**Technical Report Documentation Page**

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| 7. Author(s) | Lutfi Raad, Stephan Saboundjian, Peter Seabailey, Jon Epps, Bob Camilli, and David Bush |

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<tr>
<td>Institute of Northern Engineering</td>
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<td>University of Alaska Fairbanks</td>
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<tr>
<td>P O Box 755910</td>
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<tr>
<td>Fairbanks, AK 99775-5910</td>
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**16. Abstract**

Low temperature cracking is a major distress mode in Alaskan pavements due to the extreme temperature conditions that range, in some instances, from about -50°C in winter to 40°C in summer. The use of asphalt modifiers in Alaskan pavements occurred over the past 15 years. These modifiers include SBR polymers, SBS polymers, ULTRAPAVE and CRM (both the dry process, PlusRide, and the wet process). Field observations and laboratory studies in Alaska and elsewhere, indicate that the use of these modifiers would improve the low temperature cracking resistance of pavements. The degree these modifiers provide for Alaskan pavements needs to be evaluated. The objectives of this research were: 1) To characterize asphalt and polymer modified asphalt mixes from a number of selected sites using SHRP Superpave PG grading system, thermal stress restrained specimen test (TSRST), and Superpave IDT laboratory tests on field specimens; 2) To compare low temperature cracking performance using field surveys; 3) To verify the applicability of SHRP Superpave thermal cracking, and 4) To assess the preliminary economic benefits from using polymer modified asphalts.

Results of this study indicate in general significant improvement in the low temperature cracking resistance when polymer modifiers are used. The corresponding reduction in crack sealing costs are estimated to be between 30% and 40%. Minimum air and pavement temperature correlations were developed using field data covering Alaska’s climatic zones. Contour maps for Alaskan roads corresponding to 50% and 98% reliability minimum pavement temperature were developed. Design recommendations to minimize low temperature cracking and estimate crack progression with age were established.

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LOW TEMPERATURE CRACKING OF POLYMER MODIFIED AC MIXES
IN ALASKA

Executive Summary

by

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ABSTRACT

Low temperature cracking is a major distress mode in Alaskan pavements due to the extreme temperature conditions that range, in some instances, from about -50°C in winter to 40°C in summer. The use of asphalt modifiers in Alaskan pavements occurred over the past 15 years. These modifiers include SBR polymers, SBS polymers, ULTRAPAVE and CRM (both the dry process, PlusRide, and the wet process). Field observations and laboratory studies in Alaska and elsewhere, indicate that the use of these modifiers would improve the low temperature cracking resistance of pavements. The degree these modifiers provide for Alaskan pavements needs to be evaluated. The objectives of this research were: 1) To characterize asphalt and polymer modified asphalt mixes from a number of selected sites using SHRP Superpave PG grading system, thermal stress restrained specimen test (TSRST), and Superpave IDT laboratory tests on field specimens; 2) To compare low temperature cracking performance using field surveys; 3) To verify the applicability of SHRP Superpave thermal cracking, and 4) To assess the preliminary economic benefits from using polymer modified asphalts.

Results of this study indicate in general significant improvement in the low temperature cracking resistance when polymer modifiers are used. The corresponding reduction in crack sealing costs are estimated to be between 30% and 40%. Minimum air and pavement temperature correlations were developed using field data covering Alaska’s climatic zones. Contour maps for Alaskan roads corresponding to 50% and 98% reliability minimum pavement temperature were developed. Design recommendations to minimize low temperature cracking and estimate crack progression with age were established.
ACKNOWLEDGMENTS

This work has been sponsored by the Alaska Department of Transportation and Public Facilities and the Federal Highway Administration under Project SPR-95-14. Numerous students and staff at the University of Alaska Fairbanks Transportation Research Center contributed to this study: George Minassian, Ting Zhang, Xiaolin Yuan, Ruan Chukui and Matt Stone. Other support was provided by Eric Johnson, Scott Gartin, Dave Sterley, Bob McHattie, and Matt Reckard of the Alaska Department of Transportation and Public Facilities. This help is greatly acknowledged.
LOW TEMPERATURE CRACKING OF MODIFIED AC MIXES IN ALASKA

EXECUTIVE SUMMARY

Asphalt modifiers have been used in Alaskan pavements over the past 15 years. These modifiers include SBR polymers, SBS polymers, Ultrapave, and CRM (both the dry process, PlusRide, and the wet process). Field observations and laboratory studies, performed in Alaska and elsewhere, indicate that the use of these modifiers would improve the low temperature cracking resistance of pavements. This project aimed at evaluating the degree of improvement these modifiers provide for Alaskan pavements, specifically, in relation to SHRP Superpave binder specifications, mix evaluation using Superpave TCMODEL and TSRST, and low temperature cracking models.

RESEARCH FINDINGS

1. The low temperature PG of conventional asphalts varied from -16 (AC-5 Badger Road) to -34 (AC-5, Haines Highway). For polymer modified binders, the low temperature grade varied from -22 (AC-5 + 3%SBS (Elmendorf), AC-5 +6% SBS (Rewak Drive)) to -40 (asphalt-rubber, Danby Street). The PG Grade for binders tested in this study is summarized in Table E-1.

2. There is some indication that the PG system for binder specification tends to "mask" any beneficial effect that the polymer modifier may have on the low temperature grade. This is evidenced by comparing the specifications for conventional and polymer modified binders used on the same project (Parks Highway, Haines Highway, and Elmendorf). This "masking" effect, however, is not evidenced in the case of asphalt-rubber (Danby Street). On the other hand, the TSRST results (Table E-1) clearly reflect the improved low temperature cracking resistance exhibited by the polymer modified mixtures. All polymer modified mixtures, except the AC-20R (Denali Park Road) and the AC-5 + 6%SBS (Elmendorf), exhibited lower fracture temperatures (-31 °C to -35 °C) in comparison with the conventional unmodified mixtures (-24 °C to -28 °C).

3. Except for the Haines Highway project, the low temperature PG for all conventional unmodified binders and polymer modified binders was, in most cases, "warmer" than Superpave 50% reliability minimum air temperature, but in all cases, it was "warmer" than the 98% reliability low temperature limit. Similarly, except for the Haines Highway project, all TSRST fracture temperature values were warmer than the 98% reliability low temperature recommended by Superpave.

4. Field surveys indicated that polymer modified mixes exhibit in general better low temperature cracking performance than conventional unmodified mixes. All projects, except for the Haines Highway, showed evidence of low temperature cracking. The extent of cracking depended largely on site location, and type of
Table E-1: Binder PG Grading and TSRST Results

<table>
<thead>
<tr>
<th>Project ID</th>
<th>Site</th>
<th>Binder Type</th>
<th>Binder PG</th>
<th>TSRST Measured Fracture Temp. (°C)</th>
<th>Estimated Original Fracture Temp. (°C)</th>
<th>TSRST Measured Fracture Strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>C street, Anchorage</td>
<td>AC-5</td>
<td>PG58-22</td>
<td>-25.7</td>
<td>-29.9</td>
<td>2811</td>
</tr>
<tr>
<td>n</td>
<td>A street, Anchorage</td>
<td>PlusRide</td>
<td>-</td>
<td>-26.4</td>
<td>-31.1</td>
<td>1979</td>
</tr>
<tr>
<td>b</td>
<td>Elmendorf AFB</td>
<td>AC-5+3%SBS</td>
<td>PG58-22</td>
<td>-33.2</td>
<td>-33.7</td>
<td>1931</td>
</tr>
<tr>
<td>c</td>
<td>Elmendorf AFB</td>
<td>AC-5+6%SBS</td>
<td>PG64-22</td>
<td>-26.4</td>
<td>-28.1</td>
<td>3033</td>
</tr>
<tr>
<td>e1</td>
<td>Haines Hwy.</td>
<td>PBA3</td>
<td>PG64-34</td>
<td>-31.6</td>
<td>-32.2</td>
<td>3035</td>
</tr>
<tr>
<td>e2</td>
<td>Haines Hwy.</td>
<td>AC-5</td>
<td>PG34-34</td>
<td>-27.5</td>
<td>-28.2</td>
<td>3393</td>
</tr>
<tr>
<td>f</td>
<td>Denali Park Road</td>
<td>AC-20R</td>
<td>PG58-28</td>
<td>-23.3</td>
<td>-25.1</td>
<td>922</td>
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<tr>
<td>g1</td>
<td>Danby Str., Fairbanks</td>
<td>Asphalt-Rubber</td>
<td>PG58-40</td>
<td>-33.0</td>
<td>-36.0</td>
<td>3276</td>
</tr>
<tr>
<td>h2</td>
<td>Parks Hwy., Fairbanks</td>
<td>AC-5</td>
<td>PG52-28</td>
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<td>-24.1</td>
<td>2479</td>
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<tr>
<td>h1</td>
<td>Parks Hwy., Fairbanks</td>
<td>PBA3</td>
<td>PG58-28</td>
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<td>-33.0</td>
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<tr>
<td>i</td>
<td>Badger Rd.</td>
<td>SHRP Level I</td>
<td>PG52-16</td>
<td>-25.3</td>
<td>-25.5</td>
<td>1745</td>
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<tr>
<td>j</td>
<td>Eielson AFB</td>
<td>Arctic Grade AC-5</td>
<td>PG52-34</td>
<td>-31.6</td>
<td>-35.6</td>
<td>3382</td>
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<tr>
<td>k</td>
<td>Fort Wainwright</td>
<td>Arctic Grade AC-2.5</td>
<td>PG58-34</td>
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<td>l</td>
<td>Rewak Dr., Fairbanks</td>
<td>PBA6</td>
<td>PG64-22</td>
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binder and mix used, and seemed to be related to the difference between binder low temperature grade and Superpave recommended 50% or 98% reliability grade. Observed low temperature cracking performance of the modified sections in comparison with conventional unmodified sections is summarized as follows:

a) The PlusRide section exhibits better low temperature cracking performance when compared with the conventional section. The average crack spacing after 10 years of service was 41 m in comparison with 29 m for the conventional section. The corresponding crack density was 29 cracks/km for the PlusRide section and 45 cracks/km for the conventional pavement.

b) The Haines Highway sections surveyed exhibited excellent low temperature cracking performance. No significant cracking was observed. In fact, both the polymer modified section and the conventional section showed no evidence of low temperature cracking after 2 years of age (1995 survey). However, during the following year (1996 survey) there were a total of 13 cracks in the modified section (3600 m) but only one crack in the conventional section (266 m). The average density of cracking for both sections was essentially equal to 4 cracks/km.

c) Both the conventional and the asphalt-rubber sections on Danby Street seemed to have reached a steady state in relation to the progression of low temperature cracking with time. The crack spacing in the conventional section ranged between 5 and 12 m with an average spacing of about 6 m and average crack density of 177 cracks/km. On the other hand, only 3 cracks were observed in the asphalt-rubber section with average spacing of 32 m and average crack density of 31 cracks/km. The use of asphalt-rubber in this case reduced the crack density by a factor of 6 approximately.

d) The improvement in low temperature cracking associated with using PBA 3 compared with the conventional AC-5 on the Parks Highway Projects corresponds to an estimated reduction in crack density of 25 percent after one year of service.

e) In order to illustrate the influence of polymer content on the binder-mix performance two sites were chosen in each of the Northern Region (Parks Highway, AC-5 + 3% SBS (PBA 3), 1995 and Rewak Drive, AC-5 + 6% SBS (PBA 6), 1993) and the Central Region (Elmendorf AFB, AC-5 + 3% SBS, 1995 and Elmendorf AFB, AC-5 + 6% SBS, 1991). In both the Northern Region and Central Region sites, the use of 6% SBS with AC-5 improved the low temperature cracking resistance in comparison with a 3% SBS modification. For example, the average crack spacing of the 5 year old pavement section at Elmendorf AFB with 6% SBS is essentially the same (23 m) as the section with 3% SBS after one year of service. Similarly, Rewak Drive in Fairbanks has 6% SBS and is 3 years old, but exhibits crack...
spacing of 51 m in comparison with 34 m spacing for the 3% SBS section of the Parks Highway after one year of service.

f) Field surveys indicate that Arctic Grade AC-2.5 seems to perform better than either AC-5 + 3% SBS or AC-5 + 6% SBS. In this case, comparing the Arctic Grade pavement at Ft. Wainwright with the AC-5 + 6% SBS section at Elmendorf shows that after 5 years of service, the two sections had essentially an average crack spacing of 27 m. However, climatic conditions are less severe at Elmendorf since the minimum air temperature (50% reliability) is -28° C whereas the minimum air temperature at Ft. Wainwright is -46° C.

g) There were only two rubberized pavement sections in this study. A-Street in Anchorage, which had a PlusRide surface, and Danby Street with an asphalt-rubber pavement. The asphalt-rubber exhibited the greatest resistance to low temperature cracking in comparison with other modified sections. At an age of 8 years, the asphalt-rubber section at Danby Street, under more severe climatic conditions, reached a steady state since no additional cracking was observed between Fall 1995 and Spring 1996. Although the PlusRide section in Anchorage had essentially similar crack spacing after 11 years of service, it did not reach steady state since the average crack spacing between 1995 and 1996 decreased from about 41 m to 33 m. It is expected that asphalt-rubber mixtures similar to those at Danby Street would perform better than the PlusRide used at A-Street under similar climatic conditions.

h) The asphalt-rubber section at Danby Street performed much better than Arctic Grade AC-5 used at Eielson AFB. In this case, the crack spacing at Eielson AFB reached about 6 m in comparison with 32 m at Danby.

5. Minimum air and pavement temperature correlations were developed using field data for selected sites covering Alaska's climatic zones (Appendix E1). Results indicate that for the lower temperature range generally applicable for low temperature design considerations, the minimum pavement temperature is always higher than the minimum air temperature. The difference, though, depends on the climatic zone under consideration. For the Continental Zone, the difference is about 7 ° C higher than the minimum air temperature, whereas for the Maritime and Transitional Zones the difference is approximately 2 ° C and 4 ° C respectively.

6. Minimum air and pavement temperature correlations also indicate that Superpave's recommendation to use minimum air temperature as equal to the minimum pavement temperature is conservative for Alaskan conditions. On the other hand, the use of the Asphalt Institute recommended correlations could be unconservative.
7. Contour maps for Alaskan roads corresponding to 50% and 98% reliability minimum air and minimum pavement temperatures were developed (Appendices E2 and E3). These maps could be easily used by AKDOT&PF design engineers in the selection of low temperature binder grade for a given location.

8. Comparisons between predicted and observed low temperature cracking models using available crack progression models, including Superpave TCMODEL were poor. Superpave TCMODEL analysis was performed using the software version currently available at the Asphalt Institute. The software is difficult to work with, and in many cases attempts to obtain thermal cracking predictions were not successful. The current software is not ready for practical applications and in many cases no predictions could be made. Comparisons with field observations show that the Superpave model predicts less crack spacing than currently observed and is therefore very conservative. An improved version of Superpave TCMODEL is currently under development at the University of Maryland. Predictions using Kanerva’s TSRST model could have been improved if input values for fracture temperature and strength of the original mixtures were available.

9. A regression model was developed for predicting crack spacing with age for the observed field sections in this project. The model is expressed as a function of minimum air temperature, pavement age, and TSRST fracture temperature and strength.

10. Preliminary assessment of reduced crack sealing maintenance costs as a result of using polymer modifiers indicates that percent savings varies approximately between 6 percent and 60 percent depending on type of modifier, location, and pavement age. When the "average" performance of all conventional pavement sections was compared with "average" performance of the polymer modified sections, the savings after about 5 years of service were estimated between 30 and 40 percent. Total life-cycle costs and users’ costs were not considered.

**DESIGN RECOMMENDATIONS**

Results of this study are used to propose the following design guidelines for low temperature cracking of Alaskan roads. These guidelines address two criteria: 1) Crack initiation and 2) Crack progression.

**Crack Initiation**

In order to minimize the probability for low temperature crack initiation, it is proposed that in the case of unmodified binders, the low temperature PG be selected based on the 98% reliability minimum pavement temperature and Superpave PG tests. In other words, the binder grade should be equal or lower than the 98% reliability minimum pavement temperature. Minimum pavement temperature could be determined using one of the following methods:
1) Use the minimum air temperature \( T_{air} \) from the weather station (e.g., Superpave Weather Database) nearest to the pavement site and convert the minimum air temperature to minimum pavement temperature \( T_{min} \) using the following equations:

**Maritime Zone**

\[
T_{min} = 0.853 \ T_{air} - 1.735 \quad (R^2 = 0.96) \tag{E-1}
\]

**Transitional Zone**

\[
T_{min} = 0.779 \ T_{air} - 3.129 \quad (R^2 = 0.85) \tag{E-2}
\]

**Continental Zone**

\[
T_{min} = 0.677 \ T_{air} - 7.561 \quad (R^2 = 0.81) \tag{E-3}
\]

For all zones (Maritime, Transitional, and Continental)

\[
T_{min} = 0.809 \ T_{air} - 3.150 \quad (R^2 = 0.91) \tag{E-4}
\]

or

2) Use the developed contour maps (Appendix E3) to estimate the minimum pavement temperature. Using the contour maps is simpler as it provides a quick means for estimating pavement temperature.

For polymer modified binders, it is recommended that fracture temperature determined from the TSRST testing be used in addition to Superpave standard PG Grading tests to assess the low temperature resistance of the polymer modified binder/mix. The use of TSRST as a supplementary or "proof" test is strongly recommended since the standard PG tests may "mask" the improved low temperature cracking resistance of polymer modified binders. The determination of minimum pavement temperature remains the same, as described above, for conventional binders.

**Crack Progression**

In many cases, the use of an appropriate binder with PG Grade that would satisfy 98% reliability minimum pavement temperature is not possible because of a number of limitations that could include cost, availability, site location, and other construction
considerations. The design engineer may in this case choose a binder with a PG warmer than the 98% reliability minimum pavement temperature. The determination of how much low temperature cracking is expected after a given period of time or alternatively, the binder/mix properties required to limit thermal crack progression to an "acceptable" level for a given design period, would be very useful to the design engineer. These questions could be answered by using the following equation which utilizes TSRST fracture temperature and fracture strength to predict the progression of thermal cracking with time:

\[ S = 994.11 - 127.69(A)^{0.1} + 43.89 \times 10^6 (T) + 0.5954 \times 10^6 (T)^2 - 0.665 (F_{TO}) - 0.0249 \times 10^6 (FS) \]  
\[ (R^2 = 0.853) \]

where:
- \( S \) = crack spacing, m
- \( A \) = pavement age, years
- \( T \) = minimum air temperature (°C) at the site, 50% reliability
- \( F_{TO} \) = TSRST fracture temperature (°C) of the original (unaged) mix
- \( FS \) = TSRST fracture strength, kPa

It should be emphasized that Equation E-5 is empirical and is based on limited field and laboratory data. Its use is recommended particularly in the absence of a reliable Superpave crack progression model or other crack progression models that fit Alaskan conditions.

**LIMITATIONS**

Although this study provides some insight on the low temperature cracking performance of conventional and polymer modified pavements in Alaska, the following limitations need to be considered as part of evaluating and applying the research findings:

1. Field studies including both temperature measurements at selected sites and field surveys of low temperature cracking were limited. Temperature data was collected and analyzed during December 1995 and January 1996. In addition, low temperature cracking surveys were performed twice over a one year interval. The temperature data sites were different from crack observation sites.

2. Because of the limited number of field sections, their location, and the types and thicknesses of pavements, the derived equations for air-pavement temperature and for crack progression should be used to predict general trends of behavior and need to be upgraded as more data become available.

3. The present version of Superpave TCMODEL is very difficult to use and does not provide reliable predictions for thermal crack progression with time. An improved version is currently under development at the University of Maryland.
4. The economic benefits for using polymer modified asphalts were assessed in terms of reducing low temperature cracking. Other potential benefits associated with improved performance such as reduced rutting, increased fatigue life, and increased resistance to raveling were not included in the economic study due to lack of data for Alaskan conditions.

RESEARCH NEEDS

The following are recommended research needs that would complement the findings of this study:

1. More refined PG specifications need to be defined for Alaskan conditions. The grading system should be consistent with minimum pavement temperatures for the different climatic zones in Alaska. The results of this study clearly show that the use of a 6 degree interval for the low temperature PG grade could be too "coarse" for Alaskan conditions. The improved specifications should also consider the use of TSRST fracture temperature and strength in binder selection since the PG Grading tests seem to "mask" the beneficial effects of polymer modification.

2. Field temperature and low temperature cracking data should be monitored on a continuous basis to provide improved air-pavement correlations and crack progression models. This is particularly important since these models and correlations are empirical in nature and therefore require substantial data for reliable predictions.

3. More work needs to be done to evaluate the extent of low temperature cracking associated with embankment shrinkage. The effects of climatic conditions, and embankment materials and geometry on the development of these cracks need to be identified as they would influence the decision to use polymer modifiers.

4. Research on characterizing polymer modified mixes for use in Alaskan urban roads is needed to determine improved fatigue and rutting resistance in comparison with conventional mixes and to ascertain the cost-effectiveness of using polymer modifiers.
APPENDIX E1

ALASKA CLIMATIC ZONES
APPENDIX E2

CONTOUR MAPS

FOR

MINIMUM AIR TEMPERATURE

(50% AND 98% RELIABILITY)
Air Temperature
50% Reliability – Fairbanks

Transportation Research Center
Alaska Data Visualization & Analysis Lab
University of Alaska Fairbanks
Air Temperature
50% Reliability – Anchorage

Transportation Research Center
Alaska Data Visualization & Analysis Lab
University of Alaska Fairbanks
Air Temperature
98% Reliability – Anchorage

Transportation Research Center
Alaska Data Visualization & Analysis Lab
University of Alaska Fairbanks
Air Temperature
50% Reliability – Southeast

Transportation Research Center
Alaska Data Visualization & Analysis Lab
University of Alaska Fairbanks
Pavement Temperature
50% Reliability – Anchorage

Transportation Research Center
Alaska Data Visualization & Analysis Lab
University of Alaska Fairbanks
Pavement Temperature
98% Reliability – Anchorage

Transportation Research Center
Alaska Data Visualization & Analysis Lab
University of Alaska Fairbanks
Pavement Temperature
98% Reliability – Southeast

Transportation Research Center
Alaska Data Visualization & Analysis Lab
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