

**LOW TEMPERATURE CRACKING PERFORMANCE
OF SUPERPAVE AND COLD IN-PLACE RECYCLED PAVEMENTS
IN OTTAWA-CARLETON**

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ABSTRACT

Historically, the Regional Municipality of Ottawa-Carleton (RMOC) used 85/100 penetration grade binder with typical Performance Grade (PG) 58-22 in all conventional hot asphalt mixes. The low pavement temperature extreme encountered during any given winter in Ottawa-Carleton is generally below -26°C . This has resulted in a high frequency of low temperature cracking (transverse cracking).

The RMOC uses SUPERPAVE PG 58-34 asphalt mixes and the Cold In-Place Recycling (CIPR) process to mitigate the low temperature cracking problem. To assess the cost effectiveness of these pavement alternatives to conventional hot mix, a network wide evaluation and correlation of costing, performance, serviceability and life cycle were carried out.

In this study, a total of 38 Regional arterial roads were analyzed consisting of about 800 lane-km of roadway. Each road under analysis is further dynamically sectioned by asphalt type, last rehabilitation method, asphalt age, asphalt thickness, subgrade type and drainage condition.

Results of the data analyzed indicated that:

- low temperature cracking is the primary pavement distress mechanism triggering the RMOC's rehabilitation needs program for structurally adequate roads,
- limited data on SUPERPAVE PG mixes indicated significantly improved initial low temperature cracking performance and a substantial life cycle cost advantage when compared to conventional candidates, and
- CIPR rehabilitated candidates indicate better low temperature cracking performance than both resurfaced and reconstructed candidates using conventional hot mixes.

RÉSUMÉ

Depuis sa formation, la Municipalité Régionale d'Ottawa-Carleton (MROC) bitumen 85/100. Ce bitumen a un PG de 58-22. La température basse Ottawa-Carleton est généralement dessus -26°C . Cette température acausé beaucoup de fissures transverse dans les enrobé.

MROC utilize SUPERPAVE PG 58-34 bitumine dans l'enrobé et la process "Cold in Place Recycling"(CIPR) pour minimisé les fissures causé par les températures basses. Pour déterminé l'efficacité du cout de cette méthode, MROC a évalué les performances, serviciabilité, et cycle de vie d'une majorité de ses routes.

Dans cette étude, une totale de 38 routes régionales etait analysé. Les routes consistent d'environnement 800 "lane-km". Chaque route analysé etait décomposé par type de bitumen, la méthode au'il etait réhabilité, son age, son épaisseur, type de sous-terre, et condition de drainage.

Les résultats de l'étude son:

- les fissures causé par les températures basses est la cause principale de les conditions qui exige les réhabilitations.
- information limité sur les enrobé SUPERPAVE PG indique une résistance supérieur contre les fissures causé par la température basse.
- les enrobé CIPR montre meillieur résistance contre les fissures causé par les températures basse que les autre.

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1. INTRODUCTION

In cold regions such as the Regional Municipality of Ottawa-Carleton (RMOC), the pavement is subjected to numerous freeze thaw cycles and extreme low pavement temperature in excess of -26°C . The inadequacy of conventional 85/100 penetration grade asphalt mixes to provide for thermal protection against low temperature cracking was especially noted after the winter of 1993-94 when several roadways reconstructed in 1993 experienced intermittent transverse cracking after the first winter.

The RMOC Pavement Management System (PMS) data indicates that a majority of road rehabilitation candidates are selected based on inadequacies of the Surface Distress Index (SDI) and Ride Comfort Index (RCI) components of the aggregated Pavement Quality Index (PQI). A small portion of the road network (failed roads) is selected for reconstruction because of inadequacy of the Structural Adequacy Index (SAI) component of the PQI index.

The most common observed distress on the Regional road network in the RMOC is transverse cracking. In this study the primary distress used to gauge thermal cracking is the extent and severity of transverse cracking. The majority of transverse cracking in pavements occurs as a result of high stresses induced by thermal contraction at low temperature extremes. At low temperatures, the longitudinal stresses that develop exceed the tensile strength of the asphalt and are relieved by the cracking of the pavement in the transverse direction. This phenomenon is a result of the stiffening of the asphalt binder, which happens as the pavement cools, and also as the pavement ages. With the introduction of Performance Graded asphalt binders, limits on asphalt stiffness over a wide range of design temperatures can be specified and increased performance of the pavement over temperature extremes with the aging concept can be built in at the design stage. In overlain pavements, in addition to thermal stress, reflective cracking is also responsible for the recurrence of transverse cracks.

The RMOC has adopted SUPERPAVE binder specifications (Performance Graded 58-34 binder) and the Cold In-Place Recycling process to address the problem of low-temperature cracking of pavements since 1994 and 1989, respectively.

The purpose of this report is to examine the occurrence of transverse cracking as a function of pavement type, pavement binder type, pavement age, pavement thickness, subgrade type, and their associated impact on pavement performance indices and serviceability used for the determination of rehabilitation needs of the roadway system. These results can be used to assess the cost effectiveness of using performance graded asphalt binders and the Cold In-Place Recycling process in rehabilitation, new and reconstruction projects.

2. DATA COLLECTION AND ANALYSIS

Road inventory and pavement condition data for this study was collected using an automated multi-purpose data collection vehicle equipped with distance measuring device, high resolution video camera, ultrasonic distance measuring bar, three directional gyroscope and accelerometers. Some of the data collected simultaneously are video images of the road and road furniture within the road right-of-way, pavement cross fall, rutting, road profile and ride comfort of the pavement surface.

Transverse cracking data for this study were obtained from the video component of the PMS data library of Regional roads. The video database consisted of ten sets of video tape with front, side and downward views of the Regional road system. The tapes consist of thirty-eight Regional roads with about eight hundred lane-km of pavement. The roadway candidates consist of 95 lane-km of new and reconstructed candidates, 190 lane-km of Cold In-Place Recycled roadways and 505 lane-km of resurfaced roadways.

Using a pavement rating software, and following the procedures of the RMOC Pavement Management System Visual Condition Rating manual, all roads were rated for fifteen pavement distresses. The distresses were recorded and analyzed for location of their occurrence (chainage), their severity and the extent of their occurrence.

Information such as pavement rehabilitation type, binder type, pavement age, subgrade type and Ride Comfort Index values was obtained from the RMOC PMS database and road inventory, which quantifies roads according to chainage, thus providing a similar reference to the distress data from the videos. The transverse cracking data for each road was summarized over dynamically segmented (150 m to 1 km segments) sections of the road using all the physical attributes (rehabilitation type, binder type, subgrade type, pavement age, asphalt thickness and drainage condition) under study, to ensure cracking data are collated according to road segments having identical attributes.

In this study, pavement age was taken to be the number of years having passed since the last overlay or rehabilitation, to the nearest year, with zero years indicating that the road had been rehabilitated in 1994, and so on. However, this does not account for the time span in months that separate roads constructed at different times in the same year.

For clarity of plotted data, because of the sheer amount of data points generated by the dynamic segmentation process, regression formulas and trendlines are generated using total data set but only averages values of the attributes under consideration are plotted as data points.

New and reconstructed roads, roads that had been rehabilitated using the Cold In-Place Recycling process and roads that had been overlay are analyzed separately.

The drainage condition attribute could not be used to segregate the data in this study given that the drainage condition rating of most of the roadway is the same.

In order to give an indication of the effect of transverse cracking on road performance, transverse cracking frequency was compared to the Ride Comfort Index.

3. RESULTS AND DISCUSSIONS

3.1 Correlation of Transverse Cracking Frequency with Pavement Age

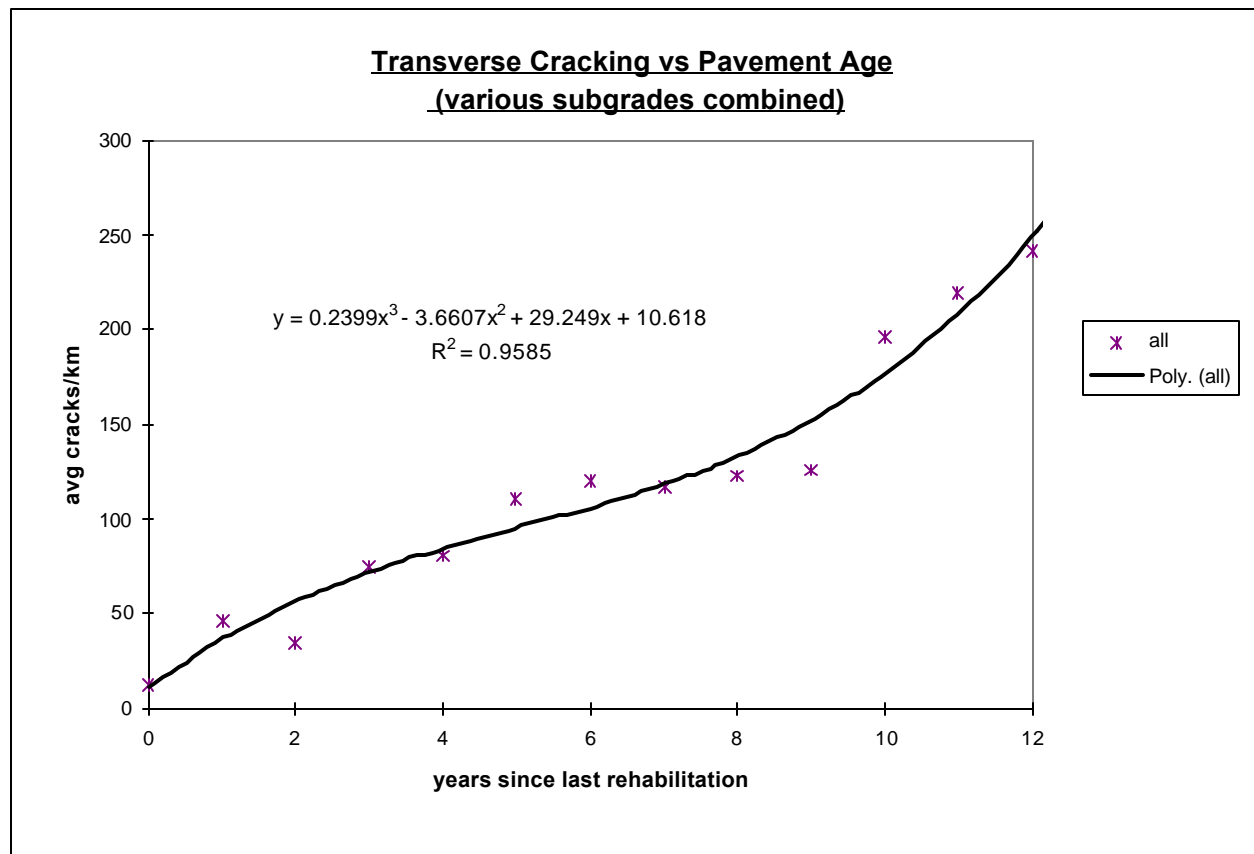
The relationship between the transverse cracking frequency and the pavement age since the last rehabilitation is presented in Figure 1 for combined subgrade conditions and pavement rehabilitation types for the whole network in this study. Figures 2 to 5 show the transverse cracking frequency and pavement age relationship for each subgrade type. Figures 6 to 8 show the cracking frequency with age of pavement

for new or reconstructed roads, Cold In-Place Recycled roads with a wear course topping and resurfaced candidates.

The method of linear regression was used to determine a line of best fit to develop the relationship between cracking frequency and pavement age. Four types of line fits were attempted: linear, exponential, and polynomials of the second and third degree. The basis for selecting the line fit is based on selecting equations providing the best R squared value. Third degree polynomial equations were found to provide the overall highest R squared value for overall combined subgrade and rehabilitation analysis of the cracking frequency and pavement age data. Table 1 shown the regression values for the line fit for the relationship between cracking frequency and pavement age for this combination of road network.

Results from Figures 1 and 6 indicated that some initial cracking after the first year can generally be expected as indicated by the y-intercept values for resurfaced candidates because of reflective cracking. Slight to no cracks were observed on Cold In-Place recycled and new or reconstructed candidates in the first year based on graphical results in Figures 7 and 8.

Cracking is observed to propagate at a relatively high rate in the first three years and again after about 10 years in service. The initial high rate of cracking is caused mainly by reflective cracking of resurfaced candidates. The increase in rate of transverse cracking after about 10 years of pavement in service is due to age stiffening of the asphalt binder. The increase in cracking frequency at this late stage in combination with the cracking frequency generally experienced at this stage of the lifecycle of the asphalt pavement when analyzed with the Ride Comfort data will be shown to govern the rehabilitation needs.



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Figure 1 - Aggregate basis Transverse Cracking Frequency Vs years since last rehabilitation

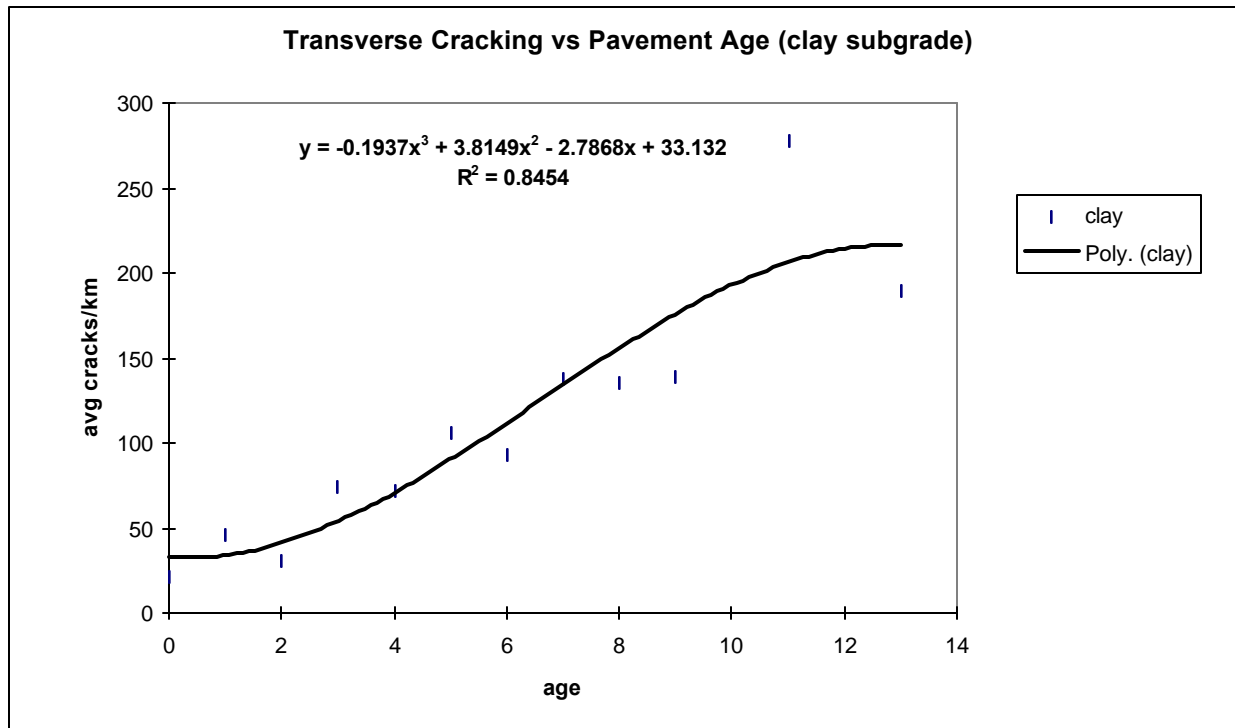


Figure 2 - Transverse Cracking Frequency Vs Pavement Age for Clay Subgrade

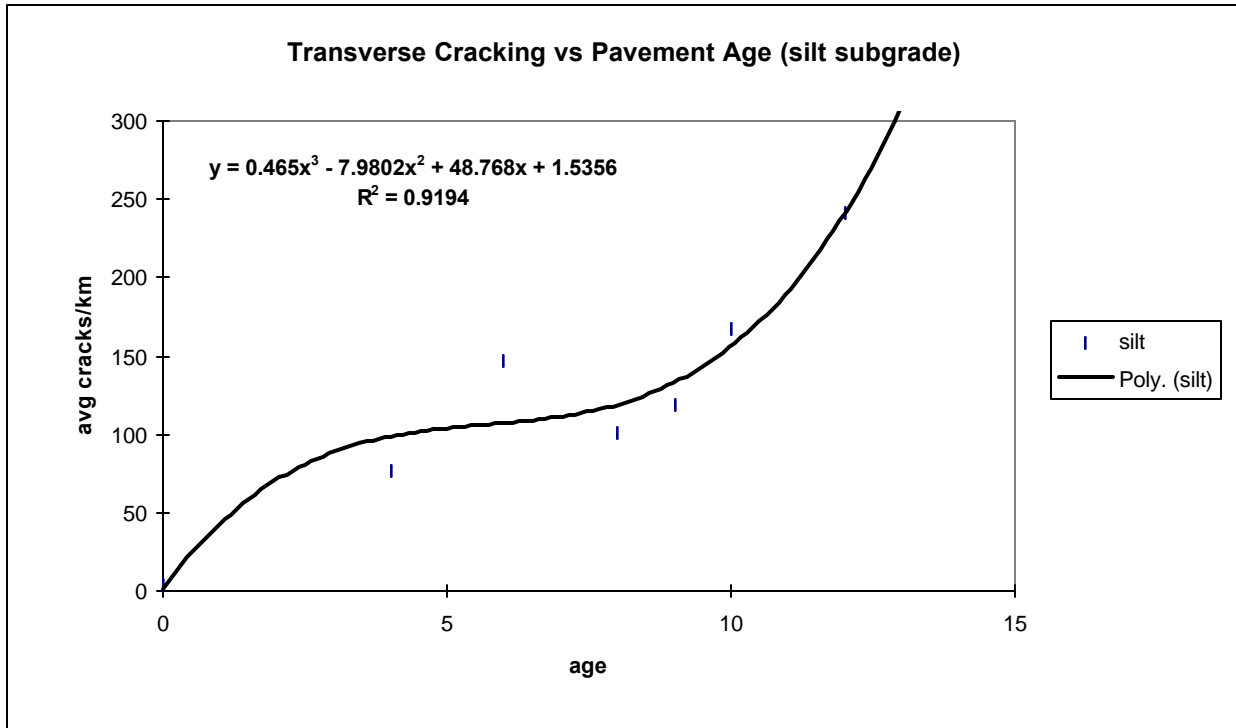


Figure 3 - Transverse Cracking Frequency Vs Pavement Age for Silt Subgrade

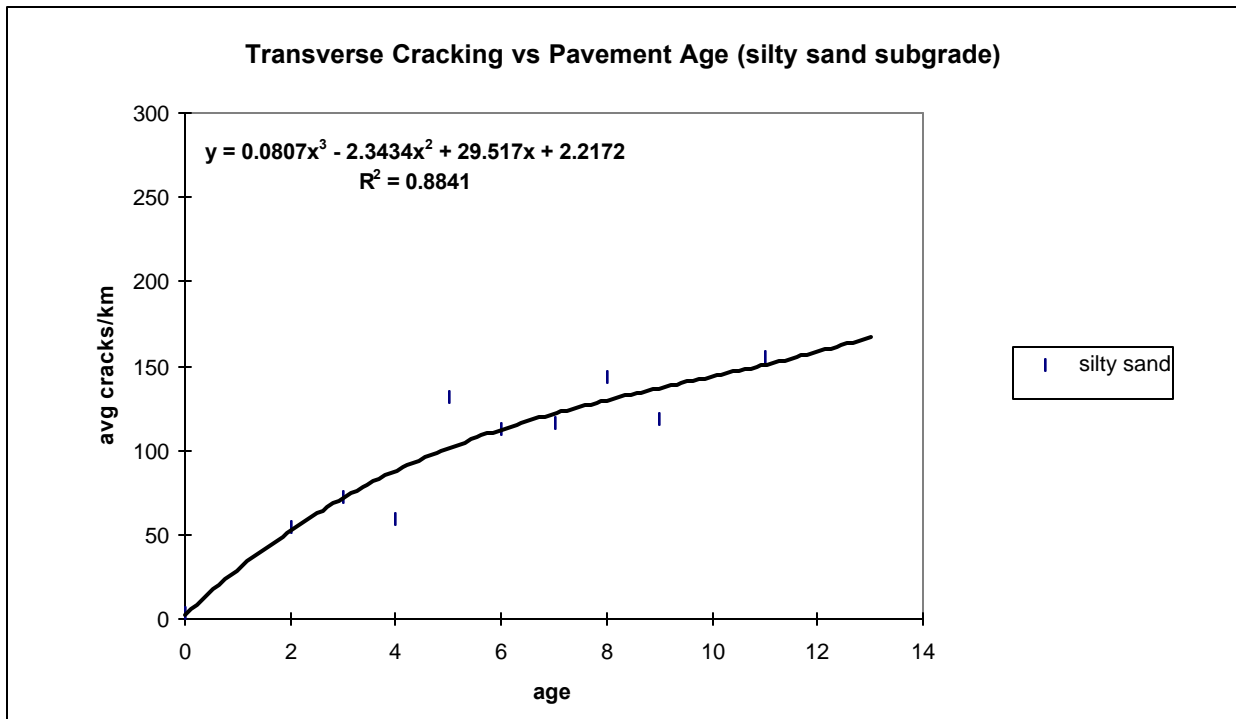


Figure 4 - Transverse Cracking Frequency Vs Pavement Age for Silty Sand Subgrade

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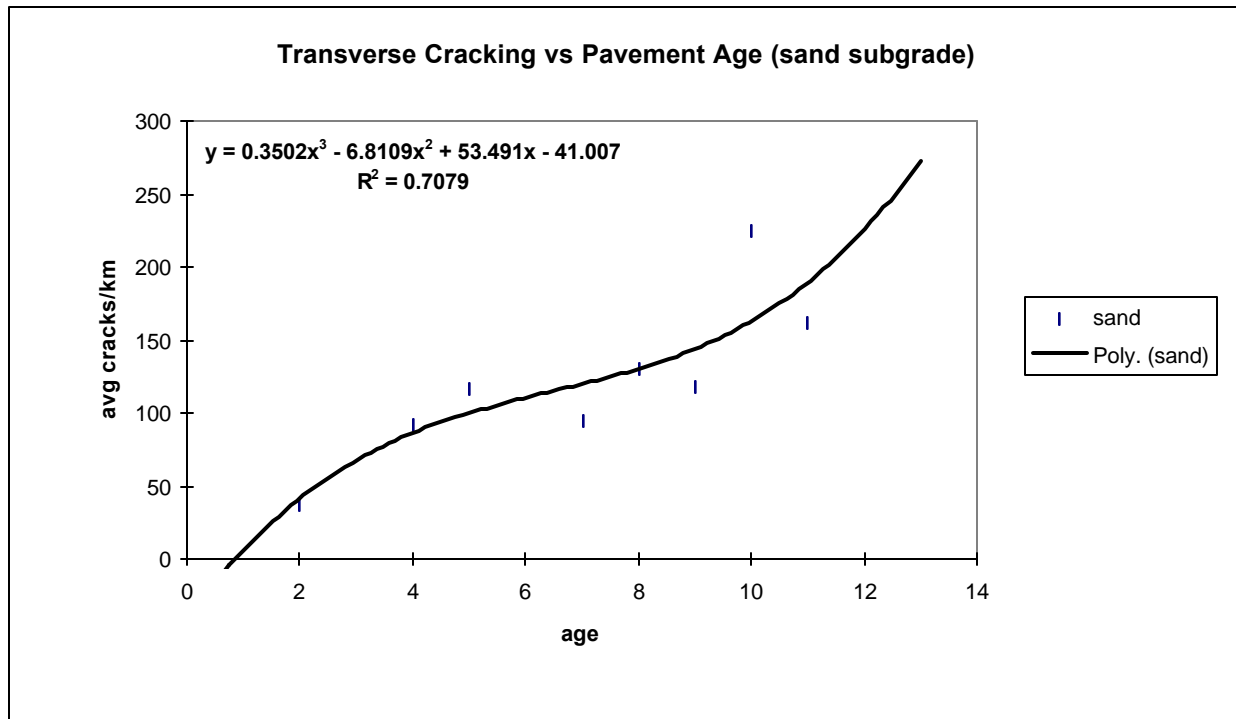


Figure 4 - Transverse Cracking Frequency Vs Pavement Age for Sand Subgrade

<u>Linetype Fit</u>	<u>R squared Value</u>	<u>Subgrade Type</u>
linear	0.905	combined subgrade
exponential	0.808	
polynomial (2 degree)	0.905	
polynomial (3 degree)	0.959	
linear	0.825	clay
exponential	0.847	
polynomial (2 degree)	0.825	
polynomial (3 degree)	0.845	
linear	0.822	silty sand
exponential	0.587	
polynomial (2 degree)	0.881	
polynomial (3 degree)	0.884	
linear	0.826	silt
exponential	0.770	
polynomial (2 degree)	0.836	
polynomial (3 degree)	0.919	

linear	0.691	sand
exponential	0.743	
polynomial (2 degree)	0.691	
polynomial (3 degree)	0.708	

Table 1 - R squared values of various linetype fits for Cracking Frequency Vs Pavement Age

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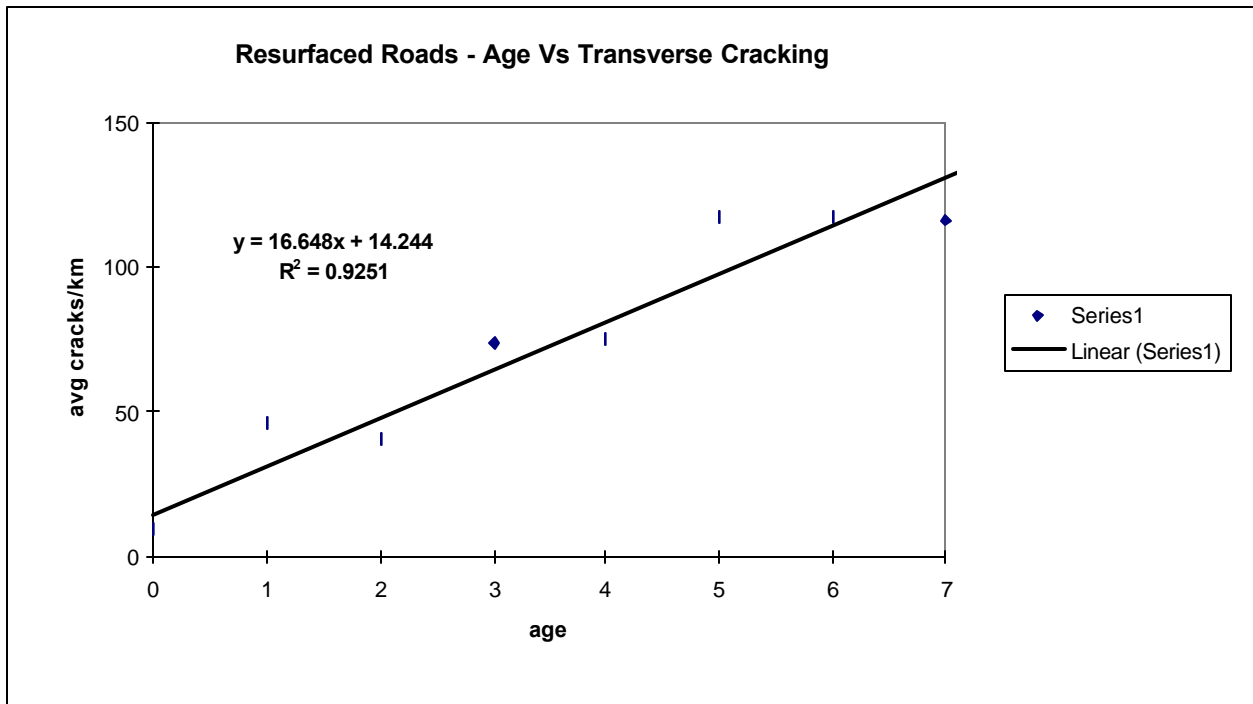


Figure 6 - Transverse Cracking Frequency for Resurfaced Roads

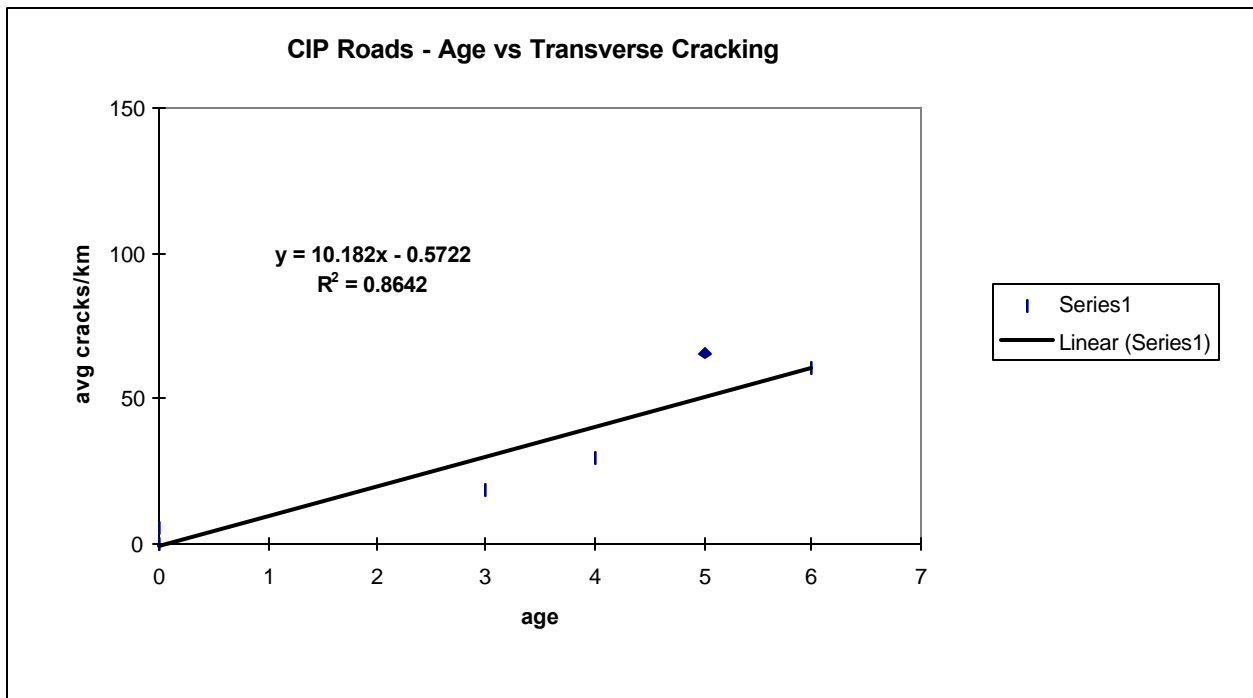


Figure 7 - Transverse Cracking Frequency for Cold In-Place Recycled Roads

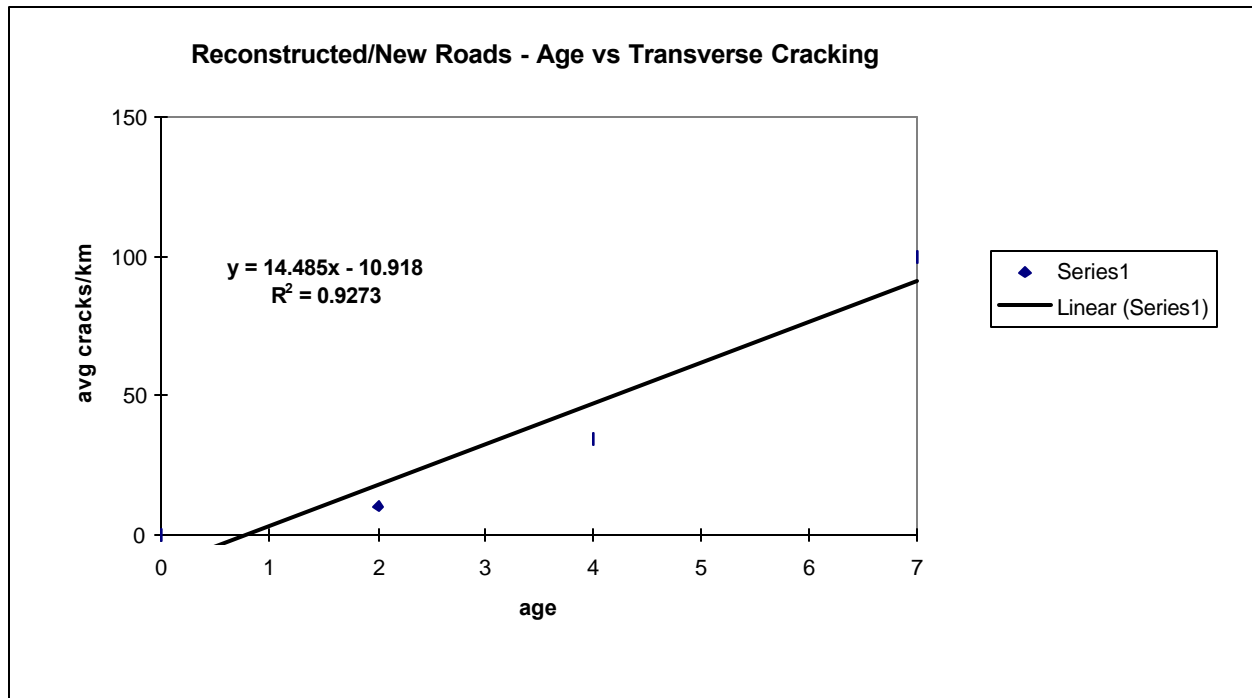


Figure 8 - Transverse Cracking Frequency for New/Reconstructed Roads

3.2 Correlation of Transverse Cracking Frequency with Ride Comfort Index

After analyzing the relationships between RCI values versus transverse cracking frequency and pavement age, the resulting R squared values for the various line fits showed more variability than for the relationship of transverse cracking frequency versus pavement age. This can be attributed to the nature of the RCI data, which was collected over a three year time span and projections were made to bring the data to the same base year for analysis purposes. The line fit that provided the best R squared values for each relationship was selected. For RCI versus transverse cracking relationship, the third degree polynomial provided the most consistent best fit, with R squared values ranging from 0.59 to 0.99 for the various subgrade types.

The critical RCI value based on RMOC PMS system is set at 5.0 to 5.5 depending on road classification and AADT, which corresponds to cracking frequencies of about 170 cracks per km or one crack every six metres results in increased discomfort for the user of a vehicle.

Results from this study shown on Figures 1, 9 and 14 where only thermal cracking is considered, performance and serviceable values such as the rehabilitation lifecycle (10 to 13 years), critical RCI value (5.0 to 5.5) and critical transverse cracking frequency (170 cracks per km) are the same when derived by the PMS system when all distresses are considered.

This indicates that thermal cracking in form of transverse cracking is the primary distress triggering the rehabilitation needs program for structurally adequate roads in RMOC.

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The original information collected incorporated both the frequency and severity of the transverse cracks. While the main focus was on the frequency of cracks in the road surface, in the RMOC PMS analysis module, the severity of the cracks will affect the results. The combined effect of both severity and extent of transverse distress is accomplished through the introduction of a modified distress index that weights value based on both severity and extent of crack occurrence, using a distress matrix as shown in Table 2.

Severity Code	Extent Codes					
	0	1	2	3	4	5
0	10	9	8	7	6	5
1	10	7	6	5	4	3
2	10	4	3	2	1	0

Table 2 - Distress Index Matrix

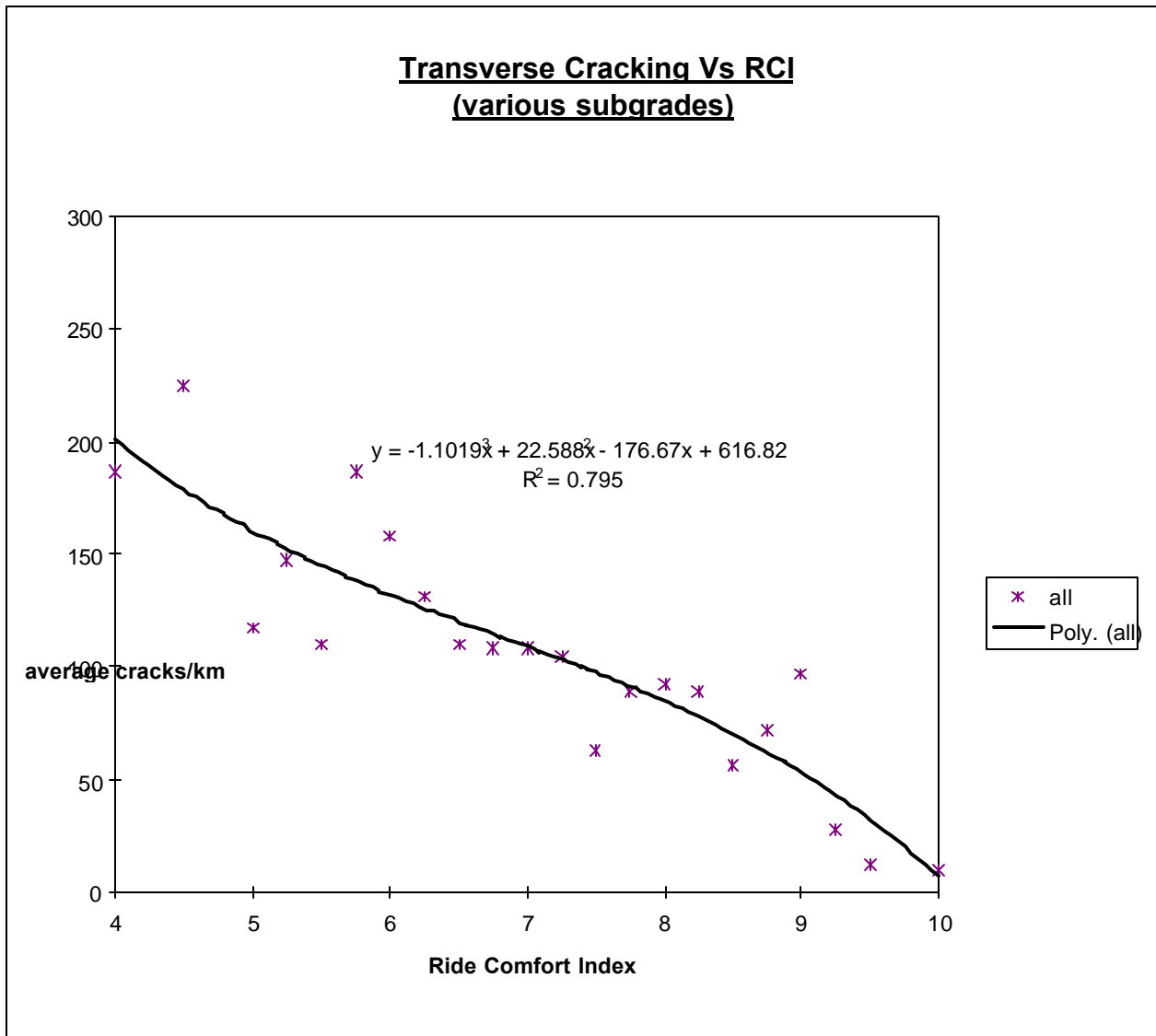


Figure 9 - Aggregate basis Transverse Cracking Frequency Vs Ride Comfort Index

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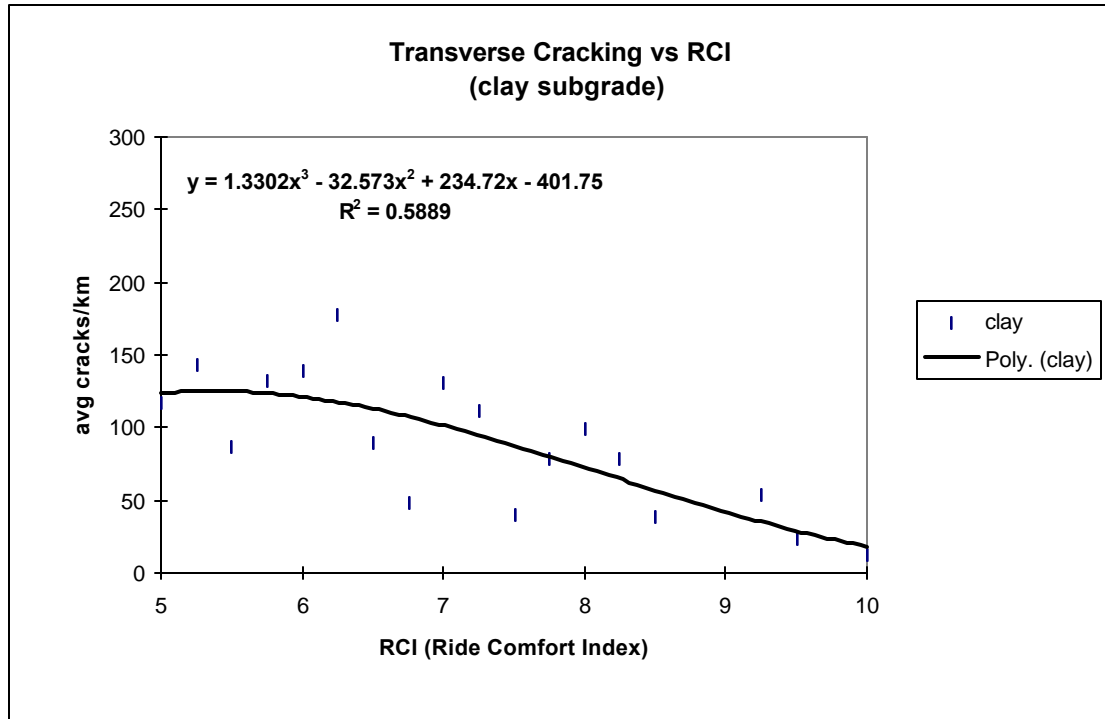


Figure 10 - Transverse Cracking Frequency Vs Ride Comfort Index for Clay Subgrade

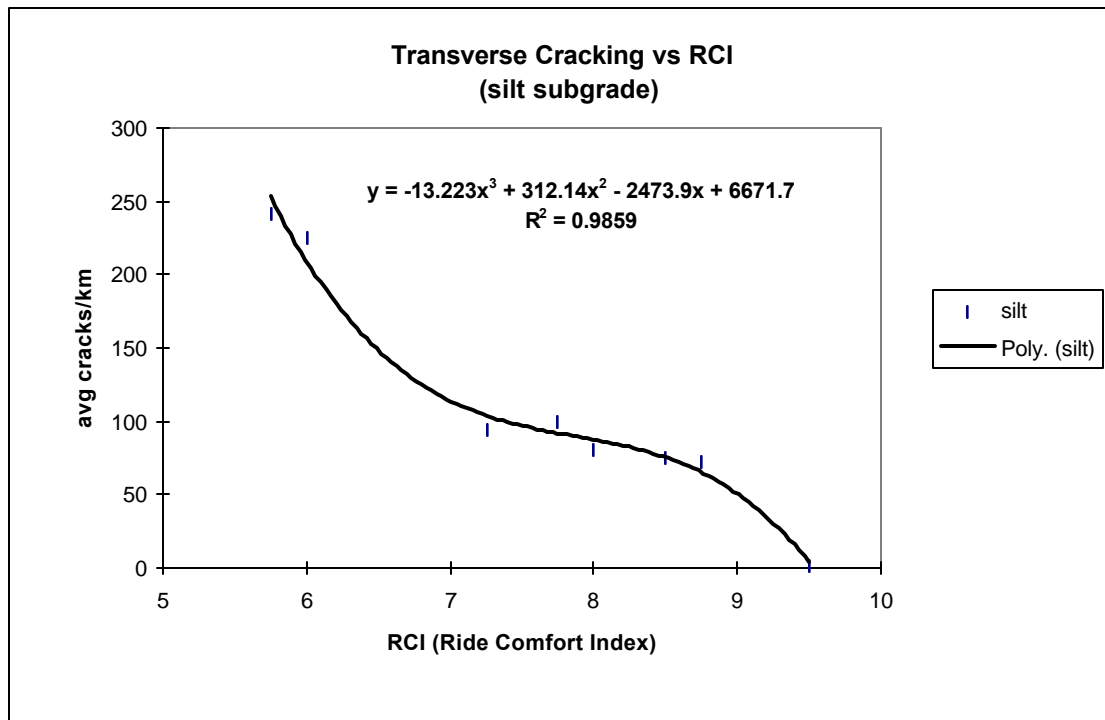


Figure 11 - Transverse Cracking Frequency Vs Ride Comfort Index for Silt Subgrade

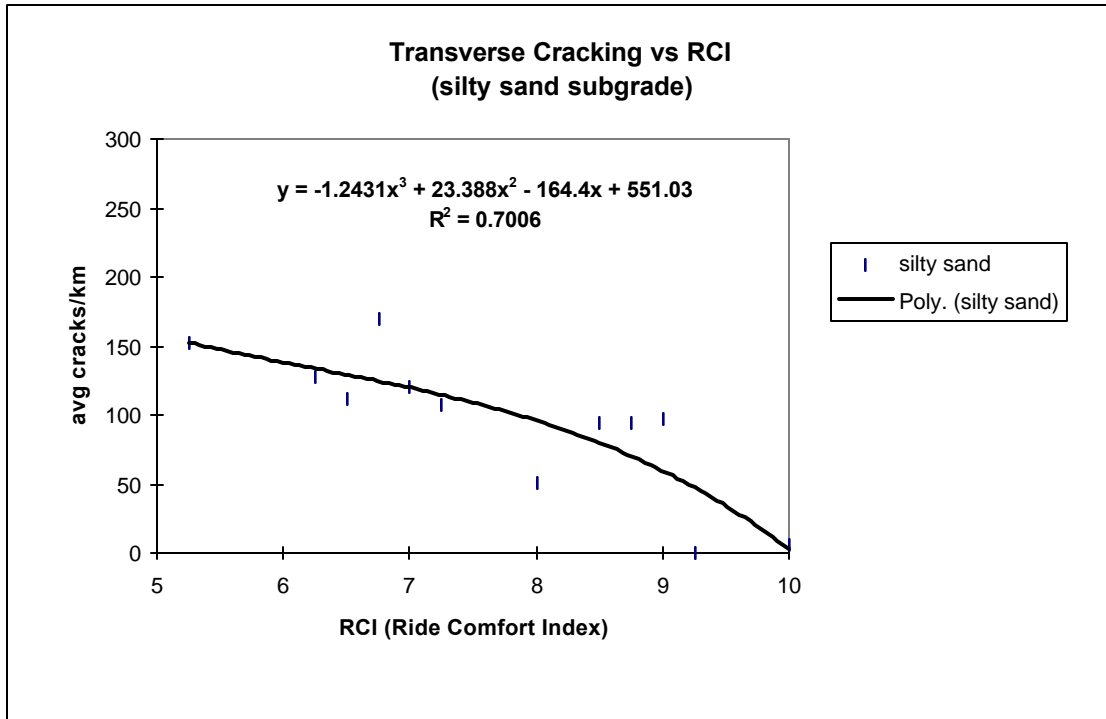


Figure 12 - Transverse Cracking Frequency Vs Ride Comfort Index for Silty Sand Subgrade

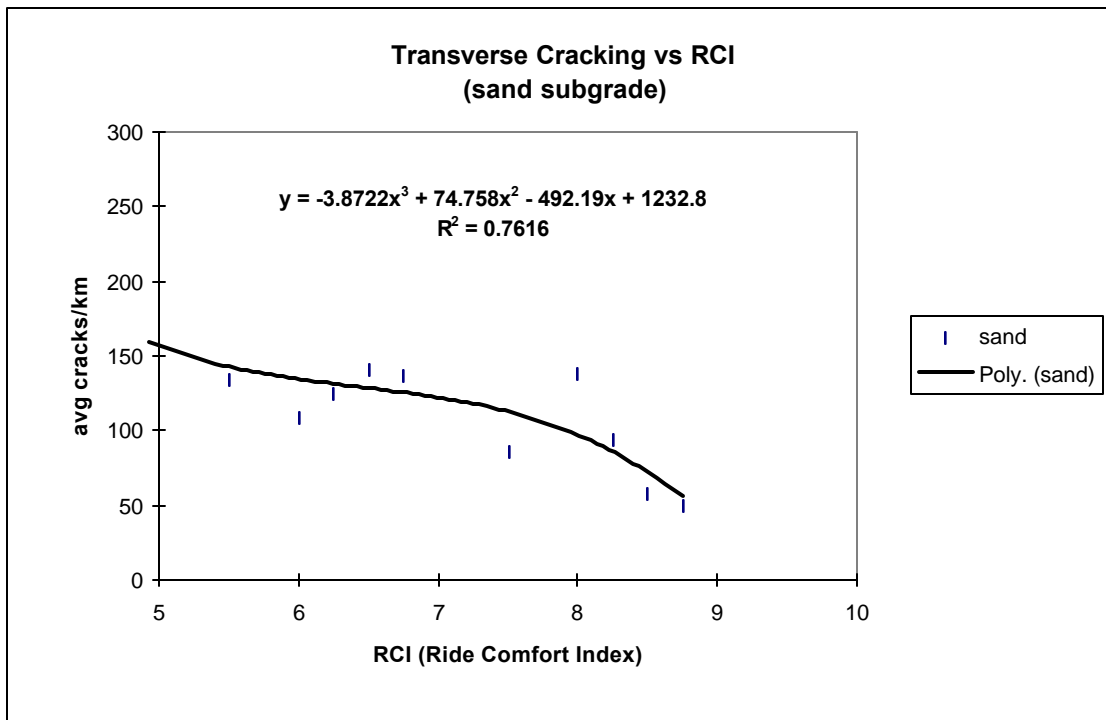


Figure 13 - Transverse Cracking Frequency Vs Ride Comfort Index for Sand Subgrade

3.3 Correlation of Ride Comfort Index with Pavement Age

The relationship that best describes RCI values versus pavement age is also the third degree polynomial with R squared values of 0.92 for aggregate network basis analyses. At the tenth year of pavement service life the RCI is about 6.8, after which it decreases very rapidly. This shows that rider discomfort is more likely to increase noticeably if the pavement is not rehabilitated after ten years. This concurs with the findings that transverse cracking begins to escalate more rapidly as well after the ten year point.

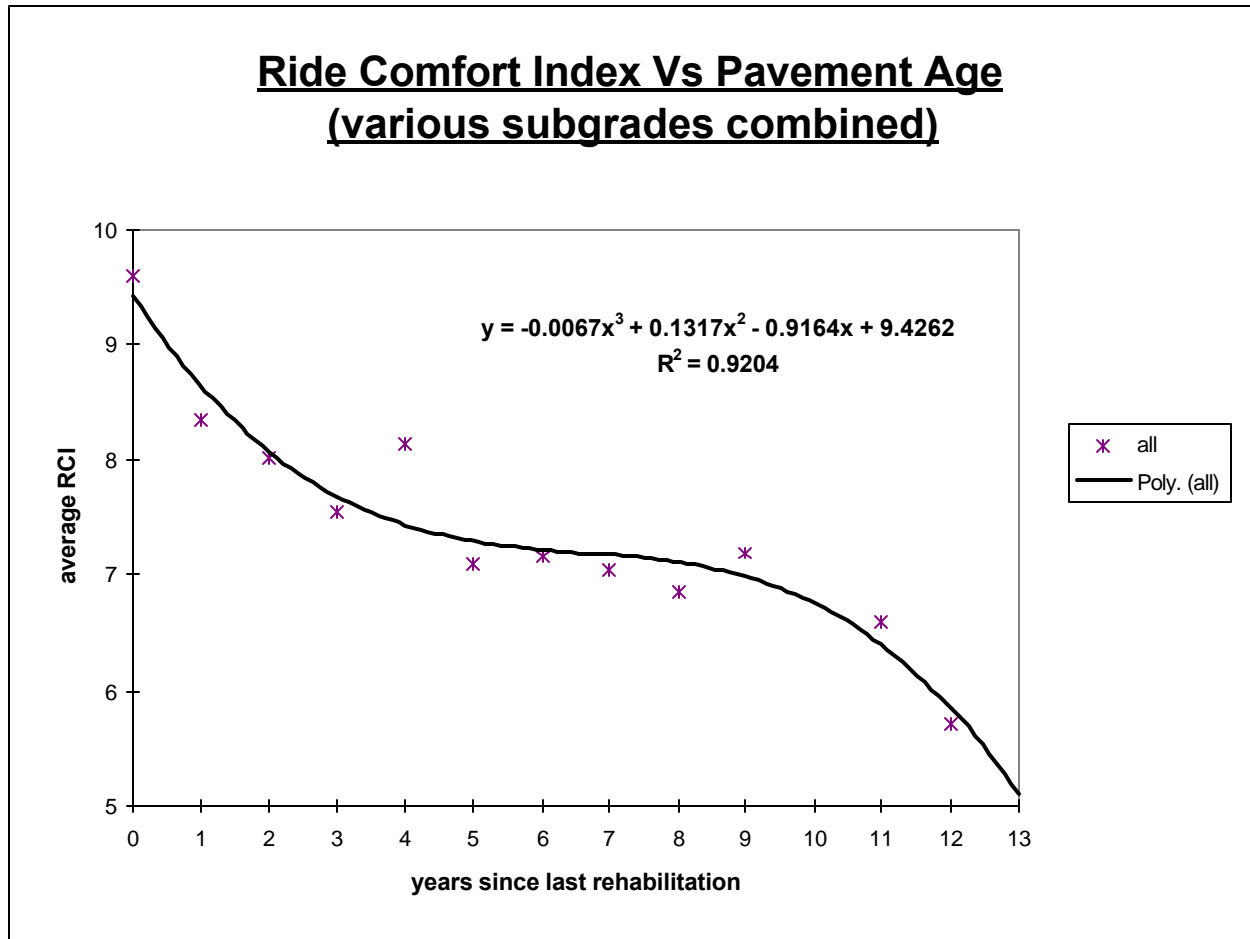


Figure 14 - Aggregate basis Pavement Age Vs Ride Comfort Index

3.4 Correlation of Transverse Cracking Frequency and Pavement Thickness

A comparison was also conducted to observe the transverse cracking performance of roads of different pavement thickness. Road candidates with pavement thickness in excess of 150 mm generally consist of resurfaced candidates. In this analysis the road sections were grouped in 50 mm increment thickness. Cracking data was then plotted versus the pavement age, but subdivided according to the above thickness groupings. Three graphical trends were isolated, the y-intercept, the line slope and the trendline value for cracks/km for various pavement ages. These values were then plotted against the average asphalt thickness to give a visual representation of pavement structure effects.

No clear trend existed when the intercept and slope of the lines were evaluated separately. However, in analyzing the trendline equation, the combination of the intercept and the slope yielded a definite trend for cracking values after five years. The year five was picked as a common reference due to the limited data available for certain pavement ages and to avoid over-extrapolation and loss of accuracy. A definite increase is noted in the amount of cracking at five years as the pavement thickness increases. Figure 15. Based on the above, pre-existing road surface conditions will determine the extent of initial reflective cracking, but thicker pavements may contribute to an increase in frequency of transverse cracking over time as age hardening progress downward in time with depth. Asphalt pavements in RMOC greater than 150 mm thickness are generally resurfaced roads, hence, the older underlying layer may also be a contributing factor.

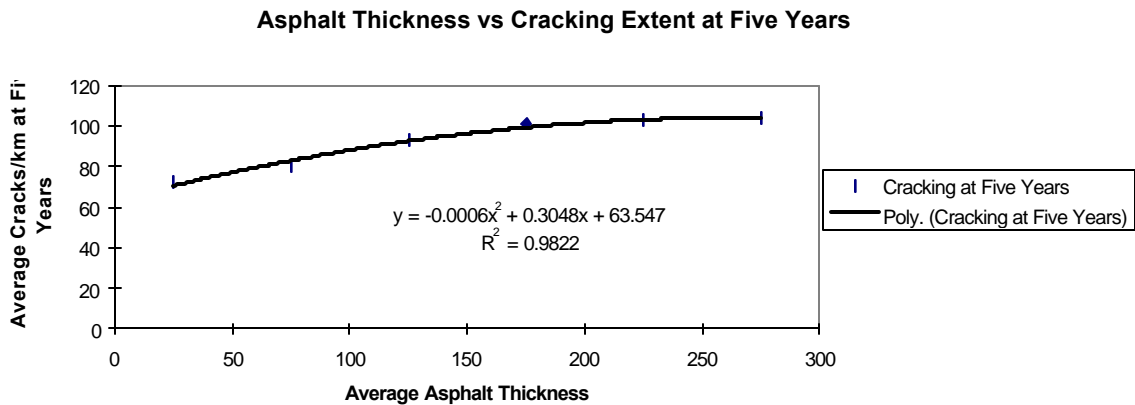


Figure 15 - Asphalt thickness and cracking frequency relationship at 5 year service life

3.5 Transverse Cracking on PG and conventional binder mixes

The frequency of transverse cracking associated with conventional and new/reconstructed roads carried out by RMOC is listed in Table 3 below. The data is based on 95 lane-km of roadway.

Using PG binder course on the surface wear course only is shown to reduced transverse cracking by 2.5 to 5 times.

The results indicate that new road constructed PG binder mixes will significantly reduce transverse cracking associated with thermal contraction and possible construction induced cracking in the initial pavement life. In full depth implementation of PG binder asphalt, to date no transverse cracking has been observed.

In rehabilitation of existing pavements using the CIPR process finished with a PG binder wear course less, than 0.2 cracks per km is observed after 2 years.

Age	Asphalt Type	Transverse Cracking Frequency Cracks/km
1	PG 58-34 all layers	0.0
	PG 58-34 surface with CIPR	0.2
	Conventional Asphalt 85/100	3.5
2	PG 58-34 surface course 85/100 base courses	6.6
	PG 58-34 surface with CIPR	0.0
	PG 58-34 all layers	0.0
	Conventional 85/100	17.9

Table 3 - Summary of Transverse Cracking on conventional and new/reconstructed roads

3.6 Cost Effectiveness of PG binder asphalt and Cold In-Place recycled process

Based on RMOC PMS whole road network analysis, roads constructed using conventional asphalt are rehabilitated at about 10 to 13 year intervals on the average.

Based on Figures 6, 7 and 8, resurfaced roads, CIPR roads with integral overlay, and new/reconstructed roads have a respective projected life expectancy of about 10, 17 and 13 years before they reached the critical RCI value of 5.0 to 5.5 and transverse cracking frequency of 170 cracks per km. The cost of resurfacing road in RMOC is about \$30,000 per lane-km. The cost of carrying out CIPR with an integral overlay is about \$42,000 per lane-km. New/reconstruction of pavement structure costs about \$120,000 per lane-km. Respective lifecycles between rehabilitation of CIPR road with integral overlay and new/reconstructed road are about 1.7 and 1.3 times that of conventional resurfaced road. CIPR road and new/reconstruction capital costs are respectively about 1.4 and 4.0 times that of resurfaced road. Hence, the ratio of present worth annualized unit cost over the lifecycle of resurfaced, CIPR with integral overlay and new/reconstruction road is about \$3, 000 : \$2,450 : \$9,200 (ratio of 1.0 : 0.8 : 3.1). Based on the above,

CIPR with integral overlay road is about 25% more cost effective than conventional overlay for the appropriate road candidate.

In RMOC, PG 58-34 binder asphalt generally costs about 10% above conventional 85/100 penetration grade asphalt. Based on limited data on PG binder asphalt in Table 3, extension of life expectancy of only one year will justify the use PG binder asphalt given the lifecycle between rehabilitation of conventional binder asphalt is about 10 years. Based on the rate of gain due to the reduction of transverse cracking and using data after two years of experience, an anticipated gain of two years over conventional asphalt cracking frequency has been already attained. The gain in reduced rate of cracking is anticipated to continue over the PG binder asphalt lifecycle. Hence, a significant lifecycle extension far beyond the conservative estimate of two years can be expected. It is postulated that areas experiencing larger temperature extremes can be expected to attain higher returns when using PG binder asphalt because this is where the shortfall of the conventional penetration grade asphalt is apparent.

4. CONCLUSIONS

Analysis of the results in this study indicated that thermal cracking manifested as transverse cracking has a significant effect on pavement performance over time. The consistent relationship between transverse cracking, pavement age and the Ride Comfort Index, was found to be a third degree polynomial relationship.

In RMOC after approximately ten years of service life, conventional asphalt pavements will exhibit a significant increase in the rate of transverse cracking. This is likely related to age stiffening of the binder in the mix. Beyond this critical lifecycle of convention asphalt pavement, the RCI values are observed to begin decreasing at a more rapid rate. The critical RCI values of 5.0 to 5.5 correspond with a transverse crack frequency of approximately 170 cracks per km (1 crack per 6 m). This cracking frequency also corresponds to a pavement service age of about 10 to 13 years.

It can be concluded that thermal distress, in the form of transverse cracking, reduces the effective length of a pavement's lifecycle, as well as reducing the performance of the pavement. Transverse cracking is the principle distress type triggering rehabilitation needs in RMOC roadway. Hence, it can be hypothesized that a decrease in thermal distresses could prolong the life of a road.

The CIPR process with integral overlay is shown to provide about additional 25% in cost-effectiveness when compared to the conventional resurfacing strategy over their lifecycles. RMOC has implemented the CIPR process combined with a PG binder hot mix overlay with the expectation of obtaining superior transverse cracking resistance.

Limited data todate on PG binder asphalt have already provided indications that a very conservative extension of life cycle by more than 2 years can easily be attained and is likely to be exceeded for conditions in the Ottawa-Carleton area. Use of SUPERPAVE PG 58-34 binder mixes in RMOC will definitely provide significant pay back given the premium to use such mix is about 10% for the anticipated lifecycle extension mentioned above.

REFERENCES

1. Gavin, Langlois and Kennepohl. "Low Temperature Performance of Three Canadian Test Roads", Proceeding Canadian Technical Asphalt Association, Edmonton, Alberta, 417-444 (1996)
2. Deme IJ, Young FD. "Ste. Anne Test Road Revisited Twenty Years Later", Proceeding Canadian Technical Asphalt Association, 254-283 (1987)