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CalRecycle

Asphalt Rubber Performance Models

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Executive Summary

The California Department of Transportation (Caltrans) is the largest user of rubberized asphalt mixes in the United States. Rubberized asphalt mixes used in California include rubberized hot mix asphalt gap-graded (RHMA-G) and open-graded (RHMA-O) mixes and rubberized asphalt chip seals. The use of rubberized asphalt mixes by cities and counties in California has increased over the past decade with assistance from the California Department of Resources Recycling and Recovery's (CalRecycle) Rubberized Pavement Grant Program.

To demonstrate the benefits, and potentially increase statewide usage of rubberized asphalt treatments, additional research was needed to quantify rubberized asphalt mix performance and to develop rubberized hot mix asphalt (RHMA) and rubberized asphalt chip seal performance prediction models to be considered for incorporation into local agency pavement management programs.

The objective of this study is to quantify and compare the performance of RHMA and rubberized asphalt chip seals to non-rubberized dense-graded hot mix asphalt and non-rubberized chip seals on the California local roadway network. This study also developed performance models for typical rubberized asphalt treatments used in California.

The dataset for this project was compiled from CalRecycle grant records (2003 to 2023) and the associated pavement maintenance and condition history records for local agencies throughout California. The pavement maintenance and condition history records were provided courtesy of the Metropolitan Transportation Commission for all roadways whose agency has an active StreetSaver® pavement management program (49 local agencies). A rigorous effort was made to align projects from the CalRecycle Rubberized Pavement Grant Program with the available StreetSaver® data.

For RHMA overlays, project data were plotted based on pavement condition and age and subsequently compared to the StreetSaver® performance model for conventional hot mix asphalt (HMA) overlays. The analysis included comparisons by roadway functional classification, overlay thickness, climate zone, and combinations thereof. For rubberized asphalt chip seal projects, a similar analysis was conducted based on roadway functional classification (data was insufficient to analyze based on climate zone).

Table ES1 provides the estimated RHMA overlay life extension (i.e., additional years of life compared to a conventional HMA overlay).

Table ES1. RHMA Overlay Life Extension (years)

Climatic Zone	Overlay Thickness (in.)	Arterial	Collector	Residential
Dry no freeze	≤ 1.5	1.3	0.8	1.5
Dry no freeze	1.5 – 2.5	3.2	4.5	6.0
Wet no freeze	≤ 1.5	4.4	6.1	---
Wet no freeze	1.5 – 2.5	5.9	8.2	---
Wet no freeze	> 2.5	7.0	---	---

Notes: “---” indicates insufficient data to assess life extension.
Wet no freeze climates include Caltrans Districts 1 and 4 and the western portion of Districts 2 and 3.
Dry no freeze climates include Caltrans Districts 5 through 12 and the eastern portion of Districts 2 and 3.

Rubberized asphalt chip seals placed when the existing pavement was in good condition showed similar performance to generic (i.e., non-rubberized) surface seals. However, when the existing pavements were in fair to good condition, the rubberized asphalt chip seal performed better (i.e., less pavement distress, longer performance life) than the generic surface seals.

The models developed herein will be provided to the Metropolitan Transportation Commission for consideration for adoption into the StreetSaver® program. While the data used for model development was consolidated from StreetSaver® databases, the models are applicable to and will be made available for potential adoption in other pavement management systems.

Introduction

The California Department of Transportation (Caltrans) is the largest user of rubberized asphalt mixes in the United States. Rubberized asphalt mixes used by Caltrans predominately include rubberized hot mix asphalt gap- and open-graded (RHMA-G and RHMA-O, respectively) mixes and rubberized asphalt chip seals.

Several studies have quantified hot mix asphalt (HMA) and RHMA performance specific to California highway conditions. For Caltrans, the University of California Pavement Research Center in 2007 quantified the reflective cracking performance of gap-graded asphalt concrete mixtures using a control binder, a binder with a minimum of 15% recycled tire rubber, and a terminal blend binder with at least 15% recycled crumb rubber.[*] All the mixtures with crumb rubber were more resistant to reflective cracking than were the mixtures without crumb rubber. The following year, a study was conducted to evaluate the performance and cost-effectiveness of pavement preservation treatments with conventional and rubberized asphalt.[†] The study findings indicated the rubberized asphalt overlays had a 3-year-longer performance life than did the dense-graded overlays with conventional asphalt binder. The open-graded rubberized asphalt overlays showed an approximately 2-year-shorter performance life than did the open-graded asphalt overlay. Overall, the rubberized asphalt chip seals had zero to 4 years shorter performance life than the conventional chip seals; however, relatively few rubberized asphalt treatments were included in the analysis. More recently, in 2022, NCE evaluated the performances of RHMA and conventional HMA-Type A mixes on the California highway network. In general, RHMA-G overlays performed better than HMA-Type A overlays. The average expected service lives of RHMA and HMA-Type A are similar; however, on the highway network, pavements with an RHMA-G overlay typically carry a higher volume of truck traffic than do pavements with an HMA-Type A overlay.

* D. Jones, J. Harvey, and C. Monismith, Reflective Cracking Study: Summary Report (2007), https://www.ucprc.ucdavis.edu/PDF/4.10_Phase3-03_Summary_Long_Stg6_09-12-08.pdf.

† D. Jones and J. Harvey, "Accelerated Pavement Testing Experiment to Assess the Use of Modified Binders to Limit Reflective Cracking in Thin Asphalt Concrete Overlays," *Transportation Research Circular E-C139: Use of Accelerated Pavement Testing to Evaluate Maintenance and Pavement Preservation Treatments* (2009): 11–31.

In 2014, the California State University, Chico, conducted a study to evaluate the performance of rubberized asphalt pavement projects on local agency-maintained roadways.[‡] The study evaluated several RHMA projects constructed in the San Francisco Bay Area and Los Angeles County to develop performance models. At the time of the study, most of the rubberized asphalt treatments (e.g., chip seals and RHMA) had in-service pavement lives of less than 10 years. In addition, the study was limited to only RHMA overlays 1.5 and 2 inches thick. Beyond the Chico study, few, if any, studies have quantified the in-service performance life of rubberized asphalt treatments on California local agency roadways.

To demonstrate the benefits, and potentially increase statewide usage of rubberized asphalt treatments, additional research is needed to quantify performance and develop RHMA and rubberized asphalt chip seal performance models for potential incorporation into local agency pavement management programs.

The objective of this study is to quantify the performances of RHMA and rubberized asphalt chip seals and compare these to non-rubberized dense-graded HMA and non-rubberized chip seals on the California local roadway network. Additionally, contingent on the availability of sufficient data, the study will develop performance models for typical rubberized asphalt treatments used in California.

[‡] D. Cheng, B. Fraser, R. G. Hicks, and M. B. Garcia, “Evaluating the Performance of Asphalt Rubber Used in California” (2014).

Data for Performance Evaluation

The dataset for this project was compiled from CalRecycle's rubberized pavement grant records, as well as maintenance and condition history records for local agencies throughout California, provided courtesy of the Metropolitan Transportation Commission (MTC).

Data Sources

CalRecycle provided a list of local agency projects awarded rubberized pavement grants over the past 20 years. This list included the RHMA overlay grant programs and one rubberized asphalt chip seal grant program, representing 780 grants provided to 49 local agencies:

- Rubberized Pavement Grant Program (2011 – 2012 to present)
- Targeted Rubberized Asphalt Concrete Incentive Grant Program (2005 – 2006 to 2010 – 2011)
- Rubberized Asphalt Concrete Chip Seal Grant Program (2007 – 2008 to 2010 – 2011)
- Rubberized Asphalt Concrete Grant Program (2003 – 2004 to 2008 – 2009)

The grant project list included the fiscal year, grantee, funds awarded, material quantity, material type and unit cost, manufacturer, supplier, contractor, and roadways paved. The compiled list of grant projects was provided to MTC to obtain the associated maintenance history and pavement condition data.

MTC provided pavement maintenance history and pavement condition data for all listed grant agencies with active StreetSaver® subscriptions. The maintenance history information included functional classification, treatment type, project limits, project area, maintenance date, and pavement condition before treatment and up to 16 years after treatment. The pavement condition before treatment was projected from the previous condition survey to just before the maintenance application date. The pavement condition after treatment was obtained from post-maintenance condition surveys.

The MTC-provided maintenance and pavement condition database was searched for any historical maintenance projects with a derivative of "rubber" in the maintenance treatment name (e.g., rubberized asphalt concrete, rubberized chip seal, RHMA overlay). These projects formed the basis of the project dataset.

Performance Factors

Pavement performance is a function of factors such as material type, layer thickness, climate, pre-treatment pavement condition, and truck traffic loading. To the extent possible, each of these factors was identified for projects in the dataset.

The appropriate Long-Term Pavement Performance (LTPP) program climate zone was identified for each project based on its location (Figure 1). Since the dataset included only California agencies, the dry freeze and wet freeze climate zones were not represented. Consequently, only the dry no freeze and wet no freeze climate zones were represented by projects in the analysis.

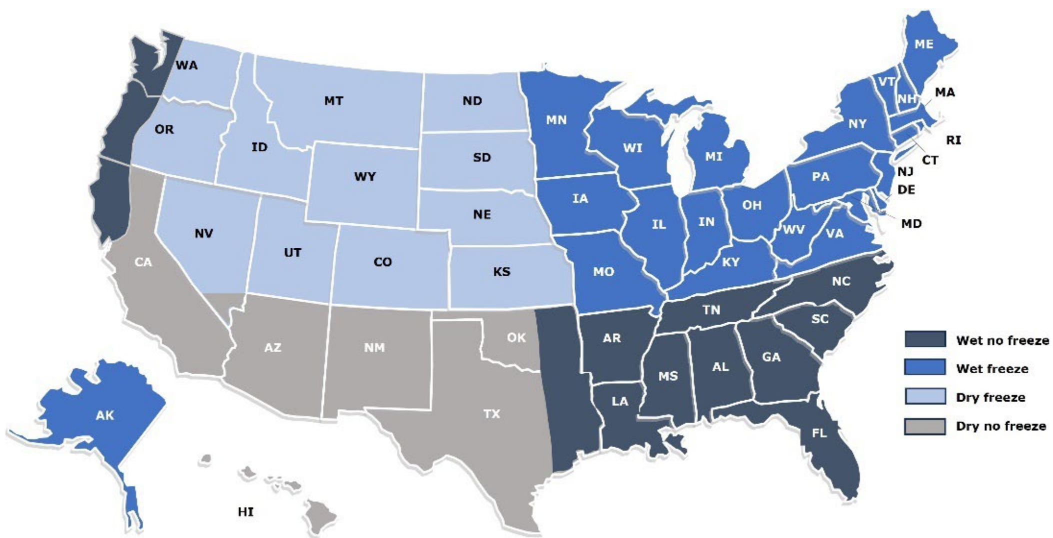


Figure 1. LTPP climate zone map (source: NCE)

Dry no freeze climate zones in California include District 1, the northern portion of District 4, and the western portions of Districts 2 and 3. Wet no freeze climate zones include the eastern portions of Districts 2 and 3, the southern portion of District 4, and Districts 5 through 12 (Figure 2).

For the RHMA overlay projects, the overlay thickness was taken from the maintenance history treatment name (e.g., 1-3/4-in. Grind and RHMA Overlay). If the maintenance history treatment name did not include the overlay thickness, it was estimated based on the material quantity listed in the CalRecycle grant information and from the project area included in the maintenance and condition history. Overall, RHMA thicknesses included in the analysis ranged from 0.5 to 8.0 inches and were grouped into 3 categories: thin (< 1.5 inches), moderate (1.5 to 2.5 inches), and thick (> 2.5 inches).

Figure 2. Caltrans districts and approximate location of climate zones (source: cwwp2.dot.ca.gov, NCE edited)

The condition of project pavements prior to treatment was also included in the analysis. Pavement condition was quantified in terms of the pavement condition index (PCI), as is typical for StreetSaver®. PCI ranges from 0 to 100, with 100 representing new construction (or new overlay), and values less than 25 representing highly distressed or failed pavements (Figure 3).

PCI increases when pavements are treated with surface seals; this change is referred to as delta PCI. Treatment always increases PCI, but the magnitude of the increase depends on the condition of the pavement before treatment (i.e., the worse the pre-treatment condition, the lower the delta PCI). To analyze delta PCI, the PCI before treatment was grouped into four categories within the ranges that typically warrant chip seal application (PCI 50 to PCI 90).

In summary, the factors used in the analysis included:

- Treatment type: RHMA overlay, rubberized asphalt chip seal
- Functional classification: arterial, collector, residential
- Climate zone: dry no freeze, wet no freeze

- Overlay thickness: thin, moderate, thick
- PCI before treatment: 50 to 59, 60 to 69, 70 to 79, 80 to 89

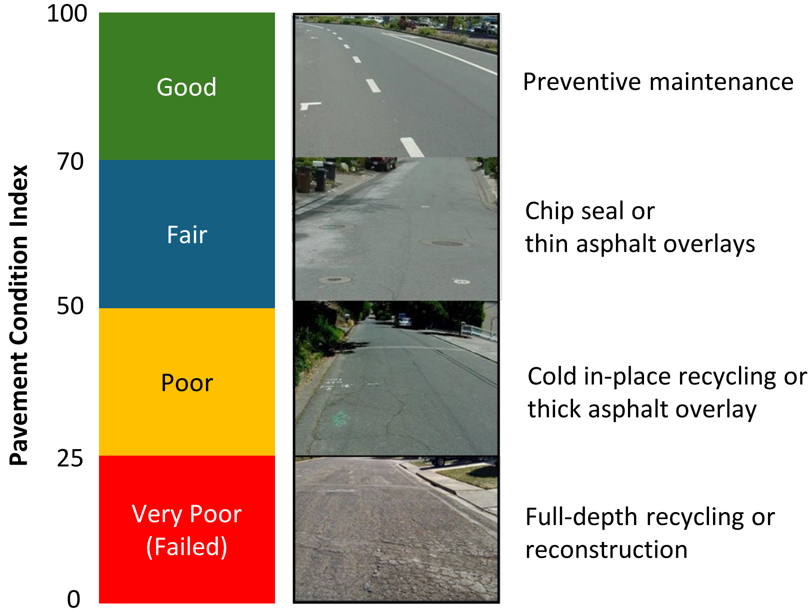


Figure 3. Example PCI thresholds, conditions, and typical treatments (source: NCE)

Data Cleaning

Real-world data from uncontrolled studies such as this can be imperfect. For example, historical maintenance treatments and dates may be missing from agency records or a rigorous quality control process may not have been followed by each agency during pavement condition assessment. Such circumstances require the data to be reviewed and cleaned to remove outliers and inconsistencies and identify sections with missing data in order to obtain the best quality dataset for analysis.

If project information was obtained solely from the maintenance and condition history and no grant information was available, or if the resulting overlay thickness estimate was unreasonable, the project was excluded from the analysis.

The maintenance history and PCI values were reviewed for each project in the dataset. If the section received a rubberized asphalt treatment and a subsequent non-rubberized maintenance treatment, the PCIs after the non-rubberized asphalt treatment were removed from the dataset. If the PCI after the rubberized asphalt treatment increased unexpectedly (suggesting that, e.g., an overlay was applied but not recorded), the PCI data after the increase was removed from the dataset. Finally, agencies with limited data, very few projects, or very little post-construction PCI data were removed from the dataset.

An example of the cleaning process is shown in Figure 4. As illustrated, the example pavement section received an RHMA overlay at age 0, which increased the PCI to 100. From ages 1 to 6, the PCI decreased a few points each year. In year 7, a slurry seal was applied, and the PCI increased a few points, after which the PCI deteriorated again over time. In this example, the PCI data points from years 7 to 16 were removed from the dataset to ensure the PCI points corresponded to the RHMA overlay only.

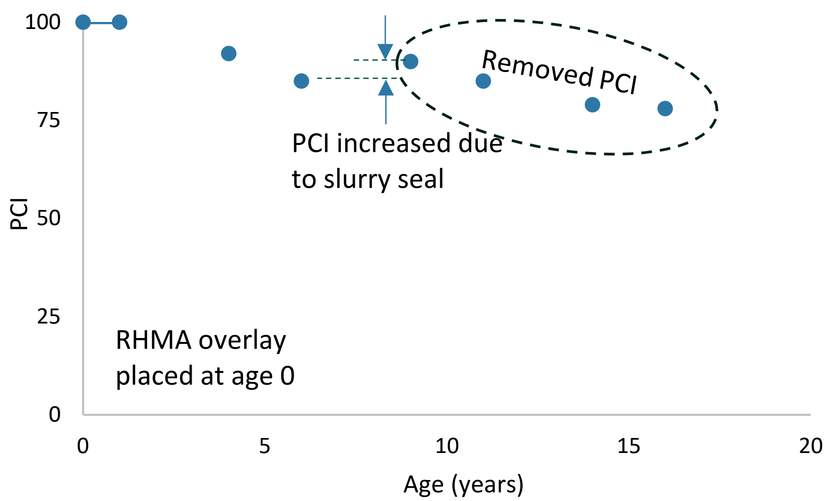


Figure 4. Example data cleaning for RHMA overlay project

The data collection, combination, and cleaning process resulted in a dataset comprising 11,682 observations from 3,404 asphalt rubber treatment projects in 49 counties. Table 1 and Table 2 summarize the number of observations for RHMA overlays and asphalt rubber chip seals, respectively.

Limitations

The data for this study is not without limitations. First, this data was derived from an uncontrolled, unpaired study, meaning the data was not collected specifically for this study (e.g., pavement condition was assessed by different raters), and there were no control sections (i.e., non-rubberized asphalt treatment) constructed for direct comparison of performance. As noted, the data was collected by many agencies and consultants over 20 years, likely with inconsistent quality control practices across geography and time.

Second, the completeness of the maintenance and pavement condition history of the agencies is unknown. While the goal of data cleaning is to isolate the PCI data after treatment corresponding only to the treatment being investigated, there may have been treatments unaccounted for in the dataset.

Table 1. Numbers of RHMA overlay observations of each functional classification, climate zone, and overlay thickness

Functional Classification	Dry No Freeze Thin	Dry No Freeze Moderate	Dry No Freeze Thick	Wet No Freeze Thin	Wet No Freeze Moderate	Wet No Freeze Thick	All
Arterial	942	981	251	90	294	207	2,765
Collector	404	433	331	26	64	5	1,263
Residential	329	873	109	6	3	2	1,322
Total	1,675	2,287	691	122	361	214	5,350

Table 2. Numbers of asphalt rubber chip seal observations of each functional classification and PCI before treatment

Functional Classification	< 30	30 – 40	40 – 50	50 – 60	60 – 70	70 – 80	80 – 90	All
Arterial	19	11	17	50	63	60	51	271
Collector	48	27	42	78	124	95	24	438
Residential	427	205	352	409	456	276	115	2,240
Total	494	243	411	537	643	431	190	2,949

Third, the pavement condition data after treatment represented a maximum of 16 years of post-treatment condition. This data range may not represent a complete pavement service life; therefore, the performance of the investigated pavement treatments beyond 16 years is unknown.

Fourth, while the available data included several factors, some of the factors did not have sufficient data to support analysis. Specifically, the dataset did not include projects in wet freeze climates, and very few data points represented dry freeze climates. Therefore, 2 LTPP climate zones were uninvestigated in the analysis.

Finally, additional factors relevant to the treatment performance may not be accounted for in the dataset and subsequent analyses. For example, RHMA material requirements (e.g., reduction in fines content and minimum binder content), and construction acceptance criteria have changed over the past 20 years.

RHMA Overlays

Analysis

Models describing RHMA overlay performance were developed and compared to standard HMA overlay performance models to quantify differences in performance between RHMA overlay and standard HMA overlay. The standard HMA overlay performance models constitute proprietary information and were provided courtesy of StreetSaver® for use in this analysis.

The data for each investigation group (i.e., functional class only, functional class and climate zone, and functional class and climate zone and overlay thickness) were used to develop the model comparing the PCI to the overlay age. The StreetSaver® standard HMA overlay performance models for each functional classification were included in each respective plot. The performance model was based on a logarithmic sigmoidal (s-shaped) model of the format shown in Equation 1[§]. This is the standard format for performance models used in pavement management decision-support software such as StreetSaver®. The χ value in this equation is typically used to modify models to better fit the observed data for a specific treatment. All other coefficients are specific to each investigation group.

$$PCI = 100 - \frac{\chi * \rho}{\left(ln\left(\frac{\alpha}{AGE}\right)\right)^{\frac{1}{\beta}}} \qquad \text{(Eq. 1)}$$

where,

PCI	=	pavement condition index
χ	=	PCI bending multiplicative adjustment factor
AGE	=	age at which the PCI is to be calculated (date being analyzed minus date of construction in decimal year values since surface construction)
ρ	=	regression constant, controls the age at which the performance model inflection point occurs
α	=	regression constant, controls the age to which the performance model is asymptotic
β	=	regression constant, controls how sharply the performance model bends

§ R.E. Smith, Developing Family Curves Technical Description for StreetSaver® Pavement Management Program (2023).

All model coefficients (ρ, α, β) were held constant and the χ value was adjusted to improve the fit for the RHMA overlay data. However, if the performance model could not be improved with this adjustment, then a best-fit logarithmic sigmoidal model was developed using different values for the regression constants. The best-fit performance models with the highest coefficient of determination (R^2) value and the lowest root mean squared error (RMSE) were selected. R^2 describes the proportion of variation explained by the model (typically the higher, the better) and the RMSE measures the average difference between the values predicted by the model and the observed values (the lower, the better).

Each investigation group's RHMA overlay performance model was compared to the standard HMA overlay performance model for its functional classification. The performance life of RHMA overlays was calculated and compared to the performance life of a standard HMA overlay for each investigation group based on the following assumptions:

- RHMA overlay performance models developed in this study are relevant after 16 years.
- Pavement service life ends when the pavement falls into failed condition (PCI < 25).

Life extension is defined as the number of years of additional service life associated with RHMA overlay relative to standard HMA overlay at PCI = 25 (Figure 5). Both overlay types start at a PCI of 100 immediately following construction and deteriorate over time. The life extension associated with an RHMA overlay is the time difference between the total service life of the RHMA overlay and the total service life of the HMA overlay at a PCI of 25.

To investigate whether thick RHMA overlays are typically placed on pavements in poor condition, a histogram of PCI before treatment was prepared for thick (> 2.5 inch) RHMA overlay projects.

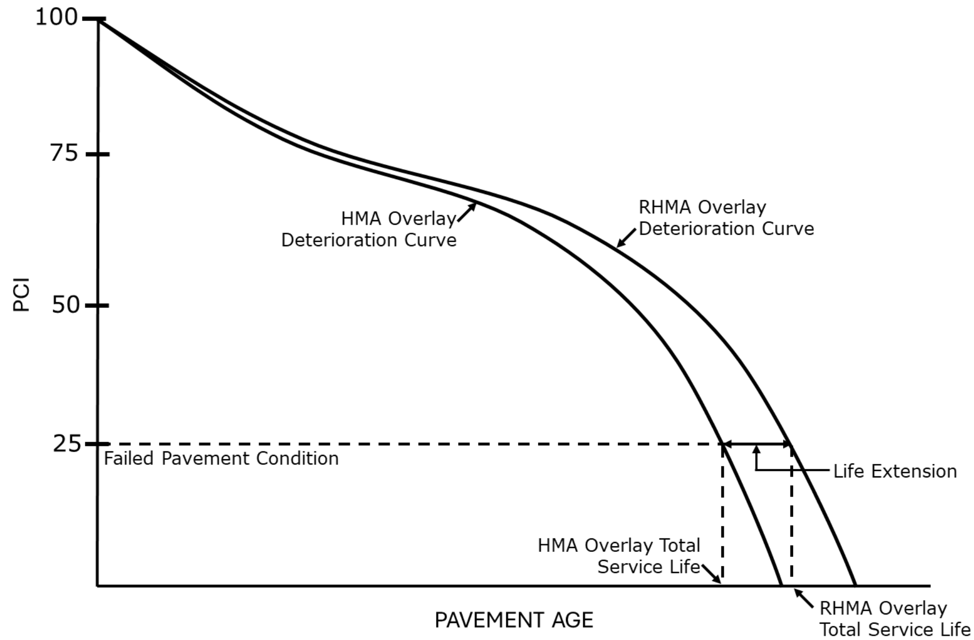


Figure 5. Life extension calculation for RHMA overlays compared to HMA overlays

Results

For most of the investigation groups, the RHMA overlay performance models were modified by adjusting the χ value for the HMA overlay performance models. Only the thick (> 2.5 inch) RHMA overlay by functional classification, and the thick RHMA overlay, dry no freeze climate zone by functional classification investigation groups could not be modified by adjusting the χ value, requiring new coefficients to obtain best-fit models.

Figure 6 to Figure 8 show the RHMA overlay (solid blue line) and the conventional HMA overlay (black dotted line) performance models by functional classification (arterial, collector, and residential, respectively). The RHMA overlay performance model shows slower deterioration (improved performance) over the analysis period for arterials, collectors, and residential streets. This trend is typical for most of the investigation groups. The performance models for all RHMA overlay investigation groups are included in Appendix A.

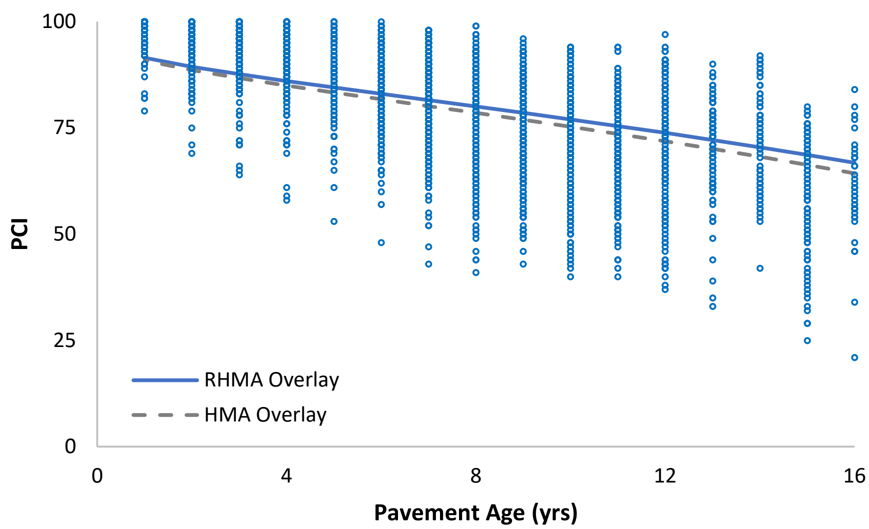


Figure 6. RHMA overlay performance model — Arterials

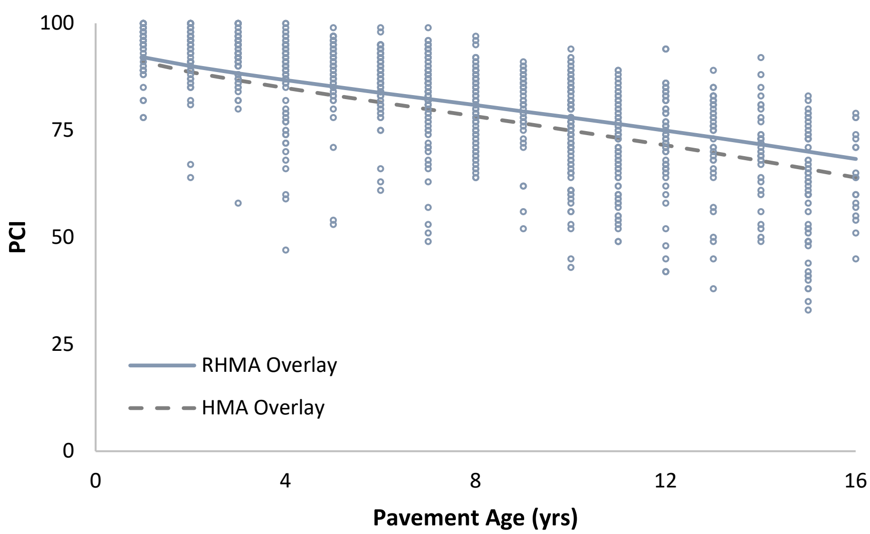


Figure 7. RHMA overlay performance model — Collectors

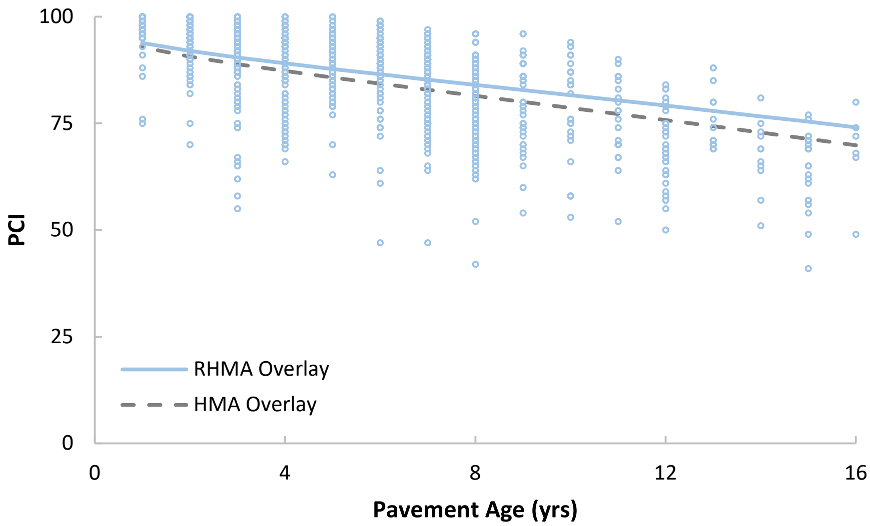


Figure 8. RHMA overlay performance model — Residentials

Notably, the thick (> 2.5 inch) RHMA overlay by functional classification, and the thick RHMA overlay, dry no freeze climate zone by functional classification models showed more rapid deterioration than standard HMA overlay (Figure 9 and Figure 10, respectively). This may be related to the condition of street sections on which thick RHMA overlay is typically applied.

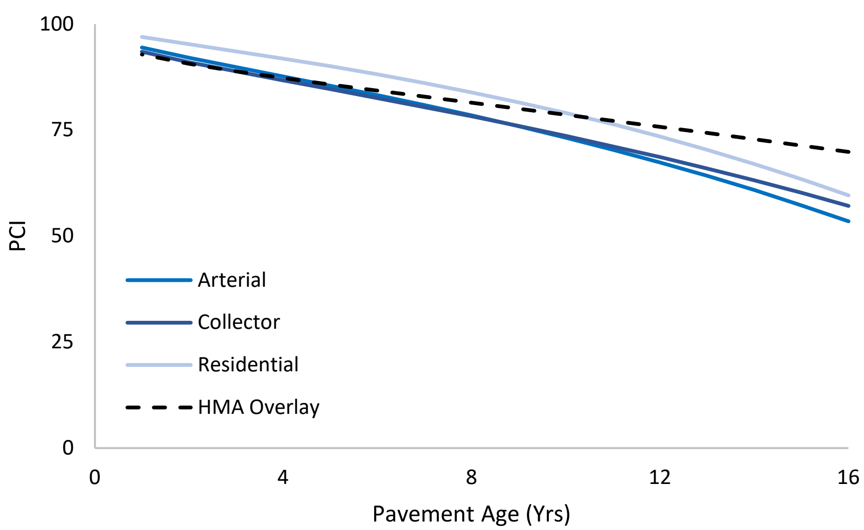


Figure 9. RHMA performance model — thick overlays — all functional classifications

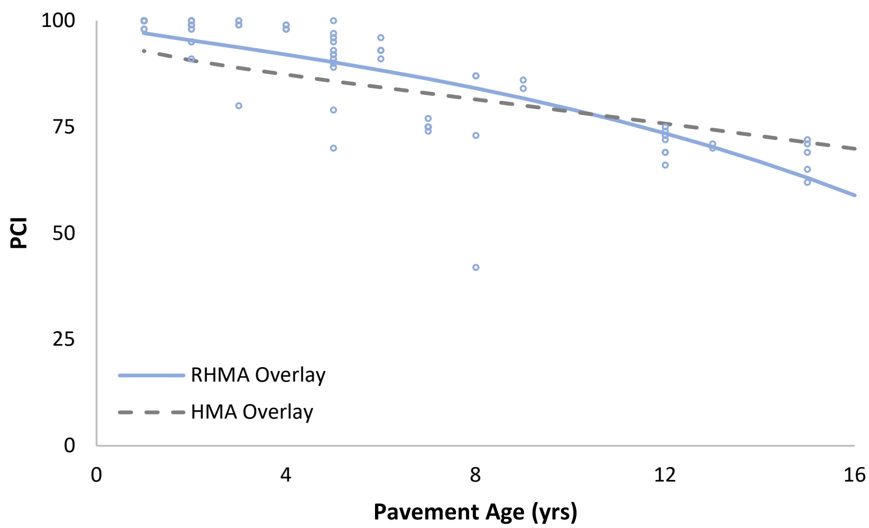


Figure 10. RHMA performance model — thick overlays — all functional classification — dry no freeze climate zone

Figure 11 shows the frequencies of the PCIs before treatment for thick RHMA overlays for streets of each functional classification. The PCI distribution for arterial streets with thick overlay is fairly bell-shaped, with a center in the PCI 51 to 60 range. The PCI distribution for collector streets with thick overlay is slightly left skewed, with the bulk of the data between PCIs of 41 to 80. The PCI distribution for residential streets is also slightly left skewed, with the bulk of the data between PCIs of 61 to 80. Based on the available data, thick RHMA overlays are not generally performed on pavements in poor condition (PCIs less than 50), but they are typically placed on pavements in fair condition. Thus, the pavement condition before treatment is likely not the only explanation for the relatively poor performance of thick RHMA overlays. Additional evaluation is needed to identify potential causes of poorer performance of the thick RHMA overlays; however, this evaluation is beyond the scope of this study.

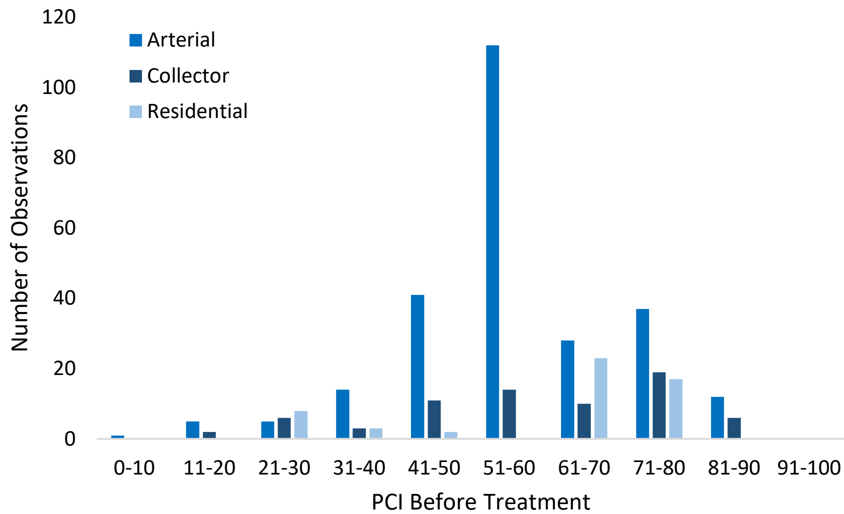


Figure 11. Distribution of thick RHMA overlay by PCI before treatment

The effect of RHMA overlay thickness on pavement performance exhibits an interesting trend across all functional classifications (Figure 12). Thin RHMA overlays deteriorate more slowly than standard HMA overlays. Moderate RHMA overlays with thicknesses between 1.5 and 2.5 inches deteriorate even more slowly and have an even greater benefit than the thinner RHMA. However, thick RHMA overlays deteriorate more rapidly than standard HMA overlays after about 5 years.

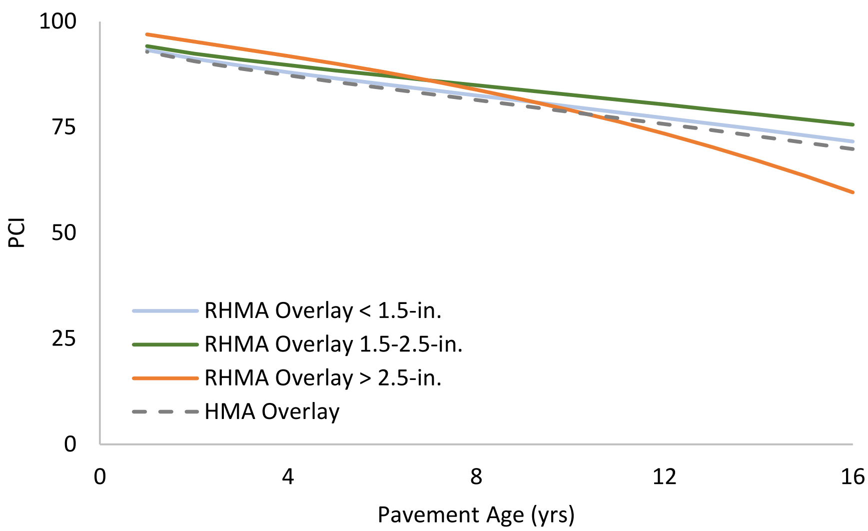


Figure 12. RHMA performance models — residential streets and overlay thickness

Climate zone also impacts RHMA overlay performance (Figure 13). RHMA overlays constructed in areas with a wet no freeze climate perform better than those constructed in a dry no freeze climate zone.

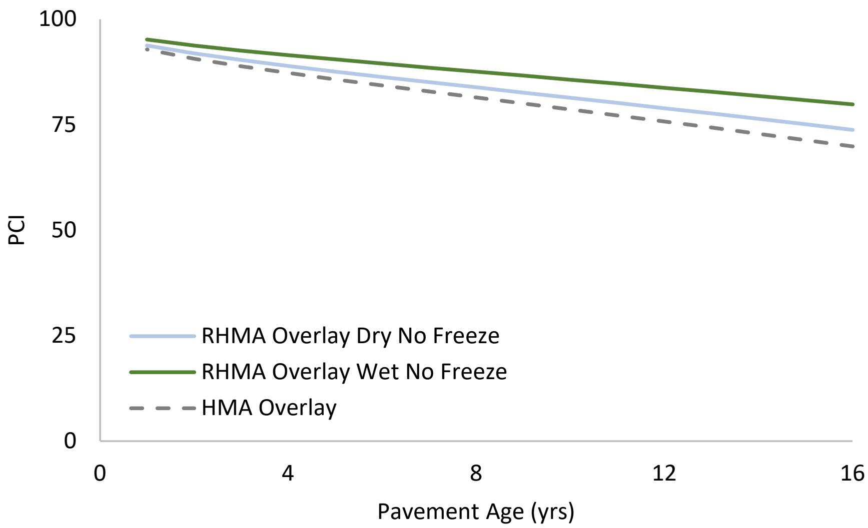


Figure 13. RHMA performance models — residential streets and climate zone.

Table 3 summarizes the life extension associated with RHMA overlays compared to standard HMA overlays for all investigation groups. The results indicate the RHMA overlays provide the greatest benefit and life extension for residential streets, projects in wet no freeze climates, and overlays of moderate thickness. RHMA overlays perform similarly for arterial and collector streets irrespective of climate, with collectors generally performing slightly better than arterials. Thick RHMA overlays do not perform better than standard HMA overlays.

Table 3. RHMA overlay life extension (years)

Investigation Group	Arterial	Collector	Residential
Functional Classification Only	1.3	2.4	4.3
Segments only in Dry No Freeze Climates	0.5	1.8	4.0
Segments only in Wet No Freeze Climates	5.0	6.1	11.5
Overlay ≤ 1.5 in.	1.3	1.0	1.8
Overlay 1.5 – 2.5 in.	3.6	4.9	6.0
Overlay > 2.5 in.	-7.4	-6.0	-15.9
Dry No Freeze Climates, Overlay ≤ 1.5 in.	1.3	0.8	1.5
Dry No Freeze Climates, Overlay 1.5 – 2.5 in.	3.2	4.5	6.0
Dry No Freeze Climates, Overlay > 2.5 in.	-12.3	-7.3	-16.4
Wet No Freeze Climates, Overlay ≤ 1.5 in.	4.4	6.1	NA
Wet No Freeze Climates, Overlay 1.5 – 2.5 in.	5.9	8.2	NA
Wet No Freeze Climates, Overlay > 2.5 in.	7.0	NA	NA

Rubberized Asphalt Chip Seals

Analysis

Models describing rubberized asphalt chip seal performance were developed and compared to generic surface seal performance models to quantify differences in performance between rubberized asphalt chip seal and generic surface seal. The generic surface seal performance models constitute proprietary information and were provided courtesy of StreetSaver® for use in this analysis.

Data from the first 2 years after treatment was excluded from the analysis because inspections performed within the first couple of years of surface seal applications can yield artificially high PCIs due to underlying distress being hidden by the seal. Post-treatment data from beyond 10 years was also excluded because surface seals are often performed on a set cycle (e.g., every 8 years), and the likelihood of the data reflecting unrecorded treatments increases over time.

Using this data, a model describing rubberized chip seal performance was developed for each investigation group using the logarithmic sigmoidal approach described in Equation 1. The best-fit performance model was extrapolated back to the time of the treatment (dashed portion of the line). The best-fit models were selected as those with the highest R^2 value and the lowest RMSE.

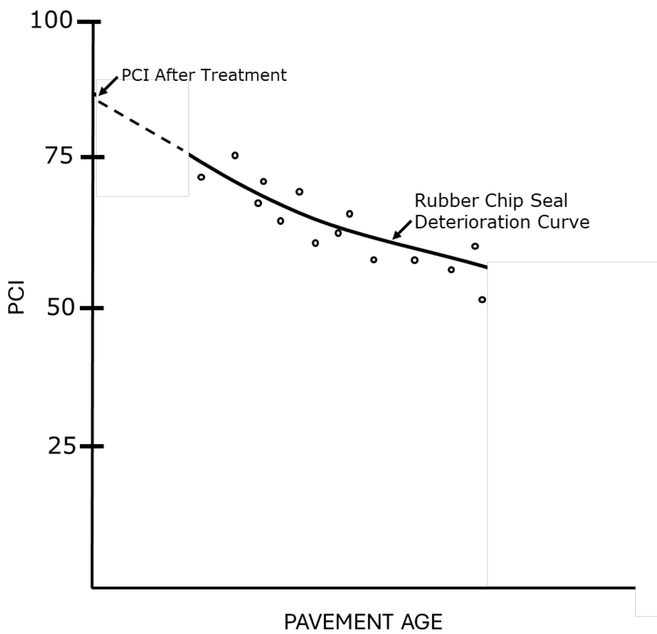


Figure 14. PCI after treatment calculation for rubberized chip seals

The average increase in PCI, or delta PCI, due to the rubberized asphalt chip seal treatment was calculated as the estimated PCI after treatment minus the average of the PCIs before treatment within each investigation group. The delta PCI for rubberized asphalt chip seals was compared to the delta PCI for the generic surface seals for each investigation group. The generic surface seal delta PCI models constitute proprietary information and were provided courtesy of StreetSaver® for use in this analysis.

Results

Figure 15 shows the performance model for the rubberized asphalt chip seals on arterial streets compared to the performance model for generic surface seal (all models are provided in Appendix B). The rubberized asphalt chip seal performs better on arterial streets than the generic surface seal. This is typical across all investigation groups.

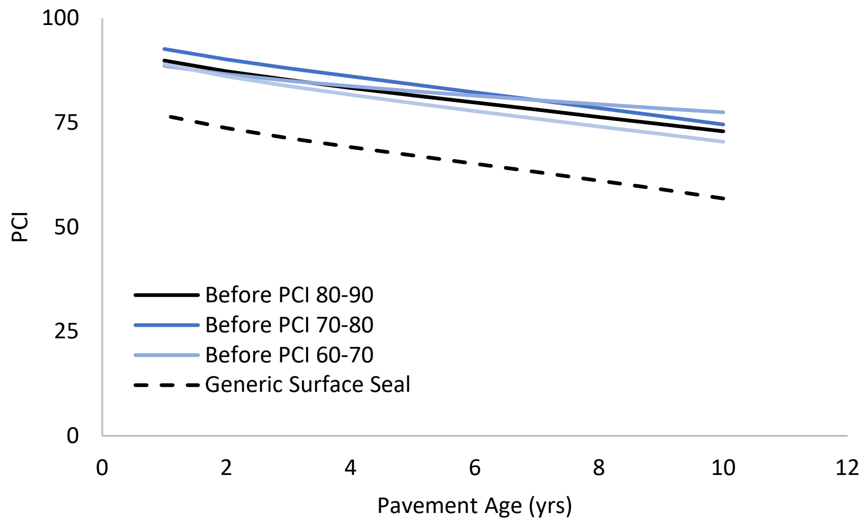


Figure 15. Rubberized asphalt chip seal performance model — arterials

Rehabilitation treatments (e.g., mill and overlay, cold in-place recycling, reconstruction) increase the PCI to 100 after placement. However, PCI after preservation treatment (e.g., crack sealing, patching, surface seals) application is dependent on the PCI before treatment and generally only results in small PCI increases (Figure 16).

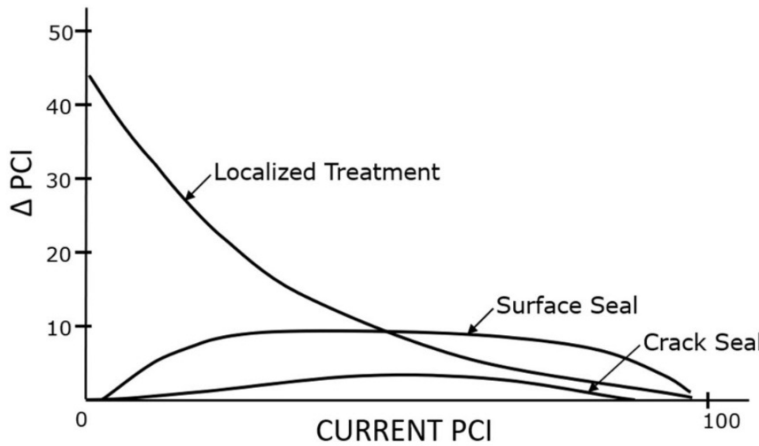


Figure 16. PCI increase by treatment type (source: Metropolitan Transportation Commission, 2023 StreetSaver User Guide Pavements).

Figure 17 summarizes the average increase in PCI, or delta PCI, due to rubberized asphalt chip seal treatment relative to the pavement condition before treatment by functional classification. The figure also includes the generic surface seal delta PCI model courtesy of StreetSaver®.

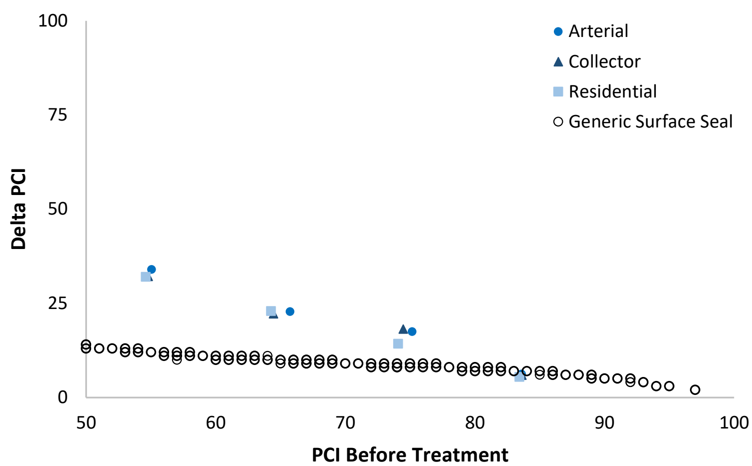


Figure 17. Delta PCI for rubberized asphalt chip seals — functional classification

All functional classifications perform similarly relative to the pavement condition before treatment. Overall, rubberized asphalt chip seal increases the PCI similarly to the generic surface seals when the pavement is in excellent condition (PCI > 80). However, when the PCI before treatment is good or fair (PCI 50 to 80), rubberized asphalt chip seal can increase the PCI by 10 to 20 points.

Similarly, Figure 18 and Figure 19 illustrate the PCI increase due to rubberized asphalt chip seal in dry no freeze and wet no freeze climate zones, respectively.

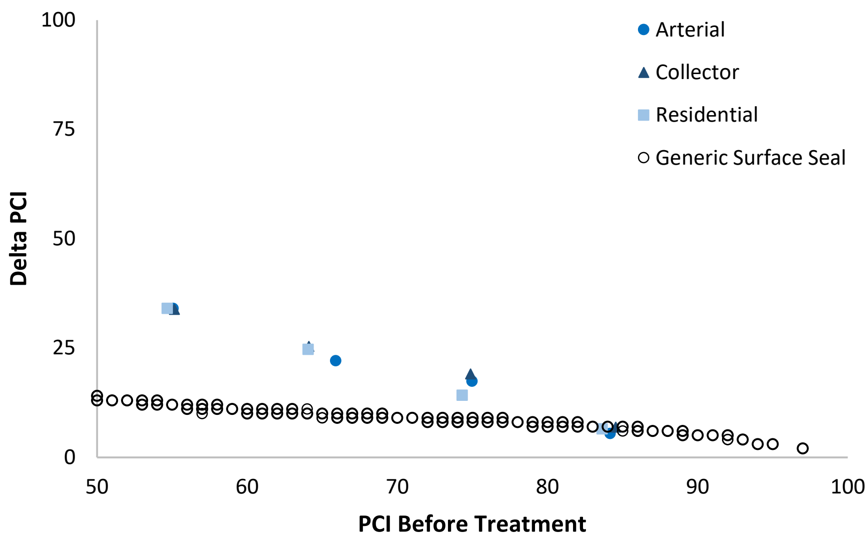


Figure 18. Delta PCI rubberized asphalt chip seals — functional classification and dry no freeze climate zone

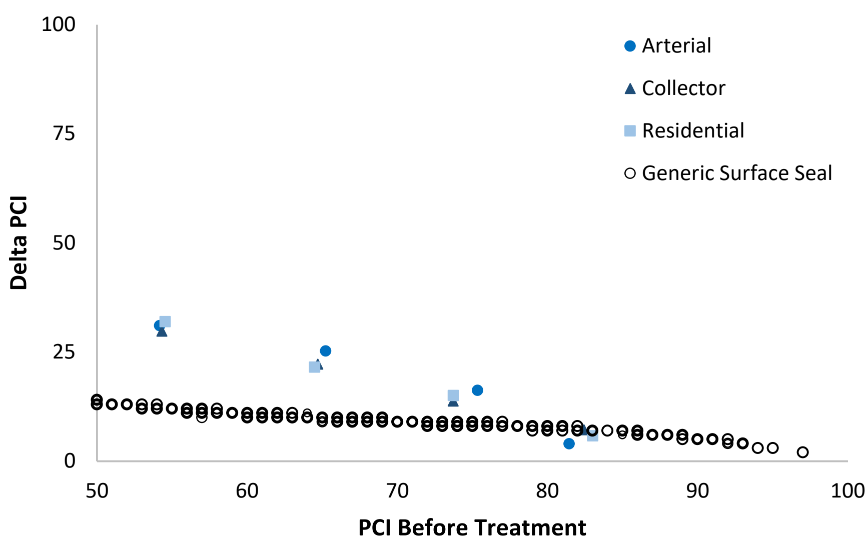


Figure 19. Delta PCI rubberized asphalt chip seals — functional classification wet no freeze climate zone

Climate zone has minimal impact on rubberized asphalt chip seal performance.

Summary and Recommendations

Project Summary

This study quantified and compared the performance of RHMA and rubberized asphalt chip seals to non-rubberized dense-graded HMA and non-rubberized chip seals on the California local roadway network. The evaluation was intended to compare rubberized treatments to more traditional treatments and to develop RHMA and rubberized asphalt chip seal performance models for potential incorporation into agency pavement management systems.

RHMA and rubberized asphalt chip seal projects were identified from the list of local agencies that received CalRecycle grants over the past 20 years. The list of grant projects was provided to MTC, who obtained and extracted the associated maintenance history and pavement condition data for agencies with an active StreetSaver® subscription. The data was combined and cleaned, resulting in a dataset comprising 11,682 pavement condition observations from 3,404 RHMA and rubberized asphalt chip seal projects in 49 counties throughout California.

For the RHMA overlay analysis, data was plotted and analyzed to quantify the relationship between PCI before treatment and pavement age. Relationships were identified based on functional classifications (arterial, collector, and residential streets), RHMA overlay thickness (thin, moderate, and thick), and climate zone (dry no freeze and wet no freeze). The StreetSaver® standard HMA overlay performance models were compared to each respective RHMA pavement performance plot.

Similarly, for the rubberized asphalt chip seal analysis, the PCI after treatment was plotted to quantify the relationship between PCI and pavement age for pavements between 3 and 10 years old. PCI data from the first 2 years after treatment was excluded because underlying distress can be hidden by the seal in the first 2 years, resulting in artificially high PCIs. PCI data beyond 10 years was excluded since surface seals are often applied on a set cycle (e.g., every 8 years), and the likelihood of the data being impacted by unrecorded treatments increases over time.

Results Summary

In general, the analysis indicated performance benefits associated with RHMA and rubberized asphalt chip seals over conventional HMA overlays and chip seals. RHMA overlays were found to perform best on arterial and collector roadways in wet no freeze climates and may extend pavement service life 4.4 to 8.2 years, depending on functional classification (Table 4). In dry no freeze climates, the RHMA may extend pavement life 0.8 to 6.0 years, depending on functional classification. The data indicated thick RHMA overlays (> 2.5 inches) in dry no freeze climates did not perform as well as thick conventional HMA overlays. Additional evaluation is needed to identify potential causes of poorer performance of the thick RHMA overlays; however, this evaluation is beyond the scope of this study.

Table 4. Summary of RHMA Overlay Life Extension (years)

Climate Zone	Overlay Thickness	Arterial	Collector	Residential
Dry No Freeze	≤ 1.5 in.	1.3	0.8	1.5
Dry No Freeze	1.5 – 2.5in.	3.2	4.5	6.0
Wet No Freeze	≤ 1.5 in.	4.4	6.1	---
Wet No Freeze	1.5 – 2.5 in.	5.9	8.2	---
Wet No Freeze	> 2.5 in.	7.0	---	---

Note: “---” indicates insufficient data to assess life extension.

For chip seals placed when the existing pavement is in excellent condition (PCI > 80), the analysis showed the rubberized asphalt chip seals and generic surface seals resulted in similar increases in PCI after treatment. However, for chip seals placed when the existing pavement is in fair to good condition (PCI 50 – 80), the rubberized asphalt chip seals increase the PCI by 10 to 20 points compare to the generic surface seals after treatment application. This suggests improved performance with rubberized asphalt chip seals compared to generic chip seals for existing pavements in fair or better condition (PCI > 50).

Recommendations

The data used to develop performance models was impacted by the unavailability of comparisons from a paired controlled study (i.e., placement of adjacent sections of RHMA and conventional HMA with the same thickness and subject to the same traffic conditions). Therefore, the analysis was limited to comparing RHMA and rubberized asphalt chip seal performance to StreetSaver® standard curves for conventional HMA and generic chip seals. Constructing RHMA overlays (or rubberized asphalt chip seals) adjacent to conventional HMA overlays (or conventional chip seals) and monitoring performance over time would assist in confirming (and modifying, if applicable) the results of this analysis.

The worse-than-expected performance of thick RHMA may require additional investigation. A more detailed project-by-project analysis may be warranted to better understand the performance trends observed in this study.

Abbreviations and Acronyms

HMA – Hot Mix Asphalt

LTPP – Long Term Pavement Performance

MTC – Metropolitan Transportation Commission

PCI – Pavement Condition Index

RHMA – Rubberized Hot Mix Asphalt

RMSE – Root Mean Square Error

Glossary of Terms

Asphalt rubber: Defined as “a blend of asphalt cement, reclaimed tire rubber, and certain additives in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles (ASTM D8).”

Dense-graded: Refers to a continuously graded aggregate blend typically used to make HMA with conventional or modified binders.

Dry no freeze climate zone: Characterized by relatively mild winters, low annual precipitation, and lack of significant freezing conditions.

Gap-graded: Aggregate that is not continuously graded for all size fractions but is typically missing or low on some of the finer-size fractions (minus No. 8 or finer). Such gradations typically plot below the maximum density line on a 0.45-power gradation chart. Gap grading is used to promote stone-to-stone contact in HMA and is similar to the gradations used in stone matrix asphalt, but with relatively low percentages passing the No. 200 sieve size. This type of gradation is most frequently used to make asphalt rubber gap graded paving mixtures.

Long-Term Pavement Performance (LTPP): Research project managed by the Federal Highway Administration to collect and analyze pavement performance data of in-service highways in the U.S. and Canada to improve pavement design and management practices.

Open-graded: Aggregate gradation that is intended to be free draining and consists mostly of 2 or 3 nominal sizes of aggregate particles with few fines and 0 to 4% by mass passing the No. 200 (0.075 mm) sieve. Open grading is used in hot-mix applications to provide relatively thin surface or wearing courses with good frictional characteristics that quickly drain surface water to reduce hydroplaning, splash, and spray.

Pavement condition index (PCI): Numerical rating system, ranging from 0 (poor) to 100 (very good), to assess the overall pavement condition based on, for example, cracking, rutting, and rideability.

Pavement management system: Systematic approach for collecting, analyzing, and managing pavement data to optimize funding and pavement maintenance for long-term serviceability.

Performance prediction models: Statistical models used in pavement management systems to predict future pavement conditions.

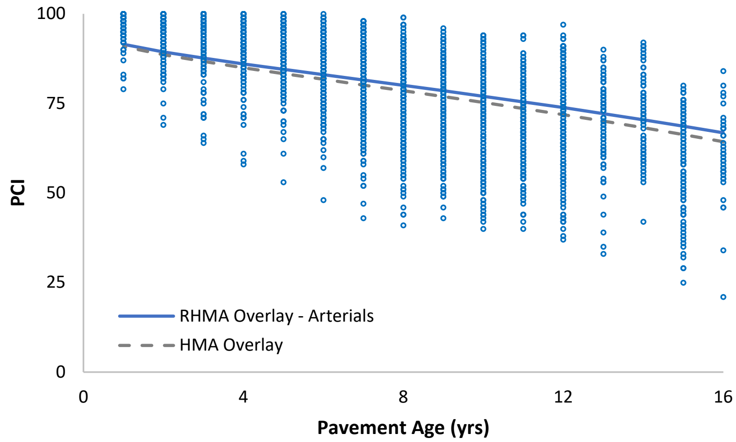
Reflective cracking: Cracks occurring in asphalt pavement overlays directly above existing cracks in the underlying pavement.

StreetSaver®: Pavement management system provided by the San Francisco Bay Area Metropolitan Transportation Commission.

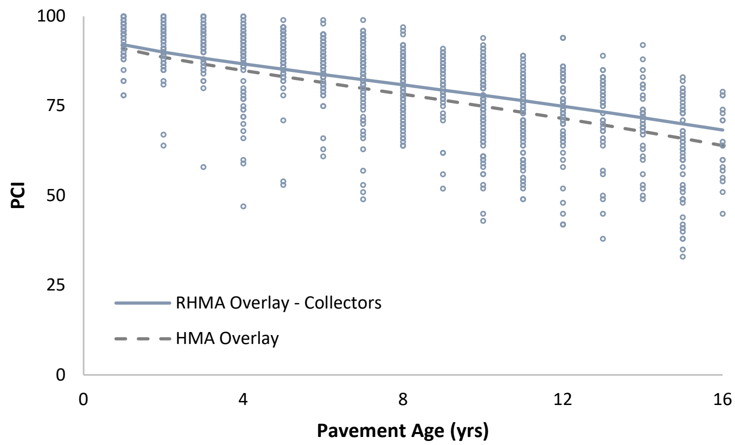
Wet no freeze climate zone: Characterized by consistently high moisture levels throughout the year, with little to no freezing temperatures.

Appendix A
RHMA Deterioration Curves

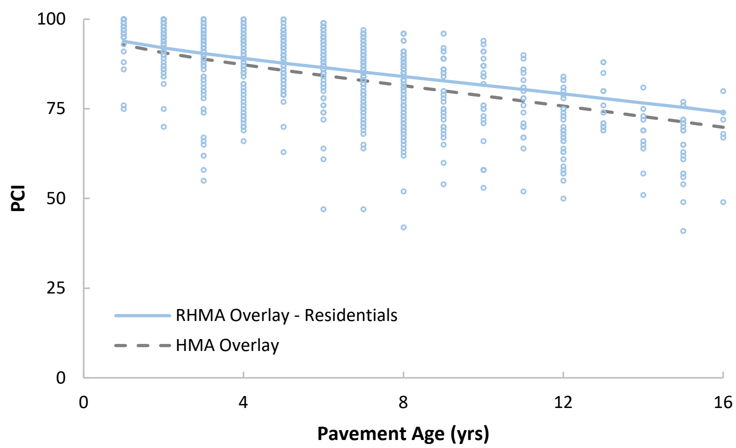
Functional Classification



Data Points: 3,822
R^2: 0.44
RMSE: 10.561
$\alpha = 60$
$\beta = 0.83$
$\rho = 50$
$\chi = 0.93$

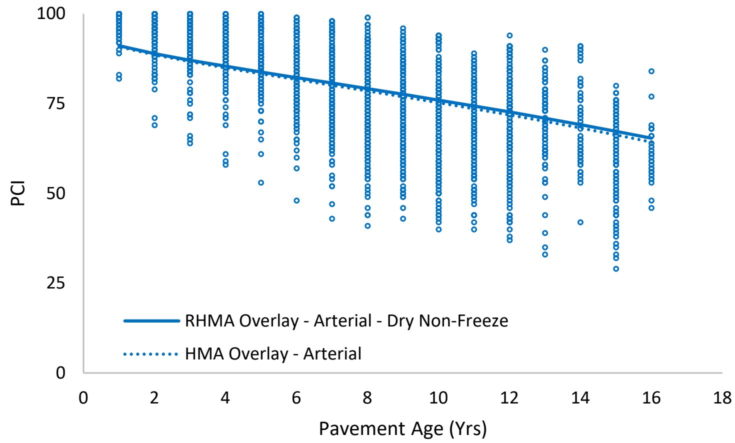


Data Points: 1,389
R^2: 0.46
RMSE: 9.296
$\alpha = 69$
$\beta = 0.77$
$\rho = 59$
$\chi = 0.88$

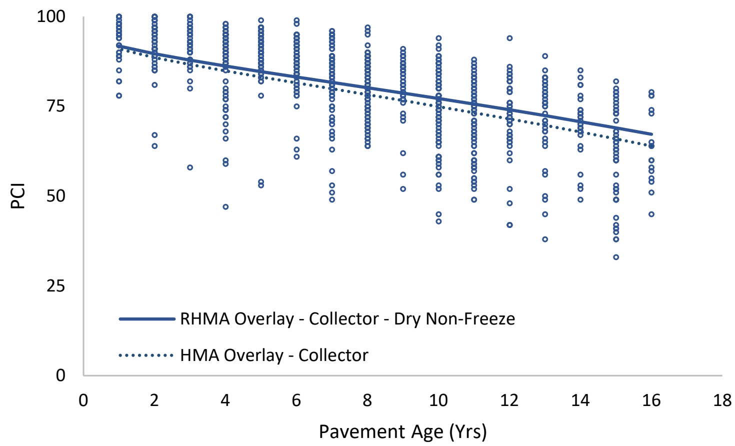


Data Points: 1,598
R^2: 0.40
RMSE: 8.073
$\alpha = 136$
$\beta = 0.58$
$\rho = 112$
$\chi = 0.86$

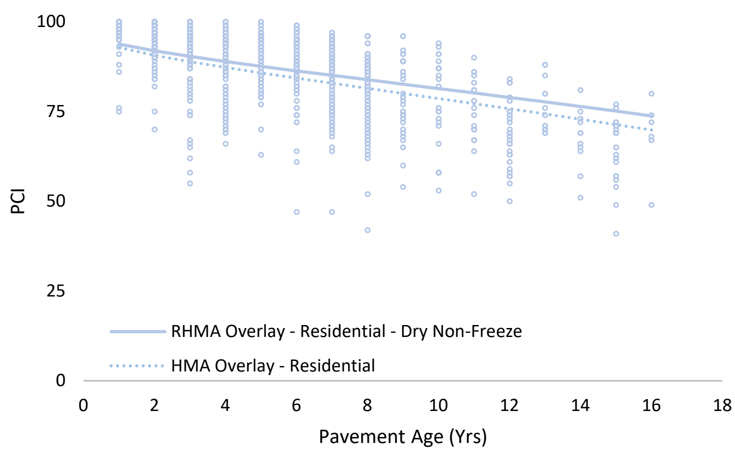
Dry No Freeze Climate Zone and Functional Classification



Data Points: 3,209
R^2: 0.44
RMSE: 10.802
$\alpha = 60$
$\beta = 0.83$
$\rho = 50$
$\chi = 0.97$

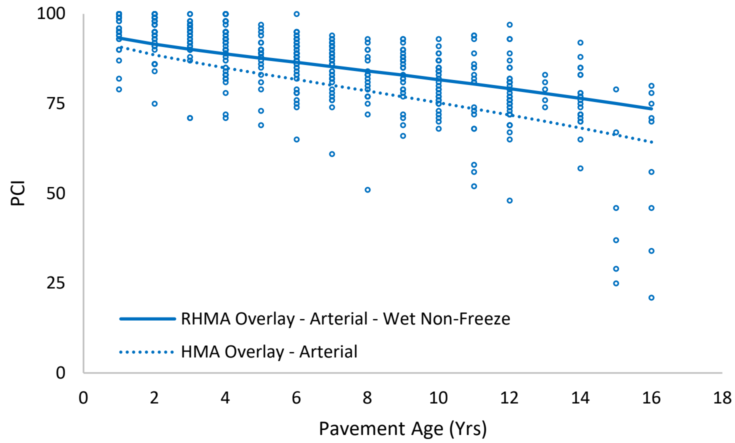


Data Points: 1,529
R^2: 0.40
RMSE: 8.178
$\alpha = 69$
$\beta = 0.77$
$\rho = 59$
$\chi = 0.91$

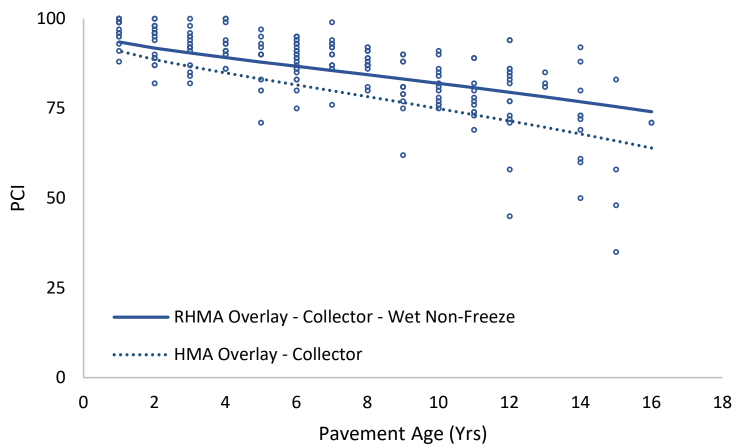


Data Points: 1,168
R^2: 0.46
RMSE: 9.438
$\alpha = 136$
$\beta = 0.58$
$\rho = 112$
$\chi = 0.87$

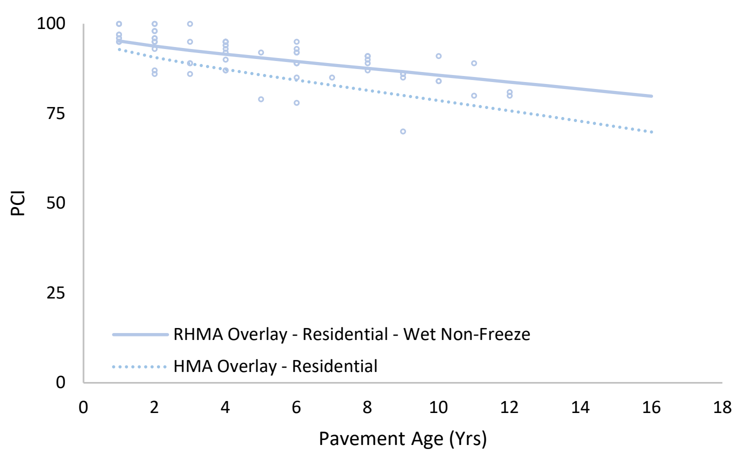
Wet No Freeze Climate Zone and Functional Classification



Data Points: 606
R^2: 0.45
RMSE: 8.194
α = 60
β = 0.83
ρ = 50
χ = 0.74

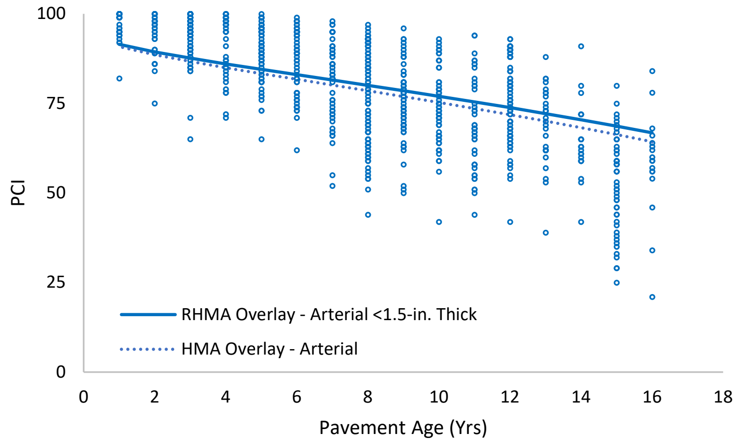


Data Points: 207
R^2: 0.45
RMSE: 7.896
α = 69
β = 0.77
ρ = 59
χ = 0.72

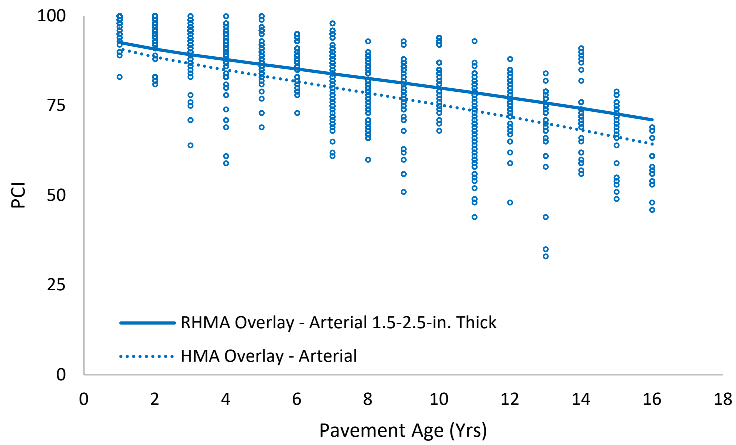


Data Points: 69
R^2: 0.46
RMSE: 4.421
α = 136
β = 0.58
ρ = 112
χ = 0.67

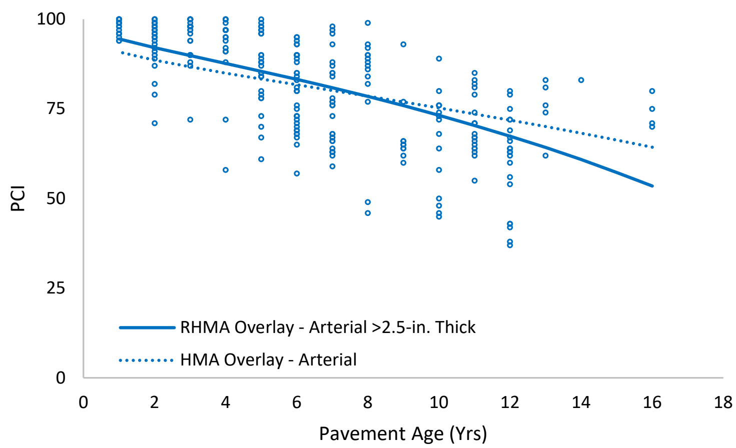
Arterial and Overlay Thickness



Data Points: 1,048
R^2: 0.45
RMSE: 11.381
α = 60
β = 0.83
ρ = 50
χ = 0.93

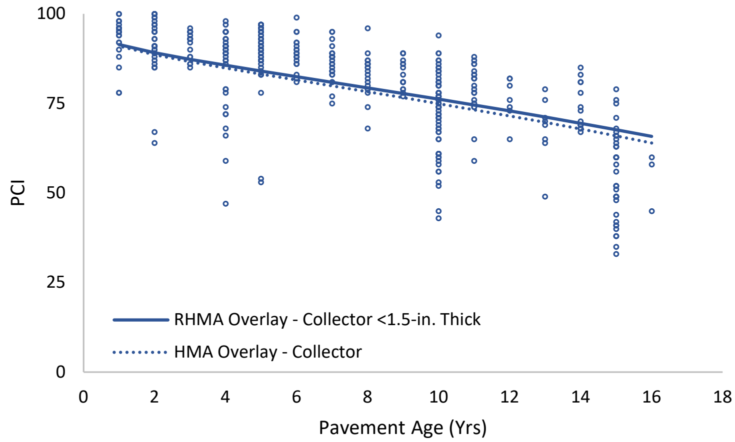


Data Points: 1,275
R^2: 0.50
RMSE: 8.194
α = 60
β = 0.83
ρ = 50
χ = 0.81

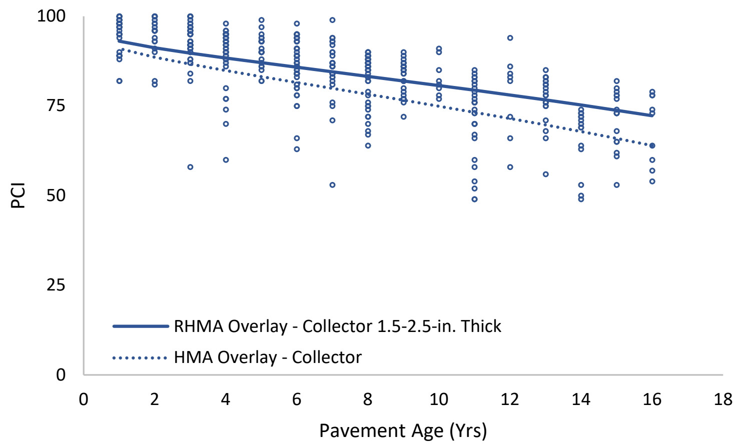


Data Points: 314
R^2: 0.50
RMSE: 10.644
α = 73
β = 0.49
ρ = 109
χ = 1.0

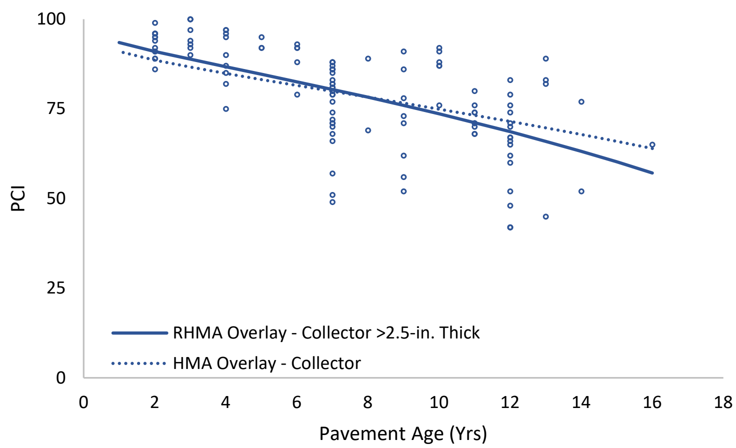
Collector and Overlay Thickness



Data Points: 433
R2: 0.49
RMSE: 9.957
α = 69
β = 0.77
ρ = 59
χ = 0.95

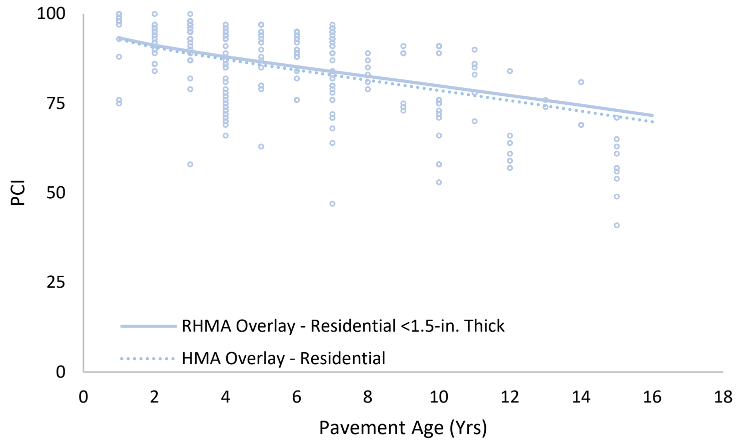


Data Points: 497
R2: 0.49
RMSE: 7.541
α = 69
β = 0.77
ρ = 59
χ = 0.77

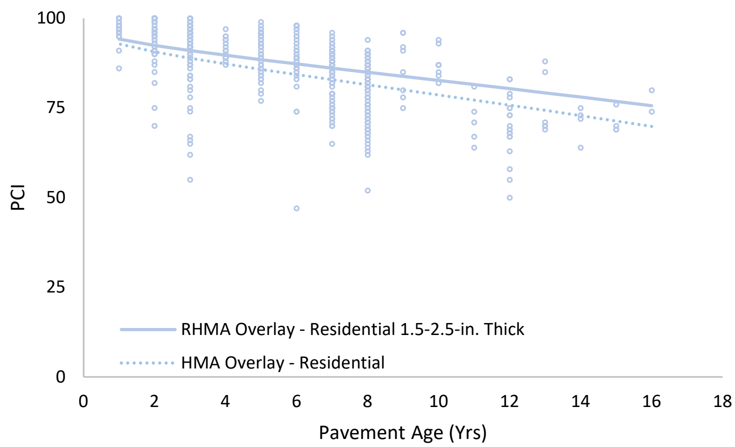


Data Points: 116
R2: 0.4259
RMSE: 10.866
α = 77
β = 0.54
ρ = 99
χ = 1.0

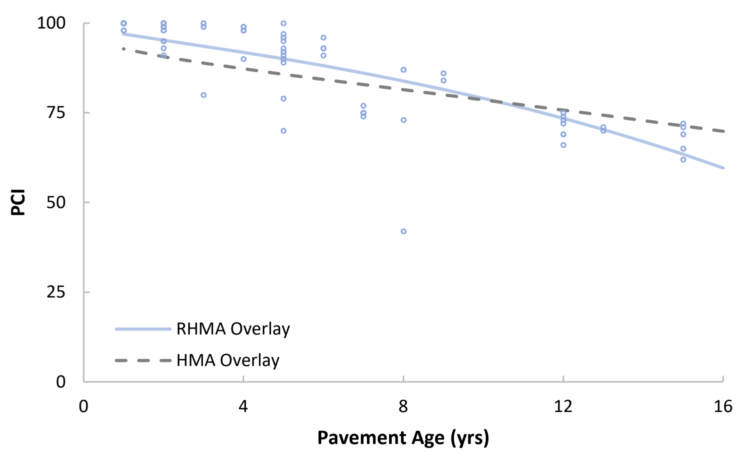
Residential and Overlay Thickness



Data Points: 335
R^2: 0.35
RMSE: 9.325
$\alpha = 136$
$\beta = 0.58$
$\rho = 112$
$\chi = 0.94$

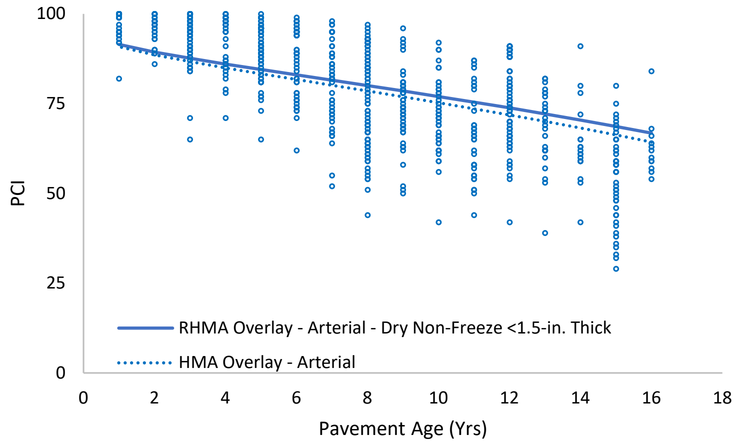


Data Points: 876
R^2: 0.40
RMSE: 7.348
$\alpha = 136$
$\beta = 0.58$
$\rho = 112$
$\chi = 0.81$

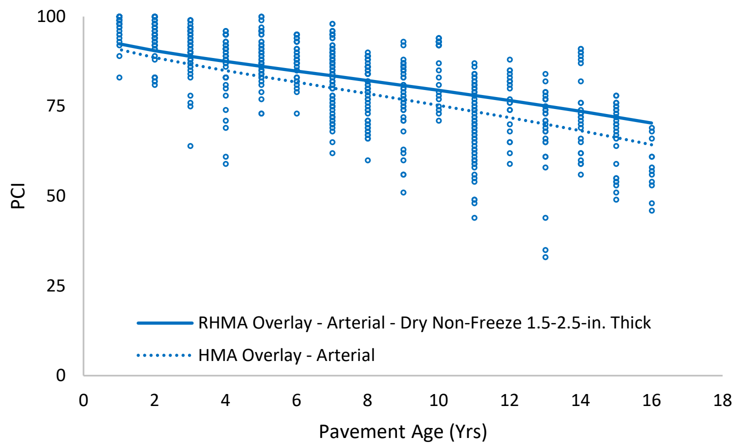


Data Points: 111
R^2: 0.68
RMSE: 6.782
$\alpha = 84$
$\beta = 0.38$
$\rho = 153$
$\chi = 1.0$

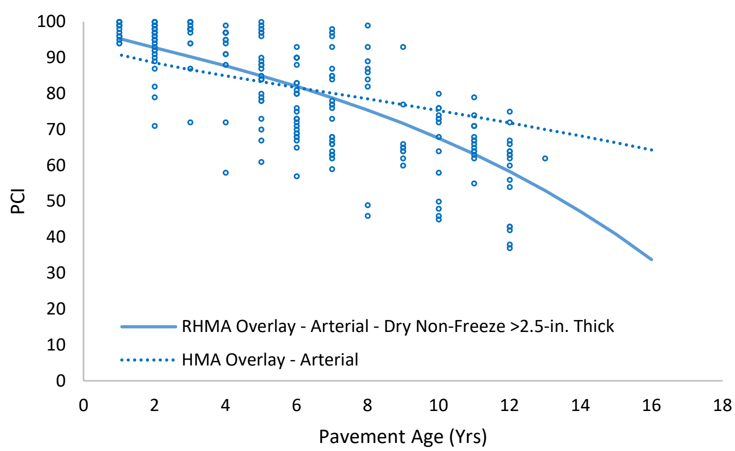
Dry No Freeze Climate Zone, Arterial, and Overlay Thickness



Data Points: 942
R^2: 0.46
RMSE: 11.249
$\alpha = 60$
$\beta = 0.83$
$\rho = 50$
$\chi = 0.93$

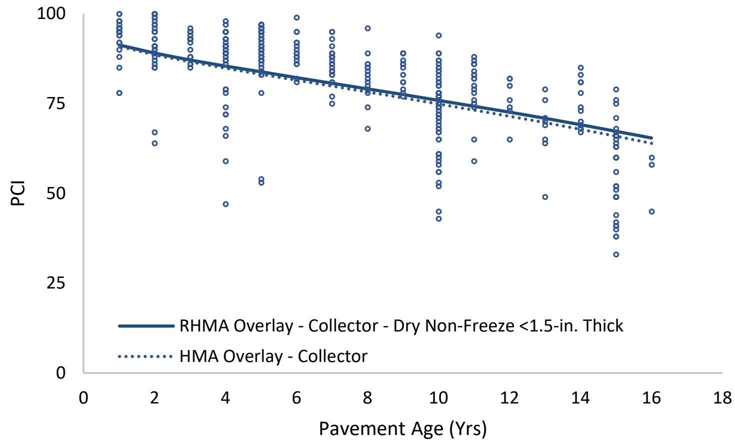


Data Points: 981
R^2: 0.49
RMSE: 8.521
$\alpha = 60$
$\beta = 0.83$
$\rho = 50$
$\chi = 0.83$

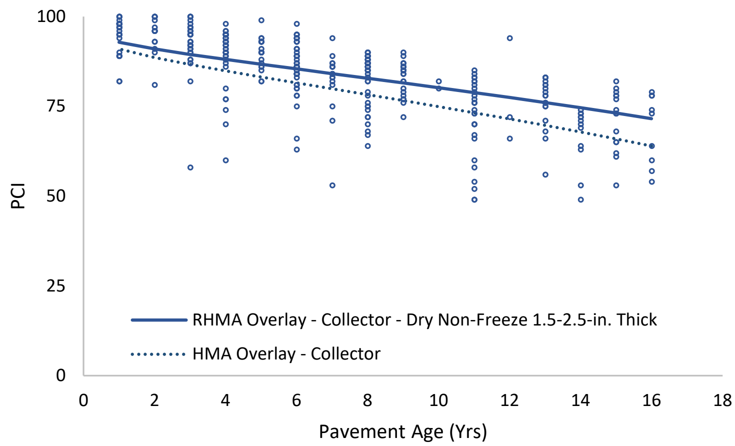


Data Points: 251
R^2: 0.61
RMSE: 9.944
$\alpha = 59$
$\beta = 0.43$
$\rho = 123$
$\chi = 1.0$

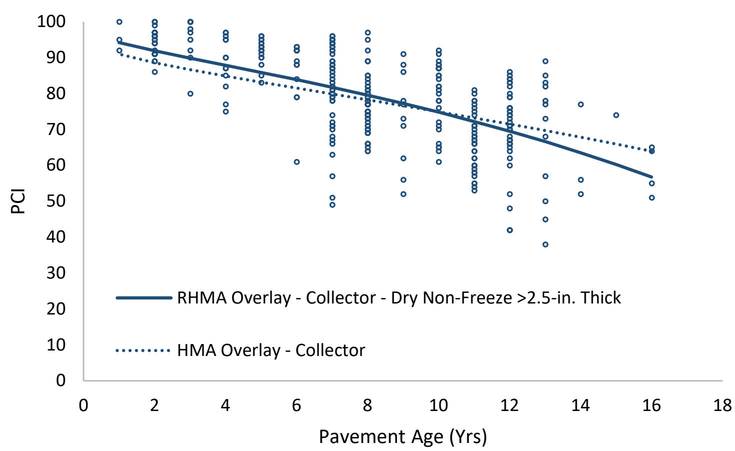
Dry No Freeze Climate Zone, Collector, and Overlay Thickness



Data Points: 404
R^2: 0.49
RMSE: 10.013
α = 69
β = 0.77
ρ = 59
χ = 0.96

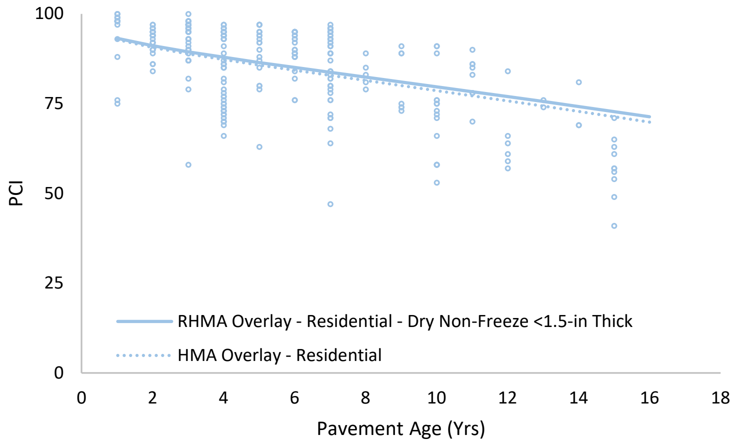


Data Points: 433
R^2: 0.50
RMSE: 7.514
α = 68
β = 0.77
ρ = 59
χ = 0.79

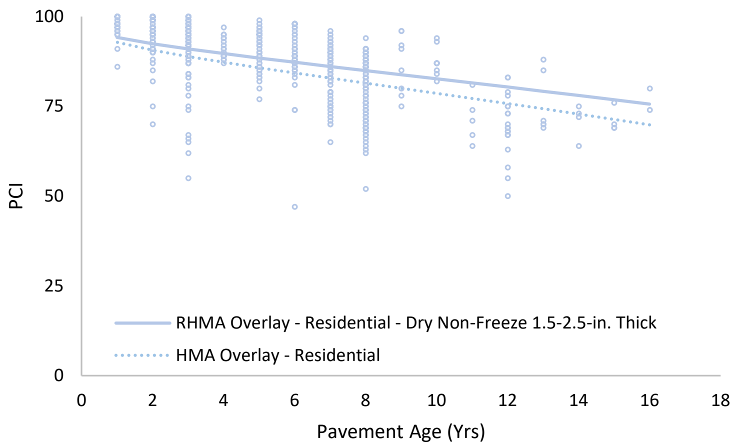


Data Points: 331
R^2: 0.45
RMSE: 9.787
α = 59
β = 0.57
ρ = 69
χ = 1.0

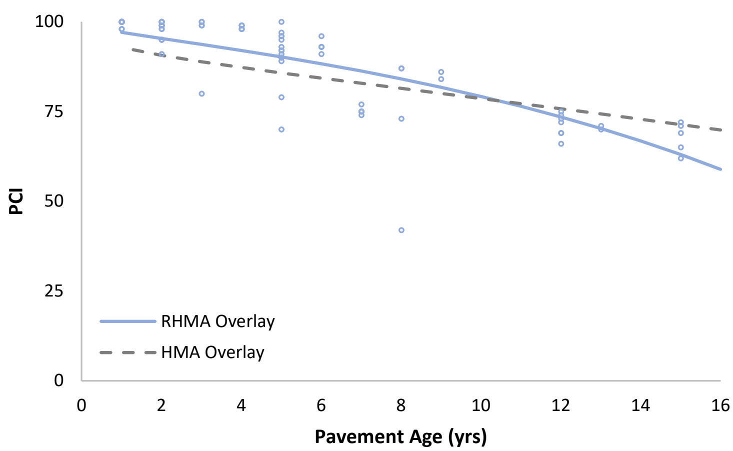
Dry No Freeze Climate Zone, Residential, and Overlay Thickness



Data Points: 329
R^2: 0.35
RMSE: 9.346
$\alpha = 138$
$\beta = 0.58$
$\rho = 112$
$\chi = 0.95$

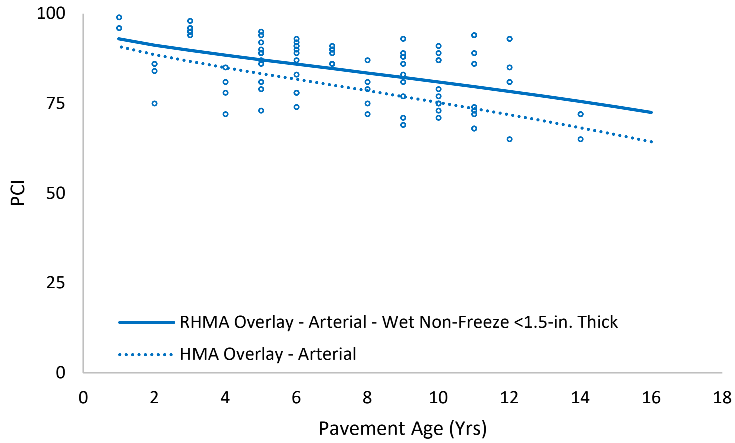


Data Points: 873
R^2: 0.40
RMSE: 7.351
$\alpha = 136$
$\beta = 0.58$
$\rho = 112$
$\chi = 0.81$

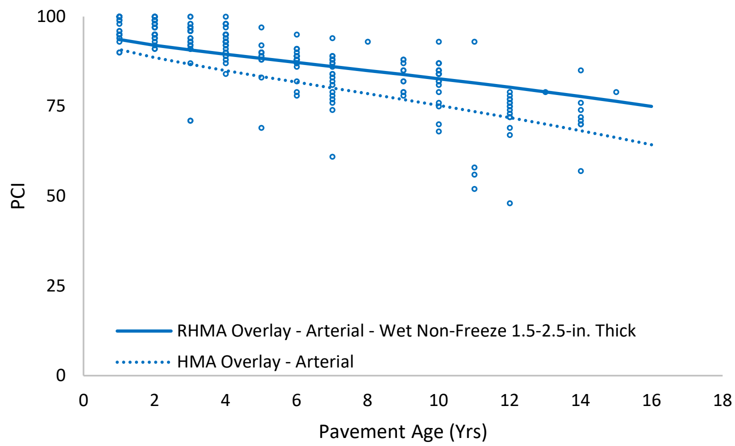


Data Points: 109
R^2: 0.68
RMSE: 6.856
$\alpha = 72$
$\beta = 0.40$
$\rho = 114$
$\chi = 1.0$

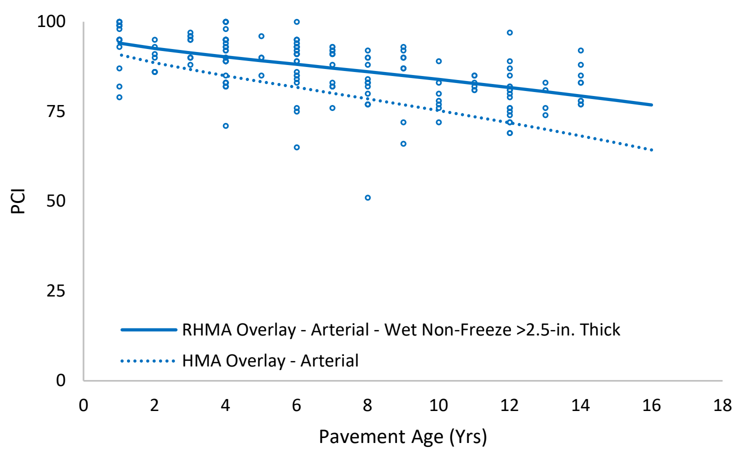
Wet No Freeze Climate Zone, Arterial, and Overlay Thickness



Data Points: 90
R^2: 0.22
RMSE: 7.627
$\alpha = 60$
$\beta = 0.83$
$\rho = 50$
$\chi = 0.77$

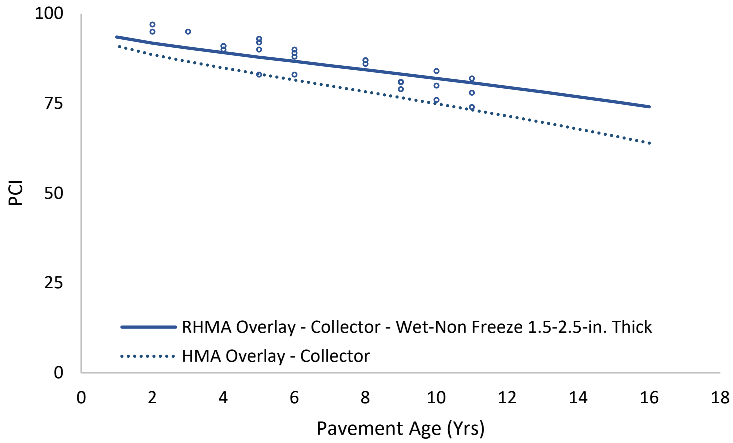


Data Points: 294
R^2: 0.51
RMSE: 6.655
$\alpha = 60$
$\beta = 0.83$
$\rho = 50$
$\chi = 0.70$

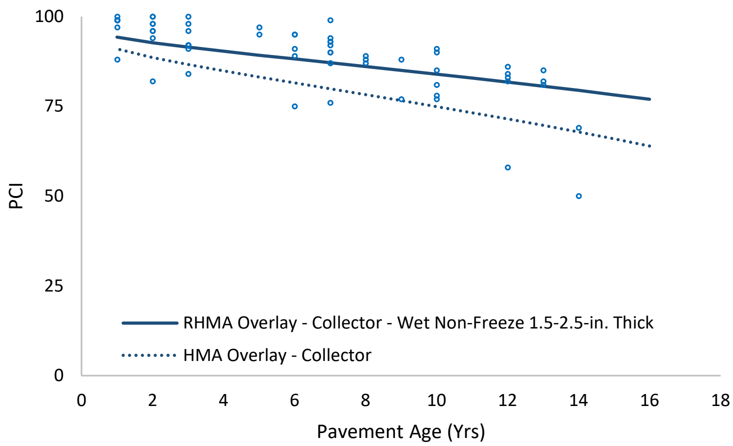


Data Points: 207
R^2: 0.37
RMSE: 6.664
$\alpha = 60$
$\beta = 0.83$
$\rho = 50$
$\chi = 0.65$

Wet No Freeze Climate Zone, Collector, and Overlay Thickness



Data Points: 26
R^2: 0.68
RMSE: 3.459
$\alpha = 69$
$\beta = 0.77$
$\rho = 59$
$\chi = 0.72$

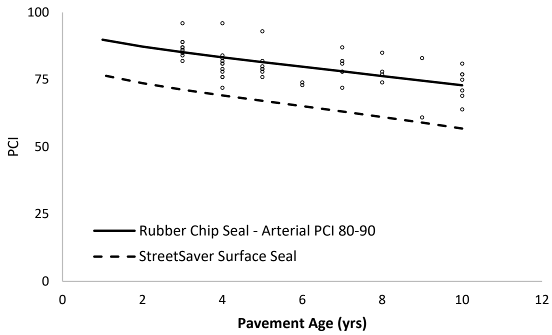


Data Points: 64
R^2: 0.44
RMSE: 7.215
$\alpha = 63$
$\beta = 0.77$
$\rho = 59$
$\chi = 0.64$

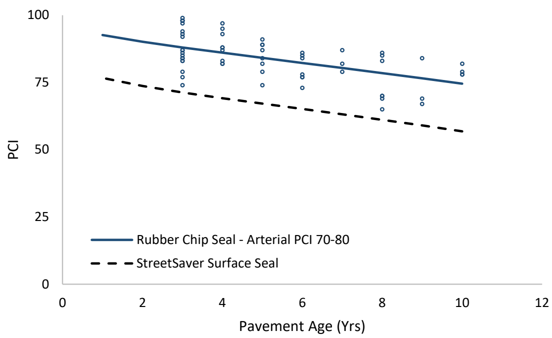
Appendix B

Rubberized Asphalt Chip Seal Deterioration Curves

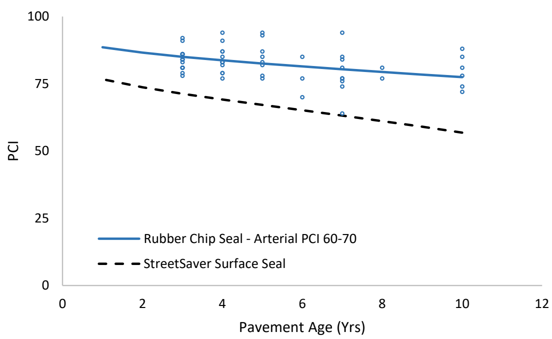
Arterial and PCI Before Treatment



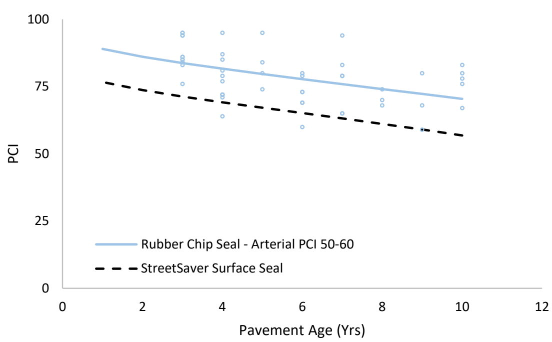
Data Points: 51
R^2: 0.36
RMSE: 5.557
α = 67
β = 0.81
ρ = 60
χ = 1.0



Data Points: 60
R^2: 0.33
RMSE: 6.680
α = 90
β = 0.58
ρ = 99
χ = 1.0

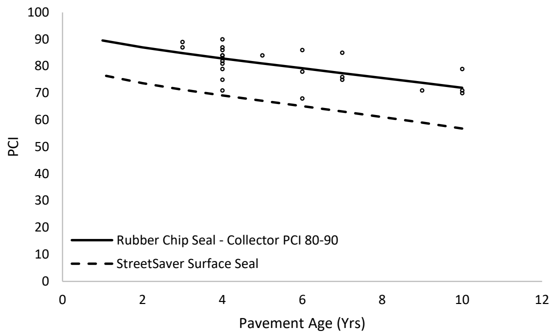


Data Points: 63
R^2: 0.13
RMSE: 5.372
α = 112
β = 0.99
ρ = 55
χ = 1.0

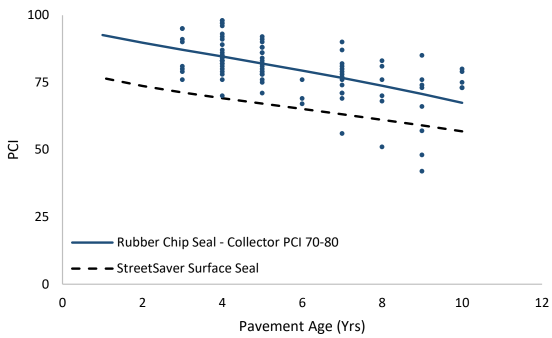


Data Points: 50
R^2: 0.20
RMSE: 8.470
α = 101
β = 0.70
ρ = 98
χ = 1.0

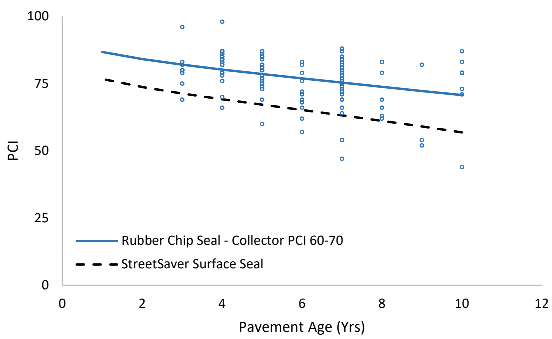
Collector and PCI Before Treatment



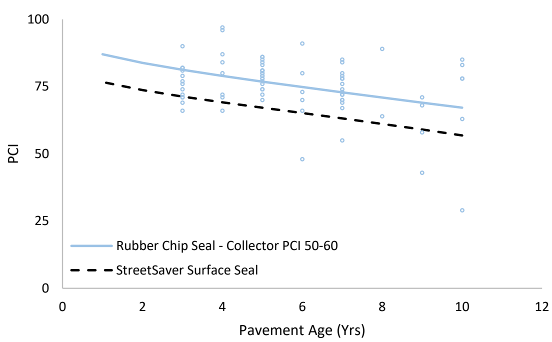
Data Points: 24
R^2: 0.36
RMSE: 5.140
$\alpha = 63$
$\beta = 0.82$
$\rho = 59$
$\chi = 1.0$



Data Points: 95
R^2: 0.32
RMSE: 8.353
$\alpha = 52$
$\beta = 0.59$
$\rho = 76$
$\chi = 1.0$

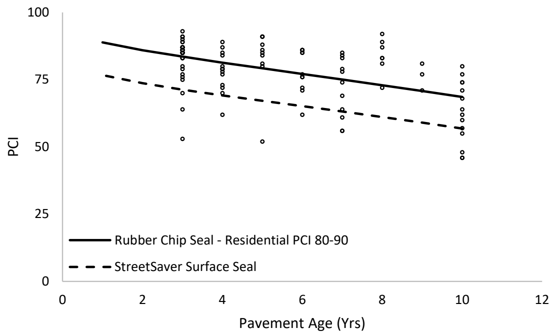


Data Points: 124
R^2: 0.12
RMSE: 8.694
$\alpha = 66$
$\beta = 1.01$
$\rho = 55$
$\chi = 1.0$

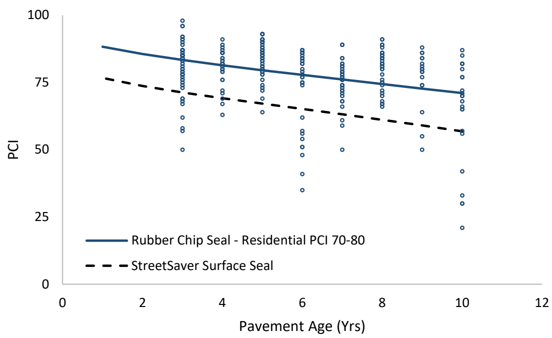


Data Points: 78
R^2: 0.11
RMSE: 9.975
$\alpha = 100$
$\beta = 0.75$
$\rho = 100$
$\chi = 1.0$

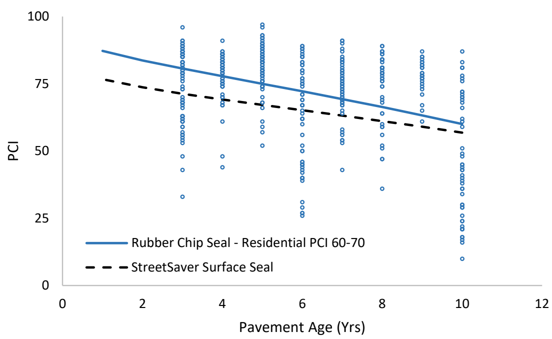
Residential and PCI Before Treatment



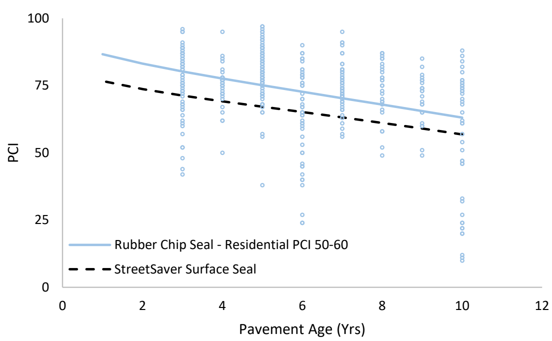
Data Points: 115
R^2: 0.28
RMSE: 9.205
$\alpha = 56$
$\beta = 0.82$
$\rho = 61$
$\chi = 1.0$



Data Points: 276
R^2: 0.10
RMSE: 11.210
$\alpha = 87$
$\beta = 0.80$
$\rho = 76$
$\chi = 1.0$

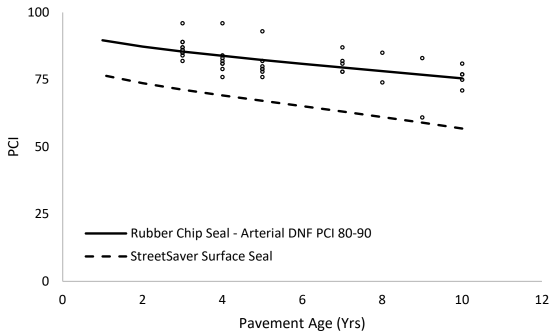


Data Points: 456
R^2: 0.15
RMSE: 15.633
$\alpha = 41$
$\beta = 0.85$
$\rho = 60$
$\chi = 1.0$

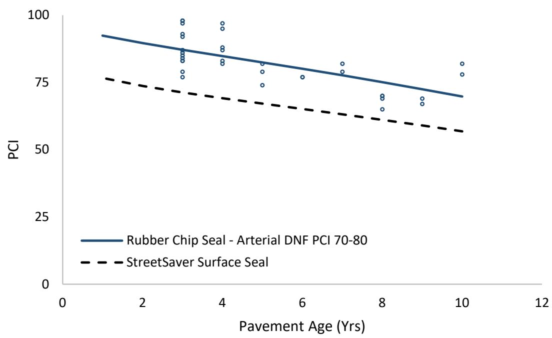


Data Points: 409
R^2: 0.13
RMSE: 14.038
$\alpha = 75$
$\beta = 0.75$
$\rho = 94$
$\chi = 1.0$

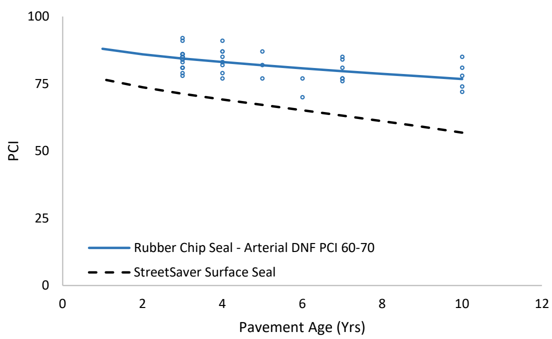
Dry No Freeze Climate Zone, Arterial and PCI Before Treatment



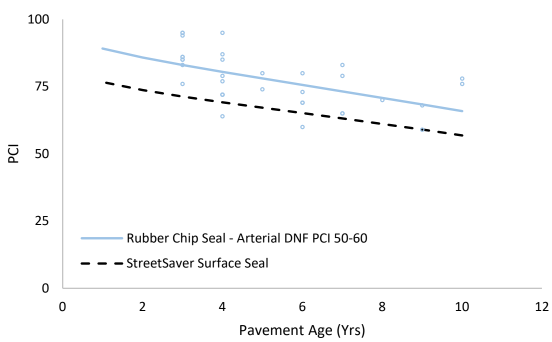
Data Points: 40
R^2: 0.34
RMSE: 5.211
$\alpha = 95$
$\beta = 0.82$
$\rho = 66$
$\chi = 1.0$



Data Points: 35
R^2: 0.48
RMSE: 6.471
$\alpha = 60$
$\beta = 0.60$
$\rho = 80$
$\chi = 1.0$

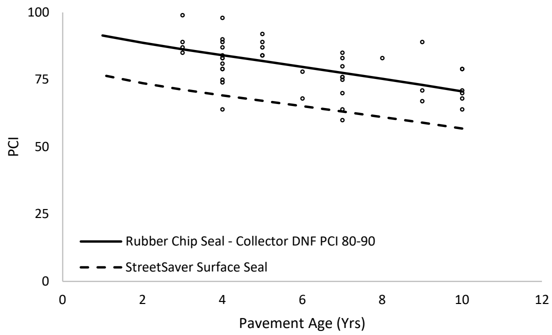


Data Points: 49
R^2: 0.27
RMSE: 3.958
$\alpha = 126$
$\beta = 0.98$
$\rho = 60$
$\chi = 1.0$

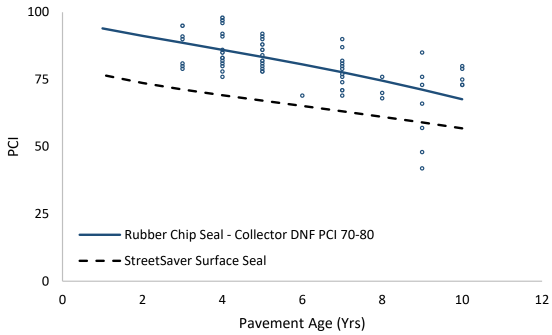


Data Points: 34
R^2: 0.31
RMSE: 8.106
$\alpha = 85$
$\beta = 0.64$
$\rho = 112$
$\chi = 1.0$

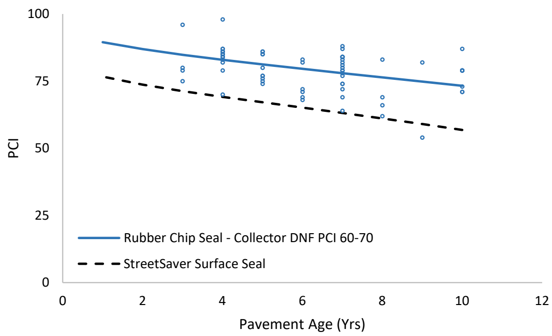
Dry No Freeze Climate Zone, Collector, and PCI Before Treatment



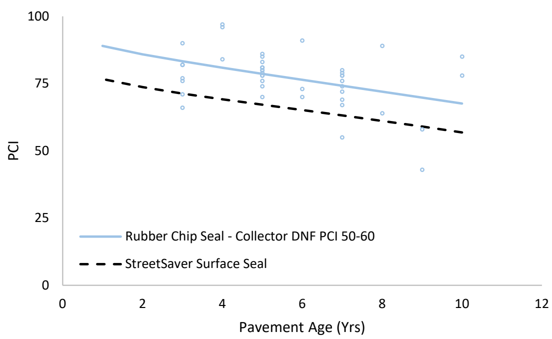
Data Points: 43
R^2: 0.28
RMSE: 7.788
α = 63
β = 0.66
ρ = 74
χ = 1.0



Data Points: 71
R^2: 0.39
RMSE: 8.012
α = 58
β = 0.50
ρ = 100
χ = 1.0

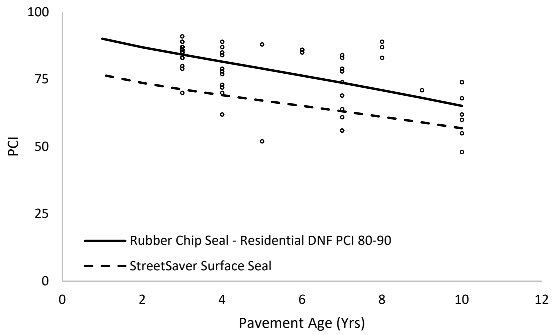


Data Points: 71
R^2: 0.15
RMSE: 6.900
α = 97
β = 0.75
ρ = 80
χ = 1.0

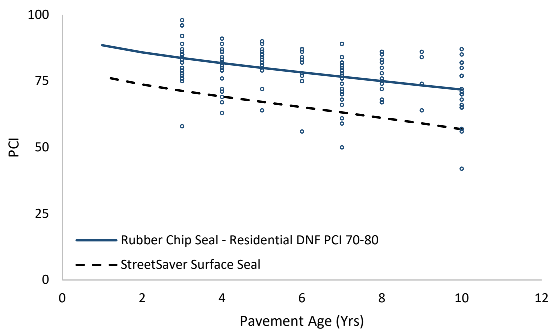


Data Points: 44
R^2: 0.15
RMSE: 9.241
α = 77
β = 0.70
ρ = 90
χ = 1.0

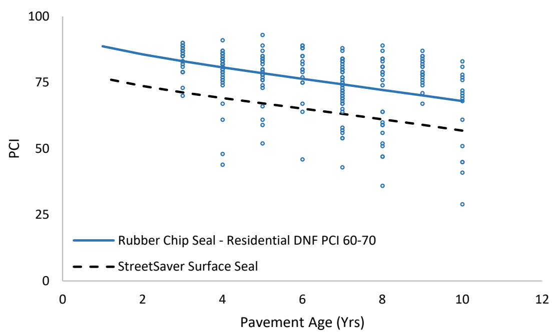
Dry No Freeze Climate Zone, Residential, and PCI Before Treatment



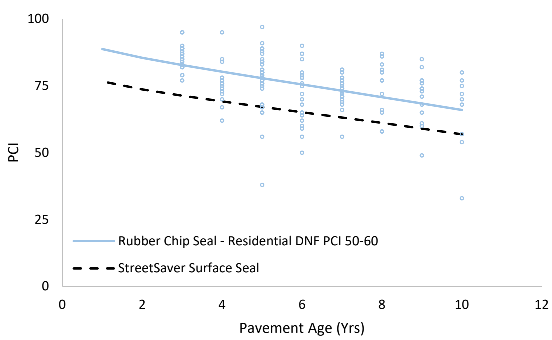
Data Points: 73
R^2: 0.38
RMSE: 8.115
α = 51
β = 0.70
ρ = 70
χ = 1.0



Data Points: 146
R^2: 0.18
RMSE: 8.264
α = 93
β = 0.79
ρ = 78
χ = 1.0

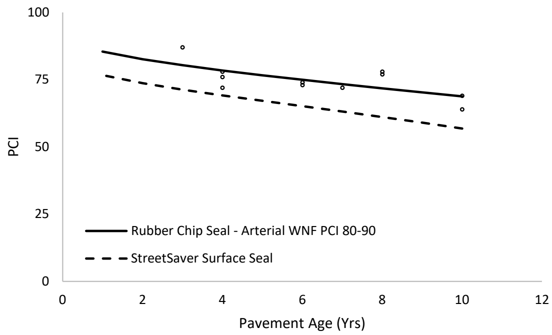


Data Points: 225
R^2: 0.15
RMSE: 10.556
α = 85
β = 0.70
ρ = 95
χ = 1.0

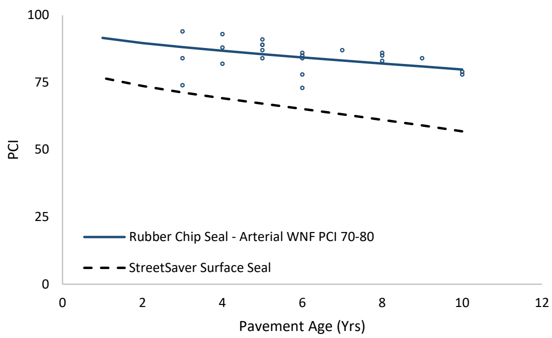


Data Points: 177
R^2: 0.19
RMSE: 8.912
α = 72
β = 0.70
ρ = 90
χ = 1.0

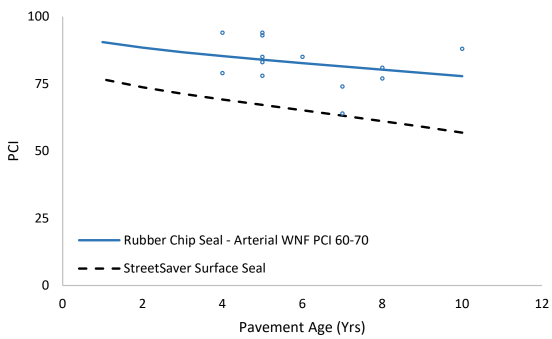
Wet No Freeze Climate Zone, Arterial, and PCI Before Treatment



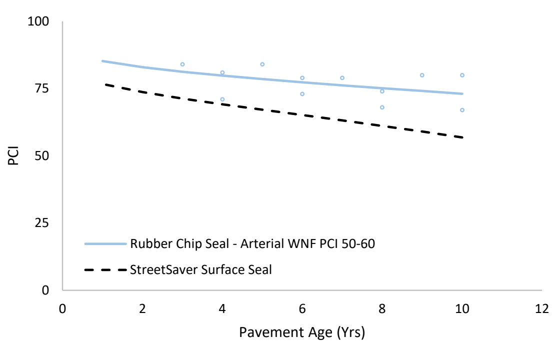
Data Points: 11
R^2: 0.46
RMSE: 4.114
$\alpha = 103$
$\beta = 0.90$
$\rho = 80$
$\chi = 1.0$



Data Points: 23
R^2: 0.07
RMSE: 5.098
$\alpha = 95$
$\beta = 0.81$
$\rho = 55$
$\chi = 1.0$

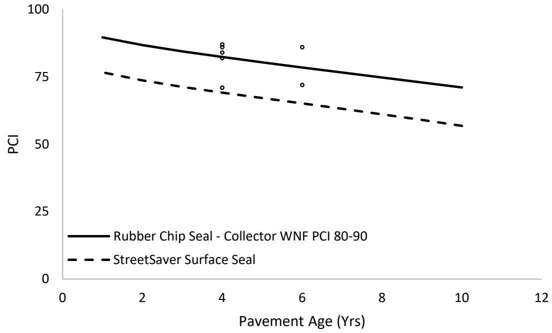


Data Points: 13
R^2: 0.10
RMSE: 7.916
$\alpha = 90$
$\beta = 0.85$
$\rho = 56$
$\chi = 1.0$

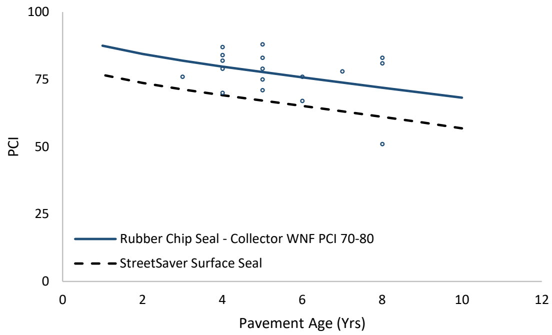


Data Points: 12
R^2: 0.17
RMSE: 5.146
$\alpha = 114$
$\beta = 1.11$
$\rho = 60$
$\chi = 1.0$

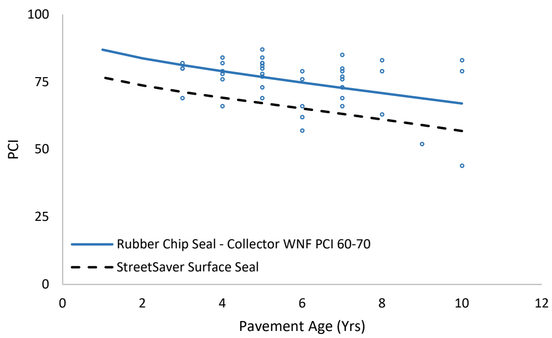
Wet No Freeze Climate Zone, Collector, and PCI Before Treatment



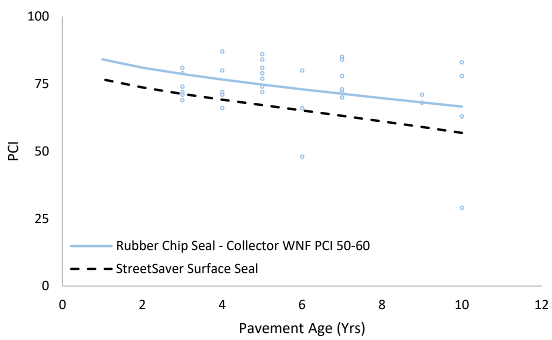
Data Points: 7
R^2: 0.04
RMSE: 6.155
α = 99
β = 0.68
ρ = 98
χ = 1.0



Data Points: 17
R^2: 0.10
RMSE: 8.158
α = 97
β = 0.75
ρ = 95
χ = 1.0

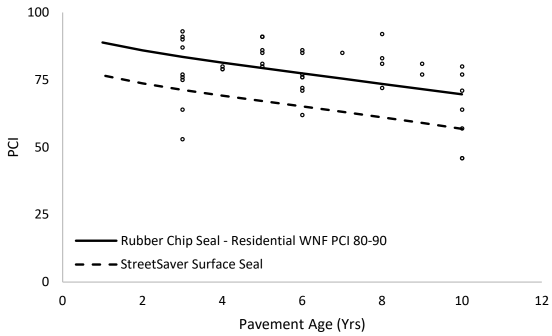


Data Points: 41
R^2: 0.11
RMSE: 8.657
α = 81
β = 0.77
ρ = 93
χ = 1.0

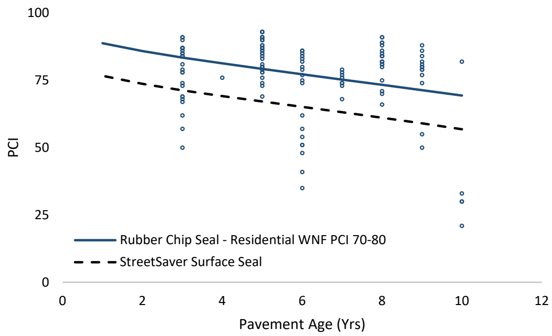


Data Points: 34
R^2: 0.07
RMSE: 10.496
α = 106
β = 0.92
ρ = 85
χ = 1.0

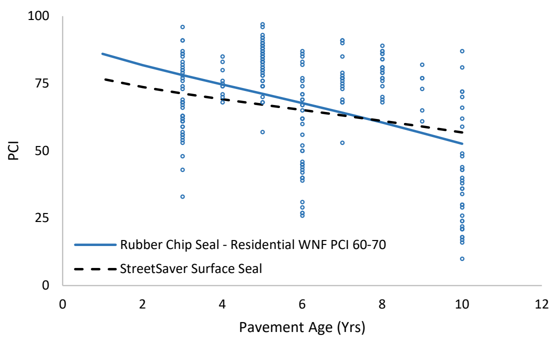
Wet No Freeze Climate Zone, Residential, and PCI Before Treatment



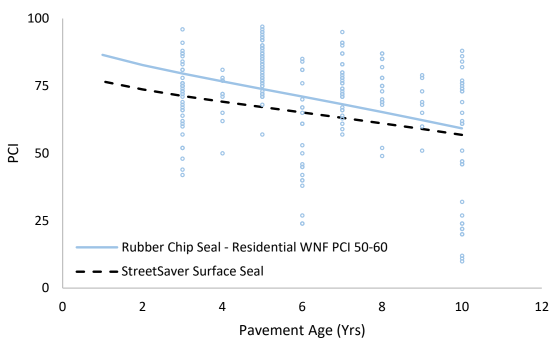
Data Points: 41
R^2: 0.14
RMSE: 10.819
α = 79
β = 0.75
ρ = 80
χ = 1.0



Data Points: 128
R^2: 0.06
RMSE: 13.854
α = 78
β = 0.75
ρ = 80
χ = 1.0



Data Points: 224
R^2: 0.18
RMSE: 18.320
α = 44
β = 0.77
ρ = 79
χ = 1.0



Data Points: 226
R^2: 0.12
RMSE: 16.794
α = 51
β = 0.80
ρ = 75
χ = 1.0