Impact of Virgin Binders on IDEAL-CT Results of RAP Asphalt Mixtures

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ABSTRACT: This study evaluated the impact of virgin binders on the Indirect Tensile Asphalt Cracking Test (IDEAL-CT) results of asphalt mixtures containing reclaimed asphalt pavement (RAP). A total of 14 RAP mixtures were tested, covering two U.S. climate zones, four mix designs, and six virgin binders. Each virgin binder underwent rheological characterization at three aging conditions: unaged, rolling thin film oven (RTFO) plus 20-hour pressure aging vessel (PAV) aging, and RTFO plus 40-hour PAV aging. The test results showed that using a softer virgin binder improved the IDEAL-CT results, whereas using a polymer modified asphalt binder did not show similar benefits. The impact of binder source on the IDEAL-CT results was found to vary depending on the RAP mix design. Moreover, the modified Glover-Rowe (G-R) parameter at 15°C and 10 Hz after 40-hour PAV aging demonstrated the strongest correlation to the IDEAL-CT results, suggesting its potential utility as a mix design tool for screening virgin binders to assess the cracking resistance of RAP mixtures.

1 INTRODUCTION

The asphalt pavement industry in the United States is committed to achieving net-zero carbon emissions by 2050 [1]. One key strategy to meet this goal is to increase the use of RAP in asphalt mixtures. Although this approach provides significant economic and environmental benefits, it also presents pavement performance challenges as RAP mixtures can be susceptible to cracking and durability issues due to increased binder stiffness and brittleness. To address these challenges, many state highway agencies are considering the implementation of a laboratory cracking test to evaluate the cracking resistance of RAP mixtures as part of the mix design and production acceptance process. Among many mixture cracking tests developed over past decades, the Indirect Tensile Asphalt Cracking Test (IDEAL-CT) has gained increasing popularity [2]. This test is favored for its practicality in specimen preparation, simplicity in providing results quickly, and relevance in providing a reasonably strong correlation to field cracking performance [3-4]. Meanwhile, the asphalt pavement industry is actively exploring mix design strategies to improve IDEAL-CT results. One of the most common strategies is to change the source, grade, or type of virgin binder in RAP mixtures. However, limited guidance exists on selecting virgin binders to improve the cracking resistance of RAP mixtures.

2 STUDY OBJECTIVE

The objectives of the study were twofold: (1) to determine the impact of virgin binders on the long-term cracking resistance of RAP asphalt mixtures, as measured by the IDEAL-CT after aging; and (2) to relate binder rheological properties to mixture IDEAL-CT results.

3 EXPERIMENTAL PLAN

3.1 *Materials*

This study included four RAP mix designs, including two from a northern state and two from a southern state in the United States. The RAP content in the mix designs ranged from 20% to 41%, which corresponds to a recycled binder ratio (RBR) of 0.16 to 0.37, assuming 100% binder availability. Table 1 summarizes the key mix design variables. More detailed information is available elsewhere [5].

Table 1. RAP Mix Design Summary

Mix Design ID	Climate Zone	NMAS	Aggregate Type	RBR	Asphalt Content
Northern 25% RAP	Northern State	9.5mm	Granite Dolomite	0.21	5.95
Northern 41% RAP	Northern State	9.5mm	Granite Dolomite	0.37	5.61
Southern 20% RAP	Southern State	9.5mm	Granite	0.16	5.79
Southern 35% RAP	Southern State	9.5mm	Granite	0.29	5.75

The RAP mix designs were evaluated using different virgin asphalt binders to assess mixture cracking performance. The virgin binders included five unmodified performance grade (PG) binders (PG 52-34, two PG 58-28, and two PG 64-22 binders) and a PG 76-22 styrene-butadiene-styrene (SBS) polymer-modified asphalt (PMA) binder. The PG 58-28 and PG 64-22 asphalt binders were sourced from different crude oils and, despite meeting the same PG requirements per AASHTO M 320, were expected to have notably different rheological properties.

3.2 *Virgin Binder Testing*

Each virgin binder was tested using a Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR) to verify Superpave PG. In addition, the DSR frequency sweep test was conducted for rheological characterization at three aging conditions: unaged, RTFO plus 20-hour PAV, and RTFO plus 40-hour PAV. The frequency sweep test was performed across a temperature range of 10°C to 90°C (10°C increments) and an angular frequency range of 0.1 to 30 Hz. The strain level was maintained constant at 0.1% throughout the test. The results were analyzed using RHEA™ software to determine a battery of rheological parameters, including the phase angle (δ) at a complex shear modulus (|G*|) of 8.967 MPa and 15°C (variable frequency), δ at |G*| of 10 MPa and 10 rad/s (variable temperature), crossover frequency (ω_c), crossover modulus (G_c), crossover temperature (T_{Gc}), Glover-Rowe (G-R) parameter at 15°C and 0.005 rad/s, modified G-R parameter at 15°C and 10 Hz (other temperature and frequency combinations were also included, but the results are not included in the paper due to space limitations), and R-value. The R-value results were obtained from DSR master curve analysis utilizing the Christensen-Anderson model at a reference temperature of 15°C with variable glassy modulus G_g and |G*| greater than 10^5 Pa.

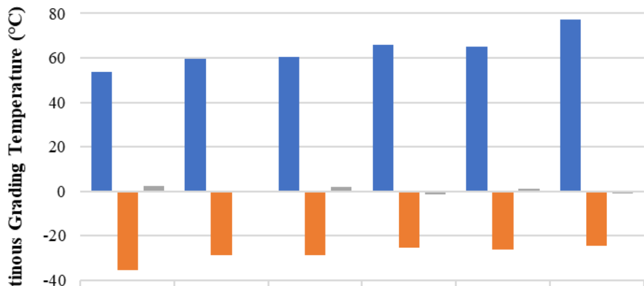
3.3 *RAP Mixture Testing*

The study included fourteen RAP mixtures prepared with different mix design and virgin binder combinations. Each mixture was tested for intermediate-temperature cracking resistance using the IDEAL-CT per ASTM D8225. To account for the impact of asphalt aging, the IDEAL-CT was conducted after long-term aging. The aging procedure involved short-term aging of loose mixtures for 4 hours at 135°C, followed by long-term aging for 6 or 8 hours at 135°C for PG 52-34, PG 58-28, and PG 64-22 binders, and 5 days at 95°C for the PG 76-22 binder. The 95°C aging procedure was used for the PG 76-22 binder to prevent the potential thermal degradation of SBS polymer at an elevated aging temperature, but it was expected to provide an equivalent level of asphalt aging as the 135°C aging procedure according to the |G*| aging kinetics model by Kim et al [6]. Shorter aging times (6 hours) were applied to the two northern mix designs, while longer aging times (8 hours or 5 days) were applied to the southern mix designs. These aging procedures were expected to simulate approximately 5 to 6 years of surface aging for asphalt pavements in the United States [7].

4 TEST RESULTS AND DISCUSSIONS

4.1 *Rheological Characterization of Virgin Binders*

Figure 2 summarizes the virgin binder continuous PG temperatures and ΔT_c results, determined in accordance with ASTM D7643 (AASHTO M 320). All binders met their as-supplied PG requirements. The two PG 58-28 binders from different crude sources showed a 1.6°C difference in ΔT_c, despite having nearly identical continuous grading temperatures. Among the two PG 64-22 binders, Source 2 was slightly softer but exhibited significantly better relaxation properties, as indicated by a 2.7°C higher ΔT_c compared to Source 1. Overall, the virgin binders evaluated in the study covered a wide range of PG and ΔT_c results.



	52-34	58-28 Source 1	58-28 Source 2	64-22 Source 1	64-22 Source 2	76-22 SBS
High	53.6	59.6	60.3	65.7	65.0	77.4
Low	-35.5	-28.6	-28.8	-25.3	-26.4	-24.6
DTc	2.5	0.4	2.0	-1.4	1.3	-1.0

Figure 2. Virgin Binder Continuous PG Temperatures and ΔT_c Results

Tables 2 through 4 summarize the rheological parameters of the virgin binders, determined from the DSR frequency sweep test at three aging conditions. The softer virgin binders (PG 52-34, PG 58-29 Source 1, PG 58-28 Source 2) exhibited lower G-R parameter values (at 15°C and 0.005 rad/s and 15°C and 10 Hz) than the PG 64-22 Source 1, PG 64-22 Source 2, and PG 76-22 PMA binders across all aging conditions. Even after extended aging, the softer binders did not enter the cracking damage zone (i.e., G-R parameter criteria of 180 kPa at 15°C and 0.005 rad/s). Only the PG 64-22 Source 1 binder exceeded the criterion for visible surface cracking (i.e., G-R parameter criteria of 600 kPa at 15°C and 0.005 rad/s) after RTFO plus 40-hour PAV. Among the unmodified binders, PG 64-22 Source 1 exhibited the highest change in G-R parameters, indicating greater susceptibility to aging. Caution is advised when interpreting the G-R parameter (and possibly the R-value) for the PG 76-22 PMA binder, as polymer modification can significantly increase failure strain at a given binder modulus. As expected, as aging progressed for all binders, a decrease in the crossover frequency (ω_c) and crossover modulus (G_c) and an increase in the crossover temperature (T_{Gc}) and R-value were observed.

Table 2. Virgin Binder Rheological Parameter Results at Unaged Condition

Asphalt Binder Properties	52-34	58-28 Source 1	58-28 Source 2	64-22 Source 1	64-22 Source 2	76-22
R-value	1.8	1.7	1.6	1.7	1.7	1.9
δ at |G*| = 8.967 MPa, 15°C (°)	55.5	51.5	56.3	52.0	52.9	49.9
δ at |G*| = 10 MPa, 10 rad/s (°)	54.4	50.4	55.6	51.4	52.3	49.0
ω_c (rad/s)	7.28E+03	1.09E+02	6.90E+02	6.23E+01	8.54E+01	2.31E+01
G_c (Pa)	3.96E+07	1.86E+07	3.28E+07	1.97E+07	2.14E+07	1.53E+07
T_{Gc} (°C)	−8.2	7.3	1.4	8.4	7.2	11.6
$G\text{-}R_{15°C,0.005rad/s}$ (kPa)	0.007	0.3	0.1	0.7	0.7	8.2
$G\text{-}R_{15°C,10Hz}$ (kPa)	5.55E+02	8.98E+03	3.42E+03	1.43E+04	1.24E+04	2.20E+04

Table 3. Virgin Binder Rheological Parameter Results at RTFO plus 20-hour PAV Aging Condition

Asphalt Binder Properties	52-34	58-28 Source 1	58-28 Source 2	64-22 Source 1	64-22 Source 2	76-22
R-value	2.6	2.3	2.1	2.2	2.1	2.1
δ at |G*| = 8.967 MPa, 15°C (°)	44.1	40.7	45.3	39.8	43.7	42.3
δ at |G*| = 10 MPa, 10 rad/s (°)	43.4	39.9	44.8	39.4	43.2	41.9
ω_c (rad/s)	2.52E+01	1.76E+00	5.92E+00	2.34E-02	1.69E+00	2.61E-01
G_c (Pa)	6.77E+06	4.74E+06	8.91E+06	3.83E+06	6.93E+06	5.53E+06
T_{Gc} (°C)	10.7	20.7	15.7	34.6	19.9	25.8
$G\text{-}R_{15°C,0.005rad/s}$ (kPa)	4.2	21.7	16.3	205.8	47.0	191.6
$G\text{-}R_{15°C,10Hz}$ (kPa)	8.47E+03	2.79E+04	2.69E+04	6.70E+04	4.03E+04	7.66E+04

Table 4. Virgin Binder Rheological Parameter Results at RTFO plus 40-hour PAV Aging Condition

Asphalt Binder Properties	52-34	58-28 Source 1	58-28 Source 2	64-22 Source 1	64-22 Source 2	76-22
R-value	2.8	2.4	2.4	2.9	2.2	2.5
δ at |G*| = 8.967 MPa, 15°C (°)	39.4	37.1	41.7	35.6	41.7	38.8
δ at |G*| = 10 MPa, 10 rad/s (°)	38.8	36.4	40.9	35.1	41.3	38.4
ω_c (rad/s)	1.52E+00	2.23E-01	5.88E-01	4.57E-03	2.35E-01	2.50E-02
G_c (Pa)	3.17E+06	2.69E+06	5.03E+06	1.36E+06	4.81E+06	2.84E+06
T_{Gc} (°C)	20.7	26.6	24.2	40.2	26.4	34.2
$G\text{-}R_{15°C,0.005rad/s}$ (kPa)	30.3	111.3	88.3	966.8	189.2	736.9
$G\text{-}R_{15°C,10Hz}$ (kPa)	1.81E+04	3.66E+04	5.02E+04	9.66E+04	7.07E+04	1.05E+05

4.2 *IDEAL-CT Testing of RAP Mixtures*

Figure 3 presents the IDEAL-CT results of RAP mixtures using different mix design and virgin binder combinations. The columns and error bars represent the average and standard deviation, respectively, of the cracking tolerance index (CT_{Index}). The letters represent statistical groupings for individual mix designs according to the Tukey-Kramer test. For all RAP mix designs, using a softer virgin binder increased the CT_{Index}, suggesting improved cracking resistance. While the degree of improvement varied across different mix designs, it was statistically significant in all cases except for the northern 25% RAP mix design with PG 58-28 Source 2 binder and the northern 41% RAP mix design with PG 58-28 Source 1 binder.

For the two southern RAP mix designs, using a PG 76-22 SBS modified binder or changing the PG 64-22 binder source did not statistically affect the CT_{Index}, when the test variability was considered. However, changing the PG 58-28 binder from Source 1 to Source 2 (with a 2.7°C lower ΔT_c) increased the CT_{Index} of the two northern mix designs, but the improvement was not statistically significant for the 41% RAP mix design according to the statistical grouping letters.

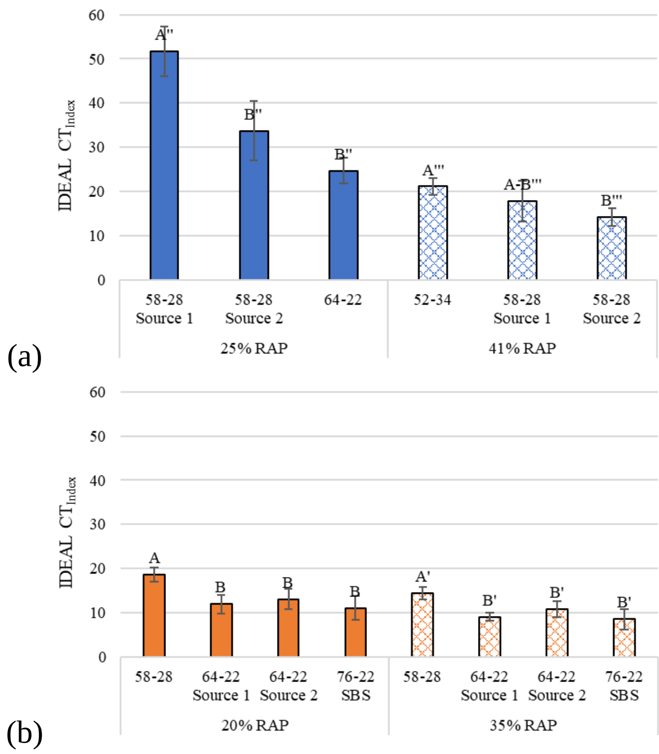
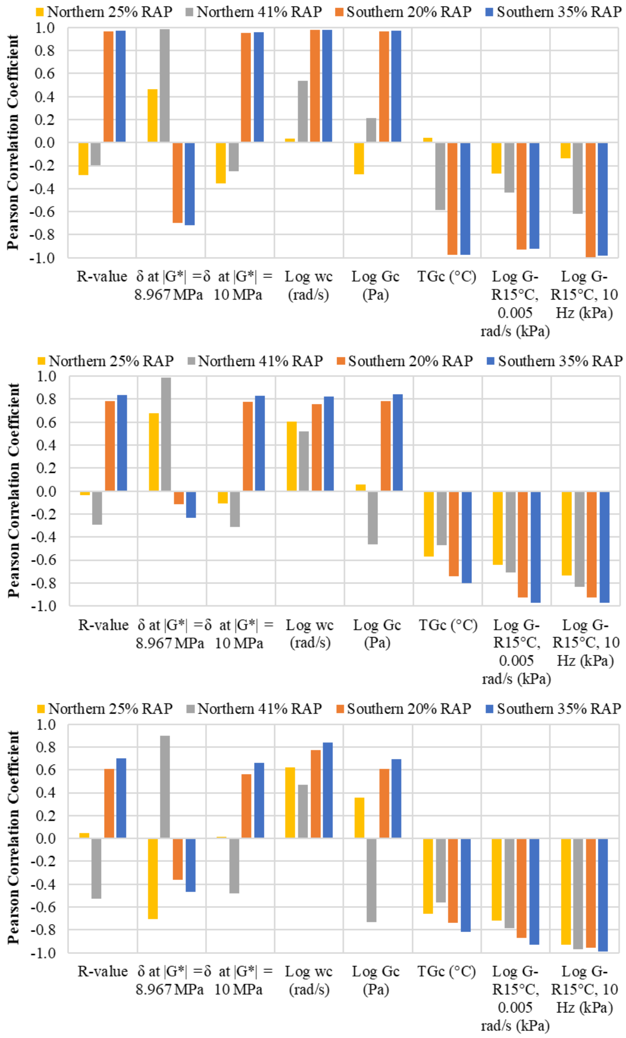


Figure 3. RAP Mixture IDEAL-CT Results: (a) Northern Mix Designs, (b) Southern Mix Designs

4.3 *Relating Virgin Binder Rheological Parameters to Mixture IDEAL-CT Results*

Pearson correlation analysis was conducted to relate the rheological properties of virgin binders to the IDEAL-CT results of RAP mixtures. The analysis focused on RAP mixtures using the same mix design but with different virgin binders, allowing for the isolation of potential confounding impacts of other design variables, such as RAP content, aggregate type, and aggregate gradation. Furthermore, the analysis was conducted separately for each binder aging condition, and the Pearson correlation coefficient (*r*) results are summarized in Figure 4.



(a)

(b)

(c)

Figure 4. Pearson Correlation Coefficients for CT_{Index} versus Binder Rheological Parameters: (a) Unaged, (b) RTFO plus 20-hour PAV Aging, (c) RTFO plus 40-hour PAV Aging

Among all the rheological parameters evaluated in the study, only ω_c and G-R showed consistent trends (either positive or negative correlations) with the IDEAL-CT results across all RAP mix designs and binder aging conditions. For both G-R parameters, the correlation to CT_{Index} improved as binder aging increased, especially from unaged to 20-hour PAV aging. After 40-hour PAV aging, the modified G-R parameter at 15°C and 10 Hz exhibited a strong correlation with CT_{Index}, with an $|r|$ value exceeding 0.9 across all RAP mix designs, as shown in Figure 5. This suggests that the modified G-R parameter can serve as a potential mix design tool for screening virgin binders to enhance the IDEAL-CT results of RAP mixtures.

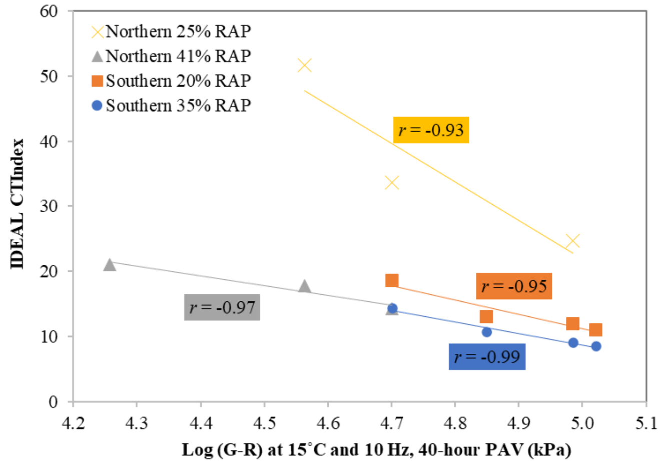


Figure 5. Correlation of Modified G-R Parameter at RTFO plus 40-hour PAV Aging to IDEAL-CT

5 FINDINGS AND CONCLUSIONS

This study concluded that using a softer virgin binder significantly improved the IDEAL-CT results of RAP mixtures, whereas using a PMA binder did not yield comparable advantages. The effects of changing the binder source on the IDEAL-CT results were inconclusive due to the limited data available. Among the various binder rheological parameters evaluated, the modified G-R parameter at 15°C and 10 Hz after RTFO plus 40-hour PAV aging exhibited the strongest correlation with the IDEAL-CT results. Therefore, this parameter holds promise as a mix design tool for screening virgin binders to improve the cracking resistance of RAP mixtures. However, further verification is necessary for additional asphalt mixtures incorporating different virgin binder sources, RAP sources, and aggregate types.

6 REFERENCES

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