquement. Présentement les entrepreneurs d'enrobés à chaud ont tendance à utiliser seulement jusqu'à 20 pourcent de RAP dans leurs enrobés. Cela est dû à la directive du Ministère des Transports de l'Ontario (MTO) qui permet l'utilisation jusqu'à 20 pourcent de RAP dans leurs enrobés sans avoir besoin de changer le grade de bitume. Le MTO aimerait augmenter le pourcentage de RAP dans toutes les régions de la province, cependant très peu de recherche a été réalisé pour guider le choix du bitume à utiliser dans les enrobés recyclés. Le but de cette étude de laboratoire était de déterminer comment les divers grades de bitume quand ils sont combinés à différents pourcentages de RAP affecteront le grade selon la performance final du mélange fini.

L'étude comporte l'utilisation de deux sources de RAP et de dix liants PGAC différents. Les liants vierges ont été mélangés avec les liants récupérés des RAP à divers pourcentages et testés selon la spécification M320 de l'AASHTO. En se basant sur les résultats obtenus on peut faire diverses conclusions et recommandations.

## 1.0 INTRODUCTION

### 1.1 Overview

With the switch to Performance Grading Asphalt Cements (PGAC) from the traditional penetration and viscosity system in Ontario, the use of Recycled Asphalt Pavement (RAP) has decreased dramatically. Currently, hot mix contractors tend to use only 20 percent RAP (or less) in their mixes. This is due to a recent directive from the Ministry of Transportation of Ontario (MTO) that allows contractors to use up to 20 percent RAP in their mixes without needing to change the grade of virgin asphalt cement [1].

In Northern Ontario, this has created large stockpiles of RAP because traditionally up to 40 percent RAP was incorporated in Hot Mix Asphalt (HMA). For economic and environmental reasons, the MTO would like to increase RAP percentage in both the northern and southern parts of the Province. However, very little research has been done concerning the effect of RAP type and percentage upon the final blended PGAC properties. The objective of this study is to determine how various grades of PGAC react when combined with different percentages of RAP.

### 1.2 PGAC Requirements in Ontario

Due to its considerable size, the Province of Ontario is subjected to a wide range of climatic conditions. In consultation with industry stakeholders, the MTO assigned three climatic zones for the Province with respect to PGAC selection [2], as described below:

Zone 1 is considered “Northern Ontario” including the northern portion of the Province whose southern border runs from Georgian Bay eastward along the French River, Lake Nipissing, the Mattawa River and terminating at the Ottawa River (Ontario/Quebec provincial border). For Zone 1, PG 52-34 is specified to resist permanent deformation and low temperature cracking.

Zone 2 is considered “Eastern Ontario,” bounded by the Zone 1 southern border in the north and whose southern border runs from Honey Harbour south easterly through Langford, Taylor Corners, Caven, Campbellford and terminates in Mallorytown. For Zone 2, PG 58-34 is specified.

Zone 3 is considered “Southern Ontario” and includes the remainder of the Province south of the Zone 2 southern border. For Zone 3, PG 58-28 is specified.

The second version of [2] indicated that Zones 2 and 3 could be combined into a single “Southern Ontario” zone.

As outlined in Section 1.1, the MTO current allows up to 20 percent RAP to be used with virgin PGAC without grade modification, although the actual affect of RAP type and percentage upon the final blended PGAC is not yet well understood.

## 2.0 LABORATORY PROTOCOL

In order to evaluate the use of PGAC in the recycling process, various grades of PGAC had to be obtained (existing and laboratory prepared), as well as the RAP material. It was felt that in order to cover the Province of Ontario, two different RAP materials would be required. To simulate Southern Ontario (Zones 2 and 3), a RAP material from the Ottawa area was obtained. This material would be typical of the type of asphalt cement (85/100) that has been used in the southern part of the Province over the last 15 to 20 years. A second RAP material was obtained from the New Liskeard (Elk Lake) area of Northern Ontario (Zone 1). This RAP would represent the typical 150/200 grade of asphalt cement that has been used in the northern part of the Province over the same time span.

The asphalt cement was extracted from the RAP material using the abson recovery method (ASTM D1856) [3]. Sufficient quantities were extracted to allow for the various blends to be made. The recovered asphalt cements were then tested for their performance properties using the current AASHTO M320 [4] SHRP testing protocols (see Table 1) plus a few traditional asphalt cement tests.

**Table 1. Reclaimed Asphalt Pavement (RAP) Material – Testing Requirements**

| Test |
|---|
| Penetration @ 25°C |
| Kinematic Viscosity @ 135°C |
| Brookfield Viscosity @ 135°C and 165°C |
| DSR @ 64, 70, 76°C (run on Original Setting) |
| DSR @ 22, 19, 16, 13°C |
| BBR @ -12, -18, -24°C |

Note: DSR is Dynamic Shear Rheometer
BBR is Bending Beam Rheometer

Sufficient quantities of the various virgin PGACs were obtained. In order to cover the environmental conditions present throughout the entire Province of Ontario (not simply the standardized zones), the following PGACs were obtained; PG 58-28, PG 52-28, PG 58-34, PG 52-34, PG 52-40, PG 46-34, PG 46-40, PG 46-46, PG 40-40, and PG 40-46. Each grade of PGAC was then tested to the current AASHTO M320 SHRP testing protocols (see Table 2) plus additional asphalt cement tests such as penetration, softening point and kinematic viscosity [3].

Once all PGAC were tested, blends were prepared using the virgin PGAC in combination with the two extracted asphalt cements in the proportions shown in the testing matrices shown in Tables 3 and 4. These blends were then tested to the AASHTO M320 SHRP testing protocols, as well as the extra conventional tests.

Table 5 lists the SHRP data obtained on the RAP material from the Ottawa area and the RAP material from Northern Ontario. Unfortunately, as a result of a miscommunication, insufficient virgin asphalt cement was available for blending with both RAP sources. As such, a new set of virgin asphalts was prepared and blended with the asphalt cement extracted from the northern RAP. Table 6 shows the SHRP data for the ten virgin asphalts used with the southern RAP and Table 7 contains the SHRP data on the ten virgin asphalt cements used in the blending of the northern RAP.

**Table 2. Virgin PGAC – Testing Requirements**

| **TESTS** |
|---|
| **ORIGINAL** |
| Penetration @ 25°C |
| Kinematic Viscosity @ 135°C |
| Brookfield Viscosity @ 135 and 165°C |
| DSR @ two temperatures as per PGAC being tested |
| BBR @ two temperatures as per PGAC being tested |
| **RTFO (minimum 6 bottles)** |
| Penetration @ 25°C |
| Kinematic Viscosity @ 135°C |
| Brookfield Viscosity @ 135 and 165°C |
| DSR @ two temperatures as per PGAC being tested |
| BBR @ two temperatures as per PGAC being tested |
| **PAV (3 trays minimum) (90 or 100°C as required)** |
| Penetration @ 25°C |
| Kinematic Viscosity @ 135°C |
| Brookfield Viscosity @ 135 and 165°C |
| DSR @ two temperatures as per PGAC being tested (original setting) |
| DSR @ two temperatures as per PGAC being tested (intermediate setting) |
| BBR @ two temperatures as per PGAC being tested |

Note: PGAC is Performance Graded Asphalt Cement
RTFO is Rolling Thin Film Oven
PAV is Pressure Aging Vessel

**Table 3. Testing Matrix - Southern Reclaimed Asphalt Pavement (RAP)**

| **Performance Grade (PG)** | **Percent RAP by Mass of Mixture** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **10** | **15** | **20** | **25** | **30** | **35** | **40** |
| PG 58-28 | X | X | X | X | | | |
| PG 52-28 | X | X | X | X | | | |
| PG 58-34 | | X | X | X | X | | |
| PG 52-34 | | X | X | X | X | | |
| PG 52-40 | | X | X | X | X | | |
| PG 46-34 | | X | X | X | X | | |
| PG 46-40 | | X | X | X | X | | |
| PG 46-46 | | | | X | X | X | X |
| PG 40-40 | | | | X | X | X | X |
| PG 40-46 | | | | X | X | X | X |

**Table 4. Testing Matrix - Northern Reclaimed Asphalt Pavement (RAP)**

| Performance Grade (PG) | Percent RAP by Mass of Mixture | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 | 35 | 40 |
| PG 58-28 | X | X | X | X | | | |
| PG 52-28 | X | X | X | X | | | |
| PG 52-34 | | X | X | X | X | | |
| PG 46-34 | | X | X | X | X | | |
| PG 58-34 | | X | X | X | X | | |
| PG 52-40 | | | X | X | X | X | |
| PG 46-40 | | | X | X | X | X | |
| PG 46-46 | | | | X | X | X | X |
| PG 40-40 | | | | X | X | X | X |
| PG 40-46 | | | | X | X | X | X |

**Table 5. SHRP Results on Recovered Asphalt Cement from Reclaimed Asphalt Pavement (RAP)**

| Tests on Recovered Asphalt Cement | Southern RAP | Northern RAP |
|---|---|---|
| Penetration @ 25°C, 100 g., 5 sec | 15 | 46 |
| Kinematic Viscosity @ 135°C, $mm^2/sec$ | | 830 |
| Softening Point, R & B,°C | | 58.0 |
| Brookfield Viscosity @ 135°C, Pa.s<br>@ 165°C | | 0.775<br>0.195 |
| G*/Sin δ @ 70°C, 10 rad/sec, kPa<br>@ 76°C<br>@ 82°C | 5.453<br>2.639 | 1.921<br>0.916 |
| Creep Stiffness, S, @ -12°C, MPa<br>@ -18°C<br>@ -24°C | 195.0<br>371.0 | 155.0<br>357.0 |
| Slope @ -12°C, m, 60 sec<br>@ -18°C<br>@ -24°C | 0.341<br>0.263 | 0.357<br>0.276 |
| **Performance Grade Range** | **83.5-25.2** | **75.3-32.2** |

**Table 6. SHRP Results on Virgin PGAC for Southern Reclaimed Asphalt Pavement**

| **Performance Grade (PG)** | **58-28** | **52-28** | **58-34** | **52-34** | **52-40** |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 96 | 137 | 150 | 185 | 358 |
| Kinematic Viscosity @ 135°C, mm²/sec | 320 | 272.7 | 408.0 | 294.0 | 708.0 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.344 | 0.306 | 0.406 | 0.231 | 0.600 |
| @ 165°C | 0.119 | 0.094 | 0.144 | 0.094 | 0.212 |
| G*/Sin δ @ 52°C, 10 rad/sec, kPa | | 2.137 | | 1.692 | 1.019 |
| @ 58°C | 0.421 | 0.984 | 1.302 | 0.796 | 0.680 |
| @ 64°C | 0.674 | | 0.681 | | |
| Creep Stiffness, S, @ -18°C, MPa | 135.5 | 68.6 | | | |
| @ -24°C | 326.0 | 201.5 | 144.0 | 118.0 | |
| @ -30°C | | | 450.0 | 323.5 | NA |
| @ -36°C | | | | | 94.5 |
| m-value, m, @ -18°C | 0.425 | 0.455 | | | |
| @ -24°C | 0.324 | 0.359 | 0.389 | 0.384 | |
| @ -30°C | | | 0.303 | 0.309 | NA |
| @ -36°C | | | | | 0.405 |
| **Tests on Rolling Thin Film Oven Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 58 | 60 | 101 | 100 | 193 |
| Kinematic Viscosity @ 135°C, mm²/sec | 442.6 | 324.4 | 550.0 | 391.2 | 784.6 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.456 | 0.531 | 0.556 | 0.344 | 0.557 |
| @ 165°C | 0.144 | 0.181 | 0.206 | 0.106 | 0.181 |
| */Sin δ @ 52°C, 10 rad/sec, kPa | | | | | 2.782 |
| @ 58°C | 3.531 | 2.266 | 2.516 | 3.658 | 1.714 |
| @ 64°C | 1.584 | 1.054 | 1.300 | 1.651 | |
| Creep Stiffness, S, @ -18°C, MPa | 103.0 | 147.0 | | | |
| @ -24°C | 411.0 | 374.0 | 140.5 | 151.5 | |
| @ -30°C | | | 359.0 | 392.0 | 37.1 |
| @ -36°C | | | | | 112.5 |
| m-value, m, @ -18°C | 0.360 | 0.374 | | | |
| @ -24°C | 0.284 | 0.297 | 0.371 | 0.359 | |
| @ -30°C | | | 0.294 | 0.280 | 0.424 |
| @ -36°C | | | | | 0.375 |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 26 | 65 | 51 | 87 | 95 |
| Kinematic Viscosity @ 135°C, mm²/sec | 910.5 | 654.0 | 1043.0 | 2458.0 | 3304 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.819 | 0.681 | 0.912 | 0.600 | 2.400 |
| @ 165°C | 0.194 | 0.181 | 0.244 | 0.156 | 0.463 |
| G*x Sin δ, @ 7°C, 10 rad/sec, kPa | | | | 5457 | 352.0 |
| @ 10°C | | | | 4133 | 64.0 |
| @ 13°C | | 3961 | 4043 | 2920 | |
| @ 16°C | 6041 | 2653 | 2588 | | |
| @ 19°C | 4113 | | | | |
| Creep Stiffness, S, @ -18°C, MPa | 212.5 | 107.5 | | | |
| @ -24°C | 491.0 | 259.0 | 202.5 | 163.5 | |
| @ -30°C | | | 543.0 | 399.5 | 81.4 |
| @ -36°C | | | | | 127.0 |
| m-value, m, @ -18°C | 0.305 | 0.351 | | | |
| @ -24°C | 0.251 | 0.291 | 0.303 | 0.309 | |
| @ -30°C | | | 0.264 | 0.262 | 0.404 |
| @ -36°C | | | | | 0.311 |
| **Temperature Range** | **60.8-28.6** | **57.9-33.1** | **59.2-34.5** | **55.8-35.2** | **52.3-46.7** |

**Table 6 Cont'd. SHRP Data on Virgin PGAC for Southern Reclaimed Asphalt Pavement**

| **Performance Grade (PG)** | **46-34** | **46-40** | **46-46** | **40-40** | **40-46** |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 325 | 594 | 580+ | 580+ | 279 |
| Kinematic Viscosity @ 135°C, mm²/sec | 231 | 362 | 487.4 | 341.3 | 400 |
| Brookfield Viscosity @ 135, Pa.s | 0.194 | 0.463 | 0.431 | 0.344 | 0.404 |
| @ 165°C | 0.063 | 0.194 | 0.194 | 0.119 | 0.175 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | 1.631 | 1.200 | 1.182 | 1.050 | 1.124 |
| @ 52°C | 0.802 | 0.704 | 0.698 | 0.621 | 0.660 |
| Creep Stiffness, S, @ -24°C, MPa | 48.8 | | | | |
| @ -30°C | 144.5 | NA | NA | | |
| @ -36°C | | 46.7 | NA | 60.4 | NA |
| m-value, m, @ -24°C | 0.482 | | | | |
| @ -30°C | 0.397 | | NA | | |
| @ -36°C | | 0.441 | NA | 0.423 | NA |
| **Tests on Rolling Thin Film Oven Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 180 | 261 | 283 | 289 | 261 |
| Kinematic Viscosity @ 135°C, mm²/sec | 306.1 | 543.0 | 647.2 | 415.8 | 626.2 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.331 | 0.606 | 0.606 | 0.519 | 0.606 |
| @ 165°C | 0.131 | 0.256 | 0.206 | 0.163 | 0.194 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | | 2.708 | 2.461 | 2.294 | 3.353 |
| @ 52°C | 2.231 | 1.549 | 1.513 | 1.319 | 1.908 |
| @ 58°C | 1.054 | | | | |
| Creep Stiffness, S, @ -24°C, MPa | 60.0 | | | | |
| @ -30°C | 144.0 | NA | NA | | |
| @ -36°C | | 63.2 | 33.8 | 59.7 | 33.8 |
| m-value, m, @ -24°C | 0.408 | | | | |
| @ -30°C | 0.354 | NA | NA | | |
| @ -36°C | | 0.388 | 0.411 | 0.397 | 0.399 |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 115 | 130 | 135 | 120 | 113 |
| Kinematic Viscosity @ 135°C, mm²/sec | 590.6 | 1693.0 | 409.5 | 1482.0 | NA |
| Brookfield Viscosity @ 135°C, Pa.s | 0.481 | 1.738 | 2.175 | 1.106 | 3.375 |
| @ 165°C | 0.157 | 0.369 | 0.419 | 0.275 | 0.544 |
| G*x Sin δ, @ 7°C, 10 rad/sec, kPa | 4189 | 106 | 73 | 552 | 144 |
| @ 10°C | 2944 | 79 | 32 | 353 | 70 |
| @ 13°C | 1877 | | | | |
| Creep Stiffness, S, @ -24°C, MPa | 90.6 | | | | |
| @ -30°C | 206.5 | 62.4 | NA | 52.0 | 33.1 |
| @ -36°C | | 83.5 | 51.5 | 90.2 | 64.9 |
| m-value, m, @ -24°C | 0.307 | | | | |
| @ -30°C | 0.286 | 0.416 | NA | 0.433 | 0.338 |
| @ -36°C | | 0.313 | 0.323 | 0.315 | 0.307 |
| **Temperature Range** | **50.1-36.0** | **48.1-46.8** | **47.4-47+** | **46.5-46.8** | **47.3-47.4** |

**Table 7. SHRP Data on Virgin PGAC for Northern Reclaimed Asphalt Pavement**

| **Performance Grade (PG)** | **58-28** | **52-28** | **58-34** | **52-34** | **52-40** |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 112 | 165 | 179 | 198 | 278 |
| Kinematic Viscosity @ 135°C, mm²/sec | 386 | 260 | 477.8 | 269 | 978 |
| Brookfield Viscosity @ 135°C, Pa.s | | | | | |
| @ 165°C | | | | | |
| G*/Sin δ @ 52°C, 10 rad/sec, kPa | | 1.936 | | 1.789 | 1.490 |
| @ 58°C | 1.846 | 0.925 | 1.265 | 0.840 | 0.965 |
| @ 64°C | 0.876 | | 0.677 | | |
| Creep Stiffness, S, @ -18°C, MPa | 132.0 | 97.7 | | | |
| @ -24°C | 368.0 | 272.0 | 127.0 | 131.0 | |
| @ -30°C | | | 335.0 | | NA |
| @ -36°C | | | | | 95.1 |
| m-value, m, @ -18°C | 0.440 | 0.479 | | | |
| @ -24°C | 0.328 | 0.348 | 0.409 | 0.411 | |
| @ -30°C | | | 0.317 | | NA |
| @ -36°C | | | | | 0.411 |
| **Tests on Rolling Thin Film Oven Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 60 | 109 | 102 | 104 | 209 |
| Kinematic Viscosity @ 135°C, mm²/sec | 501 | 369.9 | 628.2 | 417.9 | 1077.8 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.513 | 0.325 | 0.690 | 0.438 | 0.894 |
| @ 165°C | 0.130 | 0.100 | 0.175 | 0.125 | 0.235 |
| G*/Sin δ @ 52°C, 10 rad/sec, kPa | | 3.992 | | 4.871 | 2.913 |
| @ 58°C | 4.172 | 1.781 | 2.724 | 2.143 | 1.744 |
| @ 64°C | 1.921 | | 1.389 | | |
| Creep Stiffness, S, @ -18°C, MPa | 172.0 | 119.0 | | | |
| @ -24°C | 409.0 | 301.0 | 161.0 | 181.0 | |
| @ -30°C | | | 386.0 | 408.0 | 36.3 |
| @ -36°C | | | | | 110.0 |
| m-value, m, @ -18°C | 0.395 | 0.424 | | | |
| @ -24°C | 0.284 | 0.320 | 0.362 | 0.354 | |
| @ -30°C | | | 0.293 | 0.282 | 0.424 |
| @ -36°C | | | | | 0.358 |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 42 | 72 | 61 | 66 | 126 |
| Kinematic Viscosity @ 135°C, mm²/sec | 878 | 565 | 1277.2 | 586.6 | 2061 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.838 | 0.425 | 1.175 | 0.518 | 1.544 |
| @ 165°C | 0.195 | 0.120 | 0.268 | 0.145 | 0.357 |
| G*x Sin δ, @ 7°C, 10 rad/sec, kPa | | | | | 1348 |
| @ 10°C | | | | 4527 | 784 |
| @ 13°C | | 3761 | 3868 | 3275 | |
| @ 16°C | 6492 | 2706 | 2585 | | |
| @ 19°C | 4431 | | | | |
| Creep Stiffness, S, @ -18°C, MPa | 256.0 | 169.0 | | | |
| @ -24°C | 486.0 | 372.0 | 202.0 | 217.0 | |
| @ -30°C | | | 444.0 | 439.0 | 60.1 |
| @ -36°C | | | | | 138.0 |
| m-value, m, @ -18°C | 0.318 | 0.370 | | | |
| @ -24°C | 0.249 | 0.290 | 0.323 | 0.313 | |
| @ -30°C | | | 0.247 | 0.258 | 0.347 |
| @ -36°C | | | | | 0.318 |
| **Temperature Range** | **62.9-29.5** | **56.4-32.4** | **59.9-35.8** | **56.6-35.4** | **55.3-49.7** |

**Table 7 Cont'd. SHRP Data on Virgin PGAC for Northern Reclaimed Asphalt Pavement**

| **Performance Grade (PG)** | **46-34** | **46-40** | **46-46** | **40-40** | **40-46** |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 259 | 388 | 580+ | 356 | 323 |
| Kinematic Viscosity @ 135°C, mm²/sec | 213.1 | 649.3 | 902.4 | 361.3 | 548.6 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.200 | 1.132 | 1.336 | 0.836 | 1.032 |
| @ 165°C | 0.070 | 0.672 | 0.886 | 0.482 | 0.630 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | 1.877 | 1.132 | 1.336 | 0.836 | 1.032 |
| @ 52°C | 0.882 | 0.672 | 0.886 | 0.482 | 0.630 |
| Creep Stiffness, S, @ -24°C, MPa | 49.5 | | | | |
| @ -30°C | 141.0 | NA | NA | | NA |
| @ -36°C | | NA | NA | 43.6 | NA |
| m-value, m, @ -24°C | 0.474 | | | | |
| @ -30°C | 0.392 | NA | NA | | |
| @ -36°C | | NA | NA | 0.455 | NA |
| **Tests on Rolling Thin Film Oven Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 173 | 240 | 250 | 265 | 184 |
| Kinematic Viscosity @ 135°C, mm²/sec | 331.9 | 765.9 | 1191.7 | 515.2 | 806.7 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.275 | 0.613 | 0.900 | 0.488 | 0.675 |
| @ 165°C | 0.090 | 0.170 | 0.225 | 0.150 | 0.188 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | | 3.256 | 2.429 | 3.318 | 3.069 |
| @ 52°C | 2.295 | 1.812 | 1.562 | 1.711 | 1.825 |
| @ 58°C | 1.222 | | | | |
| Creep Stiffness, S, @ -24°C, MPa | 70.0 | | | | |
| @ -30°C | 190.0 | NA | NA | 31.1 | NA |
| @ -36°C | | NA | 30.7 | 64.2 | 44.8 |
| m-value, m, @ -24°C | 0.471 | | | | |
| @ -30°C | 0.345 | NA | NA | 0.384 | NA |
| @ -36°C | | NA | 0.389 | 0.377 | 0.401 |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 99 | 127 | 162 | 144 | 144 |
| Kinematic Viscosity @ 135°C, mm²/sec | 478.1 | 1891.2 | 2967.4 | 859.2 | 2143.4 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.438 | 1.169 | 2.100 | 0.775 | 1.462 |
| @ 165°C | 0.130 | 0.288 | 0.406 | 0.200 | 0.325 |
| G*x Sin δ, @ 7°C, 10 rad/sec, kPa | 5701 | 572 | 122 | 486 | 339 |
| @ 10°C | 3548 | 340 | 87 | 262 | 206 |
| Creep Stiffness, S, @ -24°C, MPa | 93.5 | | | | |
| @ -30°C | 213.0 | 50.3 | NA | 43.2 | 32.5 |
| @ -36°C | | 100.0 | 43.9 | 81.4 | 70.0 |
| m-value, m, @ -24°C | 0.334 | | | | |
| @ -30°C | 0.302 | 0.340 | NA | 0.334 | 0.343 |
| @ -36°C | | 0.316 | 0.329 | 0.316 | 0.328 |
| **Temperature Range** | **51.0-40.4** | **47.4-50.0** | **47.6-49+** | **43.2-51.3** | **46.5-52.5** |

## 3.0 DATA DISCUSSION

The following sections deal with the test data collected on the recovered asphalt cement from the two RAP sources, as well as the data obtained on the asphalt blends from the northern and southern RAP and the ten different virgin asphalt cements.

### 3.1 Discussion on Extracted RAP Material

The data from Table 5 indicate that the RAP material from Ottawa (Southern RAP) was most likely 85/100 penetration grade asphalt cement. The 85/100 asphalt cement used in Ontario during the late 1980s and early 1990s almost always graded as a PG 58-22. The low temperature value of -25.2°C would be a very low temperature value for the typical 85/100 used in southern Ontario. Certainly throughout the 1970s to early 1990s the Ottawa area and most of the rest of southern Ontario used 85/100 penetration grade as the asphalt cement of choice.

The data obtained on the asphalt cement recovered from the northern RAP material indicate that the original asphalt cement was most likely 150/200 penetration. The 150/200 generally grades as PG 52-28. The low temperature value of –32.2º C is fairly typical for a PG 52-28. The northern part of the province generally used 150/200 penetration asphalt cement as the base grade in virgin HMA mixes prior to 1996.

### 3.2 Discussion of Blending Data from Southern RAP

Based on the data obtained by blending the virgin PGACs with asphalt cement extracted from the southern RAP, the following information provides valuable results for future recycling work. The most common virgin asphalt cements used for recycling will be discussed in detail.

#### 3.2.1 PG 58-28

The SHRP data obtained on the PG 58-28 blend with the southern RAP is shown in Table 8.

For Zone 3, a low temperature grade of -28°C (i.e., PG 58-28 or 52-28) is required. The RAP obtained from the Ottawa area yielded a low temperature value of -25.2°C and therefore does not meet the requirement. As suggested in Figure 1, addition of the southern RAP increased the high temperature grade considerably. With respect to the low temperature requirement, however, blending virgin PG 58-28 with a maximum of only 5 or 10 percent of the southern RAP can be permitted (see Figure 2).

Currently the MTO allows up to 20 percent RAP in mixes without a change in PG for the virgin asphalt cement. Based on the data available, the RAP value should be decreased to 10 percent when using PG 58-28 as the virgin PGAC. The low temperature value of the blended material is very dependent on the low value of not only the RAP material but the value of the virgin PGAC.

**Table 8. PG 58-28 + Southern Reclaimed Asphalt Pavement**

| Percent Reclaimed Asphalt Pavement | 0 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 96 | 80 | 74 | 70 | 63 |
| Kinematic Viscosity @ 135°C, mm²/sec | 320 | 400 | 394 | 439 | |
| Brookfield Viscosity @ 135°C, Pa.s | 0.344 | 0.381 | 0.407 | 0.444 | 0.494 |
| @ 165°C | 0.119 | 0.106 | 0.119 | 0.131 | 0.137 |
| G*/Sin δ @ 58°C, 10 rad/sec, kPa | 1.421 | | | | |
| @ 64°C | 0.674 | 1.108 | 1.170 | 1.201 | 1.563 |
| @ 70°C | | 0.561 | 0.576 | 0.628 | 0.752 |
| Creep Stiffness, S, @ -12°C, MPa | | 47.7 | 50.0 | 52.8 | 61.8 |
| @ -18°C | 135.5 | 136.0 | 159.0 | 150.0 | 156.0 |
| @ -24°C | 326.0 | | | | |
| m-value, m, @ -12°C | | 0.502 | 0.479 | 0.480 | 0.454 |
| @ -18°C | 0.425 | 0.395 | 0.398 | 0.382 | 0.387 |
| @ -24°C | 0.324 | | | | |
| **Tests on Rolling Thin Film Oven Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 58 | 45 | 47 | 41 | 40 |
| Kinematic Viscosity @ 135°C, mm²/sec | 442.6 | | | | |
| Brookfield Viscosity @ 135°C, Pa.s | 0.456 | 0.619 | 0.600 | 0.650 | 0.725 |
| @ 165°C | 0.144 | 0.175 | 0.175 | 0.237 | 0.175 |
| G*/Sin δ @ 58°C, 10 rad/sec, kPa | 3.531 | | | | |
| @ 64°C | 1.584 | 2.720 | 2.686 | 2.750 | 3.344 |
| @ 70°C | | 1.270 | 1.234 | 1.320 | 1.550 |
| Creep Stiffness, S, @ -12°C, MPa | | 70.0 | 65.7 | 76.6 | |
| @ -18°C | 103.0 | 174.0 | 183.0 | 189.0 | 178.0 |
| @ -24°C | 411.0 | | | | 456.0 |
| m-value, m, @ -12°C | | 0.429 | 0.439 | 0.429 | |
| @ -18°C | 0.360 | 0.363 | 0.364 | 0.358 | 0.338 |
| @ -24°C | 0.284 | | | | 0.272 |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 26 | | | | |
| Kinematic Viscosity @ 135°C, mm²/sec | 910.5 | | | | |
| Brookfield Viscosity @ 135°C, Pa.s | 0.819 | 1.212 | 1.188 | 1.144 | 1.612 |
| @ 165°C | 0.194 | 0.263 | 0.257 | 0.256 | 0.325 |
| G*x Sin δ, , 10 rad/sec, kPa @ 16°C | 6041 | | | | |
| @ 19°C | 4113 | | | | |
| @ 22°C | | 3381 | 2871 | 985 | |
| @ 25°C | | 2001 | 2005 | 551 | 1770 |
| Creep Stiffness, S, @ -12°C, MPa | | 108.0 | 110.0 | 123.0 | 118.0 |
| @ -18°C | 212.5 | 228.0 | 229.0 | 223.0 | 229.5 |
| @ -24°C | 491.0 | | | | 481.0 |
| m-value, m, @ -12°C | | 0.348 | 0.361 | 0.342 | 0.343 |
| @ -18°C | 0.305 | 0.293 | 0.304 | 0.295 | 0.291 |
| @ -24°C | 0.251 | | | | 0.234 |
| **Temperature Range** | **60.8-28.6** | **64.9-27.2** | **65.3-28.4** | **65.8-27.4** | **67.3-27.0** |

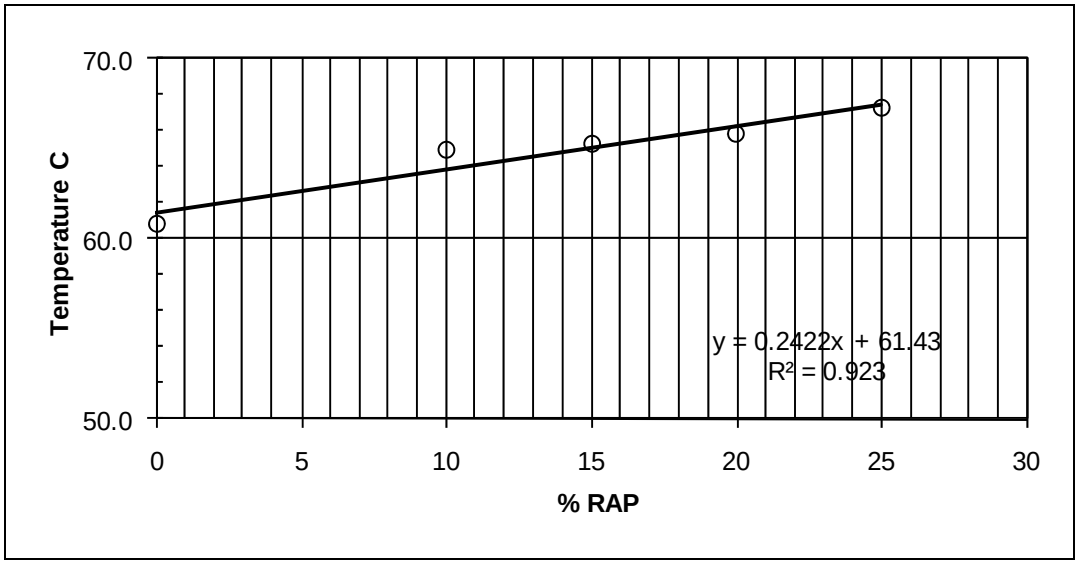


**Figure 1. High Temperature Data using PG 58-28**

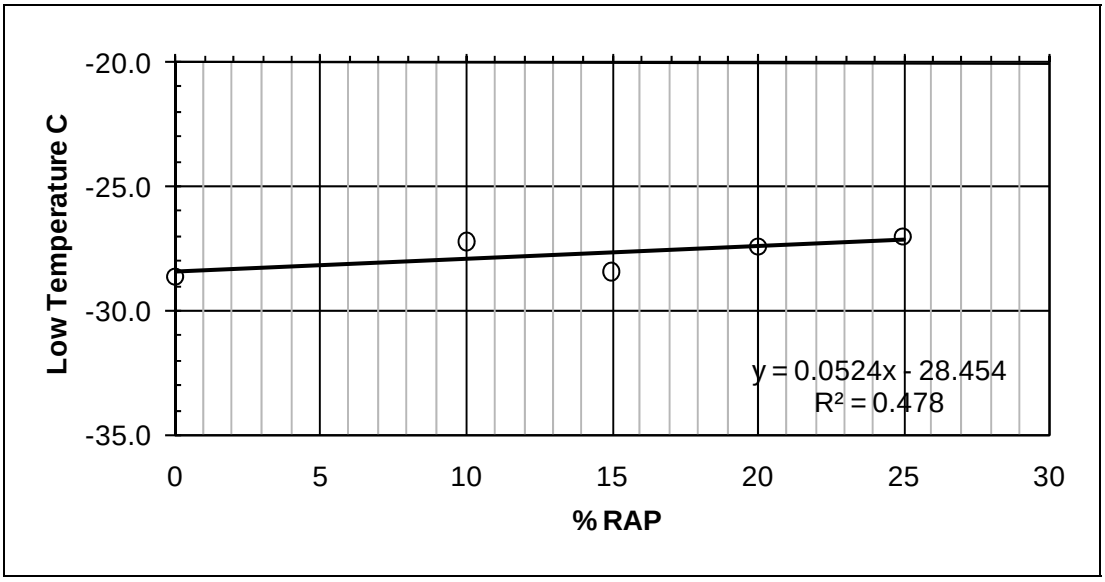


**Figure 2. Low Temperature Data using PG 58-28**

### 3.2.2 PG 52-34

The SHRP data obtained on the PG 52-34 blend with the southern RAP is shown in Table 9.

PG 52-34 is the most common grade of virgin asphalt cement used in southern Ontario to produce recycled HMA. The data in Figure 3 indicate that a minimum high temperature of 58°C is met without any problems (with 10 percent RAP or higher) and if more than 25 percent RAP is added, a minimum high temperature of 64°C can be achieved.

**Table 9. PG 52-34 + Southern Reclaimed Asphalt Pavement**

| Percent Reclaimed Asphalt Pavement | 0 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 185 | 131 | 121 | 97 | 85 |
| Kinematic Viscosity @ 135°C, mm²/sec | 294 | 373 | 404 | 452 | 468 |
| Flash Point , COC, °C | 230+ | 230+ | 230+ | 230+ | 230+ |
| Brookfield Viscosity @ 135°C, Pa.s | 0.231 | 0.269 | 0.357 | 0.375 | 0.425 |
| @ 165°C | 0.094 | 0.115 | 0.112 | 0.110 | 0.120 |
| G*/Sin δ @ 52°C, 10 rad/sec, kPa | 1.692 | | | | |
| @ 58°C | 0.796 | 1.467 | 1.954 | | |
| @ 64°C | | 0.704 | 0.928 | 1.025 | 1.247 |
| @ 70°C | | | | 0.525 | 0.623 |
| Creep Stiffness, S, @ -18°C, Mpa | | | | | |
| @ -24°C | 118.0 | 165.0 | 224.0 | 188.0 | 212.0 |
| @ -30°C | 323.5 | 392.0 | 410.0 | 428.0 | 470.0 |
| m-value, m, @ -18°C | | | | | |
| @ -24°C | 0.384 | 0.375 | 0.345 | 0.366 | 0.332 |
| @ -30°C | 0.309 | 0.291 | 0.277 | 0.268 | 0.264 |
| **Tests on Rolling Thin Film Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 100 | 77 | 67 | 57 | 57 |
| Kinematic Viscosity @ 135°C, mm²/sec | 391 | 497 | 590 | 660 | 662 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.344 | 0.432 | 0.525 | 0.563 | 0.613 |
| @ 165°C | 0.106 | 0.125 | 0.144 | 0.148 | 0.160 |
| G*/Sin δ @ 52°C, 10 rad/sec, kPa | 3.658 | | | | |
| @ 58°C | 1.651 | 3.476 | 3.918 | | |
| @ 64°C | | 1.617 | 1.870 | 2.303 | 2.445 |
| @ 70°C | | | | 1.130 | 1.183 |
| Creep Stiffness, S, @ -18°C, Mpa | | | | | 114.0 |
| @ -24°C | 151.5 | 204.0 | 218.0 | 240.0 | 212.0 |
| @ -30°C | 392.0 | 330.0 | 441.0 | 515.0 | 516.0 |
| m-value, m, @ -18°C | | | | | 0.365 |
| @ -24°C | 0.359 | 0.328 | 0.320 | 0.307 | 0.320 |
| @ -30°C | 0.280 | 0.271 | 0.257 | 0.278 | 0.276 |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 87 | 66 | 40 | 32 | 30.5 |
| Kinematic Viscosity @ 135°C, mm²/sec | 458 | 729 | 857 | 907 | 950 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.600 | 0.625 | 0.763 | 0.875 | 0.919 |
| @ 165°C | 0.156 | 0.160 | 0.185 | 0.198 | 0.211 |
| G*x Sin δ, @ 7°C, 10 rad/sec, kPa | 5457 | | | | |
| @ 10°C | 4133 | | | | |
| @ 13°C | 2920 | | | | |
| @ 16°C | | 2885 | 3324 | | |
| @ 19°C | | 1976 | 2242 | 2176 | 2253 |
| @ 22ºC | | | 1336 | 1307 | 1655 |
| Creep Stiffness, S, @ -18°C, Mpa | | 115.0 | 123.0 | 128.0 | 144.0 |
| @ -24°C | 163.5 | 227.0 | 259.0 | 262.0 | 285.0 |
| @ -30°C | 399.5 | 460.0 | 483.0 | | |
| m-value, m, @ -18°C | | 0.344 | 0.328 | 0.326 | 0.317 |
| @ -24°C | 0.309 | 0.291 | 0.282 | 0.287 | 0.277 |
| @ -30°C | 0.264 | 0.240 | 0.234 | | |
| **Temperature Range** | **55.8-35.2** | **61.1-33.0** | **62.7-31.7** | **64.2-32.0** | **64.9-30.6** |

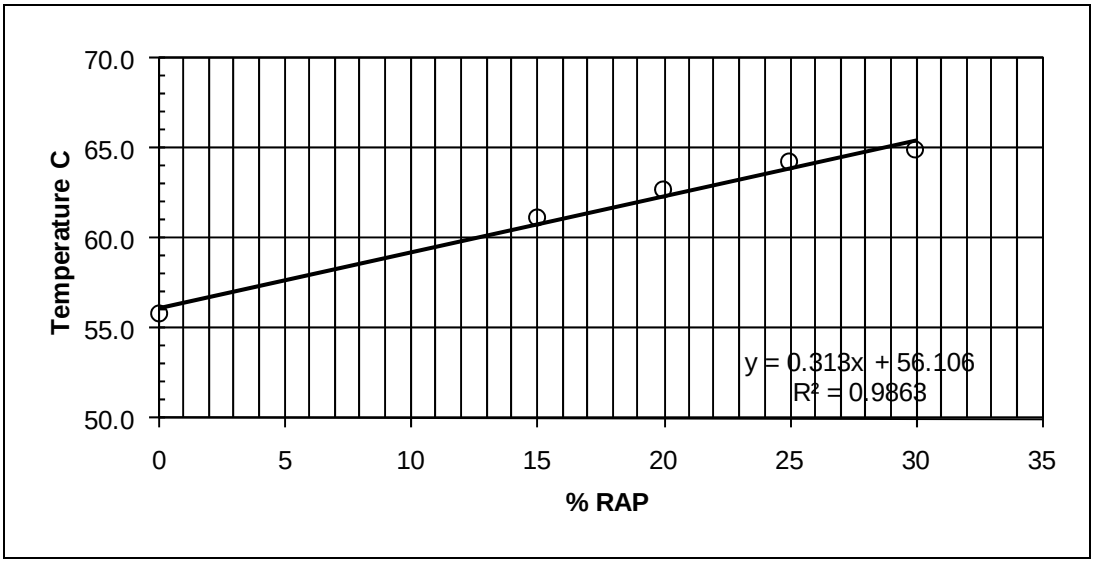


**Figure 3. High Temperature Data using PG 52-34**

Figure 4 shows the effect of PG 52-34 on the low temperature properties. The test data in Table 9 indicate that using up to 30 percent RAP still meets the -28°C specification requirement for Zone 3 (Southern Ontario). Extrapolation of the mathematical equation generated by the low temperature data, the indication is that up to 40 percent RAP could be used and still meet the minimum low temperature requirement.

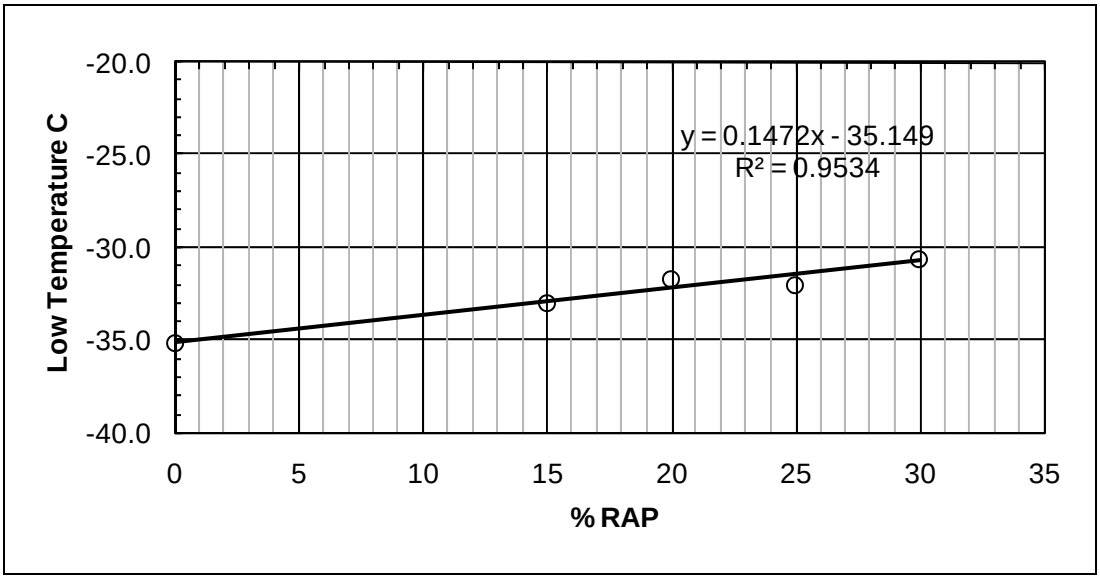


**Figure 4. Low Temperature Data using PG 52-34**

### 3.2.3 PG 46-34

Table 10 shows the test data obtained on the PG 46-34 blends.

The high temperature data indicates that with this particular RAP, the minimum of 58°C can be achieved with 20 percent RAP (Figure 5) while the low temperature value of -28°C can be easily maintained (as can the -34°C) with up to 40 percent RAP (Figure 6). This will allow the use of high content RAP mixes throughout the northern part of Southern Ontario, as this area requires a grade of PG 58-34 as the minimum.

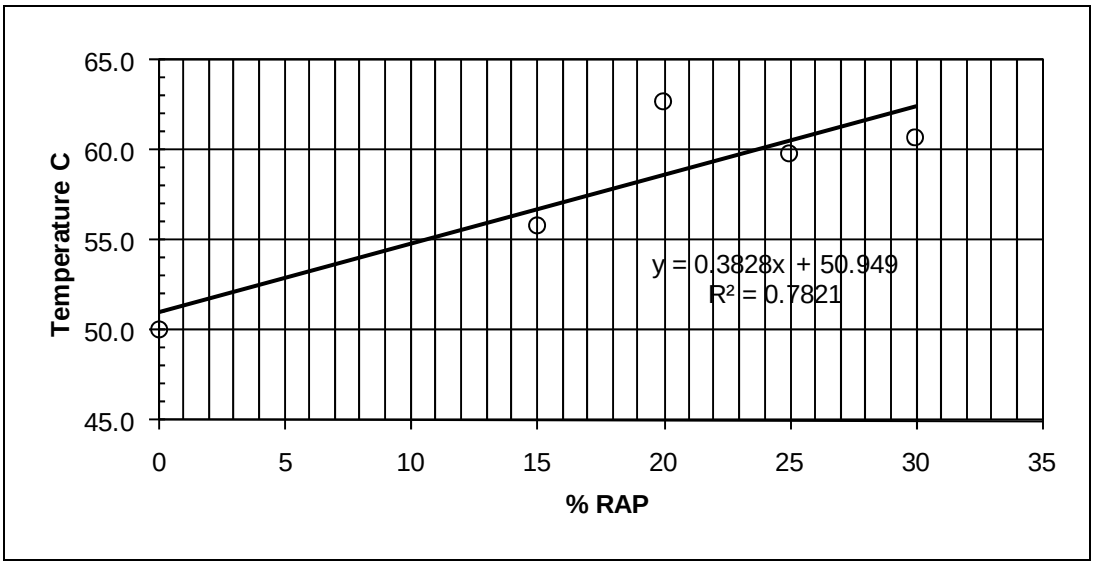


**Figure 5. High Temperature Data using PG 46-34**

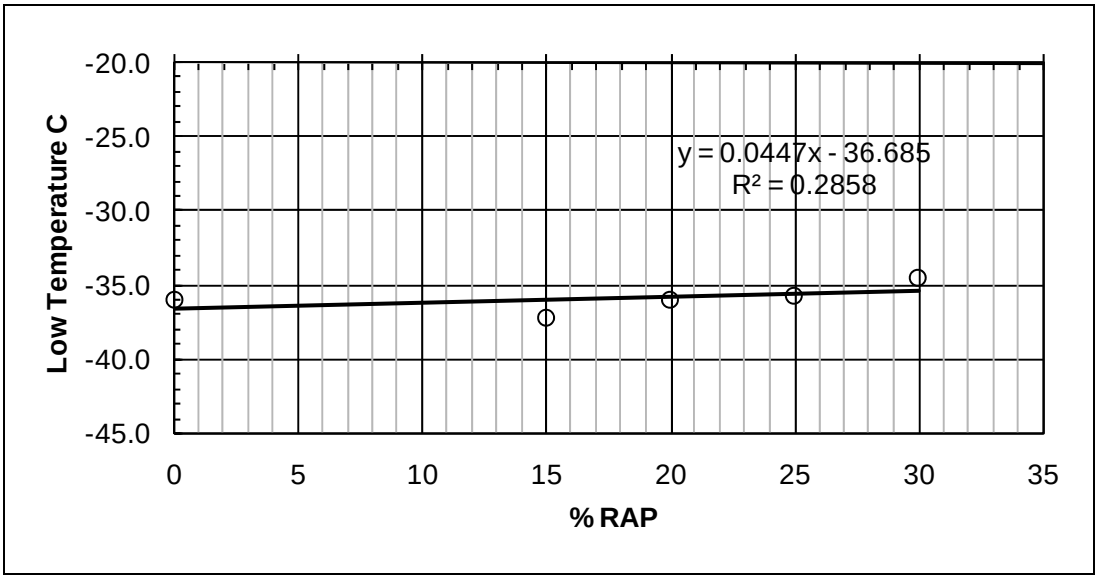


**Figure 6. Low Temperature Data using PG 46-34**

**Table 10. PG 46-34 + Southern Reclaimed Asphalt Pavement**

| **Percent Reclaimed Asphalt Pavement** | **0** | **15** | **20** | **25** | **30** |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 325 | 209 | 187 | 149 | 125 |
| Kinematic Viscosity @ 135°C, mm²/sec | 231 | 299 | 305 | 334 | 383 |
| Softening Point, R & B, ºC | 36.0 | 41.0 | 47.0 | 43.3 | 46.5 |
| Flash Point , COC, °C | 230+ | 230+ | 230+ | 230+ | 230+ |
| Brookfield Viscosity @ 135°C, Pa.s | 0.194 | 0.250 | 0.275 | 0.300 | 0.356 |
| @ 165°C | 0.063 | 0.080 | 0.088 | 0.095 | 0.119 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | 1.631 | | | | |
| @ 52°C | 0.802 | 1.595 | | | |
| @ 58°C | | 0.780 | 1.524 | 1.235 | 1.369 |
| @ 64°C | | | 0.751 | 0.620 | 0.887 |
| Creep Stiffness, S, @ -24°C, Mpa | 48.8 | 79.7 | 91.1 | 111.0 | 112.0 |
| @ -30°C | 144.5 | 193.0 | 274.0 | 229.0 | 298.0 |
| m-value, m, @ -24°C | 0.482 | 0.421 | 0.406 | 0.392 | 0.361 |
| @ -30°C | 0.397 | 0.315 | 0.315 | 0.317 | 0.302 |
| **Tests on Rolling Thin Film Oven Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 180 | 111 | 89.5 | 87 | 72 |
| Kinematic Viscosity @ 135°C, mm²/sec | 306.1 | 382 | 460 | 456 | 528 |
| Softening Point, R & B, ºC | 44.0 | 49.2 | 50.0 | 51.0 | 51.5 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.331 | 0.363 | 0.419 | 0.400 | 0.500 |
| @ 165°C | 0.131 | 0.108 | 0.120 | 0.120 | 0.145 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | 2.231 | | | | |
| @ 52°C | 1.054 | 4.019 | | | |
| @ 58°C | | 1.855 | 3.165 | 2.769 | 3.690 |
| @ 64°C | | | 1.501 | 1.335 | 1.784 |
| Creep Stiffness, S, @ -24°C, Mpa | 60.0 | 93.5 | 101.0 | 121.0 | 137.0 |
| @ -30°C | 144.0 | 247.0 | 266.0 | 338.0 | 279.0 |
| m-value, m, @ -24°C | 0.408 | 0.376 | 0.365 | 0.367 | 0.350 |
| @ -30°C | 0.354 | 0.307 | 0.292 | 0.294 | 0.286 |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 115 | 75 | 57 | 56 | 33 |
| Kinematic Viscosity @ 135°C, mm²/sec | 591 | 663 | 918 | 726 | 639 |
| Softening Point, R & B, ºC | 57.0 | 56.0 | 58.1 | 61.8 | 62.5 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.481 | 0.400 | 0.613 | 0.692 | 0.763 |
| @ 165°C | 0.157 | 0.120 | 0.165 | 0.171 | 0.183 |
| G*x Sin δ, @ 7°C, 10 rad/sec, kPa | 4189 | | | | |
| @ 10°C | 2944 | 4112 | | | |
| @ 13°C | 1877 | 2682 | 1732 | 2025 | 2146 |
| @ 16°C | | | 1229 | 1043 | 1518 |
| @ 19°C | | | | | 986 |
| Creep Stiffness, S, @ -18°C, Mpa | | 53.5 | 64.2 | 71.8 | |
| @ -24°C | 90.6 | 113.0 | 141.0 | 151.0 | 163.0 |
| @ -30°C | 206.5 | 303.0 | 296.0 | 360.0 | 353.0 |
| m-value, m, @ -18°C | | 0.374 | 0.363 | 0.339 | |
| @ -24°C | 0.307 | 0.332 | 0.319 | 0.319 | 0.304 |
| @ -30°C | 0.286 | 0.272 | 0.261 | 0.253 | 0.254 |
| **Temperature Range** | **50.1-36.0** | **55.9-37.2** | **62.7-36.0** | **59.8-35.7** | **60.7-34.5** |

### 3.2.4 PG 52-40

Table 11 shows the blend data obtained on the PG 52-40 virgin asphalt with the southern RAP. Based on the test data, the PG 52-40 is the best virgin PGAC to use when trying to obtain the PG 58-34 grade. The use of only 15 percent RAP will achieve the high temperature minimum of 58°C (Figure 7) and there are no issues with the low temperature value of -34°C up to 40 percent RAP (Figure 8).

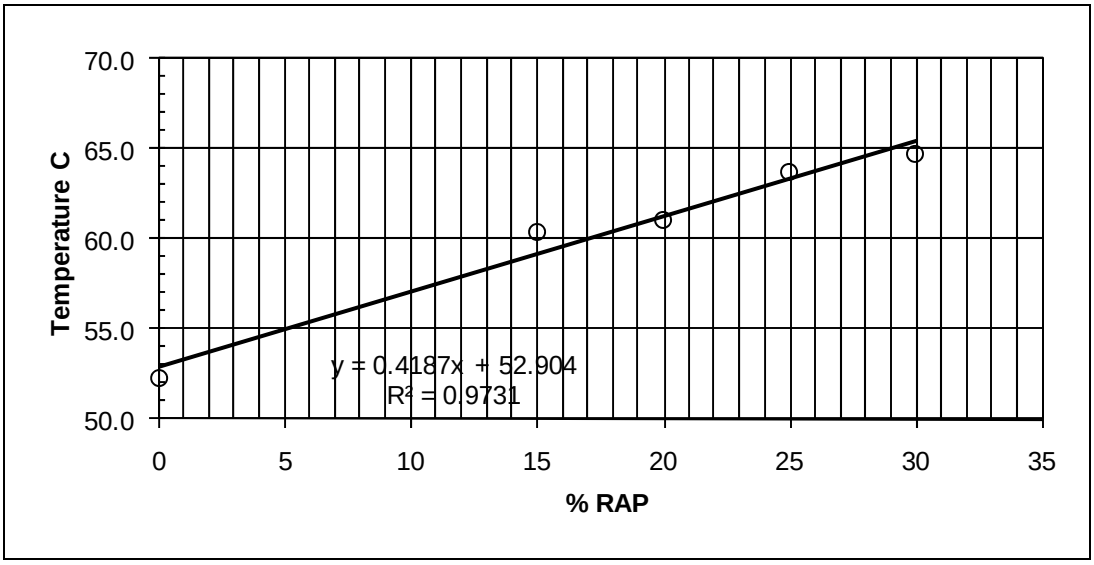


**Figure 7. High Temperature Data using PG 52-40**

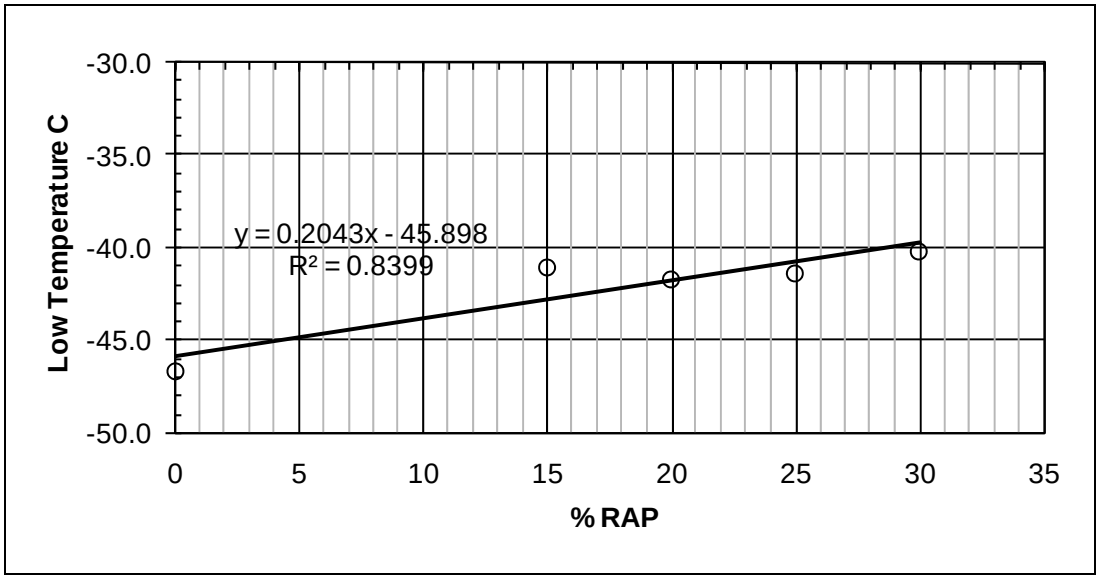


**Figure 8. Low Temperature Data using PG 52-40**

**Table 11. PG 52-40 + Southern Reclaimed Asphalt Pavement**

| Percent Reclaimed Asphalt Pavement | 0 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 358 | 223 | 194 | 180 | 141 |
| Kinematic Viscosity @ 135°C, mm²/sec | 708.0 | 925 | 861 | 881 | 915 |
| Flash Point , COC, °C | 230+ | 230+ | 230+ | 230+ | 230+ |
| Brookfield Viscosity @ 135°C, Pa.s | 0.194 | 0.650 | 0.782 | 0.694 | 0.813 |
| @ 165°C | 0.063 | 0.200 | 0.272 | 0.225 | 0.240 |
| G*/Sin δ @ 52°C, 10 rad/sec, kPa | 1.019 | | | | |
| @ 58°C | 0.680 | 1.420 | | | |
| @ 64°C | | 0.841 | 1.156 | 1.421 | 1.518 |
| @ 70°C | | | 0.683 | 0.853 | 0.863 |
| Creep Stiffness, S, @ -18°C, Mpa | | | | | |
| @ -24°C | | | | | |
| @ -30°C | NA | 59.1 | 69.0 | 95.3 | 117.0 |
| @ -36°C | 94.5 | 152.0 | 214.0 | 237.0 | 239.0 |
| m-value, m, @ -18°C | | | | | |
| @ -24°C | | | | | |
| @ -30°C | NA | 0.409 | 0.398 | 0.373 | 0.367 |
| @ -36°C | 0.405 | 0.353 | 0.330 | 0.320 | 0.290 |
| **Tests on Rolling Thin Film Oven Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 193 | 142 | 126 | 131 | 92 |
| Kinematic Viscosity @ 135°C, mm²/sec | 784.6 | 999 | 972 | 937 | 1015 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.557 | 0.750 | 0.782 | 0.791 | 0.863 |
| @ 165°C | 0.181 | 0.210 | 0.272 | 0.281 | 0.291 |
| G*/Sin δ @ 52°C, 10 rad/sec, kPa | 2.782 | | | | |
| @ 58°C | 1.714 | 2.729 | 2.930 | | |
| @ 64°C | | 1.605 | 1.674 | 3.763 | 2.356 |
| @ 70°C | | | | 2.136 | 1.326 |
| Creep Stiffness, S, @ -30°C, Mpa | 37.1 | 69.6 | 86.3 | 103.0 | 120.0 |
| @ -36°C | 112.5 | 181.0 | 218.0 | 271.0 | 269.0 |
| m-value, m, @ -30°C | 0.424 | 0.373 | 0.367 | 0.362 | 0.337 |
| @ -36°C | 0.375 | 0.326 | 0.322 | 0.297 | 0.298 |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 95 | 69 | 68 | 69 | 58 |
| Kinematic Viscosity @ 135°C, mm²/sec | 3304 | 2038 | 2811 | 1809 | 1749 |
| Brookfield Viscosity @ 135°C, Pa.s | 2.400 | 1.606 | 1.320 | 1.475 | 1.513 |
| @ 165°C | 0.463 | 0.320 | 0.300 | 0.325 | 0.375 |
| G*x Sin δ, @ 7°C, 10 rad/sec, kPa | 352.0 | | | | |
| @ 10°C | 64.0 | 1421 | 1130 | 325 | |
| @ 13°C | | 824 | 739 | 170 | 129 |
| @ 16°C | | | | 55 | 44 |
| Creep Stiffness, S, @ -24°C, Mpa | | | | | |
| @ -30°C | 81.4 | 99.3 | 119.0 | 138.0 | 157.0 |
| @ -36°C | 127.0 | 489.0 | 261.0 | 261.0 | 343.0 |
| m-value, m, @ -24°C | | | | | |
| @ -30°C | 0.404 | 0.318 | 0.311 | 0.307 | 0.301 |
| @ -36°C | 0.311 | 0.218 | 0.273 | 0.278 | 0.270 |
| **Temperature Range** | **52.3-46.7** | **60.4-41.1** | **61.1-41.7** | **63.7-41.4** | **64.7-40.2** |

### 3.3 Discussion on Blending Data from Northern RAP

#### 3.3.1 PG 52-40

For Zones 1 and 2, a low temperature grade of -34°C is required. The blending data (Table 12) indicates that for the high temperature, the PG 52-40 can be used to meet 52°C or higher (Figure 9). The PG 52-40 can be used if the RAP content is at 25 percent or lower in order to meet the minimum temperature of -34°C (Figure 10).

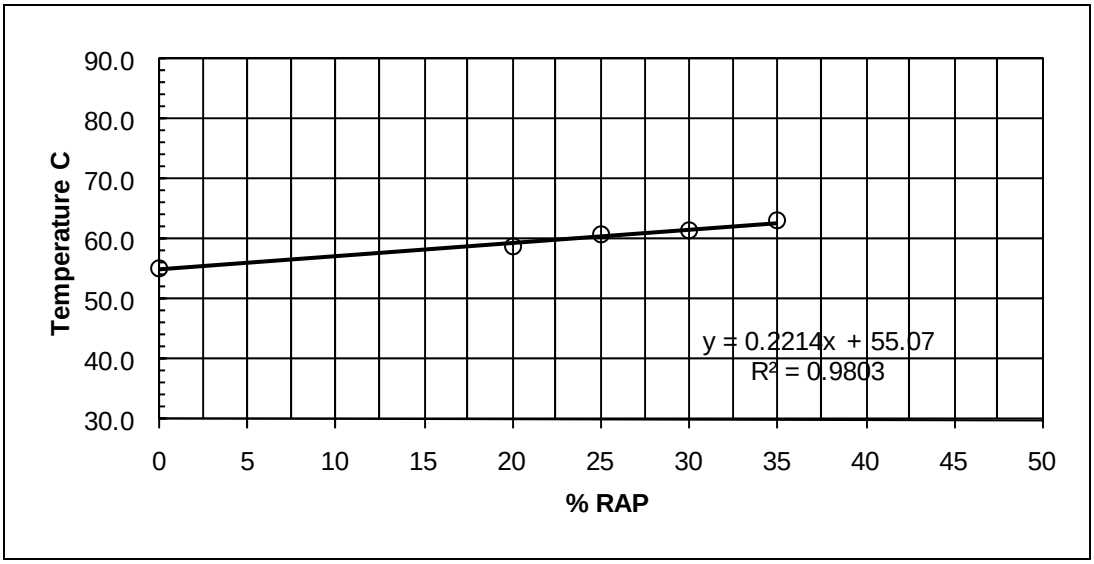


**Figure 9. High Temperature Data for PG 52-40**

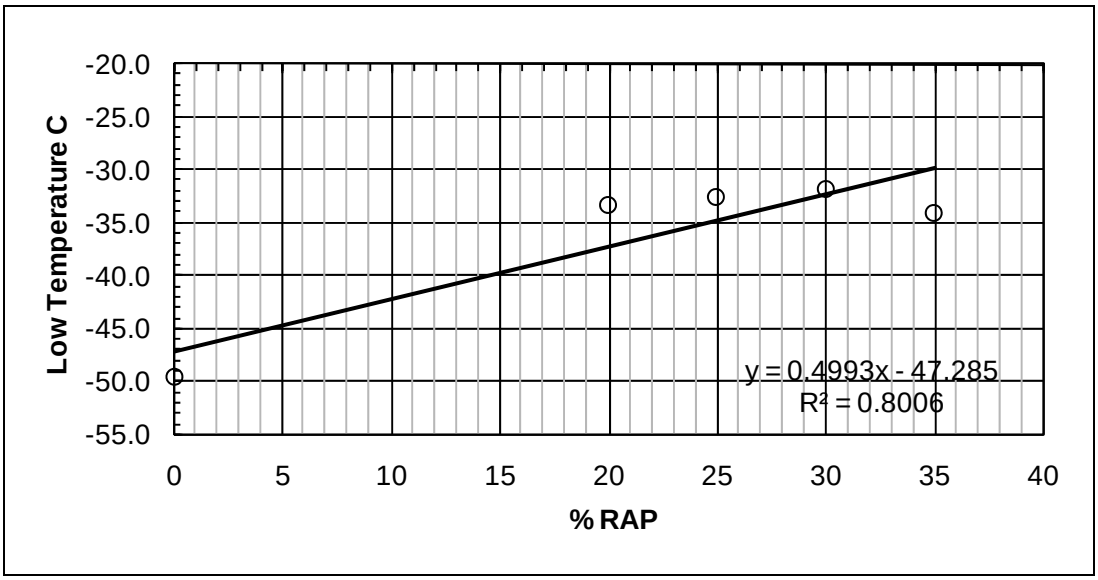


**Figure 10. Low Temperature Data for PG 52-40**

**Table 12. PG 52-40 + Northern Reclaimed Asphalt Pavement**

| **Percent Reclaimed Asphalt Pavement** | **0** | **20** | **25** | **30** | **35** |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 278 | 229 | 214.3 | 196 | 179 |
| Kinematic Viscosity @ 135°C, mm²/sec | 978.0 | 788.2 | 703.3 | 670.2 | 685.8 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.847 | 0.700 | 0.725 | 0.750 | 0.787 |
| @ 165°C | 0.195 | 0.193 | 0.205 | 0.219 | 0.250 |
| G*/Sin δ @ 52°C, 10 rad/sec, kPa | 1.490 | | | | |
| @ 58°C | 0.965 | 1.138 | 1.444 | 1.446 | 1.612 |
| @ 64°C | | 0.695 | 0.783 | 0.838 | 0.918 |
| Creep Stiffness, S, @ -24°C, Mpa | | | | 33.8 | 40.4 |
| @ -30°C | NA | 76.5 | 85.3 | 99.1 | 135.0 |
| @ -36°C | 95.1 | 254.0 | 268.0 | 301.0 | 355.0 |
| m-value, m, @ -24°C | | | | 0.434 | 0.438 |
| @ -30°C | NA | 0.396 | 0.400 | 0.342 | 0.343 |
| @ -36°C | 0.411 | 0.316 | 0.308 | 0.274 | 0.273 |
| **Tests on Rolling Thin Film Oven Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 209 | 142 | 126 | 111 | 102 |
| Kinematic Viscosity @ 135°C, mm²/sec | 1077.8 | 905.0 | 882.3 | 870.9 | 912.9 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.894 | 0.806 | 0.832 | 0.875 | 0.887 |
| @ 165°C | 0.235 | 0.215 | 0.215 | 0.235 | 0.250 |
| G*/Sin δ @ 52°C, 10 rad/sec, kPa | 2.913 | | | | |
| @ 58°C | 1.744 | 2.364 | 2.919 | 3.017 | 3.909 |
| @ 64°C | | 1.421 | 1.603 | 1.783 | 2.088 |
| Creep Stiffness, S, @ -24°C, Mpa | | 32.4 | 39.6 | 55.1 | 64.7 |
| @ -30°C | 36.3 | 92.6 | 104.0 | 153.0 | 170.0 |
| @ -36°C | 110.0 | 220.0 | 255.0 | 268.0 | 367.0 |
| m-value, m, @ -24°C | | 0.410 | 0.392 | 0.371 | 0.356 |
| @ -30°C | 0.424 | 0.352 | 0.343 | 0.312 | 0.301 |
| @ -36°C | 0.358 | 0.301 | 0.305 | 0.275 | 0.260 |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 126 | 89 | 78 | 67 | 45 |
| Kinematic Viscosity @ 135°C, mm²/sec | 2061 | 2594.4 | 1842.6 | 2030.7 | 2365.7 |
| Brookfield Viscosity @ 135°C, Pa.s | 1.544 | 1.250 | 1.435 | 1.732 | 2.250 |
| @ 165°C | 0.357 | 0.363 | 0.413 | 0.442 | 0.600 |
| G*x Sin δ, @ 7°C, 10 rad/sec, kPa | 1348 | | | | |
| @ 10°C | 784 | | | | |
| @ 13°C | | | | | 2418 |
| @ 16°C | | 879 | 1462 | 1019 | 1763 |
| @ 19°C | | 730 | 894 | 868 | 1242 |
| Creep Stiffness, S, @ -18°C, Mpa | | 44.2 | 39.9 | 43.2 | |
| @ -24°C | | 68.9 | 84.9 | 105.0 | 90.1 |
| @ -30°C | 60.1 | | | | 217.0 |
| @ -36°C | 138.0 | | | | |
| m-value, m, @ -18°C | | 0.321 | 0.335 | 0.317 | |
| @ -24°C | | 0.297 | 0.289 | 0.290 | 0.301 |
| @ -30°C | 0.347 | | | | 0.250 |
| @ -36°C | 0.318 | | | | |
| **Temperature Range** | **55.3-49.7** | **58.8-33.3** | **60.9-32.6** | **61.6-31.8** | **63.1-34.1** |

### 3.3.2 PG 46-40

If greater than 10 percent RAP is used, the PG 46-40 will meet the minimum high temperature requirement of 52°C (Figure 11). In order to meet 58°C (Zones 2 and 3), at least 30 percent RAP is required. In order to meet the minimum low temperature requirement of -34°C no more than 25 percent northern RAP can be used (Figure 12). Table 13 contains the test data on the blends made with RAP and PG 46-40.

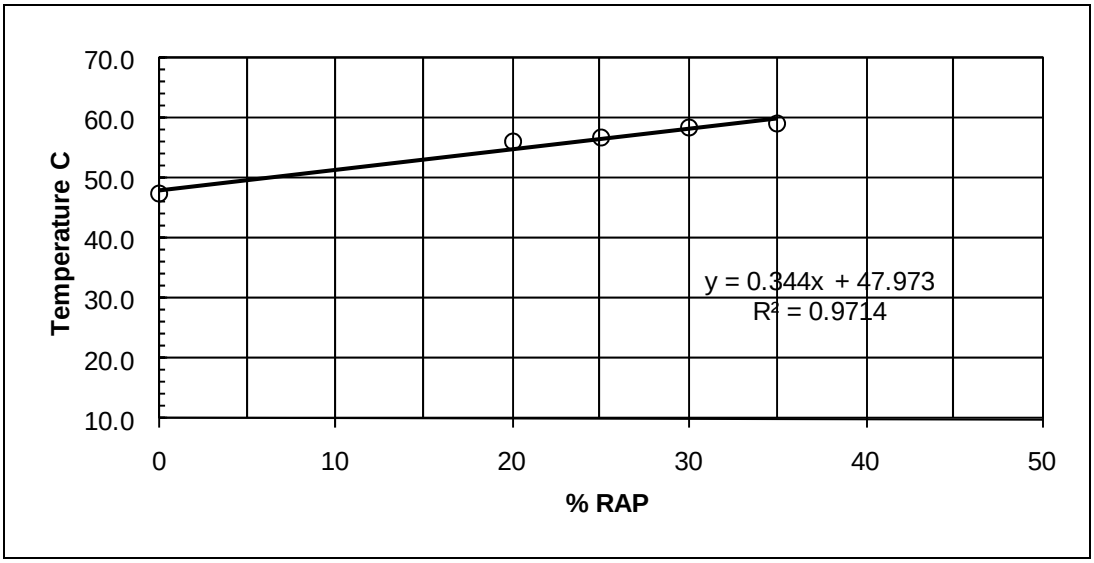


**Figure 11. High Temperature Data for PG 46-40**

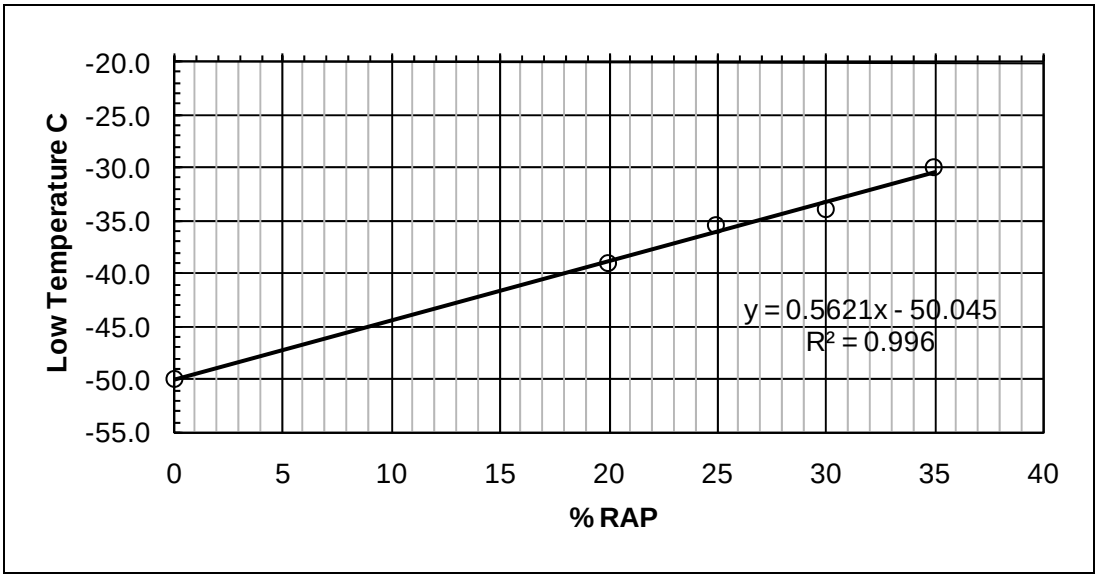


**Figure 12. Low Temperature Data for PG 46-40**

**Table 13. PG 46-40 + Northern Reclaimed Asphalt Pavement**

| Percent Reclaimed Asphalt Pavement | 0 | 20 | 25 | 30 | 35 |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 388 | 300+ | 262 | 215 | 191 |
| Kinematic Viscosity @ 135°C, mm²/sec | 771.5 | 549.9 | 532.6 | 536.5 | 524.8 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.538 | 0.445 | 0.457 | 0.467 | 0.475 |
| @ 165°C | 0.153 | 0.143 | 0.148 | 0.155 | 0.162 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | 1.132 | | | | |
| @ 52°C | 0.672 | 1.461 | 1.597 | | |
| @ 58°C | | 0.830 | 0.889 | 1.458 | 1.123 |
| @ 64°C | | | | 0.814 | 0.603 |
| Creep Stiffness, S, @ -24°C, Mpa | | | | | 30.3 |
| @ -30°C | NA | 44.9 | 51.4 | 76.6 | 58.9 |
| @ -36°C | NA | 142.0 | 184.0 | 188.0 | |
| m-value, m, @ -24°C | | | | | 0.438 |
| @ -30°C | NA | 0.407 | 0.396 | 0.382 | 0.397 |
| @ -36°C | NA | 0.366 | 0.338 | 0.311 | |
| **Tests on Rolling Thin Film Oven Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 240 | 144 | 139 | 130 | 124 |
| Kinematic Viscosity @ 135°C, mm²/sec | 765.9 | 757.2 | 740.6 | 663.7 | 648.5 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.613 | 0.694 | 0.607 | 0.619 | 0.639 |
| @ 165°C | 0.170 | 0.178 | 0.194 | 0.170 | 0.180 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | 3.256 | | | | |
| @ 52°C | 1.812 | 4.032 | 3.863 | | |
| @ 58°C | | 2.153 | 2.050 | 2.292 | 2.458 |
| @ 64°C | | | | 1.220 | 1.316 |
| Creep Stiffness, S, @ -24°C, Mpa | | | | | 42.0 |
| @ -30°C | NA | 47.6 | 77.1 | 90.2 | 85.1 |
| @ -36°C | NA | 187.0 | 205.0 | 240.0 | |
| m-value, m, @ -24°C | | | | | 0.386 |
| @ -30°C | NA | 0.381 | 0.359 | 0.343 | 0.341 |
| @ -36°C | NA | 0.313 | 0.311 | 0.307 | |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 127 | 85 | 84 | 64 | 60 |
| Kinematic Viscosity @ 135°C, mm²/sec | 1891.2 | 1256.0 | 1229.9 | 1534.0 | 1353.9 |
| Brookfield Viscosity @ 135°C, Pa.s | 1.169 | 1.163 | 1.025 | 1.462 | 1.506 |
| @ 165°C | 0.288 | 0.282 | 0.300 | 0.333 | 0.350 |
| G*x Sin δ, @ 7°C, 10 rad/sec, kPa | 572 | 1850 | | | |
| @ 10°C | 340 | 1107 | 1204 | | |
| @ 13°C | | 97 | 805 | | |
| @ 16°C | | | | 1203 | 659 |
| @ 19°C | | | | 807 | 388 |
| Creep Stiffness, S, @ -18°C, Mpa | | | | 32.5 | 41.0 |
| @ -24°C | | 44.4 | 59.3 | 64.1 | 81.7 |
| @ -30°C | 50.3 | 95.5 | 116.0 | | |
| @ -36°C | 100.0 | | | | |
| m-value, m, @ -18°C | | | | 0.342 | 0.305 |
| @ -24°C | | 0.378 | 0.302 | 0.299 | 0.290 |
| @ -30°C | 0.340 | 0.284 | 0.294 | | |
| @ -36°C | 0.316 | | | | |
| **Temperature Range** | **47.4-50.0** | **56.0-39.0** | **56.8-35.5** | **58.4-33.9** | **59.1-30.0** |

### 3.3.3 PG 46-46

The test data showing the blend results for the RAP plus PG 46-46 are provided in Table 14. Based on Figure 13, if more than 15 percent RAP is used the minimum high temperature of 52°C can be met and if greater than 30 percent RAP is used the high temperature of 58°C can be met. In order to meet the minimum low temperature of -34°C, no more than 35 percent RAP can be used (Figure 14).

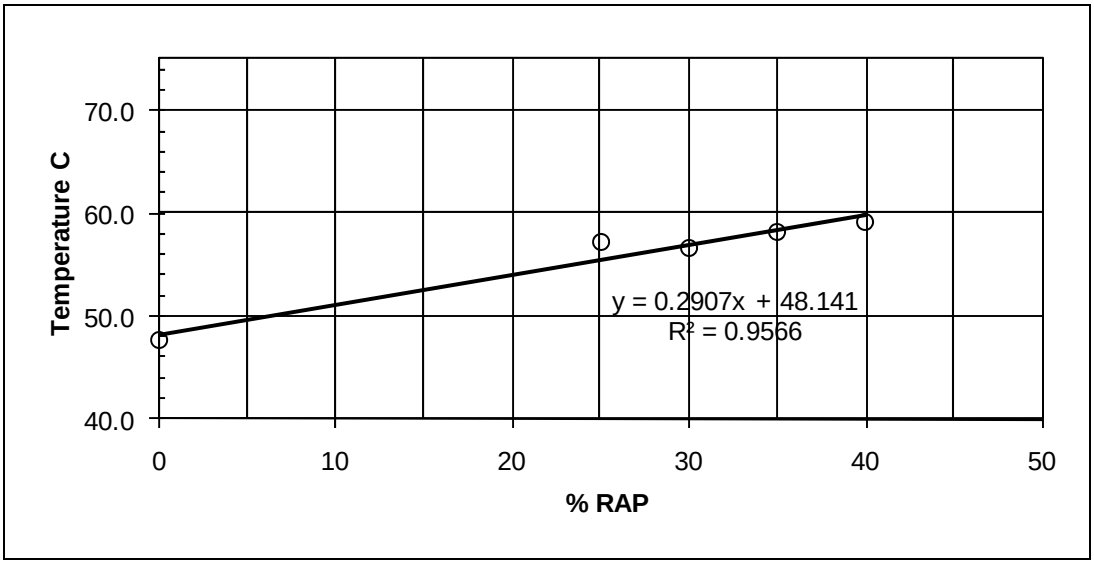


**Figure 13. High Temperature Data for PG 46-46**

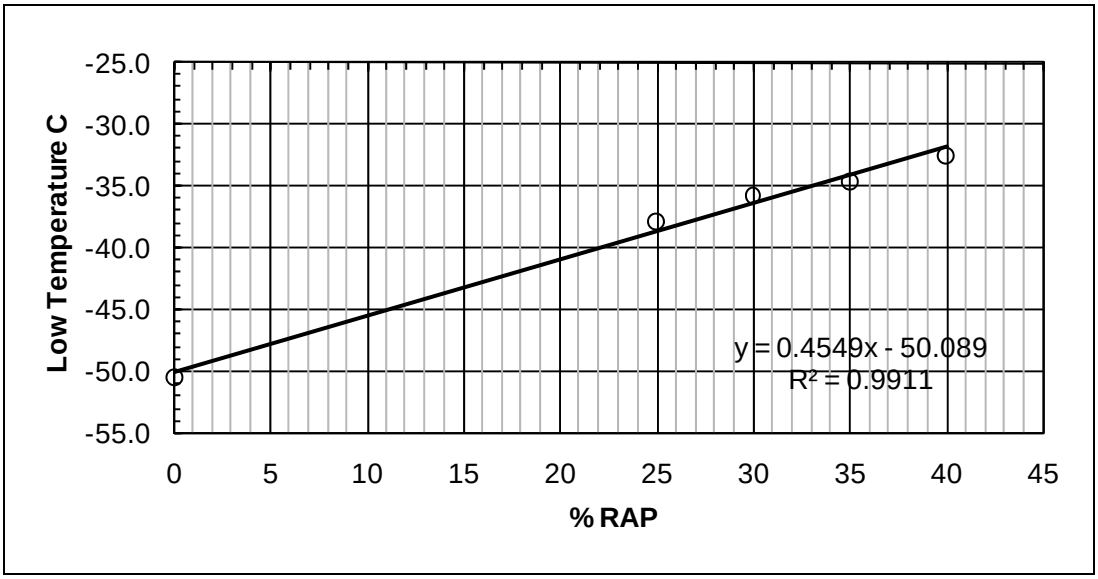


**Figure 14. Low Temperature Data for PG 46-46**

**Table 14. PG 46-46 + Northern Reclaimed Asphalt Pavement**

| Percent Reclaimed Asphalt Pavement | 0 | 25 | 30 | 35 | 40 |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 580+ | 273 | 230 | 199 | 176 |
| Kinematic Viscosity @ 135°C, mm²/sec | 902.4 | 614.1 | 633.1 | 614.9 | 567.9 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.788 | 0.600 | 0.625 | 0.605 | 0.569 |
| @ 165°C | 0.283 | 0.175 | 0.187 | 0.185 | 0.175 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | 1.336 | | | | |
| @ 52°C | 0.886 | 1.574 | | | |
| @ 58°C | | 0.921 | 1.006 | 1.093 | 1.055 |
| @ 64°C | | | 0.602 | 0.641 | 0.623 |
| Creep Stiffness, S, @ -30°C, Mpa | NA | 33.9 | 50.7 | 61.9 | 79.2 |
| @ -36°C | NA | 86.5 | 129.0 | 164.0 | 194.0 |
| m-value, m, @ -30°C | NA | 0.426 | 0.410 | 0.391 | 0.382 |
| @ -36°C | NA | 0.378 | 0.353 | 0.341 | 0.351 |
| **Tests on Rolling Thin Film Oven Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 250 | 156 | 146 | 136 | 128 |
| Kinematic Viscosity @ 135°C, mm²/sec | 1191.7 | 935.0 | 753.5 | 643.0 | 754.8 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.900 | 0.738 | 0.750 | 0.762 | 0.775 |
| @ 165°C | 0.225 | 0.205 | 0.205 | 0.210 | 0.218 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | 2.429 | | | | |
| @ 52°C | 1.562 | 3.474 | 3.340 | | |
| @ 58°C | | 2.019 | 1.944 | 2.209 | 2.511 |
| @ 64°C | | | | 1.263 | 1.498 |
| Creep Stiffness, S, @ -24°C, Mpa | | | | | 37.2 |
| @ -30°C | NA | 57.5 | 60.7 | 32.0 | |
| @ -36°C | 30.7 | 120.0 | 168.0 | 92.5 | 248.0 |
| m-value, m, @ -24°C | | | | | 0.358 |
| @ -30°C | NA | 0.366 | 0.359 | 0.397 | |
| @ -36°C | 0.389 | 0.316 | 0.316 | 0.333 | 0.293 |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 162 | 104 | 93 | 80 | 69 |
| Kinematic Viscosity @ 135°C, mm²/sec | 2967.4 | 1310 | 1760.6 | 1381.0 | 1724.4 |
| Brookfield Viscosity @ 135°C, Pa.s | 2.100 | 1.125 | 1.388 | 1.492 | 1.587 |
| @ 165°C | 0.406 | 0.300 | 0.306 | 0.325 | 0.345 |
| G*x Sin δ, @ 7°C, 10 rad/sec, kPa | 122 | | | | |
| @ 10°C | 87 | 550 | 1083 | | |
| @ 13°C | | 284 | 961 | 1298 | |
| @ 16°C | | | | 693 | 1141 |
| @ 19°C | | | | | 935 |
| Creep Stiffness, S, @ -18°C, Mpa | | | | | 37.5 |
| @ -24°C | | 40.4 | 48.6 | 57.3 | 73.4 |
| @ -30°C | NA | 86.0 | 112.0 | 124.0 | 147.0 |
| @ -36°C | 43.9 | | | | |
| m-value, m, @ -18°C | | | | | 0.336 |
| @ -24°C | | 0.321 | 0.310 | 0.305 | 0.288 |
| @ -30°C | NA | 0.289 | 0.276 | 0.254 | 0.259 |
| @ -36°C | 0.329 | | | | |
| **Temperature Range** | **47.6-49+** | **57.1-37.9** | **56.6-35.8** | **58.1-34.6** | **59.1-32.5** |

### 3.3.4 PG 40-46

Table 15 shows the test data on the RAP blends using PG 40-46 as the virgin binder. In order to meet the high temperature minimum of 52°C at least 15 percent RAP has to be added to the mix. To achieve a high temperature of 58°C at least 30 percent RAP has to be added to the mix (Figure 15). From Figure 16, the low temperature minimum of -34°C can be met with up to 30 percent RAP being added to the mix.

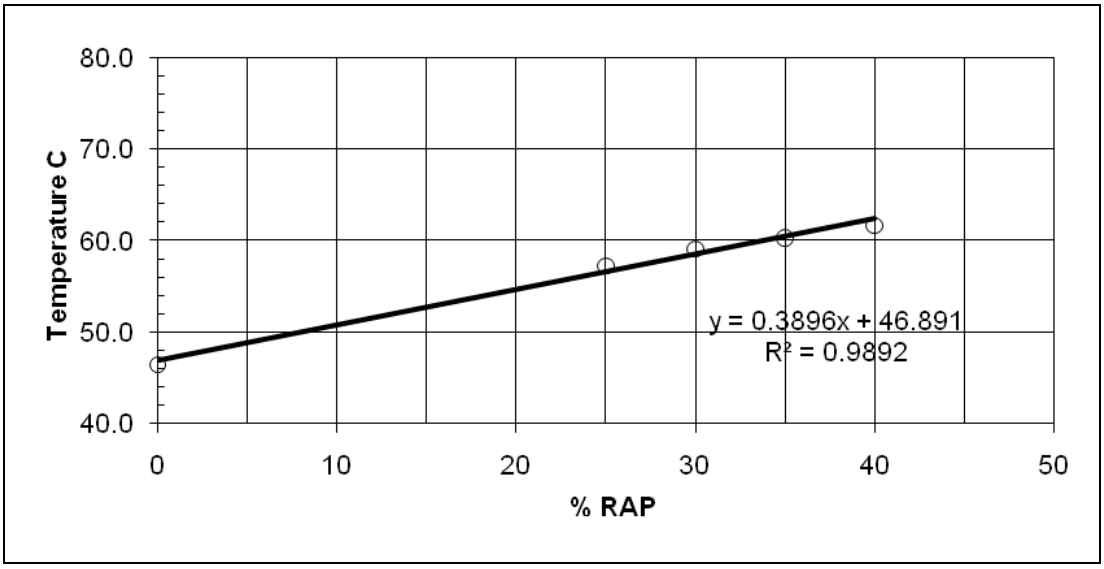


**Figure 15. High Temperature Data for PG 40-46**

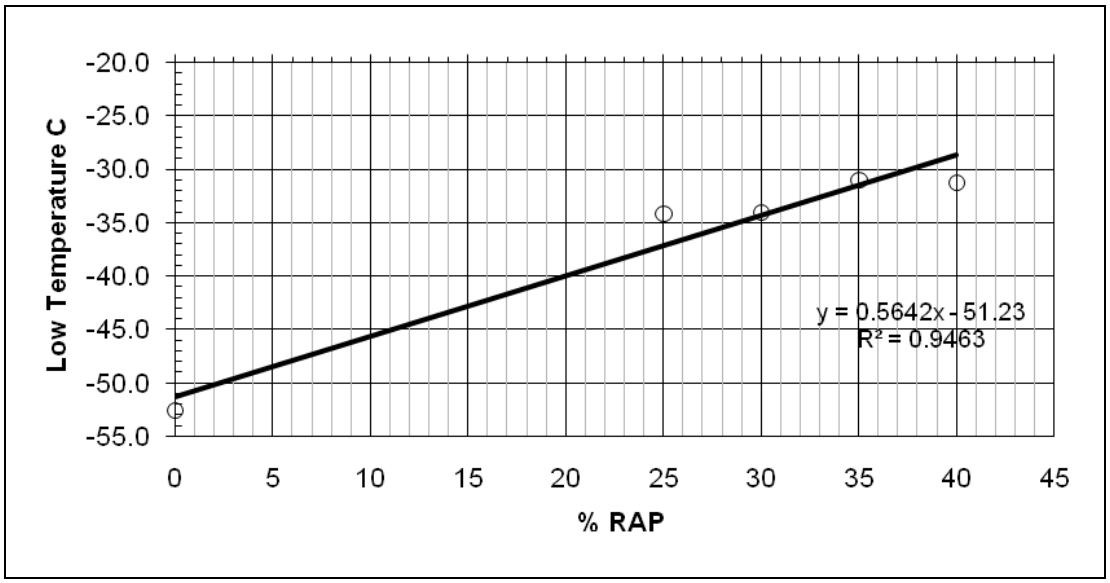


**Figure 16. Low Temperature Data for PG 40-46**

**Table 15. PG 40-46 + Northern Reclaimed Asphalt Pavement**

| Percent Reclaimed Asphalt Pavement | 0 | 25 | 30 | 35 | 40 |
|---|---|---|---|---|---|
| **Tests on Original Binder** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 323 | 177 | 165 | 137 | 121 |
| Kinematic Viscosity @ 135°C, mm²/sec | 548.6 | 461.4 | 483.4 | 509.9 | 761 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.500 | 0.517 | 0.482 | 0.482 | 0.506 |
| @ 165°C | 0.170 | 0.140 | 0.163 | 0.150 | 0.158 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | 1.032 | | | | |
| @ 52°C | 0.630 | | | | |
| @ 58°C | | 1.091 | 1.423 | 1.701 | 1.514 |
| @ 64°C | | 0.606 | 0.752 | 0.767 | 0.773 |
| Creep Stiffness, S @ -24°C, Mpa | | 46.3 | 52.7 | 57.5 | 66.3 |
| @ -30°C | NA | 103.0 | 108.0 | 140.0 | 164.0 |
| @ -36°C | NA | 216.0 | 310.0 | 311.0 | 397.0 |
| m-value, m, @ -24°C | | 0.419 | 0.403 | 0.396 | 0.385 |
| @ -30°C | NA | 0.306 | 0.369 | 0.328 | 0.342 |
| @ -36°C | NA | 0.315 | 0.289 | 0.272 | 0.311 |
| **Tests on Rolling Thin Film Oven Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 184 | 119 | 111 | 101 | 95 |
| Kinematic Viscosity @ 135°C, mm²/sec | 806.7 | 524 | 580.1 | 600.1 | 821.8 |
| Brookfield Viscosity @ 135°C, Pa.s | 0.675 | 0.540 | 0.625 | 0.603 | 0.8 |
| @ 165°C | 0.188 | 0.160 | 0.194 | 0.180 | 0.2 |
| G*/Sin δ @ 46°C, 10 rad/sec, kPa | 3.069 | | | | |
| @ 52°C | 1.825 | 4.007 | | | |
| @ 58°C | | 2.043 | 2.503 | 2.879 | 3.516 |
| @ 64°C | | | 1.289 | 1.477 | 1.730 |
| Creep Stiffness, S, @ -30°C, Mpa | NA | 115.0 | 147.0 | 168.0 | 224.0 |
| @ -36°C | 44.8 | 295.0 | 345.0 | 321.0 | 371.0 |
| m-value, m, @ -30°C | NA | 0.336 | 0.321 | 0.312 | 0.301 |
| @ -36°C | 0.401 | 0.292 | 0.279 | 0.225 | 0.226 |
| **Tests on Pressure Aging Vessel Residue** | | | | | |
| Penetration @ 25°C, 100g, 5 sec | 144 | 70 | 61 | 49 | 37 |
| Kinematic Viscosity @ 135°C, mm²/sec | 2143.4 | 995 | 1170.2 | 1208.3 | 1616.7 |
| Brookfield Viscosity @ 135°C, Pa.s | 1.462 | 1.075 | 1.269 | 1.313 | 1.415 |
| @ 165°C | 0.325 | 0.263 | 0.319 | 0.340 | 0.420 |
| G*x Sin δ, @ 7°C, 10 rad/sec, kPa | 339 | | | | |
| @ 10°C | 206 | | | | |
| @ 13°C | | | 2565 | | |
| @ 16°C | | 571 | 1671 | 1392 | 1313 |
| @ 19°C | | 378 | | 1107 | 865 |
| Creep Stiffness, S, @ -18ºC, Mpa | | 40.2 | | 51.0 | |
| @ -24°C, | | 84.8 | 96.5 | 123.0 | 139.0 |
| @ -30°C | 32.5 | 173.0 | 194.0 | | 244.0 |
| @ -36°C | 70.0 | | | | |
| m-value, m, @ -18ºC | | 0.331 | | 0.329 | |
| @ -24°C | | 0.301 | 0.300 | 0.271 | 0.284 |
| @ -30°C | 0.343 | 0.254 | 0.261 | | 0.250 |
| @ -36°C | 0.328 | | | | |
| **Temperature Range** | **46.5-52.5** | **57.3-34.1** | **59.2-34.0** | **60.4-31.0** | **61.7-31.2** |

## 4.0 PG GRADING SUMMARY

With the restrictions on paper length, much test data has not been included in the paper. Tables 16 and 17 contain a summary of all the data collected during the study. The tables show the PG grade that would result if the various virgin asphalt cements were blended with the different percentages of Southern and Northern RAP, respectively.

The grades are based on the mathematical equation generated for each mix. The $R^2$ values for the equations are all acceptable and indicate a good correlation with regard to both the high and low temperature values obtained. The data obtained here is based on only two RAP materials however, and should be used as a guideline when selecting the required virgin PG grade of asphalt cement.

**Table 16. Summary – Performance Grading – Southern Reclaimed Asphalt Pavement**

<table>
<tr><th rowspan="2">Percent RAP</th><th colspan="5">Virgin Binder</th></tr>
<tr><th>PG 58-28</th><th>PG 52-28</th><th>PG 52-34</th><th>PG 46-34</th><th>PG 58-34</th></tr>
<tr><td>0</td><td>PG 58-28</td><td>PG 52-28</td><td>PG 52-34</td><td>PG 46-34</td><td rowspan="2">PG 58-34</td></tr>
<tr><td>10</td><td>PG 58-22</td><td rowspan="3">PG 58-28</td><td rowspan="3">PG 58-28</td><td rowspan="2">PG 52-34</td></tr>
<tr><td>15</td><td rowspan="5">PG 64-22</td><td>PG 58-28</td></tr>
<tr><td>20</td><td rowspan="3">PG 58-34</td><td rowspan="4">PG 64-28</td></tr>
<tr><td>25</td><td rowspan="3">PG 64-28</td><td rowspan="4">PG 64-28</td></tr>
<tr><td>30</td></tr>
<tr><td>35</td><td rowspan="2">PG 64-34</td></tr>
<tr><td>40</td><td>PG 70-22</td><td>PG 64-22</td><td>PG 70-28</td></tr>
<tr><th rowspan="2">Percent RAP</th><th colspan="5">Virgin Binder</th></tr>
<tr><th>PG 52-40</th><th>PG 46-46</th><th>PG 46-40</th><th>PG 40-46</th><th>PG 40-40</th></tr>
<tr><td>0</td><td rowspan="2">PG 52-40</td><td>PG 46-46</td><td>PG 46-40</td><td>PG 46-46</td><td>PG 46-46</td></tr>
<tr><td>10</td><td rowspan="3">PG 52-40</td><td rowspan="2">PG 52-40</td><td rowspan="3">PG 52-40</td><td>PG 46-40</td></tr>
<tr><td>15</td><td rowspan="3">PG 58-40</td><td rowspan="2">PG 52-40</td></tr>
<tr><td>20</td><td>PG 58-40</td></tr>
<tr><td>25</td><td rowspan="2">PG 58-40</td><td rowspan="2">PG 58-34</td><td rowspan="3">PG 58-40</td><td rowspan="2">PG 58-40</td></tr>
<tr><td>30</td><td rowspan="3">PG 64-34</td></tr>
<tr><td>35</td><td>PG 58-34</td><td rowspan="2">PG 64-34</td><td>PG 58-34</td></tr>
<tr><td>40</td><td>PG 64-34</td><td>PG 64-40</td><td>PG 64-34</td></tr>
</table>

**Table 17. Summary - Performance Grading – Northern Reclaimed Asphalt Pavement**

<table>
<tr><th rowspan="2">Percent RAP</th><th colspan="5">Virgin Binder</th></tr>
<tr><th>PG 58-28</th><th>PG 52-28</th><th>PG 52-34</th><th>PG 46-34</th><th>PG 58-34</th></tr>
<tr><td>0</td><td rowspan="3">PG 58-28</td><td rowspan="7">PG 58-28</td><td>PG 52-34</td><td>PG 46-34</td><td>PG 58-34</td></tr>
<tr><td>10</td><td rowspan="6">PG 58-28</td><td rowspan="3">PG 52-34</td><td rowspan="2">PG 58-28</td></tr>
<tr><td>15</td></tr>
<tr><td>20</td><td>PG 64-28</td><td rowspan="5">PG 64-28</td></tr>
<tr><td>25</td><td rowspan="5"></td><td>PG 52-28</td></tr>
<tr><td>30</td><td rowspan="4">PG 58-28</td></tr>
<tr><td>35</td></tr>
<tr><td>40</td></tr>
<tr><th rowspan="2">Percent RAP</th><th colspan="5">Virgin Binder</th></tr>
<tr><th>PG 52-40</th><th>PG 46-46</th><th>PG 46-40</th><th>PG 40-46</th><th>PG 40-40</th></tr>
<tr><td>0</td><td>PG 52-46</td><td>PG 46-46</td><td>PG 46-46</td><td>PG 46-46</td><td rowspan="2">PG 40-52</td></tr>
<tr><td>10</td><td>PG 52-40</td><td>PG 46-40</td><td>PG 46-40</td><td>PG 46-40</td></tr>
<tr><td>15</td><td rowspan="4">PG 58-34</td><td rowspan="2">PG 52-40</td><td>PG 52-40</td><td>PG 52-40</td><td rowspan="4">PG 46-46</td></tr>
<tr><td>20</td><td rowspan="2">PG 52-34</td><td rowspan="3">PG 52-34</td></tr>
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<tr><td>35</td><td>PG 58-34</td><td rowspan="2">PG 58-28</td><td>PG 46-40</td></tr>
<tr><td>40</td><td>PG 68-28</td><td>PG 58-28</td><td>PG 52-40</td></tr>
</table>

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on this limited laboratory study, a number of conclusions have been drawn as follows:

- The low temperature value of the blended PGAC used in RAP mixes is very dependent on the low temperature value of the asphalt cement used in the RAP material, as well as the low temperature value of the virgin PGAC being blended with the RAP material.

- The use of PG 58-28 should be limited to hot mixes that contain less than 10 percent RAP when working in Zone 3. This may be adjusted to 15 percent depending on the low temperature properties of the RAP material being recycled or the low temperature value of the PG 58-28 being used as the virgin binder or both.

- The use of PG 52-34 is the most economical grade to use in southern Ontario to meet the -28°C low temperature requirement. It would appear that up to 40 percent RAP could be added and still meet this requirement. The use of PG 52-34 in Central or Northern Ontario is not recommended.

- The use of PG 52-40 is recommended in Central Ontario (Zone 2) to meet the -34°C low temperature requirement. Also there are no issues with meeting the minimum high temperature requirement of 58°C. In Northern Ontario, PG 52-40 can be used to meet the low and high temperature requirements of PG 52-34 if 20 percent RAP or less is incorporated into the mix.

- If using a -46 PGAC, no more than 35 percent RAP can be added to the mix to meet a PG 52-34 or PG 58-34 grade.

- In order to meet high RAP content mixes, specially blended virgin PGAC may be required. Laboratory evaluation will most definitely be required.

Based on the laboratory study, we would make the following recommendations.

- For the GTA and South-Western Ontario, we would recommend the use of PG 52-34 for all RAP mixes up to a maximum of 40 percent. There are no issues with meeting the minimum high temperature of 58°C and 64°C can be achieved if greater than 25 percent RAP is used.

- Throughout Central Ontario, Eastern region and the Ottawa valley we would recommend the use of PG 52-40 in order to meet the -34°C minimum temperature requirement.

- In Northern Ontario, we would recommend the use of PG 52-40 for mixes containing no more than 20 percent RAP. If the mix contains between 20 and 35 percent RAP, the virgin asphalt cement must be either PG 40-46 or PG 46-46.

- If higher RAP percentages greater than 35 percent are used in either Southern or Northern Ontario, special blending grades will be required.

**REFERENCES**

[1] "Material Specification for Hot Mix Asphalt", OPSS 1150, Ontario Provincial Standard Specification, Ontario Ministry of Transportation, Downsview, Ontario (November, 2002).

[2] Ontario Hot Mix Producers Association (OHMPA). The ABCs of PGAC, Issue 2.0, Toronto, Ontario (April 1999).

[3] ASTM International (ASTM) D1856. "Standard Test Method for Recovery of Asphalt From Solution by Abson Method", Annual Book of ASTM Standards, Road and Paving Materials; Vehicle-Pavement Systems, 04-03, West Conshohocken, Pennsylvannia (2003).

[4] American Association of State Highway and Transportation Officials (AASHTO) M320-05. "Standard Specification for Performance Graded Asphalt Binder", Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 1B, 23rd Edition, Washington, D.C. (2003).