Constructability of Polymer-Modified Asphalts and Asphalt-Aggregate Mixtures in Alaska

FINAL REPORT

By

Hannele Zubeck,
University of Alaska Anchorage
School of Engineering

Lutfi Raad,
Stephan Saboundjian,
George Minassian
Transportation Research Center
University of Alaska Fairbanks

And

John Ryer, P.E.
State of Alaska
Department of Transportation and Public Facilities

March 24, 1999

Report No. FHWA-AK-RD-99-1

REPORT DOCUMENTATION PAGE	Form approved OMB No.

1. AGENCY USE ONLY (LEAVE BLANK)	2. REPORT DATE March, 1999	3. REPORT TYPE AND DATES COVERED Final Report

4. TITLE AND SUBTITLE Constructability of Polymer-Modified Asphalts and Asphalt-Aggregate Mixtures in Alaska	5. FUNDING NUMBERS SPR-95-14
6. AUTHOR(S) Hannele Zubeck, Ph.D., P.E., Lufti Raad, Ph.D., Stephen Saboundjian, George Minassian and John Ryer, P.E.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Alaska Anchorage, 3211 Providence Drive, Anchorage, AK 99508 Transportation Research Center, University of Alaska Fairbanks, AK 99775-5900 Alaska Department of Transportation and Public Facilities, Northern Region, Construction Section, 2301 Peger Rd., Fairbanks, AK 99709-5399	8. PERFORMING ORGANIZATION REPORT NUMBER FHWA-AK-RD-99-1
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Alaska Department of Transportation and Public Facilities, Northern Region, Construction Section, 2301 Peger Rd., Fairbanks, AK 99709-5399	10. SPONSORING/MONITORING AGENCY REPORT NUMBER FHWA-AK-RD-99-1

11. SUPPLENMENTARY NOTES
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration

12a. DISTRIBUTION / AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Polymer-modified asphalt usage in Alaska raises two important issues. The first concern is about the compatibility and storage stability when polymers are used with Alaskan crude oils. Secondly, the ability of the contractor to place polymer-modified mixes continues to trouble construction personnel. This study addresses both these issues.

After an extensive literature review, the compatibility of the polymer and the asphalt cement was investigated using fluorescent microscopic images and elasticity tests. Separation tests provided an indication of storage stability. Conventional test methods including penetration, softening point and viscosity at several temperatures indicated consistency of the binders. Of the 36 polymer-modified binders mixed in the laboratory, only a few met the criteria set for the compatibility, storage stability, improved temperature susceptibility and mixing temperature. Storage stability and maximum allowable mixing temperatures were the most discriminating factors. Both cause constructability problems in polymer-modified asphalt mixtures.

Seven polymer-modified binders and three traditional binders were analyzed using Superpave binder tests. Asphalt-aggregate mixtures were subjected to the Thermal Stress Restrained Specimen Test (TSRST) and Georgia Wheel Rutting Test.

Tests indicate that polymer-modification improved the performance of all base asphalts. However, some binders smoke excessively when the temperature was elevated to the recommended mixing temperature. This issue warrants further investigation.

14. SUBJECT TERMS Asphalt, asphalt-aggregate mixtures, polymer-modification, polymers, constructability, rutting, low-temperature cracking, cold regions	15. NUMBER OF PAGES 95
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT

Constructability of Polymer-Modified Asphalts and Asphalt-Aggregate Mixtures in Alaska

FINAL REPORT

By

Hannele Zubeck,
University of Alaska Anchorage
School of Engineering

Lutfi Raad,
Stephan Saboundjian,
George Minassian
Transportation Research Center
University of Alaska Fairbanks

And

John Ryer, P.E.
State of Alaska
Department of Transportation and Public Facilities

March 24, 1999

Report No. **FHWA-AK-RD-99-1**

ABSTRACT

Polymer-modified asphalt usage in Alaska raises two important issues. The first concern is about the compatibility and storage stability when polymers are used with Alaskan crude oils. Secondly, the ability of the contractor to place polymer-modified mixes continues to trouble construction personnel. This study addresses both these issues.

After an extensive literature review, the compatibility of the polymer and the asphalt cement was investigated using fluorescent microscopic images and elasticity tests. Separation tests provided an indication of storage stability. Conventional test methods including penetration, softening point and viscosity at several temperatures indicated consistency of the binders. Of the 36 polymer-modified binders mixed in the laboratory, only a few met the criteria set for the compatibility, storage stability, improved temperature susceptibility and mixing temperature. Storage stability and maximum allowable mixing temperatures were the most discriminating factors. Both cause constructability problems in polymer-modified asphalt mixtures.

Seven polymer-modified binders and three traditional binders were analyzed using Superpave binder tests. Asphalt-aggregate mixtures were subjected to the Thermal Stress Restrained Specimen Test (TSRST) and Georgia Wheel Rutting Test.

Tests indicate that polymer-modification improved the performance of all base asphalts. However, some binders smoke excessively when the temperature was elevated to the recommended mixing temperature. This issue warrants further investigation.

AKNOWLEDGEMENTS

This report was conducted between the University of Alaska Anchorage and Fairbanks and the State of Alaska Department of Transportation and Public Facilities. The authors are grateful to the U.S. Department of Transportation Federal Highway Administration for providing funding and technical support for the project. The authors would also like to thank the technical advisory group: Scott Gartin, David Sterley, and Aaron Weston, and research manager Billy Connor, for their guidance, invaluable insight and appreciated comments for the project. Warm thanks also to the technical assistant Denny Wohlgemuth for his invaluable work in testing, data reduction and analysis. Also, Maureen Lee was very helpful with her ideas and contribution to the study. Last but not least go thanks to the graduate students, Lynn Aleshire, and the undergraduate students, Matt Man and Sean Bakinsky for their good work conducting the tests, data reduction and analysis.

0. EXECUTIVE SUMMARY

The constructability of Alaskan polymer-modified mixtures was studied by literature review, questionnaire study, conventional asphalt testing, Superpave asphalt testing, and testing asphalt-aggregate mixtures in Georgia Wheel Rutting Tester and Thermal Stress Restrained Specimen Test. The conclusions, recommendations, and future research needs observed are summarized in following Sections.

0.1 Recommendations

- Polymer-modified products should be an end result of comprehensive product development program, in which a compatible base asphalt and polymer will be combined using optimized procedure and optimized polymer content to achieve 1) lowest possible construction temperatures with 2) improved pavement performance. This will reduce construction problems, including the smoking and air quality issues, and reduce pavement life-cycle costs.

- Recommendations on mixing temperature:
  - In general, elevated mixing temperatures could result in excessive fumes, excessive oxidation of the binder, thermal separation of modifier and binder, and thermal degradation of the polymer modifier. Conventional binders do not usually smoke at temperatures lower than 163°C (325°F). The Asphalt Institute recommends a maximum of 177°C (350°F) to prevent thermal degradation and burnout.
  - Until more experience is gained and more research is undertaken addressing the issue of mixing and compaction of polymer modified Superpave mixtures, the Asphalt Institute suggests that mixing temperatures used for polymer modified mixes be slightly higher than compaction temperature, but not to exceed 170°C (340°F).

Specification recommendations to address the constructability of the binders:
  - Viscosity ranges for mixing temperatures at hot-plant and compaction temperatures should be specified. Because of the observed smoking problems, unfortunately more research is needed to establish these viscosities. The mixing and compaction temperatures would be defined on the basis of the viscosity ranges.
  - A storage stability test should be added to specifications. Or, the binder samples tested for quality control from the hot-plant should be taken just before the binder hits the hot aggregate in the mixer, to allow the contractor to address the storage stability question with techniques, such as tank circulation.
- Specification recommendations to address the performance of the binders:
  - To address the rutting resistance, a minimum softening point could be specified (e.g. 50 to 60°C).
  - To address the low temperature cracking resistance, a minimum penetration at 10°C or lower could be established. The numerical value depends on the

minimum pavement design temperature, and could be obtained from Figure 7-3. Or, the BBR Stiffness could be used as shown in Superpave specifications.

- Fatigue cracking was not considered in this research.

0.2 Literature Review

- Compatibility is a very important parameter that governs the success of polymer modification.
- Several tests were found for evaluation the compatibility of polymer-modified asphalts. Three of them were selected for this research:, separation test (tube test), fluorescent microscopy and elastic recovery. Based on the test results, all of these tests were found to be useful.
- Two types of specifications are used: guide type specifications that use conventional asphalt testing methods, and Superpave specifications. The Superpave specifications do not consider storage stability, and therefore sampling should be conducted just before the binder is mixed with the aggregate or a separation test should be added to the Superpave specifications.

0.3 Questionnaire Study

- Polymer-modified asphalts have been in pavement industry use for fifteen years without any reported constructability problems.
- The hot-plant mixing temperatures and compaction temperatures are always elevated, and air temperature should be 10°C (50°F) or warmer.
- The compatibility of polymer-modified binders is the manufacturer’s responsibility.
- SBS-polymer is most commonly used in the modification of asphalt cements.

0.4 Consistency and Compatibility Testing of Binders

- Of the 36 polymer-modified asphalts tested only nine met the criteria set for the compatibility, storage stability, improved temperature susceptibility, and mixing temperature. This shows that polymer modified asphalts should always be an end result of an extensive product development program.
- Pre-manufactured binders, that are end results of extensive product development programs, satisfied all criteria.
- It was shown that the binder properties depend upon polymer type, polymer concentration, base asphalt, and method used in mixing the polymer with the asphalt.
- A large number of binders did not meet the storage stability criterion, or the maximum hot-plant mixing temperature criterion. Both the storage stability and too high mixing temperature cause constructability problems. The high number of binders that did not meet the criteria partly explains the construction difficulties in the field.
- On the basis of the test results, three base asphalts and seven polymer-modified asphalts were selected for the next phases of testing.

0.5 Superpave Testing of Binders

- According to the temperatures, where the high and low temperature specifications are satisfied, the polymer-modification improved the pavement performance, both rutting resistance and low temperature cracking resistance, for all base asphalts. This indicates that the polymer-modification is beneficial.

0.6 Quantitative and Qualitative Testing of Asphalt-Aggregate Mixtures

- Excess smoking was observed for some binders. However, the limited number of variables did not allow determining if the smoking was caused by certain materials, their concentration or the mixing temperatures.
- Some polymer additives will produce noxious odors at high temperatures.
- Workability appears to be a function of polymer type and concentration, and of mixing and compacting the mixture at an adequately high temperature.
- Both of the pre-manufactured proprietary polymer-modified asphalt products showed good workability at the design construction temperatures. The use of these types of products is recommended, where economically feasible, if they meet all other criteria.

0.7 Superpave Testing of Binder-Aggregate Mixtures

- The pre-manufactured binders and SBS-modified binders with 4 to 5% polymer content had the best rutting resistance.
- SBS-modification improved the rutting resistance dramatically.
- The SBR-modification also generally improved the rutting resistance when compared to the straight asphalts.
- Mixtures with the pre-manufactured binders exhibited the best low temperature cracking performance with fracture temperature values –34 and –36°C respectively (-29° and –33°F).

TABLE OF CONTENTS

APPENDICES

TABLE OF TABLES

TABLE OF FIGURES

1. INTRODUCTION

1.1 Background

Polymer-modified asphalt binders are frequently and effectively used in the paving industry to improve pavement performance and to increase pavement life. Polymer-modification is reported to reduce pavement cracking due to thermal stresses and repetitive loads and, especially, decrease rutting due to plastic deformation[1,2]. Application of modified asphalt concrete is more expensive than traditional asphalt pavement. Therefore, it is important that the polymer-modified pavement is manufactured and constructed properly, assuring that the improvement in pavement performance and pavement life is achieved.

Polymer-modified asphalt is typically manufactured by adding plastics, elastomers, or polymer fibers to asphalt[3]. Synthetic elastomers, such as styrene-butadiene-styrene (SBS) and styrene-butadiene-rubber (SBR), are common and very effective polymer modifiers for pavement applications. The SBS and SBR polymers are also commonly known as styrenic block copolymers or thermoplastic rubbers.

When mixed with asphalt the butadiene phase of the polymer absorbs the lighter ends of the asphalt, typically maltenes, and swells as much as 9 times its original volume.[4] The butadiene phase is cross-linked by the styrene to form a continuous network throughout the asphalt when cooled. This network significantly changes the physical properties of the asphalt and produces non-Newtonian properties in the modified binder.

Polymer-modified binders have been used on Alaskan roads for about 8 years. The improvement of the pavement performance due to the polymer-modification is reported by Raad et al.[5] The polymer-modification was shown to reduce low temperature cracking in Alaskan roads. Recently, however, there have been some problems constructing modified asphalt concretes, particularly in obtaining required compaction levels, and roughness of the pavement surface. Because of these difficulties Alaska Department of Transportation and Public Facilities (AKDOT&PF) decided to conduct a study about the constructability of polymer-modified asphalt concretes together with the University of Alaska Anchorage and Fairbanks.

1.2 Goals and Objectives

The goals of the research were as follows:

1. Analyze modified asphalt cements in order to select binders
    - with improved performance in the pavement when compared to traditional asphalt binders,
    - that can be used in asphalt-aggregate mixtures without comprehensive difficulties in mixing, laying and compaction.
2. Develop specification recommendations for binder properties at the moment of application at a hot mixing plant.
3. Develop guidelines for the mixing and compaction temperatures.

The goals were achieved by conducting the research in several phases by the University of Alaska Anchorage (UAA), University of Alaska Fairbanks (UAF) and State of Alaska, Department of Transportation and Public Facilities, Fairbanks Construction Section (AKDOT&PF) as follows:

- Literature Review – UAF
- Questionnaire Study – UAA
- Compatibility and Storage Stability – UAA,
- Consistency – UAA,
- Superpave Binder Tests - UAF,
- Quantitative and Qualitative Properties in Mix Design (Marshall) – AKDOT&PF, and
- Performance of Asphalt-Aggregate Mixtures - UAF.

1.3 Scope of Study

Approximately 40 different combinations of polymer-modified binders were mixed from 5 base asphalts and 4 different polymers. Each of the combinations was tested for consistency, compatibility, and storage stability. Binders that met the criteria set for these properties were further tested using Superpave binder tests. A mix design was conducted for testing the binders in asphalt-aggregate mixtures. At this phase, the binders were also evaluated qualitatively based on the handling properties of asphalt-aggregate mixture samples manufactured using the binders. The asphalt-aggregate mixtures were tested in the Thermal Stress Restrained Specimen Test (TSRST) and Georgia Wheel Rutting Test (GWRT).

2. LITERATURE REVIEW

2.1 Published Literature

An extensive literature search was conducted by the UAF on the general topic of polymer modified asphalts with particular emphasis on compatibility and constructability. A list of all abstracts collected is included in Appendix A of the Interim Report: "Summary of Literature Review," distributed to the investigators and technical advisors on July 1997. After a careful review of the abstracts, a number of publications that are specifically pertinent to the research project were selected. Results of the literature review are summarized and presented in "simple" and logical sequence as follows:

Polymer Types and Interaction Mechanisms

- An evaluation of polymer chemistry literature indicated those key polymer properties that influence thermal and viscoelastic properties are molecular weight and its distribution in the matrix, architecture and chemistry. The most common polymer structures found were linear and radial formations.
- The types of polymers can be separated into two main categories: elastomers and plastomers. Elastomers can stretch and recover their shape and generally improve elasticity and cyclic loading properties, adhesion and tack, and durability, softening point, impact resistance, resilience and toughness. Plastomers on the other hand, give strength to the asphalt and improve the blend properties over all service conditions particularly if the plastomers are partially crystalline.
- Typical elastomers are natural rubbers, styrene-butadiene-rubber (SBR), styrene-butadiene-styrene (SBS), and Neoprene. Typical plastomers are polyethylenes such as Novophalt, ethylene methacrylate (EMA), polypropylene, and ethylene vinyl acetate (EVA) such as Polybilt.
- There are four models which can be used to describe how polymers exist in asphalt: 1) Polymers can be a separate phase dispersed in the asphalt; 2) Asphalt can be a separate phase dispersed in the polymer; 3) Polymers can form a network within the asphalt; and 4) Polymers can be molecularly bound to the asphalt. Types (3) and (4) are most common morphology forms in common polymer modifications.
- The interaction of the polymers in the asphalt results in one important performance-related change. Polymers modify the viscoelastic properties of the asphalt.

Compatibility

- Asphalt cement chemistry is complex and defines how a given polymer may interact with the asphalt. Little was found in the literature that links asphalt cement chemistry to estimations of physico-chemical interactions with polymer additives.
- The most generally accepted concept of asphalt composition considers asphalts to be composed of asphaltenes and maltenes. The asphaltenes, which comprise the most complex fraction, are mixtures of paraffin elaborated polycyclic structures with large molecular weights in the range of 1000 to 2000. The soluble component is the maltenes and contains both neural oils and aromatic resins. Asphalts exhibit

properties that deviate from a “true” solution and thus may be considered a colloid system.

- In general, there are two interpretations of compatibility of polymers and asphalt cements: 1) The ability of the polymer to remain distributed in the asphalt cement without significant evidence of phase separation; and 2) Compatibility is defined based on the level of interaction between the polymer and the asphalt cement.
- A polymer is compatible with an asphalt if the modified asphalt exhibits typical properties of the binder in terms of homogeneity, ductility, cohesion, and adhesion. Compatibility can be established if the polymer is soluble in the asphalt cement and can maintain a homogeneous distribution without significant phase separation, or if it can be swollen by the asphalt oils without causing flocculation of the asphaltenes.
- The best polymer-asphalt blends are produced when the mixing temperature is above the melting point of the polymer crystallites.
- Compatibility is a very important parameter that governs the success of polymer modification. The asphaltenes that are suspended in the oils by the resins may flocculate upon the introduction of the polymer in the system under agitation and at high temperatures thereby causing oil bleeding and leading to a binder with little cohesion.
- Loss of compatibility could occur 1) during the blending process, 2) during mixing with the aggregates, and 3) during storage of the asphalt-polymer blend.
- In order to improve the compatibility between the polymer and the asphalt cement many methods have been proposed :

a) cross-linking additives

If SBR is cross-linked after incorporation into the asphalt by using appropriate additives during blending, it may help maintain a compatible polymer-asphalt blend with less tendency to age and segregate since most of the reactive sites in the asphalt are consumed during the cross-linking process.

b) addition of maleic anhydride

Many plastomers are much less compatible with asphalt thus the blends tend to separate at high temperatures. The addition of maleic anhydride during mixture will improve the reaction with certain compounds of asphalt, among them the carboxyl and free radical group thereby resulting in a more compatible blend.

c) chlorination

Asphalt-polyethylene mixtures have a tendency towards phase separation during storage at high temperatures for long periods. Chlorination of the polyethylene polymer is a simple technique that can be used to improve compatibility by changing polarity, reducing crystallinity, and increasing density of the polymer to match the density of the asphalt.

d) addition of other compatible polymers

The use of one compatible polymer during polymer-asphalt mixing may help suspend another. For example, SBR that may not be compatible with some asphalt cements could result in upgraded asphalt with very high specification when a small amount of polyolefin is added to the mixture.

- A number of tests have been proposed to evaluate the compatibility between asphalt cement and polymer modified additives. These tests examine physical distribution of the polymer in the asphalt cement medium, separation potential between the polymer and the asphalt cement, viscous and other related properties, and performance related properties. These tests, however, remain non-standardized. Some of these tests are summarized below:

a) tube test **[6]**

An aluminum foil tube is filled with polymer modified bitumen and placed in an upright position in a 163°C (or 180°C by some agencies) oven for an extended period of time. If the polymer and bitumen are incompatible, the polymer will migrate to the top of the tube. Any incompatibility is determined by observing the slump of the sample after it is removed from the tube. Alternatively, the difference in softening point between the top and bottom of the tube could be used to assess the degree of compatibility. There are many variations to this test in terms of length of storage time, cooling temperature, and property tested for.

b) fluorescent microscopy

The fluorescent microscopy is used to examine the macrostructure of the polymer-asphalt blend. In general, these blends are two phase systems that can be observed using fluorescent reflection microscopy. In this case, the blend is illuminated using an ultraviolet light. The polymer phase re-emits a yellow light whereas the asphalt phase does not give rise to observable fluorescence. The distribution of the polymer in the asphalt and consequently the compatibility of the blend could be visually assessed.

c) differential scanning calorimetry (DSR)

DSR has been used to determine how well the polymer blends with the asphalt and the efficiency of the polymer-asphalt interaction. In this case, the DSR is used to measure and compare the glass transition temperature, the melting point, and heat of fusion of both the virgin asphalt and the polymer-modified blend.

d) crushing test

A disk of polymer-bitumen that is 2mm thick and having a diameter of 20.5mm is placed between two sheets of absorbing filter paper and subjected to a weight of 100g at 135°C for 15 hours. Stability of the blend is assessed from measured deformation of the applied weight and migration of oil on the filter paper.

e) elastic recovery[7,8]

Elastic recovery is used to evaluate elastic properties of polymer-modified asphalts. A standard ductilometer that meets ASTM D113 specifications is used to determine elastic recovery at various temperatures. The sample is elongated 200mm, after which it is cut in half and left undisturbed for a period of time. The elastic recovery is defined as the distance between the two cut ends and is expressed as a percentage of the initial elongation.

f) mechanical tests

Static and dynamic tests are used to determine strength, stiffness, and viscoelastic properties of the polymer-modified asphalt. Tests such as direct tension, dynamic shear rheometer and bending beam rheometer (Superpave) are included in this category.

Specifications

- Polymer additives are not new to asphalt researchers. In Europe, during the past two decades, extensive practical research incorporating several potential polymers into asphalt cements supply preliminary field evaluations; the polymer-asphalt cements provide better, longer-lasting highways. In fact, polymers in Europe have become a permanent part of the highway construction program. The published literature indicates that few of the European countries use compatibility testing as part of the specifications for polymer-modified asphalts. For example, only Poland , Spain , and the Nordic-countries use storage stability in their specifications. Recently, the US paving industry became more interested in polymer-modified asphalts and there are at least 39 states that have included polymers in their road building programs and specifications.
- Specifications for using polymer-modified asphalts fall under the following categories: 1) AASHTO-AGC-ARTBA[6] guide specifications and 2) Superpave performance specifications for binders. More recently, more states and agencies are adopting the Superpave binder specifications.
- Incompatible blends of polymer-modified asphalts could lead to large variation in measured viscoelastic properties depending on which phase of the blend is sampled and tested.
- The use of the Superpave binder tests to assess the adequacy of the polymer-modified binder may not provide a sufficient measure to ensure compatibility of the polymer-asphalt blend unless proper sampling of the modified binder is conducted prior to mixing with the aggregate. A preliminary suggestion in this case will be to use storage stability tests proposed by AASHTO-AGC-ARTBA[6] *and* the Superpave PG grading as part of the polymer-modified binder specifications **.**

2.2 Questionnaire Study

A questionnaire study was conducted by the UAA to collect experiences, specifications and recommendations from other agencies in cold regions. The questionnaire given in Appendix A was mailed to road agencies in the Northern United States, Canada, Nordic Countries, Switzerland and Japan. A total of 13 responses were received, out of which Nova Scotia in Canada did not have any experience with the polymer-modified asphalts. The questionnaire responses are tabulated in Appendix B and summarized below.

Use of Polymer-modified Asphalt Pavements

Polymer-modified asphalts have been used in pavements from 2 to 15 years. In general, no specific constructability problems were reported. However, the mixing temperature is always elevated when compared to the traditional mixes. Quebec recommends 10°C for the minimum pavement temperature during the laydown. All responders were happy with the performance of the polymer-modified asphalts. Quebec reported better performance in regard to stripping and raveling. In Finland, the polymer-modified asphalts are used to counter problems related to low temperature cracking, fatigue on bridge decks and plastic deformation.

Compatibility Studies

Only the binder-suppliers and contractors reported that they study the compatibility of the polymers with asphalts. The responders that were agencies or road authorities reported that the investigation of the compatibility is the responsibility of the supplier and/or the contractor.

Test Methods

A variety of test methods is utilized in the characterization of the polymer-modified asphalts. The most commonly used test methods were penetration at 25°C, softening point (Ring&Ball), viscosity at various temperatures, storage stability, elastic recovery, fluorescent microscopic analysis, and the GPC (Gel Permeation Chromatography).

Materials used in Polymer Modification

Only few of the responders reported the base asphalt sources and grades as well as the polymers used in the modified binders. The recipes are normally proprietary information of the supplier/contractor. The reported penetration grades for base asphalts varied from 85 to 300. The polymers used are also normally proprietary information, but Quebec, Finland and Japan reported, that the SBS is the most commonly used polymer. Also, SB and SBR are used in the polymer modification of pavement asphalts. The modification degree is neither specified; however, the reported range varies from 2 to 7%. No major changes in the polymer types are predicted in the future by any of the responders.

Summary of Specification for Polymer-Modified Asphalts in Cold Regions

The specifications received for use in cold climates is given in Appendix C. The specifications from Idaho and Finland were attached with the questionnaire responses. The other specifications were obtained from various projects in the states mentioned (unpublished). Note also that most of the states are using already or will be using the Superpave specifications instead of the specifications given here. The City of Regina, SK Canada uses Superpave PG grades 34-54 and 40-60.

All specifications given are end result specifications versus recipes including the base asphalt, polymer and modification level. However, the AASHTO[6] specifications inform the user with which polymer the specifications will be met. The specifications attached with the questionnaire by Idaho, are recommended for *hot* climates according to the source, the AASHTO specifications[6].

Most Popular Specifications

Penetration at 25°C is specified by every agency expect CalTrans. The specified penetrations vary from 50 to 160 1/10mm. Softening point (Ring & Ball) is also a popular specification. A common minimum for the softening point is 60°C. Viscosity is required by all agencies at varying temperatures: a widely used maximum value for the viscosity at 135°C is 2000mm^2/s. Storage stability is tested by letting the polymer separate from the asphalt at 163°C for 48 hours. A recommended maximum value for the difference in the softening points for the bottom and top of the sample is 4°C. Finland requires a maximum difference of 25°C, but the separation conditions are more severe (180°C for 72 hours).

Several agencies specify the binder properties also after aging in the Rolling Thin Film Oven Test (RTFOT) or the Thin Film Oven Test (TFOT). The minimum penetration at 4°C (using a load of 200g and loading time of 60s) is specified to be from 15 to 30 1/10mm. A minimum value for the elastic recovery at 25°C after the RTFOT varies between 45 to 70%.

3. CONSISTENCY AND COMPATIBILITY TESTING OF BINDERS

Consistency and compatibility testing was conducted by the UAA in order to select binders for further testing that 1) have improved temperature susceptibility when compared to unmodified binders, 2) are compatible and storage stable, and 3) have reasonable mixing and compaction temperatures.

3.1 Materials

3.1.1 Base Asphalts

Five base asphalts were chosen for this study, three regular paving asphalts manufactured in Alaska and three asphalts manufactured specifically for polymer modification. The three paving asphalts are AC-5 and AC-2.5 manufactured by Mapco Alaska Petroleum/ a Williams Company (Mapco), and AC-5 manufactured by Tesoro Alaska Petroleum Company (Tesoro). The asphalts manufactured for polymer modification were obtained from Husky Oil Ltd. of Calgary, Alberta, Canada (Husky Oil) and U.S. Oil & Refining Co. of Tacoma, Washington (U.S. Oil).

3.1.2 Polymers

Four polymers were selected for mixing with base asphalts, 2 types of SBS polymers and 2 types of SBR polymers (Table 3-1). The specific polymer grades were recommended by their manufacturers. Shell SBS Kraton® 1101 has been previously used in polymer-modified asphalts in Alaska. Enichem SBS Europrene® SOL TE6317 is a new product created specifically for modification of asphalts. BASF Butanol® NS 175 and Ultrapave® SBR UP70 are latex polymers provided by their respective manufacturers. These polymers are only a small sampling of the different polymer grades available for paving applications. Many polymers are available in the chemical industry that are suitable as asphalt modifiers and this study is not intended to exclude any of those as effective modifiers.

Table 3-1. Selected Polymers

Polymer	Type	Form
Shell Kraton® 1101	Linear SBS	Porous pellet
Enichem Europrene® SOL TE6317	Radial SBS	Crumb
Ultrapave® UP70	Anionic SBR	Latex emulsion
BASF Butanol® NS 175	Anionic SBR	Latex emulsion

3.1.3 Premixed Binders

Husky Oil and U.S. Oil also supplied polymer-modified binders premixed at their processing facilities. The UPBA-6 and UPAC-53R, products of U.S. Oil, and HP, a product of Husky Oil, were tested. The type and concentration of polymer as well as any special mixing techniques in each of these products are proprietary information.

3.1.4 Polymer Concentrations

Initially, three polymer concentrations were chosen for each binder and polymer, 2%, 4%, and 6%, for a possibility of 60 combinations. For pavement applications, SBR polymers are typically mixed at concentrations of 2%-4% while SBS polymers are often mixed at higher percentages, 4%-6%. Each polymer and each binder were initially mixed at 4%. Each 4% mixture was then evaluated for consistency, compatibility, and storage stability. Based upon these results further polymer concentrations were determined. Some of the SBR's had to be mixed at 2% because the 4% concentration produced a product that was too stiff to handle and pour into sample containers.

3.2 Preparation of Polymer-Asphalt Mixes

Base asphalt and modified-asphalt shipments were received from the manufacturers in either one-gallon or five-gallon cans. The cans were heated in a 160°C oven for 2 hours and the asphalt was then poured into ½-gallon cans. Base asphalts were labeled, sealed, and allowed to cool to room temperature. Samples of modified asphalts were poured into sample containers and tested immediately.

The polymer content was calculated as a ratio of the weight of polymer to the total weight of polymer plus base asphalt as shown in Equation 1. The weight of the polymer is then obtained from Equation 2. The SBR polymers are latexes that contain 30% water that evaporates during mixing. This weight loss is accounted for by multiplying the weight of the polymer from Equation 2 by 1/0.7 or 1.426 in Equation 3.

Equation 1. Polymer Content

$$PC = \frac{Wp}{Wp + Wa} * 100\%,$$

where PC = polymer content, weight in %,
Wp = weight of polymer, and
Wa = weight of asphalt.

Equation 2. Weight of SBS Polymer

$$Wp_{(SBS)} = \frac{PC * Wa}{100 - PC},$$

where $Wp_{(SBS)}$ = weight of SBS-polymer.

Equation 3. Weight of SBR Polymer

$$Wp_{(SBR)} = 1.426 \frac{PC * Wa}{100 - PC},$$

where $Wp_{(SBS)}$ = weight of SBR-polymer.

Prior to mixing, the base asphalts were placed in a 160°C oven for 1-1/2 hours. The polymers were added into the asphalt gradually and premixed using a spatula. The temperature of the mixture dropped immediately when the polymer were added, and therefore, the mixes were returned to the oven for an additional 30 minutes to raise the temperature back to 160°C. When SBR polymers were added, the volume of the sample increased about 50% as the water boiled and formed foam on the surface.

The samples were then removed from the oven and placed on a hot plate. The actual mixing was conducted using a Silverson Model L4RT high-shear mixer with a slotted disintegrating head. The desired mixing rate was set at 5,000 rpm. The hot plate used during mixing raised and maintained the temperature of the samples at 175°C, which was necessary to obtain a uniform mixture.

SBS combinations could be mixed at 5,000 rpm immediately. Samples were, typically, mixed for 30 to 45 minutes. To determine if the polymer was completely mixed, a small spatula was dipped in the mix and smeared on clean, white paper. If the polymer grains were visible, the mixing process was incomplete. When the grains disappeared, the process was considered complete.

According to the polymer manufacturers, high-shear mixing is not necessary for SBR-latexes with asphalt. However, the same high-shear mixer was used to mix the SBR samples as was used for the SBS samples. Based on a few trials, the following method for mixing SBR-modified binders proved to be the best: The initial mixing rate was about 500 rpm. Typically, the binder climbed the shaft of the mixer, and a spatula was used to prevent it from climbing into the mixer motor. The mixing rate was kept low enough to prevent the binder from climbing past the spatula. As the temperature of the binder rose, the mixing rate could be increased gradually. The mixing rate was increased every 10 minutes until the maximum rate of 5,000 rpm was reached. Mixing was complete when the modified asphalt no longer climbed the mixer shaft.

When the mixing process was complete the sample containers for the test procedures were filled immediately.

3.3 Test Procedures

Traditional standardized tests and a few non-standardized test procedures were used to evaluate each binder's consistency, compatibility, and storage stability. Consistency was determined with traditional test procedures: penetration, softening point and viscosity. Fluorescent microscopic images and elastic recovery tests were used to evaluate compatibility. Storage stability was examined with a separation test and a slump test. Table 3-2 lists the test procedures used for this study. Test methods that are not standardized are described below.

Table 3-2. Test Procedures

	Test	Procedure
Standardized Methods	Penetration @ 10°C and 25°C Softening Point, R&B Viscosity using Brookfield viscometer	ASTM D 5 ASTM D 36 ASTM D 4402
Non-standardized Methods	Elastic recovery test using ductilometer UV fluorescent microscopy Separation test for Type I polymer modified asphalt Slump test	AASHTO Task Force31 Report, Feb. 1992[6]

3.3.1 Elastic Recovery using Ductilometer

Elastic recovery has been used to evaluate elastic properties of polymer-modified asphalts.[7] A standard ductilometer that meets ASTM D113 specifications was used to determine elastic recovery. The test temperature was selected on the basis of test results obtained by Schüller and Forsten (1990)[8], cold enough to separate binders but warm enough to allow elongation without breaking.

The ductilometer and sample were conditioned for 90 minutes at 10°C. The sample was elongated 200mm and held for 5 minutes, after which it was cut in half and left undisturbed for 60 minutes. The elastic recovery is defined as the distance between the two cut ends after 60 minutes and is expressed as a percentage of the initial elongation. Equation 4 was used to calculate elastic recovery.

Equation 4. Elastic Recovery

$$\%\,\mathrm{Recovery} = \frac{X}{200} * 100,$$

where X = distance between the cut ends after 60 minutes, mm.

3.3.2 Ultraviolet Fluorescent Microscopy

Ultraviolet fluorescent micrographs are used to observe the morphology of the polymer-modified binders. Morphology of the binders at the microscopic level is an indicator of compatibility.[9]

Samples for the microscopic slides were taken from the mix after it had cooled to room temperature. A small portion of mix was stretched and cut with a sharp knife. It was very important to check for a good sharp cut surface. The asphalt sample was placed on the slide being careful that the cut surface was facing up and a cover glass was placed on the sample. The slide was heated from the bottom just enough to compress the sample and evenly distribute it under the cover glass.

Good cut faces were obtained with varying degrees of difficulty; some mixes were very sticky or stringy and soft making it hard to get a good cut surface. Mixes that were very hard and tough allowed good samples. Typically, SBR combinations were stringy at lower concentrations and became tougher and easier to cut, though still stringy, at higher polymer concentrations. SBS-modified samples were easier to cut. Higher SBS concentrations had a much tougher texture, which allowed the best cut faces. The occurrence of stickiness in the mixes did not follow any pattern of polymer type or content. However, it was more severe in SBR combinations. For any combination, a tougher sample yielded a larger, more distinct cut face. The three pre-mixed binders each allowed good cuts.

The samples were viewed with a Leitz fluorescent microscope under a blue filter with a 10X magnification. The polymer within the binder fluoresces yellow light. Time-exposure photographs were taken with a Nikon FAC2.5 camera mounted on the microscope. Typical exposures were 5 to 7 seconds on Kodak Tri-X 400 film.

3.3.3 Storage Stability Tests

Two aluminum tubes 140mm long and 25mm in diameter were filled with freshly mixed modified asphalt and sealed. The tubes were placed upright in a 163°C oven for 48 hours then placed in a freezer for a minimum of 4 hours to solidify the sample. One frozen sample was used for the separation test and the other for the slump test.

Separation Test

For the separation test a frozen sample was cut into three equal sections. The sections from the top and bottom were placed in separate dishes in a 163°C oven until fluid enough to pour into softening point rings. Two rings were poured from each section. The ring and ball procedure described in ASTM D36 was performed with top and bottom samples tested simultaneously. The difference in softening point between top and bottom as well as the change from the original mix is an indicator of the degree to which the polymer has separated from the asphalt.[10]

Slump Test

The second frozen tube was sliced lengthwise and the aluminum was peeled back and the ends of the tubes were cut off or bent back to allow the mix to flow from the tube as it was heated. The samples were placed horizontally in foil trays and heated in an 80°C oven for 45 minutes. Photographs were taken of each sample after it was removed from the oven. The purpose of the slump test is to subjectively evaluate storage stability.

3.4. Test Results and Conclusions

3.4.1 Selection of Polymer Concentrations

As mentioned in Section 3.1.4, each polymer and base asphalt combination was originally mixed at a polymer concentration of 4%. The test results for the 4% mixes determined whether the combination would be mixed at a different concentration. Initially, modified binders that were not storage stable or compatible were not mixed at other concentrations. However, it was concluded later that compatibility and storage stability could be dependent on polymer concentration. That is, even if a mixture is not acceptably stable at a 4% concentration, it could be storage stable at another concentration level.

Of the remaining binders that were compatible and storage stable, succeeding polymer concentrations were determined using softening point and estimated hot-plant mixing temperatures as criteria. Increased polymer concentrations produce higher softening points and, therefore, improved temperature susceptibility. Estimated hot-plant mixing temperature was used as a criterion for maximum polymer concentration. The viscosity of the binder increases with the polymer concentration and raises the estimated hot-plant mixing temperature. Table 3-3 shows the combinations that were manufactured and tested. In addition to these laboratory-mixed polymer-modified binders, the five base asphalts and the three pre-mixed polymer-modified asphalts were tested.

Table 3-3. Asphalt-polymer Combinations for Binders Mixed in Laboratory

	Polymer Type ®	**S1**						**S2**						**R1**						**R2**					
	Polymer Content, % ®	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Base Asphalt	**A1**				●	●	●				●						●				●				
	A2			●	●	●	●				●						●				●		●		
	A3				●						●						●				●		●		
	A4		●		●						●				●		●				●		●		
	A5				●	●	●				●						●				●		●		

Base Asphalts: A1, A2, A3, A4, A5 – Mapco AC2.5, Mapco AC5, Tesoro AC5, Husky, and US Oil in random order.
Polymers: S1 and S2 – SBS polymers Enichem Europrene® SOL TE6317 and Shell Kraton® 1101 in random order. R1 and R2 – SBR polymers Ultrapave® UP70 and BASF Butanol® NS 175 in random order.
Pre-mixed Binders: PM1, PM2, and PM3 – one modified binder manufactured by Husky Oil and two by US Oil in random order.

3.4.2 Consistency

Consistency was evaluated using the data from the penetration, softening point, and viscosity tests. The ideal mixing temperature and the ideal compaction temperature for each modified binder were determined from the viscosity data using limiting viscosities of 170mm^2/s for mixing temperature and 280mm^2/s for compaction temperature[11]. The test results and determinations are found in Tables 3-4 and 3-5.

Table 3-4. Results of Penetration and Softening Point Tests

Binder	**Penetration, 1/10mm**		**Softening Point, °C**	**Binder**	**Penetration, 1/10mm**		**Softening Point, °C**
	10°C	**25°C**			**10°C**	**25°C**	
A1	27.7	125.0	41.6	**A1S2-4%**	20.3	100.2	79.5
A2	29.7	155.0	41.0	**A2S2-4%**	29.0	110.7	89.0
A3	67.0	238.0	37.5	**A3S2-4%**	45.3	143.0	59.5
A4	24.7	104.0	44.6	**A4S2-4%**	21.7	75.0	86.5
A5	44.7	231.3	39.0	**A5S2-4%**	40.7	155.3	86.5
PM1	64.0	182.0	80.5	**A1R1-4%**	23.0	114.3	50.3
PM2	38.3	119.0	50.5	**A2R1-4%**	27.7	115.0	49.8
PM3	50.3	154.0	61.7	**A3R1-4%**	53.0	167.3	51.1
A1S1-4%	23.3	98.0	48.0	**A4R1-2%**	24.3	101.0	49.1
A1S1-5%	23.7	87.3	86.3	**A4R1-4%**	23.3	93.0	56.8
A1S1-6%	23.3	76.0	87.0	**A5R1-4%**	38.3	175.7	48.4
A2S1-3%	31.7	110.7	46.8	**A1R2-2%**	27.0	121.7	44.9
A2S1-4%	24.3	116.7	50.2	**A2R2-2%**	28.3	127.7	44.3
A2S1-5%	22.3	91.0	85.0	**A2R2-4%**	32.0	117.0	54.3
A2S1-6%	29.0	86.0	88.8	**A3R2-2%**	55.0	211.3	40.2
A3S1-4%	38.0	121.3	65.8	**A3R2-4%**	Unpourable		
A4S1-2%	21.3	94.0	47.7	**A4R2-2%**	22.0	97.0	46.3
A4S1-4%	22.7	78.0	83.2	**A4R2-4%**	23.0	90.3	57.7
A5S1-4%	43.0	166.3	50.8	**A5R2-2%**	49.0	207.0	41.3
A5S1-5%	44.0	139.0	82.8	**A5R2-4%**	45.0	185.0	49.7
A5S1-6%	42.0	122.0	83.3				

Table 3-5. Results from Brookfield Viscometer

Binder	**Viscosity, mm^2/s**					**Ideal Mixing Temperature °C**	**Ideal Compaction Temperature °C**
	120°C	**135°C**	**150°C**	**165°C**	**180°C**		
A1	437.5	225	111.25	65	42.5	140	130
A2	387.5	187.5	100	62.5	42.5	138	128
A3	400	212.5	110	65	42.5	141	130
A4	525	250	162.5	77.5	50	150	133
A5	362.5	137.5	116	60	45	133	124
PM1	2950	800	437.5	240	157.5	175	162
PM2	1338	475	251.25	145	90	163	148
PM3	1438	775	408.75	232.5	147.5	173	157
A1S1-4%	1425	612.5	331	197.5	125	168	154
A1S1-5%	2475	950	503.75	290	180	180+	166
A1S1-6%	4125	1413	618.75	387.5	237.5	180+	175
A2S1-3%	850	437.5	235	137.5	87.5	160	145
A2S1-4%	1225	575	299	182.5	117.5	171	152
A2S1-5%	2075	850	456.25	250	160	178	162
A2S1-6%	3113	1038	587.5	355	225	180+	173
A3S1-4%	1663	850	453.75	252.5	160	180	162
A4S1-2%	875	425	225	125	80	158	145
A4S1-4%	1688	950	500	282.5	175	180+	165
A5S1-4%	900	475	280	157.5	105	164	150
A5S1-5%	1438	700	375	215	145	173	158
A5S1-6%	2350	887.5	568.75	307.5	205	180+	168
A1S2-4%	5850	787.5	365	230	142.5	178	158
A2S2-4%	4413	837.5	411.25	287.5	187.5	180+	165
A3S2-4%	2425	750	443.5	290	187.5	180+	166
A4S2-4%	6363	900	405	292	207	180+	167
A5S2-4%	3763	625	385	267.5	175	180+	162
A1R1-4%	2288	1038	708.75	587.5	375	180+	180+
A2R1-4%	2313	1175	895	557.5	565	180+	180+
A3R1-4%	2000	912.5	425	177.5	97.5	168	156
A4R1-2%	1125	525	302.5	210	145	178	152
A4R1-4%	3425	1550	1007.5	737.5	492.5	180+	180+
A5R1-4%	1825	1163	786.25	482.5	335	180+	180+
A1R2-2%	875	487.5	191.5	180	117.5	172	143
A2R2-2%	937.5	462.5	288.75	177.5	115	168	151
A2R2-4%	2338	1150	901.25	520	335	180+	180+
A3R2-2%	2338	1825	495	407.5	367.5	180+	180+
A3R2-4%	Unpourable						
A4R2-2%	1263	572.5	286.25	195	125	171	150
A4R2-4%	3328	1325	855	645	420	180+	180+
A5R2-2%	2125		495			175	162
A5R2-4%	2125	1350	791.25	457.5	315	180+	180+

The minimum softening point for the modified binders was set at 50°C. If the softening point of the 4% mixture did not exceed 50°C then that combination was not manufactured at 2% because a lower concentration would further decrease the softening point. Figures 3-1 and 3-2 show the effect of polymer content on softening point.

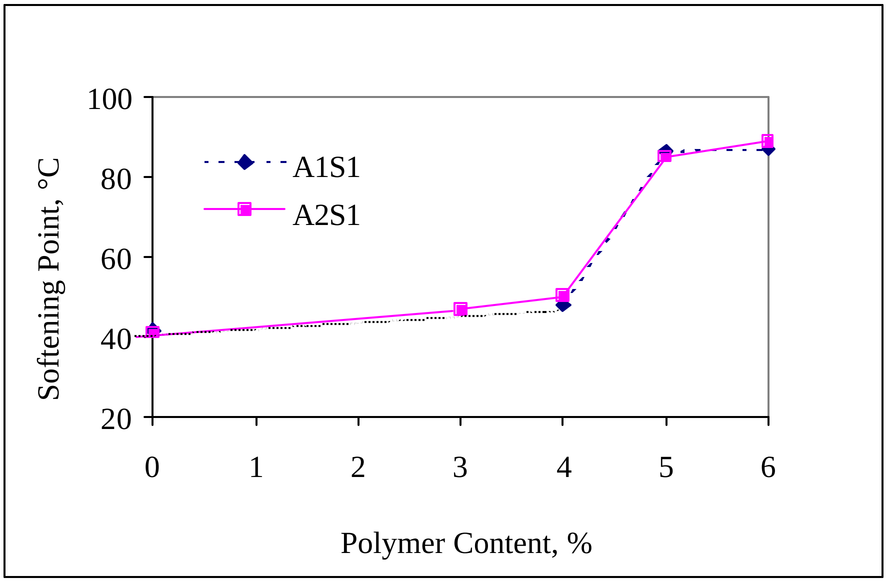


Figure 3-1. SBS Polymer Content versus Softening Point for A1S1 and A2S1 Binders

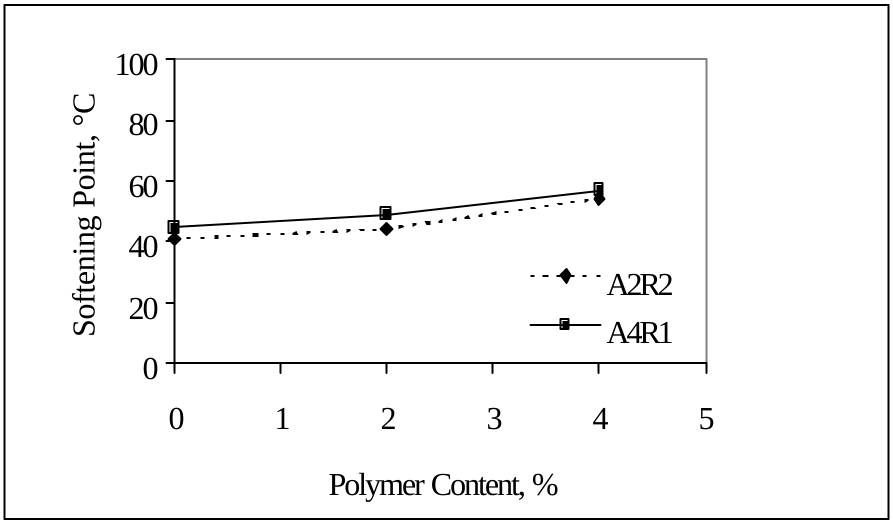


Figure 3-2. SBR Polymer Content Versus Softening Point for A2R2 and A4R1 Binders

Viscosity

The maximum ideal hot-plant mixing temperature defined as the temperature at which viscosity equals 170 mm^2/s,[11] was limited to 180°C. This temperature is close to the level at which the polymer may begin to degrade. If the mixing temperature was greater than or equal to 180°C the concentration of the polymer was not increased because viscosity increases with polymer content and, therefore, the mixing temperature also rises. For mix designs the ideal compaction temperature is defined as the temperature at which viscosity equals 280 ± 30 mm^2/s.[11] Aggregate gradation may also affect compaction temperature.[12] Figures 3-3 and 3-4 show the effect of the polymer content and temperature on the viscosity and the determination of the hot-plant mixing temperatures.

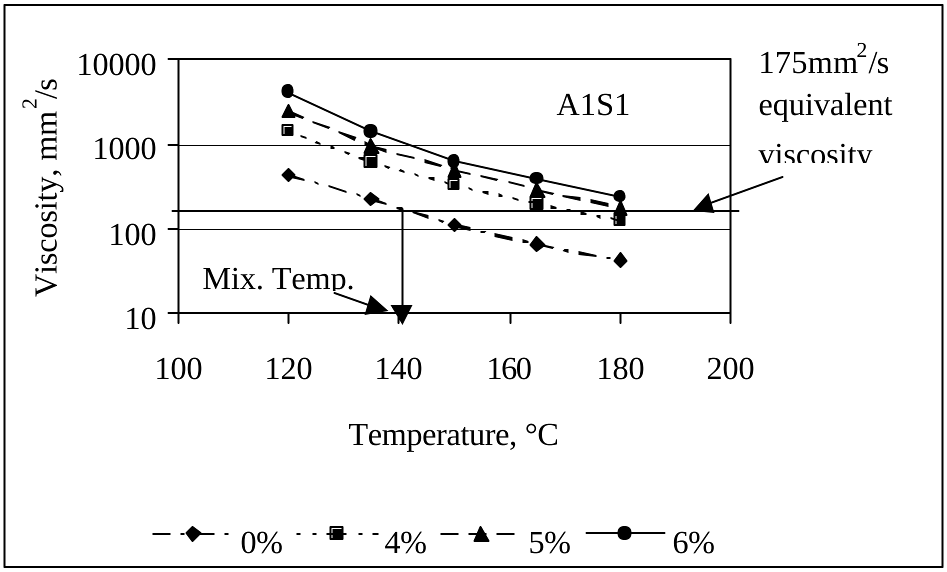


Figure 3-3. Effect of Temperature and SBS Polymer Content on Viscosity for A1S1 Binder

Polymer-modified asphalts may behave as non-Newtonian materials; i.e. the viscosity depends upon the shear rate. Non-Newtonian behavior increases with polymer concentration. Binders with SBS concentrations of about 3% are, typically, shear-rate independent while concentrations approaching 6% or greater cause shear-thinning behavior.[13] Therefore a shear-rate sweep was conducted using different spindle sizes and rotational speeds in the Brookfield viscometer. The shear-rate sweeps were run only on the modified binders that were selected for further testing. The test results of the shear-rate sweep are given in Table 3-6.

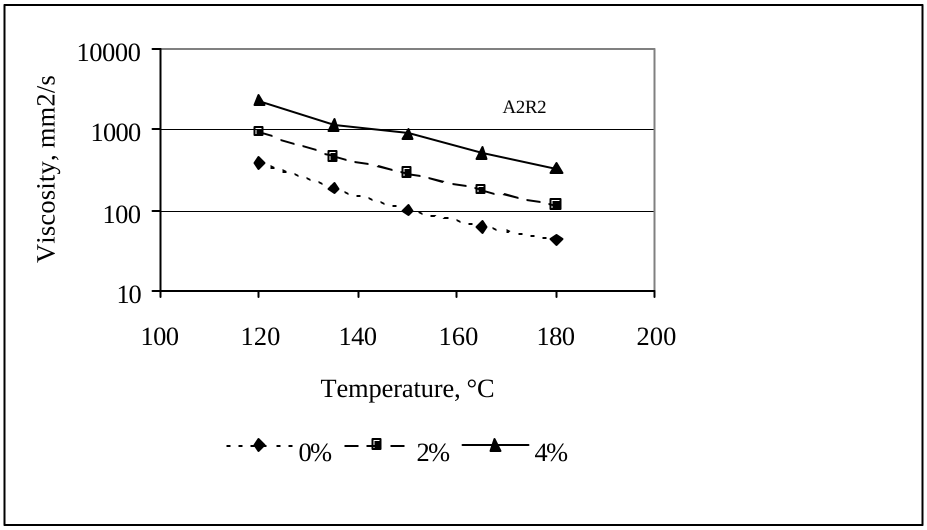


Figure 3-4. Effect of Temperature and SBR Polymer Content on Viscosity for A2R2 Binder

The shear-rate sweep was conducted at a temperature of 170°C and the polymer-modified binders were reheated for the testing. The temperature of 170°C was selected because it represented the hot-plant mixing temperatures for most of the modified binders. One of the shear-rate sweep values should plot on the best-fit curve drawn for the viscosity values given in Table 3-5. However, reheating altered the binder properties slightly and, therefore, the viscosity values do not exactly match the best-fit curves for a few of the binders (Figure 3-5). On the basis of the test results, the shear rate did not affect the mixing temperature significantly. However, the effect may be larger at lower temperatures, and needs more investigation.

Table 3-6. Viscosity (mm^2/s) at 170°C at Varying Shear Rates

Binder	**Shear rate (1/s)**			
	3.4	**6.8**	**51**	**85**
PM1	150	188	197	196
PM3	275	275	280	275
A1S1-4%	200	200	210	216
A2S1-5%	300	313	310	322
A5S1-5%	350	338	338	315
A2R2-2%	100	113	119	119
A5R2-2%	175	188	188	177

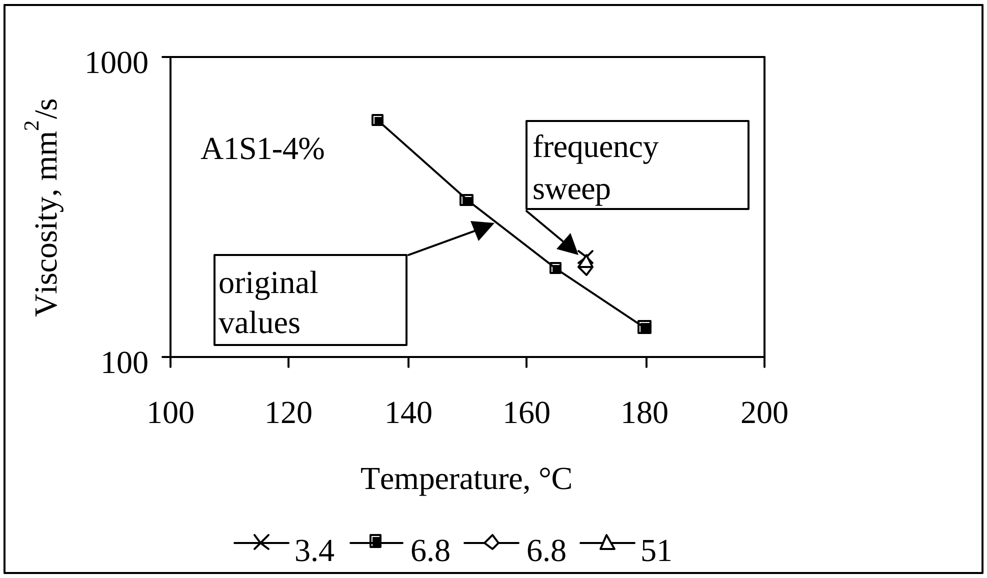


Figure 3-5. Effect of Shear Rate (1/s) on Viscosity for A1S1 Binder with 4% Polymer Concentration (at 170°C)

Temperature Susceptibility

The temperature susceptibility was evaluated using the penetration index (PI) calculated using Equation 5[14]. The PIs are shown in Table 3-7.

Equation 5: Penetration Index

$$PI = \frac{20 - 500A}{1 + 50A}$$

$$A = \frac{\log pen@T_1 - \log pen@T_2}{T_1 - T_2},$$

where, T_1, T_2 = temperature, °C
$pen\ @\ T_1$ = penetration at temperature T_1 (100g, 5s), 1/10mm
$pen\ @\ T_2$ = penetration at temperature T_2 (100g, 5s), 1/10mm

Penetration indices were calculated over three temperature intervals, 10°C to 25°C, 25°C to the softening point, and 10°C to the softening point. The three intervals were chosen because the relationship between consistency and temperature is not linear for polymer-modified asphalts at temperatures from 10°C to about 80°C. Penetration at the softening point is defined as 800 (.1mm).

A desired property for any binder is improved temperature susceptibility over the in-service temperature range. As PI increases temperature susceptibility improves; i.e. it indicates smaller changes in asphalt properties as the temperature changes. Improved temperature susceptibility indicates less low-temperature cracking and reduced pavement deformation at high temperatures. Almost all of the manufactured binders showed increases in PI over each interval. Only one binder, A4S1-2%, was eliminated from further studies because of high temperature susceptibility.

Table 3-7: Penetration Indices

Binder	Low Temp. PI (10° to 25°C)	High Temp. PI (25°C to softening point)	Overall PI (10°C to softening point)
A1	-0.58	-1.25	-0.94
A2	-1.16	-0.70	-0.93
A3	0.58	-0.34	0.14
A4	-0.27	-0.80	-0.58
A5	-1.13	0.26	-0.51
PM1	1.94	9.00	6.87
PM2	1.36	1.44	1.41
PM3	1.46	5.19	3.88
A1S1-4%	-0.25	0.06	-0.07
A1S1-5%	0.38	6.80	4.98
A1S1-6%	1.07	6.44	5.02
A2S1-3%	0.67	0.08	0.32
A2S1-4%	-0.82	1.28	0.39
A2S1-5%	-0.11	6.79	4.73
A2S1-6%	1.66	7.05	5.67
A3S1-4%	1.19	4.97	3.73
A4S1-2%	-0.47	-0.16	-0.28
A4S1-4%	0.76	6.06	4.58
A5S1-4%	0.14	2.92	1.74
A5S1-5%	1.26	8.09	6.08
A5S1-6%	1.79	7.64	6.01
A1S2-4%	-0.93	6.41	3.97
A2S2-4%	0.21	7.95	5.69
A3S2-4%	1.27	4.40	3.28
A4S2-4%	0.72	6.34	4.82
A5S2-4%	0.20	9.00	6.25
A1R1-4%	-0.97	1.24	0.30
A2R1-4%	-0.20	1.12	0.58
A3R1-4%	1.26	3.03	2.32
A4R1-2%	-0.20	0.47	0.20
A4R1-4%	-0.01	2.15	1.36
A5R1-4%	-0.64	2.46	1.04
A1R2-2%	-0.56	-0.18	-0.35
A2R2-2%	-0.56	-0.23	-0.38
A2R2-4%	0.43	2.36	1.63
A3R2-2%	0.17	0.34	0.26
A3R2-4%	Unpourable		
A4R2-2%	-0.47	-0.49	-0.48
A4R2-4%	0.07	2.24	1.46
A5R2-2%	-0.31	0.71	0.20
A1R2-4%	-0.15	3.12	1.65

3.4.3 Storage Stability

Storage stability tests evaluated the extent to which the polymer phase remains dispersed homogeneously in the asphalt. This portion of the study approximates the condition of a given binder after manufacturing and shipment to a construction site assuming there is no agitation of the binder during shipment. A storage-stable product is required to ensure a uniform pavement performance and to avoid constructability problems. Results of the ring and ball storage stability test are given in Table 3-8. The slump tests were graded visually on a scale of 1 to 10 where 1 indicates poor storage stability and 10 indicates a very stable binder. Results of the slump test are listed in Table 3-9. The separation test figures shown in Table 3-8 were calculated using Equation 6 and Equation 7.

Equation 6. Calculation of Average Temperature Difference between Top and Bottom of Sample

$$Average\Delta T = \frac{\Delta Ttest_1 + \Delta Ttest_2}{2},$$

where,

$$\Delta Ttest_2 = Ttop_{test2} - Tbottom_{test2}.$$

$$\Delta Ttest_1 = Ttop_{test1} - Tbottom_{test1},$$

Equation 7. Calculation of Average Percent Difference in Softening Point

$$Average\%Difference = \frac{Average\Delta T}{AverageT_{top}} * 100,$$

where, $Average\ T_{top}$ = the average of the top portion softening point temperatures.

The separation test provides the difference in softening point temperature between the top and bottom of a modified sample after it has been conditioned in a 163°C oven. Because the butadiene phase of the polymer has absorbed lighter ends of the asphalt it often floats to the top of the container when the mixture remains at temperatures above the glass point (T_g) for the styrene cross-linking phase. A typical T_g for a styrene domain is around 100°C.[15]

Storage stability is greatly dependent upon the relative weight difference between the polymer phase and the asphalt phase of the mix. Therefore, composition of the asphalt plays a significant role in storage stability, as does the molecular weight of the polymer. Asphalts with high asphaltene content have lower stability because of the higher relative weight difference between the swollen butadiene phase and the heavy asphaltenes. An increase in content of lighter ends, maltenes and aromatics, increases storage stability.[16] The molecular weights of the polymers were not provided by the manufacturers and the determination and analysis of polymer and asphalt molecular weights were beyond the scope of this study. Incompatibility of the polymer with the asphalt can also cause a mixture to be unstable. This will be discussed in a later section of this report.

Differences in softening point within a conditioned sample indicate changes in polymer concentration within the sample. A stable mix remains homogeneous after being conditioned in the oven because little or none of the butadiene phase has separated from the asphalt and floated to the top of the tube. Satisfactory storage stability is indicated by very little softening point temperature difference within the sample. Typically, an unstable binder displays an increased softening point in the upper portion of the sample. For the purposes of this study a 10°C difference was acceptable. AASHTO-AGC-ARTBA (1992)[6] specifies a maximum allowable difference of 4°F or 2.2°C for SBS-modified asphalts. There is no specification for asphalts modified with SBR polymers.

The slump test provides a quick, visual evaluation of storage stability. Storage-stable samples remain homogeneous after conditioning in an 80°C oven because the entire sample has the same softening point. Samples with softening points less than 80°C become fluid, whereas samples with softening points warmer than 80°C remain solid. Unstable samples show a definite change from liquid at the bottom to solid at the top of the sample. The separation tests often showed softening point temperatures near 90°C in the top of an unstable sample while the bottom portion’s softening point would be near that of the base asphalt. The slump tests confirmed these results visually.

An example of a very unstable mix was A1S1-6%. The average softening point of the top portion of the sample was 96°C compared with the bottom portion average softening point of 54°C for a 44% difference. A significant amount of polymer had risen to the top and greatly increased the softening point. The slump test confirmed these results. The top 2 inches of the sample remained solid in the 80°C oven and the remainder melted completely. A modified asphalt that met the storage stability requirements was A1S1-4%. The top portion softening point was 60.5°C and the bottom was 57°C for a difference of 1%. The photograph of the slump test shows a uniformly melted sample.

Storage stability was the most discriminating factor when selecting mixes for the next phases of testing and the great majority of the mixes were eliminated from further testing because the combination was not storage stable. Storage stability could be improved by using additives or special techniques given in Section 2.1.

Table 3-8. Results of Separation Test

Binder	Original Softening Point (SP), °C	Ave. SP of Top, °C	Ave. SP of Bottom, °C	Ave. DSP, between Top and Bottom, °C	Ave. Difference in SP, %
PM1	80.5	81.5	76.5	5.0	6.1
PM2	50.5	51.5	50.0	1.5	2.9
PM3	61.7	58.2	57.7	0.5	0.9
A1S1-4%	48.0	60.2	56.7	3.5	5.7
A1S1-5%	86.3	85.5	57.0	28.5	33.3
A1S1-6%	87.0	96.3	53.7	42.6	44.2
A2S1-3%	46.8	57.5	47.5	10.0	16.8
A2S1-4%	50.2	61.3	52.0	9.3	15.0
A2S1-5%	85.0	72.0	68.5	3.5	4.9
A2S1-6%	88.8	92.5	63.3	29.3	31.6
A3S1-4%	65.8	83.3	47.8	35.5	42.6
A4S1-2%	47.7	61.4	55.5	5.9	9.5
A4S1-4%	83.2	72.5	53.6	18.9	26.1
A5S1-4%	50.8	53.5	50.8	2.7	5.0
A5S1-5%	82.8	61.8	63.0	-1.3	-2.1
A5S1-6%	83.3	80.1	62.9	17.2	21.5
A1S2-4%	79.5	90.0	47.3	42.8	47.5
A2S2-4%	89.0	90.0	46.6	43.4	48.2
A3S2-4%	59.5	88.0	42.2	45.8	52.0
A4S2-4%	86.5	89.5	48.0	41.5	46.4
A5S2-4%	86.5	90.0	46.4	43.6	48.4
A1R1-4%	50.3	81.0	47.0	34.0	41.9
A2R1-4%	49.8	74.7	47.4	27.3	36.5
A3R1-4%	51.1	Unpourable			
A4R1-2%	49.1	69.0	45.5	23.5	34.1
A4R1-4%	56.8	Unpourable			
A5R1-4%	48.4	65.3	46.5	18.8	28.7
A1R2-2%	44.9	66.4	44.8	21.7	32.2
A2R2-2%	44.3	46.3	45.3	1.0	2.1
A2R2-4%	54.3	72.8	49.8	23.0	31.6
A3R2-2%	40.2	52.2	42.1	10.1	16.2
A3R2-4%	Unpourable				
A4R2-2%	46.3	61.5	46.5	15.0	24.0
A4R2-4%	57.7	83.5	49.0	34.5	41.3
A5R2-2%	41.3	43.6	42.0	1.6	3.6
A5R2-4%	49.7	73.0	44.0	29.0	39.7

Table 3-9. Results of Slump Test

Binder	Slump Test Grade	Binder	Slump Test Grade
	Good = 10 Fair = 5 Poor = 1		Good = 10 Fair = 5 Poor = 1
PM1	10	**A3S2-4%**	1
PM2	10	**A4S2-4%**	1
PM3	10	**A5S2-4%**	1
A1S1-4%	10	**A1R1-4%**	1
A1S1-5%	1	**A2R1-4%**	5
A1S1-6%	1	**A3R1-4%**	1
A2S1-3%	10	**A4R1-2%**	5
A2S1-4%	10	**A4R1-4%**	5
A2S1-5%	10	**A5R1-4%**	5
A2S1-6%	1	**A1R2-2%**	1
A3S1-4%	5	**A2R2-2%**	10
A4S1-2%	10	**A2R2-4%**	5
A4S1-4%	5	**A3R2-2%**	1
A5S1-4%	10	**A3R2-4%**	Unpourable
A5S1-5%	5	**A4R2-2%**	5
A5S1-6%	5	**A4R2-4%**	1
A1S2-4%	1	**A5R2-2%**	10
A2S2-4%	1	**A5R2-4%**	1

3.4.4 Compatibility

Compatibility of the asphalt with the polymer is necessary for long-lasting pavement. Incompatibility quickly leads to premature product failure due to rapid aging and loss of properties.[17]

Fluorescent microscopy and elastic recovery were used to determine compatibility. The results of these tests are given in Table 3-10. The fluorescent micrographs of each modified binder were visually graded on a scale of 1 to 10 where 1 indicates an incompatible mixture and 10 indicates a very compatible mixture.

For the study of polymer-modified binders, compatibility describes industrial blends that are thermodynamically immiscible. Immiscibility causes the formation of a two-phase mixture, for these purposes a polymer dispersed within an asphalt. Within compatible mixtures the 2 phases form a stable microscopic dispersion that resists complete separation. Incompatible blends are not stable and as a result the immiscible phases separate.[15] This incompatibility causes a mixture to have poor storage stability.

Incompatibility is apparent in the fluorescent microscopic images. The degree to which polymer is dispersed within the asphalt is easily seen.[17] An incompatible mix displays images with relatively large, homogeneous 'blobs' of undispersed polymer. Only a few mixes displayed this characteristic (Figure 3-6).

Table 3-10. Results of Elastic Recovery and Fluorescent Microscopy

Binder	Elastic Recovery, %	Fluorescent Microscopy	Binder	Elastic Recovery, %	Fluorescent Microscopy
A1	6.0	**Grade** **Good = 10** **Fair = 5** **Poor = 1**			**Grade** **Good = 10** **Fair = 5** **Poor = 1**
A2	5.0				
A3	8.0				
A4	3.8				
A5	5.8				
PM1	96.0	5-10	A3S2-4%	90.0	1
PM2	73.3	5-10	A4S2-4%	84.3	1
PM3	92.5	5-10	A5S2-4%	96.5	5-10
A1S1-4%	64.0	5-10	A1R1-4%	64.5	5-10
A1S1-5%	94.5	5-10	A2R1-4%	67.5	5-10
A1S1-6%	93.9	5-10	A3R1-4%	71.5	1
A2S1-3%	63.8	5-10	A4R1-2%	51.8	5-10
A2S1-4%	68.8	5-10	A4R1-4%	65.3	5-10
A2S1-5%	91.5	5-10	A5R1-4%	73.0	5-10
A2S1-6%	94.5	1	A1R2-2%	50.0	5-10
A3S1-4%	93.3	1	A2R2-2%	55.5	5-10
A4S1-2%	48.8	5-10	A2R2-4%	69.0	5-10
A4S1-4%	86.5	1	A3R2-2%	61.8	5-10
A5S1-4%	77.0	5-10	A3R2-4%	Unpourable	
A5S1-5%	96.8	5-10	A4R2-2%	54.0	5-10
A5S1-6%	96.0	5-10	A4R2-4%	67.0	5-10
A1S2-4%	88.1	1	A5R2-2%	51.8	5-10
A2S2-4%	93.5	1	A5R2-4%	69.0	5-10

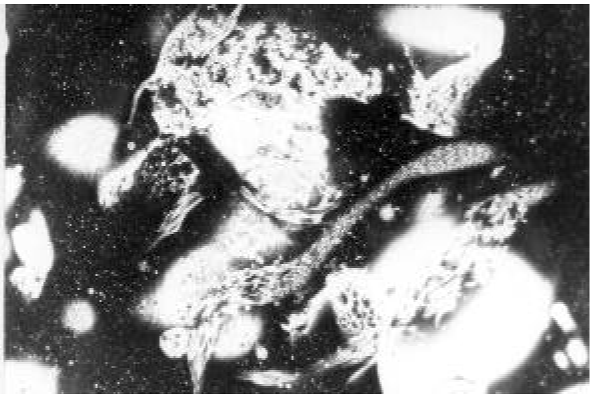


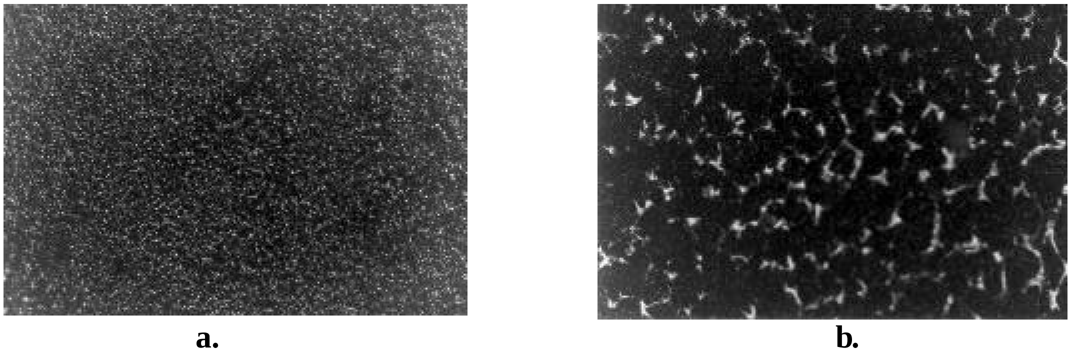
Figure 3-6. Fluorescent Micrograph of A4S2-4%; Example of a Polymer that is Incompatible with Base Asphalt

For compatible SBS-modified binders, at the microscopic level there are 2 types of binder morphology, polymer-rich as discrete particles and polymer-rich as continua.[15] Microscopic binder morphology is directly related to polymer concentration. As concentration increases the morphology progresses from discrete particle to continua. Figure 3-7 shows this progression in the fluorescent micrographs of A1S1 combinations as polymer content is increased.

The majority of the mixes viewed were classified as discreet particle morphology. Characteristically, concentrations of less than 6% display this type of morphology. The butadiene domains are visible in the microscopic images as very small, uniformly distributed white 'spots.' Binders in this category typically behave more as a plastic than as a true elastic material.[15]

The polymer-rich as continua morphology is characteristic of high SBS-polymer concentrations, 6% or greater, when the swollen butadiene phases begin to interact with each other. The butadiene domains are very apparent in the micrographs. They form a continuous rubber structure and the binder begins to behave as a rubber; i.e. elastic recoveries approach 100%. PM3 and two samples with 6% SBS content, A1S1-6% and A5S1-6%, display the continuous rubber structure in the fluorescent micrographs. All three of these binders have elastic recoveries greater than 90%.

The continuous rubber morphology is not necessary for a binder to display very high elastic recoveries. Eleven modified binders have elastic recoveries greater than 90%. Eight do not have the continuous rubber structure. The A2S1-6% is an example of a mixture that does not display a continuous rubber structure though its elastic recovery is 94.5%. Figure 3-8 shows the relationship between elastic recovery and polymer content for A2S1 and A2R2. This figure also suggests elastic recovery is dependent most upon polymer concentration and not polymer type.



a. **b.**

Figure 3-7. Fluorescent Micrographs of A1S1 Combinations; a) Discrete Particle Morphology, A1S1-4%, b) Polymer-rich as Continua Morphology, A1S1-6%

Elastic recovery can be useful for evaluating compatibility. Reduced tensile strength can be discriminating tool for evaluation. However, none of the modified binders failed when pulled during the test. All of the mixes showed improved elastic properties. None of the mixes were eliminated because of inadequate elastic recovery. Elastic recovery ranged from 3.5% to 8% for base asphalts and 50% to 97% for modified asphalts.

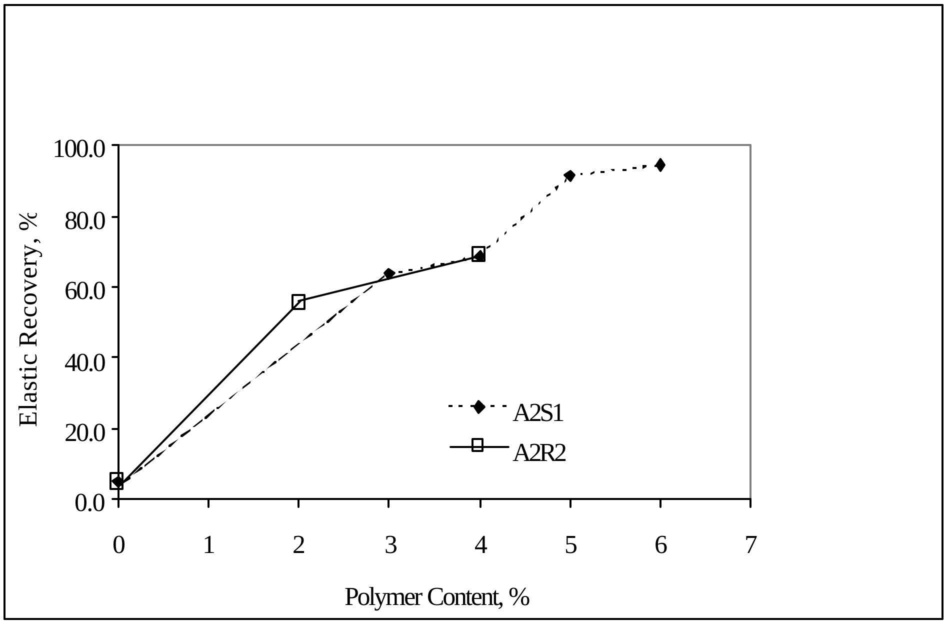
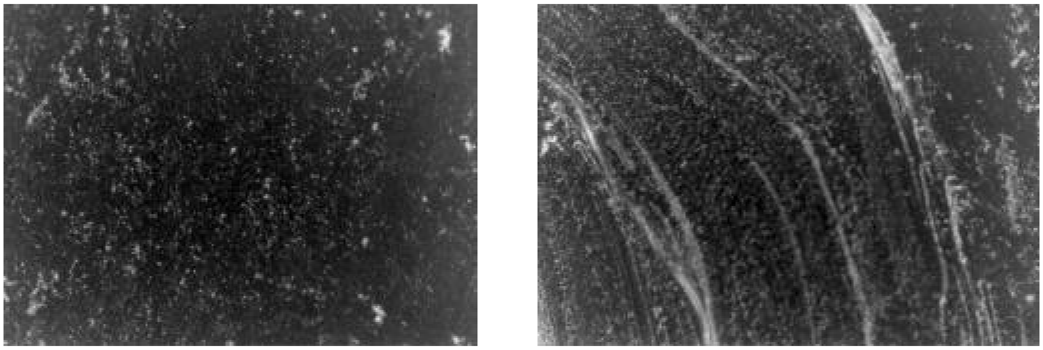


Figure 3-8. Elastic Recovery versus Polymer Content

SBR combinations consistently display discrete particle morphology when the cut face is viewed directly. The chain structures characteristic of SBR polymers are often evident in 4% concentrations. This is possibly a structure similar to the polymer-rich continua that occurs in SBS mixes though the butadiene phases of an SBR interact to form chains rather than a continuous three-dimensional network. A single sample of SBR-modified asphalt often yielded micrographs of both discrete particle morphology and chain structures. The chains are three-dimensional and if the sample is cut in the same plane as the chains the chain morphology is apparent. A sample viewed perpendicular to that direction displays an image of discrete particles. Figure 3-9 includes fluorescent micrographs displaying the 2 types of morphology taken from the same sample of A5R1-4%.



a.

b.

Figure 3-9. Fluorescent Micrographs from Single Cut Sample of A5R1-4%; a) Discrete Particle Morphology, b) SBR Chain Structure

There were no binders that were eliminated solely upon the basis of poor fluorescent microscopic images. Poor compatibility indicated in the micrographs confirmed unsatisfactory results in the consistency tests and storage stability tests.

3.5 Recommendations

Of the 36 polymer-modified asphalts tested only nine met the criteria set for the compatibility, storage stability, improved temperature susceptibility, and mixing temperature (Table 3-11). This shows that polymer modified asphalts should always be an end result of an extensive product development program. The probability of creating an acceptable product out of proper materials using proper blending technique, was less than 20%. The three premixed binders, that are end results of extensive product development programs, satisfied all criteria. It was shown that the binder properties depend upon

- polymer type,
- polymer concentration,
- base asphalt, and
- method used in mixing the polymer with the asphalt.

Table 3-11. Satisfaction of Mixing Temperature and Storage Stability Criteria

	Criteria		
	Constructability	**Storage Stability**	
Binder	**Mixing Temperature > 180°C**	**Ave. DSP, between top and bottom, >10°C**	**Satisfies Both Criteria**
PM1	No	No	Yes
PM2	No	No	Yes
PM3	No	No	Yes
A1S1-4%	No	No	Yes
A1S1-5%	Yes	Yes	No
A1S1-6%	Yes	Yes	No
A2S1-3%	No	Yes	No
A2S1-4%	No	Yes	No
A2S1-5%	No	No	Yes
A2S1-6%	Yes	Yes	No
A3S1-4%	No	Yes	No
A4S1-2%	No	No	Yes[1]
A4S1-4%	Yes	Yes	No
A5S1-4%	No	No	Yes
A5S1-5%	No	No	Yes
A5S1-6%	Yes	Yes	No
A1S2-4%	No	Yes	No
A2S2-4%	Yes	Yes	No
A3S2-4%	Yes	Yes	No
A4S2-4%	Yes	Yes	No
A5S2-4%	Yes	Yes	No
A1R1-4%	Yes	Yes	No
A2R1-4%	Yes	Yes	No
A3R1-4%	No	Yes	No
A4R1-2%	No	Yes	No
A4R1-4%	Yes	Yes	No
A5R1-4%	Yes	Yes	No
A1R2-2%	No	Yes	No
A2R2-2%	No	No	Yes
A2R2-4%	Yes	Yes	No
A3R2-2%	Yes	Yes	No
A3R2-4%	Yes	Yes	No
A4R2-2%	No	Yes	No
A4R2-4%	Yes	Yes	No
A5R2-2%	No	No	Yes
A5R2-4%	Yes	Yes	No

---

[1] Meets the criteria set for storage stability and max. mixing temperature, but modification did not improve the overall temperature susceptibility.

As seen from Table 3-11, 26 binders did not meet the storage stability criterion, and 18 binders did not meet the maximum hot-plant mixing temperature criterion. Both the storage stability and too high mixing temperature cause constructability problems. Unstable binders will form clusters of very high polymer concentration whereas the rest of the binder has a very low polymer concentration. The clusters will be hard if not impossible to mix and compact. Too high mixing temperature requires special equipment, is not cost effective, may cause smoking and may destroy the polymer. If the required mixing and compaction temperatures are not achieved, it is very hard if not impossible to get adequate aggregate coverage and the specified level of compaction. If the aggregate is not covered thoroughly, stripping will occur later. The high failure rate of the manufactured binders explains the construction difficulties in the field. To avoid these potential problems, a maximum viscosity should be specified. Also, a storage stability test should be added to specifications. Or, the binder samples tested for quality control from the hot-plant should be taken just before the binder hits the hot aggregate in the mixer. This allows the contractor to address the storage stability question with techniques, such as tank circulation.

On the basis of the test results, seven modified asphalts were selected for the next phases of testing. Two binders that met all criteria, PM2 and A5S1-4%, were dropped to limit the number of binders without limiting the number of variables in further testing. In addition, three base asphalts used as pavement asphalts in Alaska was tested as control binders. The selected binders are given in Table 3-12 together with the recommended mixing and compaction temperatures.

Table 3-12. Selected Binders and Recommended Mixing and Compaction Temperatures, °C

Binder	**Mixing**			**Compaction**		
	Ideal	**Min.**	**Max.**	**Ideal**	**Min.**	**Max.**
A1	140	136	143	130	128	137
A2	138	134	140	128	125	130
A5	133	130	136	124	122	127
PM1	175	172	178	162	157	168
PM3	173	168	177	157	158	161
A1S1-4%	168	165	172	154	152	158
A2S1-5	178	173	182	162	158	166
A5S1-5%	173	169	177	158	155	162
A2R2-2%	168	163	172	151	147	155
A5R2-2%	175	172	178	162	158	165
Based on equivalent-viscosity of (mm^2/s):						
	170	190	150	280	310	250

3.6. Future Investigations

This research used only a small part of polymer types, grades and concentrations available. More materials and manufacturing techniques could be analyzed in future studies.

4. SUPERPAVE TESTING OF BINDERS

This phase of the study conducted by the UAF determined the PG grade of the binders in order to assess the high and low temperature limits for adequate performance according to Superpave criteria[18]. The polymer-modified binders were manufactured in the UAF laboratory using the procedure explained in Section 3.2 laboratory (except PM1 and PM3 were obtained premixed). The binders tested are given in Table 3-12.

4.1 Test Procedures

All tests were performed according to AASHTO PP6 (Standard Practice for Grading or Verifying Performance Grade of an Asphalt Binder)[18]. Characterization tests were performed on original (unaged binder), Rolling Film Oven aged residue (i.e. Rolling Film Oven Test – RTFOT), and Pressure Aging Vessel (PAV) residue. RTFOT simulates short-term aging that occurs at a hot mix production plant and also during the construction phase. The PAV test is supposed to simulate long term aging for pavements in service.

4.1.1 Testing of Original Binder

Flash Point Test (AASHTO T48)

The flash point test ensures safety by measuring the temperature to which the binder could be heated without flashing in the presence of a flame. The specification for all binders is a minimum temperature of 230^{o}C.

Rotational (Brookfield) Viscosity Test (ASTM D4402)

The rotational viscosity test utilizes a Brookfield viscometer to ensure ease of pumping and handling of the binder at the hot mix production plant. This is attained by specifying a maximum viscosity of 3 Pas (≈3000mm2/s) at 135^{o}C. The range of mixing and compaction temperatures for mix design can also be obtained by determining the binder temperature corresponding to 0.17 ± 0.02 Pas and 0.28 ± 0.03 Pas (≈170 ± 20mm^2/s and 280 ± 30mm^2/s).

Dynamic Shear Rheometer (DSR) Test (AASHTO TP5)

This test is conducted on both the original and aged binder. A controlled-strain DSR is used to measure the viscoelastic behavior at different temperatures of the binder in terms of complex modulus (G*) and phase angle (δ). The DSR applies a torque to a thin film of binder specimen placed between two plates at a frequency of 10 radians per second. The applied torque and resulting shear strain are used in the computation of the complex modulus and phase angle. The specification requires determining the temperature that correspond to a minimum value of 1.0 kPa for G*/sin(δ).

4.1.2 Testing of RTFO Aged Residue

RTFO test (AASHTO T240)
This test exposes fresh thin films of binder to heat (163°C) and air for 85 minutes by rotating coated bottles (15 revolutions/minute) and blowing air into the bottles (4000 ml/minute). The average percent mass loss is calculated after testing. The specification of 1-% maximum mass loss guards against binders that age excessively.

The RTFO residue is tested again using the DSR. In this case the limit on $G^*/\sin\delta$ required is 2.2 kPa for a loading rate of 10 radians/second. DSR tests on the original and RTFO aged binders are supposed to evaluate the binder's resistance to rutting.

4.1.3 Testing of PAV Aged Residue

PAV Test (AASHTO PP1)
The RTFO residue is aged again in a PAV to simulate long term aging. In this case, the binder is subjected to high temperature (90°C, 100°C, or 110°C) and pressure of 2070 kPa for 20 hours.

The PAV residue is then tested using DSR to evaluate the fatigue resistance of the binder. The specification in this case requires determining the temperature associated with a maximum $G^*\sin\delta$ of 5000 kPa for a loading rate of 10 radians/second.

Bending Beam Rheometer (BBR) Test (AASHTO TP1)
This test is used to evaluate the stiffness of the PAV aged binder at low temperatures. The BBR subjects a small beam of binder to a constant creep load and measures the resulting deflection at a temperature related to the anticipated lowest pavement service temperature. Using simple beam theory, the binder stiffness is calculated. The creep rate (m-value) defined as the rate of change of stiffness with time is also determined. The stiffness at 60 seconds must be less than 300 MPa, and the m-value at this time of loading must be at least 0.30 in order to meet the binder specification. If the stiffness is between 300 MPa and 600 MPa, then the direct tension test should be used.

Direct Tension Test (DTT) (AASHTO TP3)
This test uses PAV residue when the BBR creep stiffness is between 300 MPa and 600 MPa. In this test, a dog-bone shaped sample of binder is pulled at a slow rate of 1 mm/minute at low temperatures. The failure strain (defined at the maximum recorded load during the test) is determined. The specification requires that the failure strain be at least 1%.

Using the suite of tests described above, the performance grade (PG) of both conventional and modified binders was determined according to AASHTO MP1 (Standard Specification for Performance Graded Asphalt Binder)[19]. These specifications and the corresponding standard tests are summarized in Tables 4-1 and 4-2.

4.2 Test Results and Conclusions

Results of Superpave binder tests are summarized in Table 4-3. Detailed testing results are presented in Appendix D. The recommended mixing temperatures from the Superpave testing in Table 4-3 differ from the mixing temperatures given in Table 3-12, because the binders were manufactured from raw materials, and there is slight variation in the end products.

Results indicate that the PG low temperature varies between –22^{o}C and –34^{o}C whereas the PG high temperature varies between 46^{o}C and 64^{o}C (Figure 4-1). The widest PG grade was for PM3, one of the pre-manufactured polymer-modified binders.

According to the PG grading, the polymer-modification improved the rutting resistance of all base asphalts (Figure 4-2). However, based on the PG grading, polymer-modification increased the tendency for low temperature cracking of the A1 and A2 base asphalts, while keeping that of the A5 base asphalt unchanged (Figure 4-3).

The temperatures at which the specification requirement is met give more information about the pavement performance than the PG-grades themselves. According to the temperatures where the high and low temperature specifications are satisfied (Table 4-4, Figures 4-4 and 4-5), the polymer-modification improved the rutting resistance of the base asphalts. It also seemed that the low temperature cracking resistance was slightly improved by the polymer modification.

Table 4-1. Performance Graded Asphalt Binder Specifications (AASHTO MP1)

Table 4-1. (Continued) Performance Graded Asphalt Binder Specifications (AASHTO MP1)

Table 4-2. Superpave Test Methods

Superpave Binder Test	Binder Condition	Test Method	Test Equipment / Model
Flash Point Tester (COC)	Original binder	AASHTO T 48	Gilson / PT-6
Rolling Thin Film Oven (RTFO)	Original binder	AASHTO T 240	Cox & Sons / CS 325 B
Rotational Viscometer (RV)	Original binder	ASTM D4402	Brookfield / RV DV-III
Pressure Aging Vessel (PAV)	RTFO-aged binder	AASHTO PP1	Applied Test Systems
Dynamic Shear Rheometer (DSR)	Original, RTFO- and PAV-aged binder	AASHTO TP5	Rheometric Scientific / ARES-RAA
Bending Beam Rheometer (BBR)	PAV-aged binder	AASHTO TP1	Cannon Instrument / TE-BBR
Direct Tension Tester (DTT)	PAV-aged binder	AASHTO TP3	Instron / BTI-3

Table 4-3. Summary of Superpave Binder Test Results

					Grade Temp. at which Specified Criterion is Satisfied, °C						PG Grade	
Binder	**Mass Loss, %**	**Viscosity @ 135°C, Pas**	**Mixing Temp.[2], °C**	**Compaction Temp.[3], °C**	**DSR Origin.**	**DSR RTFO**	**DSR PAV**	**BBR S**	**BBR m-value**	**DTT Strain**	**High**	**Low**
A1	0.179	0.166	133-137	124-128	52	52	16	-18	-18	-	**52**	**-28**
A2	0.100	0.149	130-135	121-125	52	52	16	-18	-18	-	**52**	**-28**
A5	0.428	0.109	124-129	115-119	46	46	13	-18	-18	-	**46**	**-28**
PM1	0.387	0.681	166-174	151-157	58	58	10	-18	-18	-24	**58**	**-28**
PM3	1.046	0.766	169-177	155-161	64	64	10	-24	-24	-30	**64**	**-34**
A1S1-4%	0.789	0.490	155-159	144-149	64	58	19	-18	-12	-	**58**	**-22**
A2S1-5%	0.114	0.673	167-173	154-160	64	64	13	-18	-12	-18	**64**	**-22**
A5S1-5%	0.364	0.527	160-168	147-153	58	58	7	-18	-18	-30	**58**	**-28**
A2R2-2%	0.152	1.428	203-211	186-193	64	58	13	-18	-18	-24	**58**	**-28**
A5R2-2%	0.258	1.342	194-197	178-188	58	52	10	-18	-18	-30	**52**	**-28**

---

[2] Based on Brookfield Viscometer test results and viscosity of 0.17Pas.

[3] Based on Brookfield Viscometer test results and viscosity of 0.28Pas.

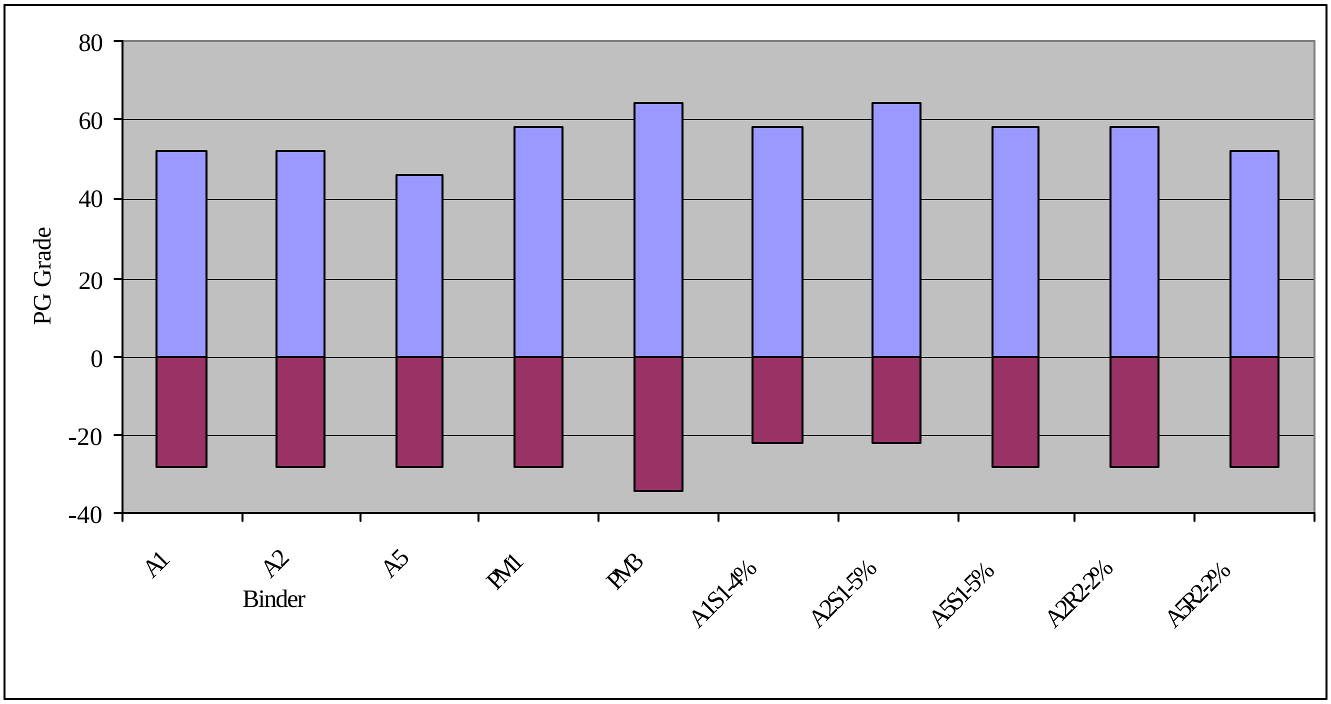


Figure 4-1. PG Grading of Binders

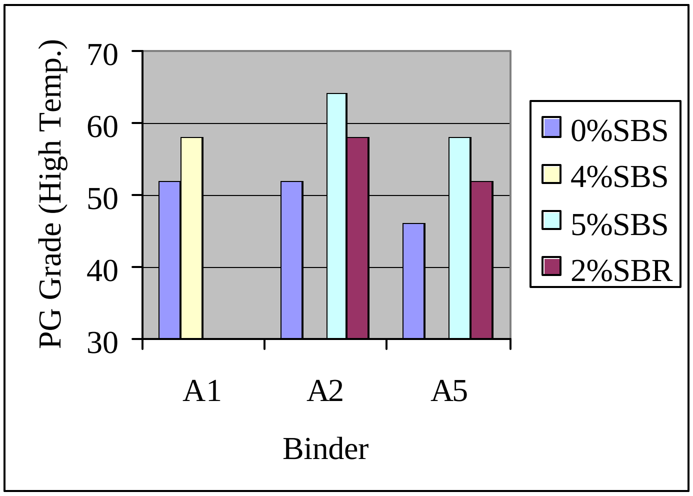


Figure 4-2. Effect of Polymer-Modification on PG High Temperature Grade

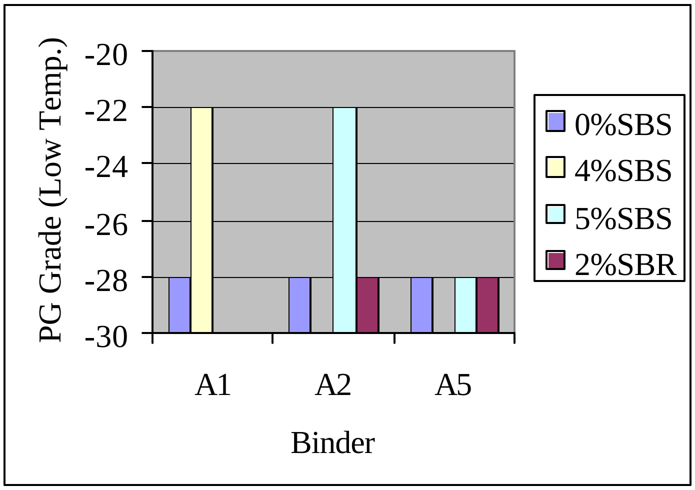


Figure 4-3. Effect of Polymer-Modification on PG Low Temperature Grade

Table 4-4. Exact Temperatures at Which PG Grades are Satisfied

Binder	Temp@G*/sin(d) =2.2kPa, °C	Temp@S=300MPa, °C
A1	55.9	-18.5
A2	53.6	-19.3
A5	49.9	-21.6
PM1	58.3	-23.7
PM3	68.4	-26.3
A1S1-4%	63.0	-19.1
A2S1-5%	66.0	-20.4
A5S1-5%	59.5	-21.8
A2R2-2%	62.4	-20.8
A5R2-2%	56.9	-23.1

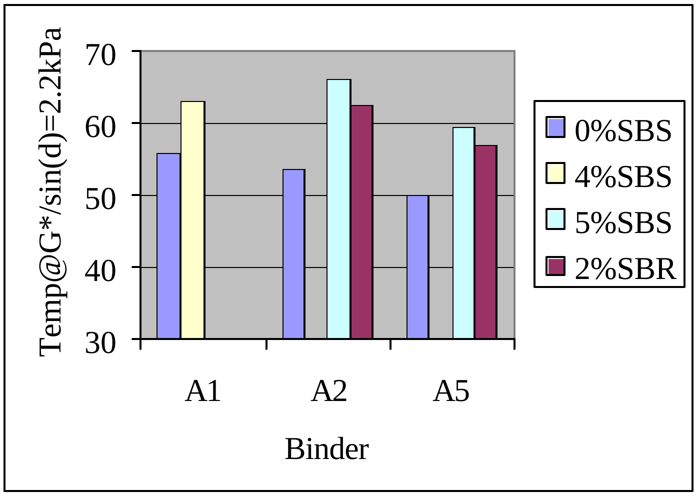


Figure 4-4. Effect of Polymer-Modification on Exact Temperature at Which High-Temperature Specification is Satisfied

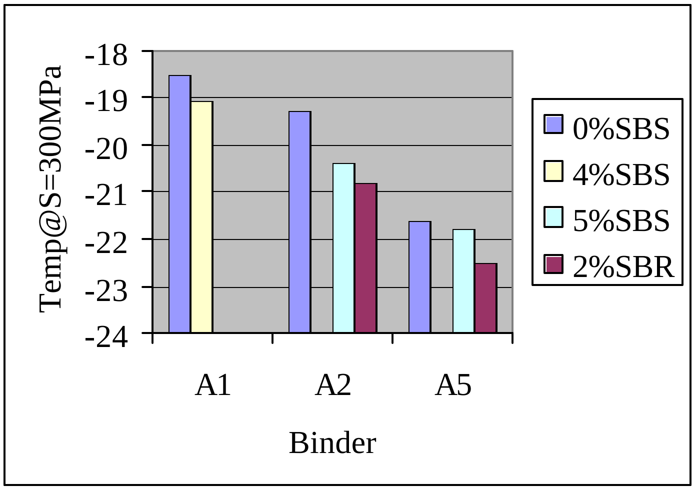


Figure 4-5. Effect of Polymer-Modification on Exact Temperature at Which Low-Temperature Specification is Satisfied

5. QUANTITATIVE AND QUALITATIVE TESTING OF ASPHALT-AGGREGATE MIXTURES

The AKDOT&PF conducted a mix design for each binder and evaluated the asphalt-aggregate mixtures qualitatively based on their handling and workability properties.

5.1 Materials

The binders used in the mix design of the asphalt-aggregate mixtures are listed in Table 3-12. The polymer-modified binders were blended in the UAF laboratory (except PM1 and PM3 were obtained pre-manufactured). The aggregate was a crushed product derived from Tanana River aggregate. It is gravelly sand that was mined from the Nordale Pit, on Badger Road in Fairbanks, Alaska. The source aggregate was comprised predominately of well-rounded quartzite. A single gradation given in Table 5-1 and Figure 5-1 was used for all of the mixtures, and only the type of binder was varied.

5.2 Quantitative Analysis

5.2.1 Test Procedure

The mix designs were performed by a National Institute of Certified Engineering Technicians (NICET) Level III Bituminous Technician in the AK DOT&PF Northern Region Materials Laboratory (NRML) AASHTO Certified facility at 2301 Peger Road in Fairbanks, Alaska.

The mix designs were conducted in accordance with AASHTO T 245, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus,[20] using the mechanically operated hammer option. The mixing and compacting temperatures provided by the UAA are given in Table 3-12. Each mix was evaluated using 75 hammer blows. To determine the need for anti-strip additive, the binders were tested in accordance with Alaska Test Method[21] T-14, Standard Method of Test for Coating and Stripping of Bitumen-Aggregate Mixtures. All binders were treated with 0.25% of anti-strip additive (Pavebond by Morton Thiokol).

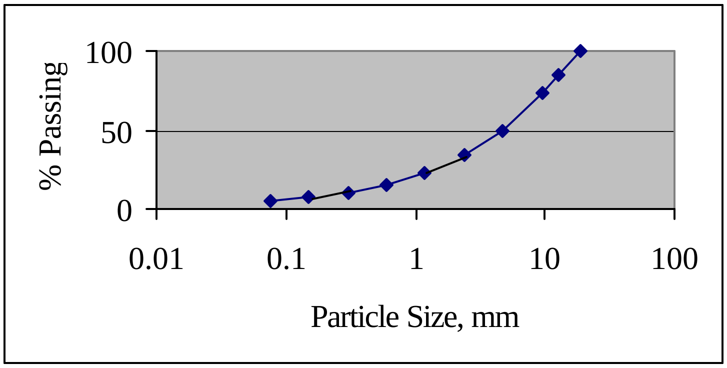


Figure 5-1. Gradation of Aggregate

Table 5.1. Gradation of Aggregate

Sieve	Opening Size, mm	% Passing
3/4"	19.0	100
1/2"	12.5	85
3/8"	9.5	73
#4	4.75	50
#8	2.36	34.2
#16	1.18	22.2
#30	0.600	14.8
#50	0.300	10.2
#100	0.150	7.4
#200	0.075	5

5.2.2 Test Results

The Marshall mix design results are summarized in Table 5-2.

5.3 Qualitative Analysis

5.3.1 Analysis Results

Each mix design form had a technician’s remarks section that relates workability characteristics as determined during the mix design procedure. The technician’s remarks are quoted below. The experience of the AKDOT&PF shows that an experienced mix design technician can reasonably predict the handling characteristics of a mix based on qualitative attributes observed in the laboratory.

A1: “The aggregate coated easily, even at the low temperatures (140°C). The mix was easy to handle and showed no tendency toward segregation.”

A2: “The aggregate coated easily, even at the low temperatures (138°C). The mix was easy to handle and showed no tendency toward segregation.”

A5: “Mixture containing the A5 binder is a typical unmodified mixture. The asphalt-aggregate mixture is mixed at “normal” temperature (133°C) so smoke is not a problem.”

Table 5-2. Summary of Marshall Mix Design Results

	A1	A2	A5	PM1	PM3	A1S1-4%	A2S1-5%	A5S1-5%	A2R2-2%	A5R2-2%
Marshall Results at Optimum %AC, (75 blows)										
Optimum AC %	4.9	5.0	4.8	4.8	5.0	4.8	4.8	4.8	5.2	4.8
Unit Weight, kN/m^3	23.61	23.69	23.67	23.64	23.64	23.69	23.67	23.73	23.55	23.55
Stability, kN	10.49	9.70	7.78	12.68	13.17	12.63	12.99	11.56	9.61	9.61
Flow, 0.25mm	10	9.8	8.6	10.6	11.9	10.4	11	9.8	12.2	9.2
Voids Total Mix, %	4.2	4	4	4.2	4	4	4	4	4	5
Voids Filled, %	70	71		70	73	70	72	72	72	66
VMA, %	13.8	14	14.1	13.9	14.2	13.8	13.8	13.6	14.8	14.2
Rice Specific Grav.	2.518	2.516		2.517	2.509	2.516	2.520	2.519	2.503	2.522
Binder Information										
Mix Temp., °C	140	138	136	175	173	168	178	173	168	175
Compact Temp., °C	130	128	126	162	157	154	162	158	151	162
Gs @25°C	1.012	1.012	1.008	1.004	1.016	1.011	1.008	1.004	1.009	1.004
Aggregate Properties										
Specific Gravity					**ATM[2] T-4 Fracture, %**	**Sodium Sulfate T-104, %**	**LA Abrasion T-96, %**	**Wash. Deg T13**	**Nordic Abrasion %**	**Sand Equivalent Test**
Aggregate	**Bulk**	**SSD**	**Apparent**	**Apsorb.**						
Coarse	2.704	2.721	2.751	0.6		0.6				
Fine	2.634	2.662	2.711	1.1		5				
Combined					90 (+#4)		26	85	6.1	74.4

PM1: "This mix was very workable. It handled well and coated the aggregate easily. There was very little odor or smoke."

PM3: "The asphalt cement smoked profusely. No odor was noticeable. The mix smoked even at low temperatures (at 138°C). The binder was easy to work with, coated the aggregate well, and was not stringy. At high temperatures (173°C), it was difficult to determine if the mix had been modified."

A1S1-4%: "The aggregate was easy to coat even with the low asphalt contents (4%). The binder did smoke some but was not a problem. Odor was not very strong. At high temperatures the mix was workable, similar to normal asphalt cements. The Marshall mix design samples with 6.0% and 6.5% asphalt contents were very "wet", and bleeding was observed. These samples were very difficult to remove from the Marshall breaking head. No rubbery strings or gummy masses were noted in the mixing bowl.[4]"

A2S1-5%: "The aggregate was easy to coat even on the low asphalt contents (4%). The binder did smoke some but was not a problem. Odor was not very strong. At high temperatures the mix was workable, similar to normal asphalt cements. The Marshall mix design samples with 6.0% and 6.5% asphalt contents were very "wet", and bleeding was observed. These samples were very difficult to remove from the Marshall breaking head. No rubbery strings or gummy masses were noted in the mixing bowl.[4]"

A5S1-5%: "The aggregate was easy to coat, even on the lower asphalt contents (4%). The binder smoked terribly. Even with good ventilation, the lab was filled with a whitish smoke. At compaction temperatures, the smoke was not quite as bad. Odor was not strong. The Marshall mix design samples with 6.0% and 6.5% asphalt had to be broken to be removed from the Marshall head. The mix was workable at the high temperatures (173°C)."

A2R2-2%: "The recommended ideal mixing temperature was one of the lowest for the modified binders. The asphalt did not produce smoke, but it was very stringy and cleanup was difficult – if not impossible. In order to clean up, the temperature was increased from 168 to 180°C, which helped a lot."

A5R2-2%: "The mixture was stringy at the recommended compaction temperature. The mix smoked very badly and the fumes made it difficult to breath. Even with the hood running, the room ventilation was not sufficient so the technician was forced to use a full-face respirator. The mix is difficult to handle due to the stringiness. Applications in the field would be difficult, even under the best conditions."

---

[4] Note: The binders A2S1-5% and A1S1-4% had very similar handling characteristics, and Marshall mix design results. The two mixes were made from two different Alaskan asphalt cement sources, and were modified with the same modifier at a slightly different concentration.

5.3.2 Smoking, Odor and Workability

Smoking:

Three of the ten mixes tested smoked profusely. The limited tests conducted by this study were not sufficient to determine whether mixing temperature or polymer/base asphalt type or concentration was the most significant cause for the smoking.

Odor:

One modified blend of the ten binders tested had a very strong noxious odor. This caused extreme discomfort to the operator, even with the hood running and the operator wearing a respirator.

Workability:

Workability appears to be a function of polymer type and concentration, and of mixing/compacting the mixture at an adequately high temperature. Both of the pre-manufactured proprietary polymer-modified asphalt products showed good workability at the design construction temperatures. Two of the ten mixes tested were stringy and difficult to handle, which may have been a function of polymer type.

6. SUPERPAVE TESTING OF BINDER-AGGREGATE MIXTURES

6.1 Materials

The same materials were used in the Superpave mixture testing as for the quantitative and qualitative testing described in Section 5. The asphalt binders given in Table 3-12 were manufactured in the UAF laboratory except the pre-manufactured binders PM1 and PM3. The aggregate was obtained from the AKDOT&PF; the source and mineral information is given in Section 5.

6.2 Sample Preparation

The asphalt-aggregate mixture samples were prepared using the mixing and compaction temperatures obtained from the Superpave binder test data given in Table 4-3. The binder content used was obtained from the AKDOT&PF and is given in Table 5-2. The exact aggregate gradation used and specific gravities for each fraction are given in Table 6-1. The samples were compacted into beam specimens (65 mm x 125 mm x 300 mm) using a rolling wheel compactor. Each beam specimen was individually batched and compacted according to the specified mix compaction temperature and density. The specific gravities, unit weight, asphalt content and air void for each sample is given in Table 6-2.

As seen from Table 4-3, the mixing temperature for all the polymer-modified blends was around 170°C or higher. Some “fuming” occurred but was not objectionable for SBS blends. For the SBR blends, however, the “fuming” increased and had a distinct odor.
The mixing temperature was determined using viscosity–temperature relationships (mixing viscosity of 0.17Pas and compaction viscosity of 0.28Pas).

6.3 Test Procedures

6.3.1 Georgia Wheel Rutting Test

The Georgia Wheel Rutting Test (GWRT) test simulates the rutting of pavement due to plastic deformation. The samples are stressed under repetitive loading cycles and the depth of the resulting rut is measured.

Each test was conducted on 3 beam specimens (65 mm x 125 mm x 300 mm). The specimens were tested at 40°C under a load of 445N (100 lb.) applied to a rubber hose with pressure equal to 690kPa (100 psi). The GWRT set-up allows the specimens to be placed in a carriage that could move back and forth under the applied load at a frequency of 0.76 cycles per second. Rut measurements were performed every 1000, 4000, and 8000 cycles and the average rut depth was reported for each number of cycles. A maximum rut depth of 3mm after the 8000 load cycles is considered acceptable.

Table 6-1. Aggregate Gradation Used in Sample Preparation

Sieve No. (mm)	% Passing Specified	Weight Needed, g	Gs Aggregate
1" (25.4)	100	0	2.630
3/4" (19)	100	0	2.630
0.5" (12.7)	84	1449.7	2.768
3/8" (9.5)	70.5	1223.2	2.725
#4 (4.75)	48.2	2020.5	2.709
#8 (2.36)	31.5	1513.1	2.699
#16 (1.18)	20.6	987.6	2.684
#30 (0.6)	13.6	634.2	2.700
#50 (0.3)	8.2	489.3	2.685
#100 (0.15)	5.5	244.6	2.692
#200 (0.075)	2.5	271.8	2.673
Pan	0	226.5	2.746
Total		9060.5	

6.3.2 Thermal Stress Restrained Specimen Test

The Thermal Stress Restrained Specimen Test (TSRST) simulates low temperature cracking of pavement in the field. The TSRST fracture temperature represents the temperature in the field at which the pavement is anticipated to crack and the TSRST fracture strength represents the corresponding thermal stress[22].

The TSRST tests were performed on 50 mm x 50 mm x 250 mm prismatic specimens. These were cut from the larger beam specimens (65 mm x 125 mm x 300 mm) that were prepared using rolling wheel compactor. Each beam specimen was glued between two flat platens (cap and base) then placed in an environmental chamber. The specimen was cooled gradually at a rate of –9.5 to –10°C/h. The length of the specimen was kept essentially constant during testing by means of a step motor that is activated when it senses contraction feedback from the two LVDTs attached across the specimen cap and base. When contraction is prevented, a thermal stress develops in the specimen. The thermal stress increases as temperature decreases until the tensile strength of the specimen is reached and the specimen breaks. Both fracture temperature and fracture strength were recorded for each tested specimen. A minimum of 3 specimens was tested for each mix and the average value of the fracture temperature and fracture strength was recorded.

Table 6-2. Mixture Data for Samples Fabricated Using Georgia Rolling Wheel Compactor

Slab ID	Bulk Sp. Gravity	Unit Weight		Specific Gravity		Calculated		Measured
		(kN/m^3)	(pcf)	Aggreg.	Asphalt	%AC	%AIR	%AIR
A1-1	2.352	23.1	146.8	2.713	1.012	4.91	6.15	6.17
A1-2	2.429	23.8	151.6	2.713	1.012	4.91	3.09	2.65
A1-3	2.398	23.5	149.7	2.713	1.012	5.13	3.96	4.51
A1-4	2.398	23.5	149.6	2.713	1.012	4.91	4.32	4.20
A1-5	2.397	23.5	149.6	2.713	1.012	4.91	4.34	4.05
A1-6	2.382	23.4	148.7	2.713	1.012	4.91	4.94	4.11
A2-1	2.394	23.5	149.4	2.713	1.012	5.00	4.33	3.56
A2-2	2.414	23.7	150.6	2.713	1.012	5.00	3.54	2.92
A2-3	2.413	23.7	150.6	2.713	1.012	5.01	3.57	2.39
A2-4	2.398	23.5	149.6	2.713	1.012	5.01	4.17	4.35
A2-5	2.423	23.8	151.2	2.713	1.012	5.01	3.16	3.05
A5-1	2.431	23.8	151.7	2.713	1.012	4.80	3.17	2.99
A5-2	2.357	23.1	147.1	2.713	1.012	4.84	6.08	6.24
A5-3	2.387	23.4	149.0	2.713	1.012	4.80	4.91	5.15
A5-4	2.393	23.5	149.3	2.713	1.012	4.84	4.64	5.13
A5-5	2.384	23.4	148.8	2.713	1.012	4.92	4.85	4.69
PM1-1	2.385	23.4	148.8	2.713	1.004	4.80	4.90	3.18
PM1-2	2.400	23.5	149.7	2.713	1.004	4.80	4.31	3.87
PM1-3	2.380	23.3	148.5	2.713	1.004	4.79	5.13	6.04
PM1-4	2.386	23.4	148.9	2.713	1.004	4.80	4.86	5.23
PM1-5	2.387	23.4	148.9	2.713	1.004	4.81	4.83	4.87
PM3-1	2.414	23.7	150.6	2.713	1.016	5.06	3.52	3.70
PM3-2	2.376	23.3	148.2	2.713	1.016	5.01	5.10	5.09
PM3-3	2.404	23.6	150.0	2.713	1.016	5.00	4.01	3.66
PM3-4	2.408	23.6	150.3	2.713	1.016	5.04	3.75	3.97
PM3-5	2.377	23.3	148.3	2.713	1.016	5.00	5.06	5.51
A1S1-4%-1	2.347	23.0	146.4	2.713	1.011	4.80	6.51	7.15
A1S1-4%-2	2.354	23.1	146.9	2.713	1.011	4.80	6.21	6.19
A1S1-4%-3	2.381	23.4	148.6	2.713	1.011	4.81	5.12	5.24
A1S1-4%-4	2.394	23.5	149.4	2.713	1.011	4.82	4.59	4.64
A1S1-4%-5	2.379	23.3	148.4	2.713	1.011	4.81	5.22	5.33
A2S1-5%-1	2.404	23.6	150.0	2.713	1.008	4.83	4.15	3.78
A2S1-5%-2	2.397	23.5	149.6	2.713	1.008	4.81	4.47	4.47
A2S1-5%-3	2.367	23.2	147.7	2.713	1.008	4.80	5.66	5.88
A2S1-5%-4	2.430	23.8	151.6	2.713	1.008	4.62	3.42	3.33
A2S1-5%-5	2.364	23.2	147.5	2.713	1.008	4.74	5.87	6.38

Table 6-2 (Continued). Mixture Data for Samples Fabricated Using Georgia Rolling Wheel Compactor

Slab ID	Bulk Sp. Gravity	Unit Weight		Specific Gravity		Calculated		Measured
		(kN/m^3)	(pcf)	Aggreg.	Asphalt	%AC	%AIR	%AIR
A5S1-5%-1	2.375	23.3	148.2	2.713	1.004	4.80	5.30	5.77
A5S1-5%-2	2.367	23.2	147.7	2.713	1.004	4.80	5.64	5.25
A5S1-5%-3	2.360	23.2	147.3	2.713	1.004	4.80	5.89	5.35
A5S1-5%-4	2.361	23.2	147.3	2.713	1.004	4.80	5.88	4.94
A5S1-5%-5	2.347	23.0	146.5	2.713	1.004	4.81	6.41	7.16
A2R2-2%-1	2.363	23.2	147.4	2.713	1.009	5.21	5.25	5.49
A2R2-2%-2	2.367	23.2	147.7	2.713	1.009	5.20	5.10	5.89
A2R2-2%-3	2.416	23.7	150.8	2.713	1.009	5.20	3.12	2.28
A2R2-2%-4	2.392	23.5	149.3	2.713	1.009	5.21	4.06	3.86
A2R2-2%-5	2.370	23.2	147.9	2.713	1.009	5.21	4.96	5.92
A5R2-2%-1	2.356	23.1	147.0	2.713	1.004	5.00	5.78	4.74
A5R2-2%-2	2.311	22.7	144.2	2.713	1.004	5.00	7.56	7.37
A5R2-2%-3	2.377	23.3	148.3	2.713	1.004	5.00	4.93	3.52
A5R2-2%-4	2.371	23.3	148.0	2.713	1.004	4.99	5.17	5.18
A5R2-2%-5	2.344	23.0	146.2	2.713	1.004	4.99	6.28	6.69

6.4 Test Results and Conclusions

6.4.1 Georgia Wheel Rutting Test

The test results are given in Table 6-3. The variation of average rut depth with load cycles is illustrated in Figure 6-1 and the final rut depth at 8000 cycles in Figure 6-2. Effect of polymer-modification on the GWRT rut depth at 8000 cycles is illustrated in Figure 6-3.

Table 6-3. Georgia Wheel Rutting Test Results

Mix	Slab ID	Rut Depth (mm) at cycle			Average Rut Depth (mm) at cycle		
		1000	4000	8000	1000	4000	8000
A1	A1-2	1.977	3.550	5.210			
	A1-3	3.367	5.133	5.697			
	A1-4	3.513	7.787	9.673	2.952	5.490	6.860
A2	A2-1	2.587	3.680	4.277			
	A2-2	2.087	3.273	4.203			
	A2-4	1.343	3.300	3.867	2.006	3.418	4.116
A5	A5-1	4.833	6.640	8.970			
	A5-2	6.663	10.000	13.000			
	A5-3	11.000	17.000	18.000	7.499	11.213	13.323
PM1	PM1-1	1.133	1.620	2.593			
	PM1-2	1.037	1.187	1.470			
	PM1-3	1.050	1.840	2.137	1.073	1.549	2.067
PM3	PM3-1	1.827	2.133	2.627			
	PM3-2	1.563	2.237	2.473			
	PM3-3	2.133	2.863	3.547	1.841	2.411	2.882
A1S1-4%	A1S1-4%-2	2.050	2.547	2.840			
	A1S1-4%-3	1.137	1.813	2.787			
	A1S1-4%-4	1.417	2.260	2.573	1.534	2.207	2.733
A2S1-5%	A2S1-5%-2	2.020	2.257	2.493			
	A2S1-5%-4	1.303	1.470	1.707	1.108	1.242	1.400
A5S1-5%	A5S1-5%-2	2.167	2.683	2.903			
	A5S1-5%-4	2.527	3.623	3.867	1.564	2.102	2.257
A2R2-2%	A2R2-1	2.810	4.353	4.803			
	A2R2-2	1.600	2.740	3.270			
	A2R2-4	2.067	5.087	5.857	2.159	4.060	4.643
A5R2-2%	A5R2-2	3.353	5.010	5.783			
	A5R2-3	2.490	3.710	3.950			
	A5R2-4	3.497	5.980	6.940	3.113	4.900	5.558

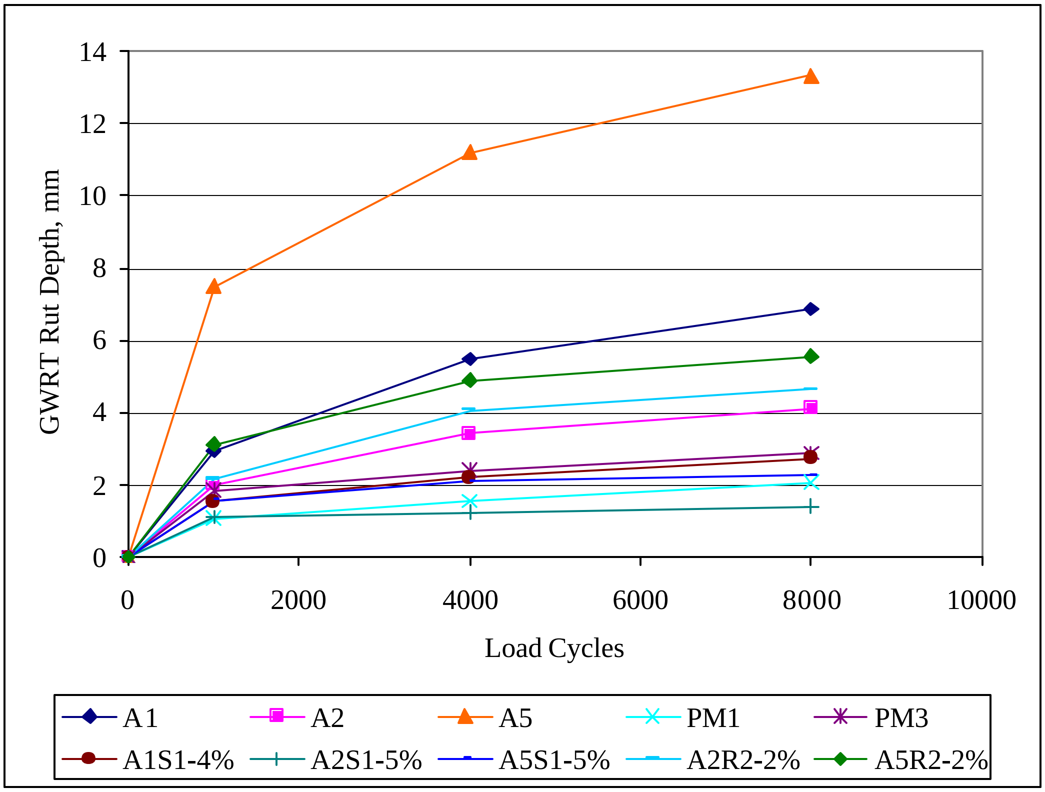


Figure 6-1. Variation of Rut Depth with Load Cycles

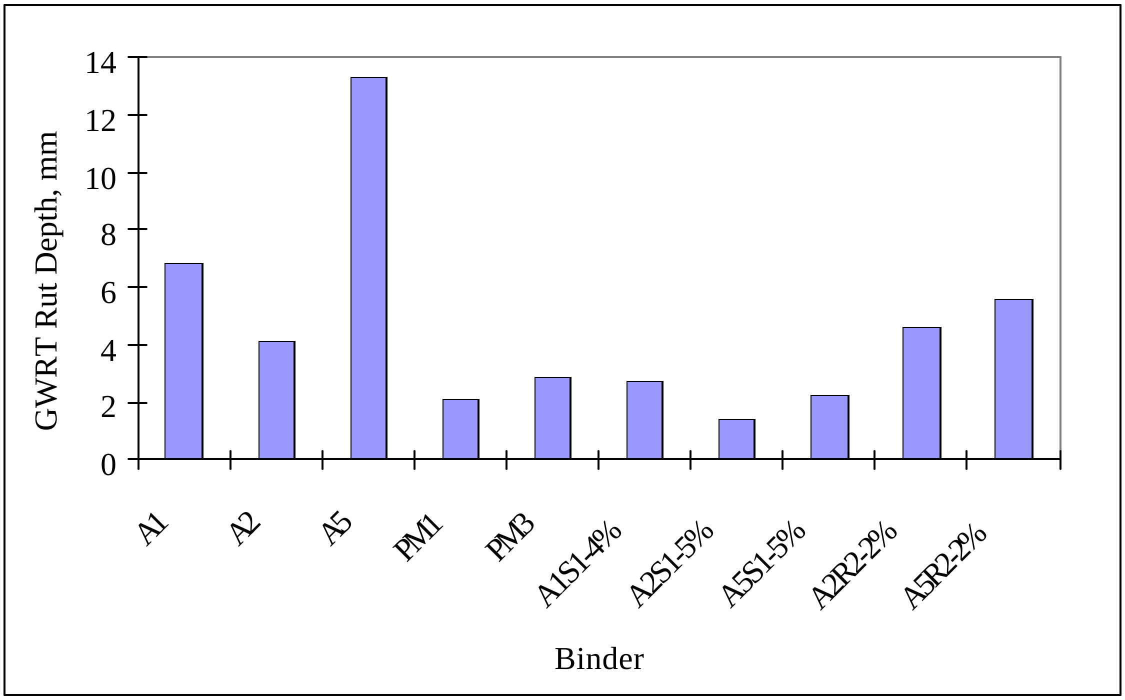


Figure 6-2 Rut Depth at 8000 Load Cycles

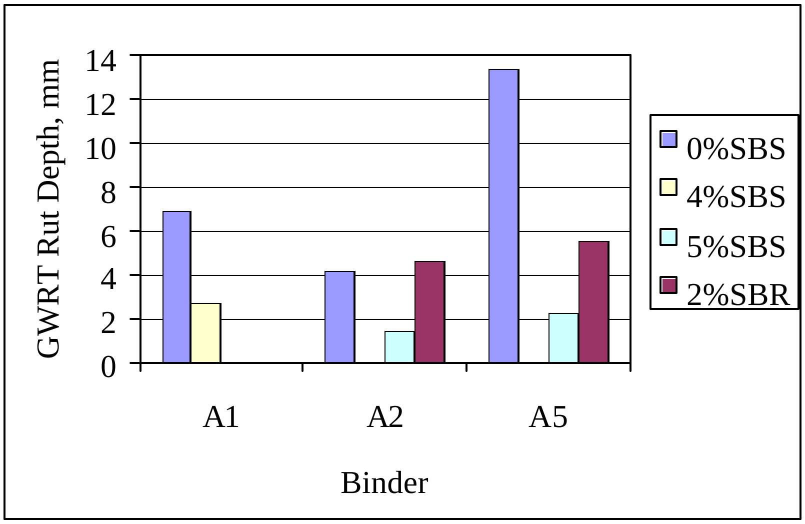


Figure 6-3. Effect of Polymer-Modification on GWRT Rut Depth at 8000 Load Cycles

The following were concluded from the test results:

- The samples with SBS-modified binders with 4 to 5% polymer content and the pre-manufactured binders had the best rutting resistance.
- The SBR-modification also improved the rutting resistance when compared to the straight asphalts, except for sample with A2R-2%.
- SBS-modification improved the rutting resistance dramatically, especially for the A5 asphalt.
- The use of 2% SBR with A5 binder improves the rutting resistance of the mix, whereas the use of the same amount of SBR with A2 binder seems to have a negligible effect on the rut resistance. (Based on softening points the polymer-modification would improve the rut resistance of each of the base asphalts only slightly).

6.4.2 Thermal Stress Restrained Specimen Test

The test results are given in Table 6-4 and Figures 6-4 and 6-5. According to Kanerva et al.[22] the average pavement temperature has to reach the fracture temperature for cracking to occur. The fracture strength is an important factor, when the spacing between the cracks is predicted. Because no spacing prediction will be conducted here, the effect of polymer-modification on fracture temperature will be considered. The effect of polymer-modification on the fracture temperature of the base asphalts is illustrated in Figure 6-6.

The following was concluded from the test results:

- Mixtures with the pre-manufactured binders, PM1 and PM3, exhibited the best low temperature cracking performance with fracture temperature values –34 and –36°C respectively. Next ranked the binders A5R2-2% and A5S1-5% with values -32 and -31°C.
- The polymer-modification improved the low temperature cracking resistance of the base asphalts slightly. When the superior performance of the pre-manufactured binders are considered, there is evidence that the polymer-modification improves the cracking resistance of the mixtures.
- The SBS-modification reduced the TSRST fracture temperature by 1.4°C for the binder A1 and 1.8°C for the binder A5, and was about the same for the binder A2.
- The SBR-modification reduced the TSRST fracture temperature by 2.0°C for the binder A2 and 3°C for the binder A5.
- In many cases it is desirable to modify conventional binders so that the resulting mix exhibits good resistance to low temperature cracking and rutting. The choice of the binder type and the polymer modifier will essentially depend on climate, traffic loads, and degree of improvement required. For example, choosing from the suite of polymer modified mixes investigated, it seems that mixtures with PM1, PM3, and A5S1-5% would be resistant to pavement temperature of –30° C, without exhibiting excessive rutting according to GWRT criterion (about 3 mm rut or less after 8000 load cycles).

Table 6-4. Thermal Stress Restrained Specimen Test Results

Sample ID	Bulk Sp. Gravity	Binder Content, %	Air Voids, %	Average Fracture Temperature, °C	Average Fracture Strength, MPa
A1-1-a	2.352	4.91	6.15	-25.1	2.842
A1-5-a	2.397	4.91	4.34		
A1-5-b	2.397	4.91	4.34		
A1-6-a	2.382	4.91	4.94		
A1-6-b	2.382	4.91	4.94		
A2-3-a	2.413	5.01	3.57	-25.7	3.702
A2-3-b	2.413	5.01	3.57		
A2-5-a	2.423	5.01	3.16		
A2-5-b	2.423	5.01	3.16		
A5-4-a	2.393	4.84	4.64	-29.2	2.480
A5-5-a	2.384	4.92	4.85		
A5-5-b	2.384	4.92	4.85		
PM1-4-a	2.386	4.80	4.86	-34.2	4.090
PM1-4-b	2.386	4.80	4.86		
PM1-5-a	2.387	4.81	4.83		
PM1-5-b	2.387	4.81	4.83		
PM3-4-a	2.408	5.04	3.75	-35.9	4.744
PM3-4-b	2.408	5.04	3.75		
PM3-5-a	2.377	5.00	5.06		
PM3-5-b	2.377	5.00	5.06		
A1S1-4%-1-a	2.347	4.80	6.51	-26.5	3.232
A1S1-4%-5-a	2.379	4.81	5.22		
A1S1-4%-5-b	2.379	4.81	5.22		
A2S1-5%-1-a	2.404	4.83	4.15	-25.4	3.602
A2S1-5%-3-a	2.367	4.80	5.66		
A2S1-5%-5-a	2.364	4.74	5.87		
A2S1-5%-5-b	2.364	4.74	5.87		
A5S1-5%-1-a	2.375	4.80	5.30	-31.0	3.508
A5S1-5%-1-b	2.375	4.80	5.30		
A5S1-5%-3-a	2.360	4.80	5.89		
A5S1-5%-3-b	2.360	4.80	5.89		
A5S1-5%-5-a	2.347	4.81	6.41		
A5S1-5%-5-b	2.347	4.81	6.41		
A2R2-2%-3-a	2.416	5.20	3.12	-27.7	4.185
A2R2-2%-3-b	2.416	5.20	3.12		
A2R2-2%-5-a	2.370	5.21	4.96		
A2R2-2%-5-b	2.370	5.21	4.96		
A5R2-2%-1-a	2.356	5.00	5.78	-32.2	3.687
A5R2-2%-1-b	2.356	5.00	5.78		
A5R2-2%-5-a	2.344	4.99	6.28		
A5R2-2%-5-b	2.344	4.99	6.28		

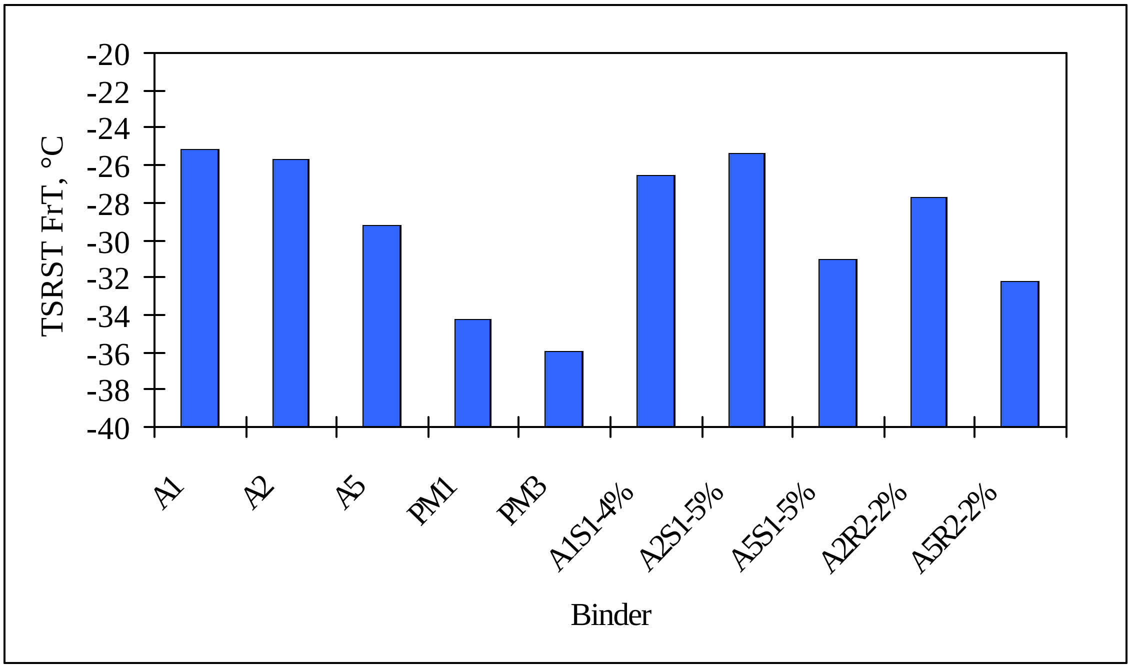


Figure 6-4. Thermal Stress Restrained Specimen Test Fracture Temperatures

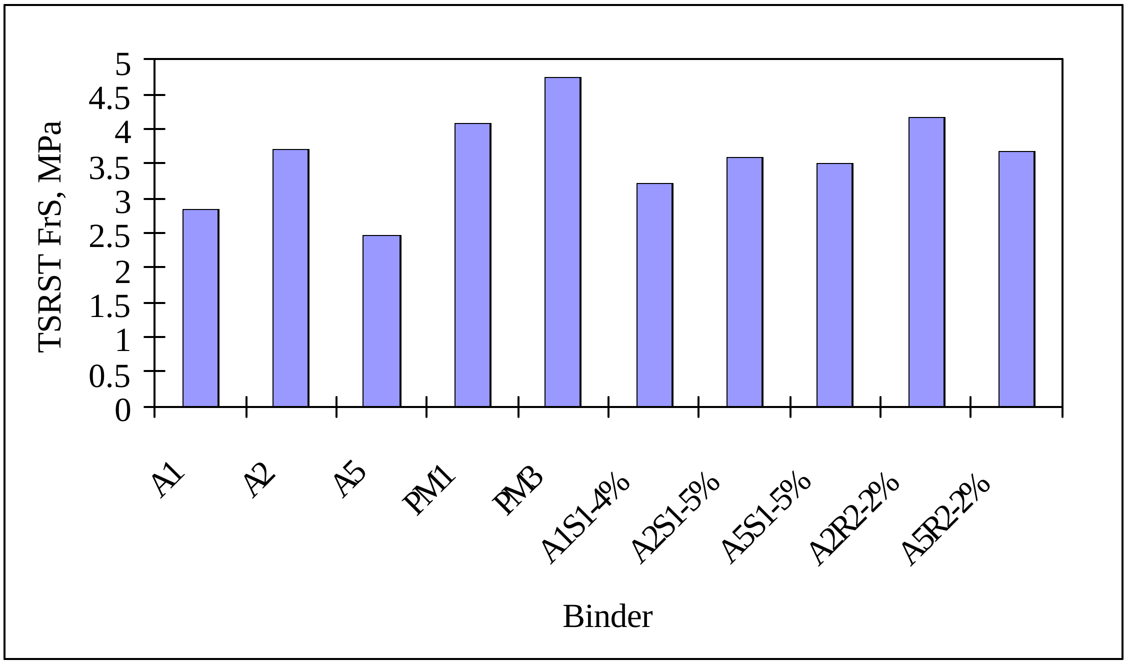


Figure 6-5. Thermal Stress Restrained Specimen Test Fracture Strengths

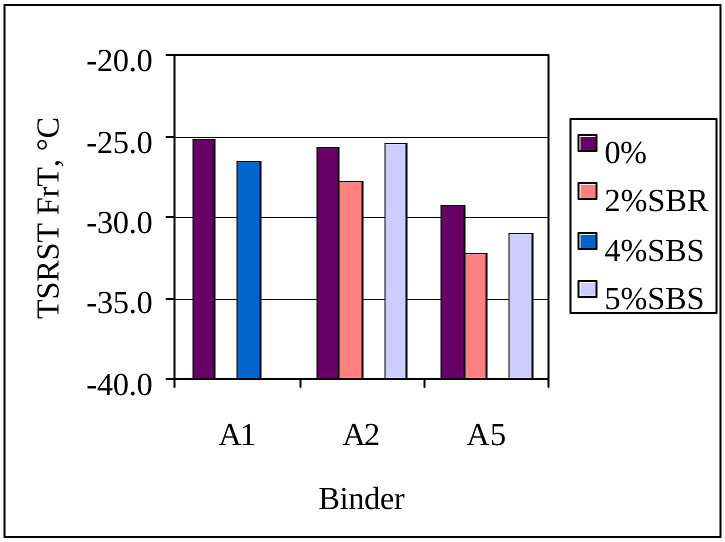


Figure 6-6. Effect of Polymer-Modification on TSRST Fracture Temperature (FrT)

7. COMPARISON BETWEEN BINDER AND MIXTURE TEST RESULTS

In the first phase of study, binder properties were used to eliminate binders that did not satisfy criteria set on improved temperature susceptibility, storage stability and tolerable mixing temperature. It is important to check, if the chosen properties correlate with the mixture test results. If they do, the use of the chosen binder properties is justified. Also, if binder specifications are established on the basis of these test results, it is important to see that the tested binder properties correlate with the mixture test results. In the following sections, the following relationships will be studied:

- Rutting resistance:
    - Softening Point versus GWRT rut depth at 8000 load cycles, and
    - RTFO G*/sin(δ) versus GWRT rut depth at 8000 load cycles.
- Low temperature cracking resistance:
    - Penetration at 10°C vs. TSRST Fracture Temperature, and
    - PAV Stiffness vs. TSRST Fracture Temperature.

7.1 Binder Tests versus Georgia Wheel Rutting Test Results

The binder tests that are related to the rutting of pavements are softening point and the temperature at which G*/sin(δ) is 2.2kPa. These binder test results together with the GWRT rut depths are given in Table 7-1 and in Figures 7-1 and 7-2. A regression analysis was performed to see if the binder properties correlate with the mixture properties. The results of the regression analysis for four models are given in Table 7-2.

Table 7.1. Binder Test Results versus Georgia Wheel Rutting Test Results

Binder	Temp @ G*/sin(d) =2.2kPa, °C	Softening Point, °C	GWRT Rut Depth, mm
A1	55.9	41.6	6.86
A2	53.6	41.0	4.12
A5	49.9	39.0	13.32
PM1	58.3	80.5	2.07
PM3	68.4	61.7	2.88
A1S1-4%	63.0	48.0	2.73
A2S1-5%	66.0	85.0	1.40
A5S1-5%	59.5	82.8	2.26
A2R2-2%	62.4	44.3	4.64
A5R2-2%	56.9	41.3	5.56

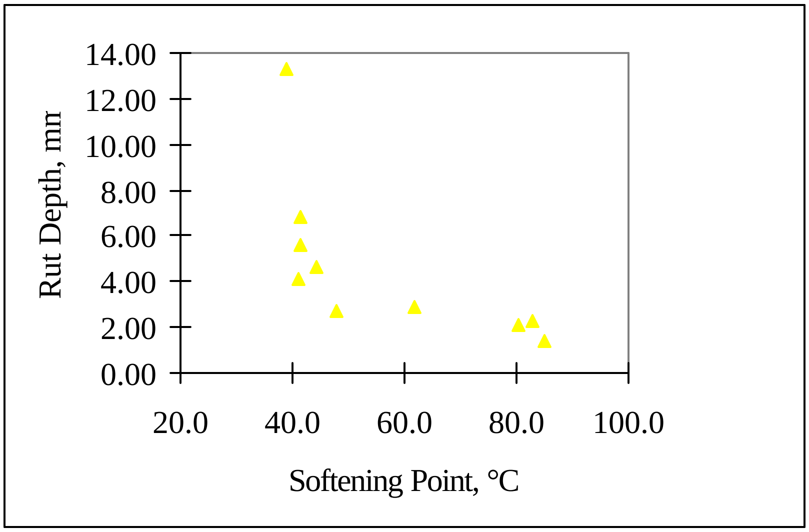


Figure 7.1. GWRT Rut Depth versus Softening Point

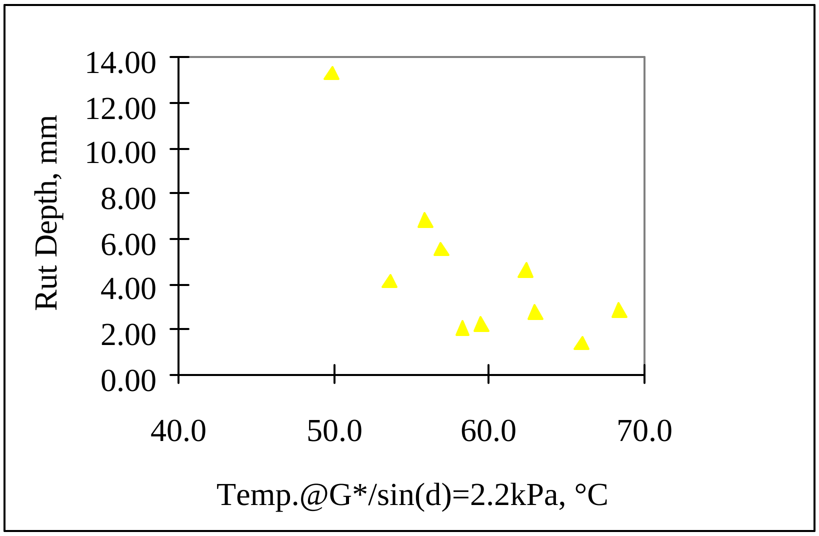


Figure 7.2. GWRT Rut Depth versus Temperature at which G*/sin(d)=2.2kPa

Table 7-2. Regression Analysis Results for Model Rut_{ave}=a + b(X)

X	Softening Point (SP)	1/log(SP)	Temp.@ G*/sin(δ) =2.2kPa	1/log(Temp. @G*/sin(δ) =2.2kPa)
Unit of X	°C	1/log(°C)	°C	1/log(°C)
a	11.385	34.389	31.406	-108.587
St. Error of a	2.882	11.127	8.899	33.697
P-value for a	0.004	0.015	0.008	0.012
b	-0.120	-17.218	-0.452	200.428
St. Error of b	0.049	6.409	0.149	59.664
P-value for b	0.038	0.028	0.016	0.010
Degrees of Freedom	9	9	9	9
Total St. Error	2.80	2.64	2.54	2.40
R^2	0.43	0.50	0.53	0.59

Neither the softening point nor the temperature at which G*/sin(δ)=2.2kPa correlated well with the GWRT rut depth (P-values 0.03 and 0.01 respectively). However, all the binders that had a softening point greater than or equal to 48°C, met the criterion for the GWRT maximum rut depth of 3mm, which justifies the use of softening point to select binders in the first phase of this research and also to use softening point in binder specifications. Binders that had softening point lower than 48°C had higher rut depth than 3mm.

The rutting test was conducted at 40°C, which means that according to the PG grading all binders should have passed the GWRT failure criterion of maximum 3mm rut depth. As seen from Table 7-1 and Figure 7-2, five of the ten binders failed, which means that the PG high temperature grading did not relate with the GWRT rut depths. Temperature at which G*/sin(δ)=2.2kPa, that would divide the binders between failed and passed, could not be found either.

7.2 Binder Tests versus Thermal Stress Restrained Specimen Test Results

Binder tests that are related to the cold temperature behavior of pavements are penetration test at lowest possible temperature (10°C in this study) and the BBR stiffness (S) and the m-value. These binder test results together with the TSRST results are given in Table 7-3 and in Figures 7-3 and 7-4.

A regression analysis was performed to see if the binder properties correlate with the mixture properties. The results of the regression analysis are given in Table 7-4. The penetration at 10°C correlates well with the TSRST fracture temperature (P-value =0.007), which means that it was justified to use the low temperature range temperature susceptibility as an indicator for improvement in pavement performance related to low temperature cracking. The BBR stiffness correlates even better with the TSRST fracture temperature (P-value = 0.00001). Based on these test results, the binder test results predicted the low temperature cracking tendency of the asphalt-aggregate mixtures. Therefore, specification recommendations could be made based on the binder test results.

Table 7-3. Binder Test Results versus Thermal Stress Restrained Specimen Test Results

Binder	Temp@S= 300MPa, °C	Temp@ m=0.3, °C	Pen@10°C, 1/10mm	TSRST Fracture Temperature, °C	TRSRT Fracture Strength, MPa
A1	-18.5	-19.3	27.7	-25.1	2.842
A2	-19.3	-20	29.7	-25.7	3.702
A5	-21.6	-23	44.7	-29.2	2.48
PM1	-23.7	-22.4	64	-34.2	4.09
PM3	-26.3	-26.4	50.3	-35.9	4.744
A1S1-4%	-19.1	-17	23.3	-26.5	3.232
A2S1-5%	-20.4	-17.4	22.3	-25.4	3.602
A5S1-5%	-21.8	-20.2	44	-31	3.508
A2R2-2%	-20.8	-19.5	28.3	-27.7	4.185
A5R2-2%	-23.1	-22.5	49	-32.2	3.687

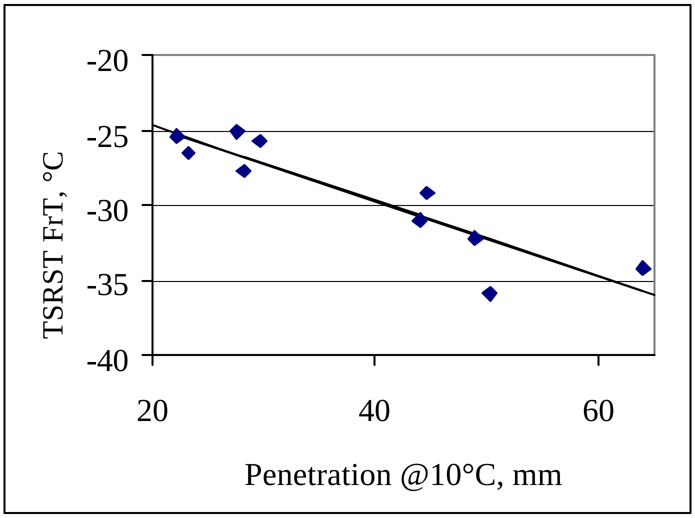


Figure 7-3. TSRST Fracture Temperature versus Penetration at 10°C

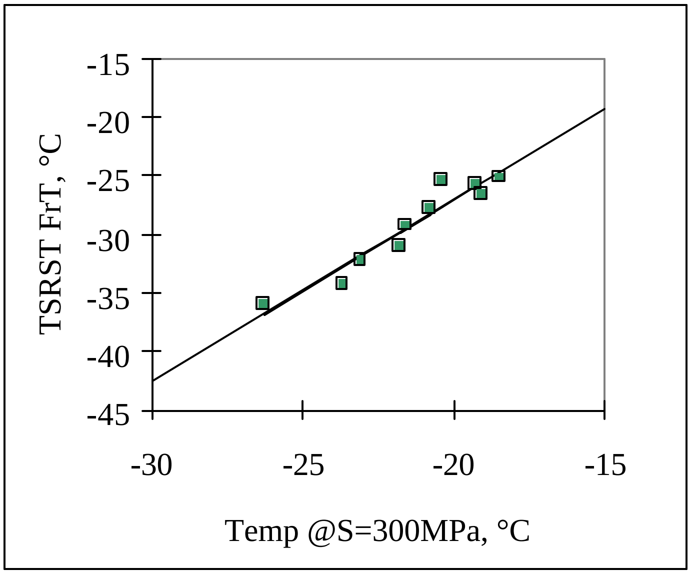


Figure 7-4. **TSRST Fracture Temperature versus Temperature at which S= 300MPa**

Table 7-4. Regression Analysis Results For Model $\text{TSRST}_{ave} = a + b(X)$

X	**Pen@10**	**Temp. @S=300MPa**
Unit of X	1/10mm	°C
a	-19.682	3.93938
St. Error of a	1.69295	3.48845
P-value for a	2.7E-06	0.29151
B	-0.2507	1.54843
St. Error of b	0.04174	0.16165
P-value for b	0.00032	1.2E-05
Degrees of Freedom	9	9
Total St. Error	1.75091	1.16369
R^2	0.81845	0.91981

8. CONCLUSIONS AND RECOMMENDATIONS

The constructability of Alaskan polymer-modified mixtures was studied by literature review, questionnaire study, conventional asphalt testing, Superpave asphalt testing, and testing asphalt-aggregate mixtures in Georgia Wheel Rutting Tester and Thermal Stress Restrained Specimen Test. The conclusions, recommendations, and future research needs observed are summarized in following Sections.

8.1 Conclusions

Literature Review

- Compatibility is a very important parameter that governs the success of polymer modification. Loss of compatibility could occur during the blending process, during mixing with the aggregates or during storage of the asphalt-polymer blend.
- Several tests were found for evaluation the compatibility of polymer-modified asphalts. Three of them were selected for this research:, separation test (tube test), fluorescent microscopy and elastic recovery.
- Two types of specifications are used: guide type specifications that use conventional asphalt testing methods, and Superpave specifications. The Superpave specifications do not consider storage stability, and therefore sampling should be conducted just before the binder is mixed with the aggregate or a separation test should be added to the Superpave specifications.

Questionnaire Study

- Polymer-modified asphalts have been in pavement industry use for fifteen years without any reported constructability problems.
- The hot-plant mixing temperatures and compaction temperatures are always elevated, and air temperature should be 10°C or warmer.
- The compatibility of polymer-modified binders is the manufacturer’s responsibility.
- SBS-polymer is most commonly used in the modification of asphalt cements.
- Most popular specifications are
  Original binder:
  - penetration at 25°C: 50 – 160 1/10mm,
  - softening point: min. 60°C,
  - viscosity at 135°C: max. 2000mm^2/s (≅2Pas that corresponds a mixing temperature about 190°C with 170mm^2/s viscosity)
  - separation test at 163°C for 48 hours: difference in the softening point for the bottom and top of the sample, max. 4°C,

  RTFO-Residue:
  - penetration at 4°C (200g load for 60s): 15 – 30 1/10mm,
  - elastic recovery at 25°C: 45 – 70%.

Consistency and Compatibility Testing of Binders

- Of the 36 polymer-modified asphalts tested only nine met the criteria set for the compatibility, storage stability, improved temperature susceptibility, and mixing temperature. This shows that polymer modified asphalts should always be an end result of an extensive product development program.

- Pre-manufactured binders, that are end results of extensive product development programs, satisfied all criteria.
- It was shown that the binder properties depend upon polymer type, polymer concentration, base asphalt, and method used in mixing the polymer with the asphalt.
- A large number of binders did not meet the storage stability criterion, or the maximum hot-plant mixing temperature criterion. Both the storage stability and too high mixing temperature cause constructability problems. The high number of binders that did not meet the criteria partly explains the construction difficulties in the field.
- On the basis of the test results, three base asphalts and seven polymer-modified asphalts were selected for the next phases of testing.

Superpave Testing of Binders

- The PG-grades were determined for each binder.
- According to the temperatures, where the high and low temperature specifications are satisfied, the polymer-modification improved the pavement performance, both rutting resistance and low temperature cracking resistance, for all base asphalts. This indicates that the polymer-modification is beneficial.

Quantitative and Qualitative Testing of Asphalt-Aggregate Mixtures

- Excess smoking was observed for some binders. However, the limited number of variables did not allow determining if the smoking was caused by certain materials, their concentration or the mixing temperatures.
- Some polymer additives will produce noxious odors at high temperatures.
- Workability appears to be a function of polymer type and concentration, and of mixing and compacting the mixture at an adequately high temperature.
- Both of the pre-manufactured proprietary polymer-modified asphalt products showed good workability at the design construction temperatures. The use of these types of products is recommended, where economically feasible, if they meet all other criteria.

Superpave Testing Of Binder-Aggregate Mixtures

- The pre-manufactured binders and SBS-modified binders with 4 to 5% polymer content had the best rutting resistance.
- SBS-modification improved the rutting resistance dramatically, especially for the A5 asphalt.
- The SBR-modification also improved the rutting resistance when compared to the straight asphalts, except for sample with A2R-2%.
- Mixtures with the pre-manufactured binders, PM1 and PM2, exhibited the best low temperature cracking performance with fracture temperature values –34 and –36°C respectively. The binders A5R2-2% and A5S1-5% ranked next with values -32 and -31°C.
- The polymer-modification improved the low temperature cracking resistance slightly.

Comparison between Binder and Mixture Test Results

- All the binders that had a softening point greater than or equal to 48°C, met the criterion for the GWRT maximum rut depth of 3mm, which justifies the use of softening point to select binders in the first phase of this research and also to use softening point in binder specifications.
- The penetration at 10°C and the BBR stiffness correlates well with the TSRST fracture temperature, which means that it was justified to use the low temperature range temperature susceptibility as an indicator for improvement in pavement performance related to low temperature cracking. Based on these test results, the binder test results predicted the low temperature cracking tendency of the asphalt-aggregate mixtures. Therefore, specification recommendations could be made based on the binder test results.

8.2 Recommendations

- Polymer-modified products should be an end result of comprehensive product development program, in which a compatible base asphalt and polymer will be combined using optimized procedure and optimized polymer content to achieve 1) lowest possible construction temperatures with 2) improved pavement performance. This will reduce construction problems, including the smoking and air quality issues, and reduce pavement life-cycle costs.
- Recommendations on mixing temperature:
  - In general, elevated mixing temperatures could result in excessive fumes, excessive oxidation of the binder, thermal separation of modifier and binder, and thermal degradation of the polymer modifier. Conventional binders do not usually smoke at temperatures lower than 163°C. The Asphalt Institute recommends a maximum of 177°C to prevent thermal degradation and burnout. If thermal separation is experienced, the modifier may be extruded from the mix on the surface under breakdown rolling.
  - Until more experience is gained and more research is undertaken addressing the issue of mixing and compaction of polymer modified Superpave mixtures, the Asphalt Institute suggests that mixing temperatures used for polymer modified mixes be slightly higher than compaction temperature, but not to exceed 170°C.

Specification recommendations to address the constructability of the binders:

  - Viscosity ranges for mixing temperatures at hot-plant and compaction temperatures should be specified. Because of the observed smoking problems, unfortunately more research is needed to establish these viscosities. The mixing and compaction temperatures would be defined on the basis of the viscosity ranges.
  - A storage stability test should be added to specifications (e.g. 5 to 10°C difference between the top and bottom softening points after conditioning at 163°C for 48 hours). Or, the binder samples tested for quality control from the hot-plant should be taken just before the binder hits the hot aggregate in the mixer, to allow the contractor to address the storage stability question with techniques, such as tank circulation.

- Specification recommendations to address the performance of the binders:
  - To address the rutting resistance, a minimum softening point could be specified (e.g. 50 to 60°C).
  - To address the low temperature cracking resistance, a minimum penetration at 10°C or lower could be established. The numerical value depends on the minimum pavement design temperature, and could be obtained from Figure 7-3. Or, the BBR Stiffness could be used as shown in Superpave specifications.
  - Fatigue cracking was not considered in this research.

8.3 Future Research

The research conducted was a literature and laboratory research. The recommended specifications should be verified in a field study. Test sections should be constructed using recommended binder criteria and the same aggregate and aggregate gradation as used in this research. Rutting due permanent deformation and low temperature cracking should be observed with time.

Questions still remain in the selected mixing and compaction temperatures. The current state-of-the-art in determining these temperatures is done according to ASTM 1559. Recommended temperatures are determined from limiting viscosities that are applicable to conventional asphalts but not necessary to polymer modified binders. It is important to study the influence of the binder-aggregate temperature on mixing, placement, compactability, and performance (i.e. rutting, thermal cracking) and find a range of mixing and compaction temperatures that are “practically” acceptable.

9. REFERENCES

---

[1] Terrel, R. and Walter, J. “Modified asphalt pavement materials the European experience.” *Proceedings, Association of Asphalt Paving Technologists*, 55, 1986, pp. 482-518.

[2] Whiteoak, D. *The Shell Bitumen Handbook*, Shell Bitumen, UK, 1990.

[3] Isacsson, U., Lu X. “Testing and appraisal of polymer modified road bitumens – state of the art.” *Materials and Structures*, Vol. 28 (1995) pp.139-159.

[4] Vonk, W.C., Korenstra, J., and Jongeneel, D.J. “The improvement of asphalt mix performance by SBS-modified binders.” *Shell Bitumen Review* 66, May 1992, pp. 1-3.

[5] Raad, L., Sebaaly, J., Epps, J., Coetzee, N., Camilli, R., “Low temperature cracking of polymer-modified AC mixes.” Alaska Cooperative Transportation and Public Facilities Research Program, Project No. SPR-95-14 Task Report, August 1996.

[6] American Association of State Highway and Transportation Officials (AASHTO)-Associated General Contractors of America (AGC)- American Road & Transportation Builders Assn. (ARTBA) Joint Committee, “Guide specifications—polymer modified asphalt,” Subcommittee on New Highway Materials, Task Force 31 Report, 1992.

[7] Muncy, H.W., King, G.N., Prudhomme, J.B., “Improved rheological properties of polymer-modified asphalts.” *Asphalt Rheology: Relationship to Mixture, ASTM STP 941*, O.E. Briscoe, Ed., American Society for Testing and Materials, Philadelphia, 1987, pp. 146-165.

[8] Schüller, S., Forsten, L., “Polymeerimodifioitujen bitumien ominaisuudet ja tutkimusmenetelmat.” ASTO TR3/1, VTT No. 814, Finland 1990.

[9] Lu, X. “Fundamental studies on styrene-butadiene-styrene polymer modified road bitumens.” Licentiate thesis, Royal Institute of Technology, Department of Highway Engineering, Stockholm, 1996.

[10] Breuer, J.U., “Storage stability test—homogeneity test for hot stored polymer modified binder”, in Proceedings of RILEM Residential Seminar, Dubrovnik, Yugoslavia, September 1988, p. 83.

[11] Asphalt Institute, “Superpave Level 1 Mix Design,” Superpave Series No. 2, (SP-2).

[12] DeSombre, R., Newcomb, D., Chadbourn, B., Vaughn, V., “Parameters to define the laboratory compaction temperature range of hot mix asphalt--Preprint,” Association of Asphalt Paving Technologists, Annual Meeting, Boston, March 1998.

---

[13] Lu, X., Isacsson, U., "Influence of styrene butadiene-styrene polymer modification on bitumen viscosity." *Fuel*, Vol. 76 (1997), No. 15, pp. 1353-1359.

[14] McLeod, N.W., "Asphalt cements: pen-vis number and its application to moduli of stiffness," ASTM *Journal of Testing and Evaluation*, Vol. 4, No. 4, July 1976.

[15] Kraus, G. "Modification of asphalt by block polymers of butadiene and styrene." *Rubber Chemistry and Technology*, 55 (1982) pp.1389-1402.

[16] Lu, X., Isacsson, U., "Compatibility and storage stability of styrene-butadiene-styrene copolymer modified bitumens." *Materials and Structures*, Vol. 30, December 1997, pp. 618-626.

[17] Moran, L E., "Compatibility – the key to modified asphalt performance." Proceedings of the 31st Annual Conference of Canadian Technical Asphalt Association, pp. 82-95.

[18] American Association of State Highway and Transportation Officials, Standard Practice for Grading or Verifying the Performance Grade of an Asphalt Binder, AASHTO PP6-93, Edition 1-B, June 1996.

[19] American Association of State Highway and Transportation Officials, Standard Specification for Performance Graded Asphalt Binder, AASHTO MP1-93, Interim Edition, June 1997.

[20] AASHTO T 245 is AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Eighteenth edition 1997, Part II Tests.

[21] State of Alaska Department of Transportation and Public Facilities Laboratory Manual of Alaska Test Methods and Standard Practices, January 1993.

[22] H.K. Kanerva, T.S. Vinson, "Prediction of Low Temperature Cracking of Asphalt Concrete Mixtures with Thermal Stress Restrained Specimen Test Results,", TRB, National Research Council, Washington DC, 1996, ISBN 0-309-05916-X

APPENDIX A

QUESTIONNAIRE

March 28, 1997

Dear Colleague,

The University of Alaska Anchorage (UAA) and Fairbanks (UAF) together with the Alaska Department of Transportation and Public Facilities (AKDOT&PF) Northern Region will conduct a study concerning constructability polymer-modified asphalts in Alaska.

The importance of research came evident last paving season when serious problems were encountered in laying and compaction of the polymer-modified asphalt pavements. The objective of the research is to analyze and select polymer-modified binders that will improve pavement performance without presenting extensive difficulties in mixing, laying and compaction when compared to traditional asphalt binders.

A segment of our research is to review information obtained through a questionnaire study, in which we collect experiences and specifications from the road-building authorities in climatic regions similar to Alaska.

We would greatly appreciate your contribution to our study. Please complete and return the attached questionnaire and also, if possible, mail any polymer-modified binder specifications used in your area to the following address:

University of Alaska Anchorage
School of Engineering
3211 Providence Drive
Anchorage, AK 99508
USA

phone 907-786-1970
fax 907-786-1079
e-mail afhkz@uaa.alaska.edu

If you have any questions, please contact me by phone or e-mail.

Sincerely,

Hannele Zubeck, Ph.D., P.E.
Assistant Professor

APPENDIX A

QUESTIONNAIRE

General

- How many years have you been using polymer-modified binders in asphalt pavements?

- Have you had notable difficulties with the constructability of polymer-modified asphalt pavements? If yes, how did you fix the problem?

- In general, are you satisfied with the performance of polymer-modified asphalts? If no, why?

- Have you investigated the compatibility of the asphalt cement and the modifier?

- Which tests do you use in the characterization of the polymer-modified asphalts? (Check all that apply.)
    Fraass Brittle Point
    Penetration at _______°C
    Softening Point
    Viscosity at ______°C
    Storage Stability: (Heat a cylindrical sample at ___° for ___ hours and test the top and bottom sample for _______________________.)
    Microscopic Analysis using a ____________________microscope.
    Superpave test: Direct Shear Rheometer
    Superpave test: Bending Beam Rheometer
    Superpave test: Direct Tension Test
    Chemical analysis: _______________________________
    Other____
    ____

Base Asphalts

- What sources of base asphalt are used in the polymer-modified binders?

- What grades of base asphalt are used?

- Are these grades designed

a) especially polymer modification in mind?

b) for general use?

- Do you conduct chemical analysis on the base asphalts that are modified? If yes, which tests?

APPENDIX A

QUESTIONNAIRE

Polymers

- Which polymers and specific grades have you used?

- Based on your experience, what is the optimal range for the polymer content? Specify for each polymer used, if it varies.

- Which polymers and specific grades you will use in the future?

Other comments or recommendations

APPENDIX B

QUESTIONNAIRE RESPONSES

Responders

Country or State	Agency	Responder
Idaho	DOT	T. Baker, Materials Engineer
Quebec	DOT	Pierre Langlois
Sweden	VTI	Ylva Edwards
Sweden	Nynas	No name given, transmitted by Ylva Edwards
Norway	Road Adm.	Torbjorn Jorgensen
Finland	Neste Oil	Timo Blomberg
Finland	VTT	Laura Apilo
Switzerland	EMPA	Martin Hugener
Saskatchewan	City of Regina	Carly LeMurray
Japan	Ohbayashi Road Co.	No name given, transmitted by Ishikawa Nishizawa

Also, Paul Renolds from the Nova Scotia Department of Transportation and Communications responded. They do not have previous experience with polymer-modified asphalts. However, they are considering the use of polymer-modified asphalt pavements for the next paving season, since a local supplier is now available.

- How many years have you been using polymer-modified binders in asphalt pavements?

Country or State	Agency	Response
Idaho	DOT	10 years
Quebec	DOT	12 years
Sweden	VTI	15 years
Sweden	Nynas	15 years
Norway	Road Adm.	15 years
Finland	Neste Oil	14 years
Finland	VTT	10 years
Switzerland	EMPA	?
Saskatchewan	City of Regina	2
Japan	Ohbayashi Road Co.	7 years

APPENDIX B

QUESTIONNAIRE RESPONSES

- Have you had notable difficulties with the constructability of polymer-modified asphalt pavements? If yes, how did you fix the problem?

Country or State	**Agency**	**Response**
Idaho	DOT	Had to raise the mixing temperature
Quebec	DOT	Pave at temperatures warmer than 10°C
Sweden	VTI	No problems
Sweden	Nynas	Higher compaction temperatures
Norway	Road Adm.	No problems
Finland	Neste Oil	No problems
Finland	VTT	Higher mix and compaction temps
Switzerland	EMPA	?
Saskatchewan	City of Regina	No problems
Japan	Ohbayashi Road Co.	No problems

- In general, are you satisfied with the performance of polymer-modified asphalts? If no, why?

Country or State	**Agency**	**Response**
Idaho	DOT	Yes
Quebec	DOT	Yes, no stripping, no raveling
Sweden	VTI	Yes
Sweden	Nynas	Yes
Norway	Road Adm.	Yes
Finland	Neste Oil	Yes
Finland	VTT	Yes
Switzerland	EMPA	?
Saskatchewan	City of Regina	Yes
Japan	Ohbayashi Road Co.	Yes

APPENDIX B

QUESTIONNAIRE RESPONSES

- Have you investigated the compatibility of the asphalt cement and the modifier?

Country or State	Agency	Response
Idaho	DOT	No
Quebec	DOT	No
Sweden	VTI	Not at VTI
Sweden	Nynas	Yes
Norway	Road Adm.	Responsibility of the producer/contractor
Finland	Neste Oil	Yes
Finland	VTT	Yes
Switzerland	EMPA	Responsibility of the manufacturer
Saskatchewan	City of Regina	Responsibility of the producer
Japan	Ohbayashi Road Co.	Yes

- Which tests do you use in the characterization of the polymer-modified asphalts?
  - Fraass Brittle Point, *Sweden, Finland, Switzerland, Saskatchewan*
  - Penetration at 25°C, *Sweden, Norway, Finland, Switzerland, Japan, Saskatchewan*
  - Penetration at 40°C, *Sweden*
  - Softening Point, *Sweden, Finland, Switzerland*
  - Viscosity at 60°C, *Japan*
  - Viscosity at 135°C, *Sweden*
  - Viscosity at 160°C, *Norway, Finland*
  - Viscosity at 180°C, *Sweden, Norway, Finland*
  - Weight Loss, *Sweden*
  - Ductility, *Sweden*
  - Storage Stability: (Heat a cylindrical sample at 163° for 48 hours and test the top and bottom sample for Softening Point.), *Quebec, Norway, Finland and Japan (at 180° for 72 hours), Switzerland (at 165°C for 72 hours)*
  - Toughness and Tenacity, *Utah*
  - Elastic Recovery using ductilometer, *Quebec (at 10°C), Sweden, Finland (at 5°C), Switzerland (at 25°C)*
  - Elastic Recovery using ARRB elastomer, *Sweden*

- Span of Plasticity (Softening Point minus Fraass Brittle Point), *Switzerland*
- Cold Bending, *Finland*
- Net Absorption Test, *Quebec*
- Microscopic Analysis using a fluorescent microscope, *Sweden, Norway, Finland, Japan, Saskatchewan*
- Superpave test: Direct Shear Rheometer, *Saskatchewan*
- Superpave test: Bending Beam Rheometer, *Sweden, Saskatchewan*
- Superpave test: Direct Tension Test, *Saskatchewan*
- Chemical analysis:
    - TLC-FID, *Quebec, Japan*
    - HPLC, *Quebec*
    - GPC, *Quebec, Sweden, Switzerland, Japan*
    - IR, *Sweden, Japan*
- Cohesion using the Vialit Pendulum Ram, *Sweden*
- *After RTFOT:*
    - Decrease in Penetration at 25°C, *Switzerland*
    - Increase/Decrease in Softening Point, *Switzerland*
    - Elastic Recovery, *Switzerland*

Base Asphalts

- What sources of base asphalt are used in the polymer-modified binders?

Country or State	**Agency**	**Response**
Idaho	DOT	Supplier's proprietary information
Quebec	DOT	Supplier's proprietary information
Sweden	VTI	?
Sweden	Nynas	?
Norway	Road Adm.	Supplier's proprietary information
Finland	Neste Oil	Specially tailored base bitumen
Finland	VTT	Russian, Venezuelan or other
Switzerland	EMPA	?
Saskatchewan	City of Regina	Lloydminster Heavy Crude
Japan	Ohbayashi Road Co.	Middle East

APPENDIX B

QUESTIONNAIRE RESPONSES

- What grades of base asphalt are used?

Country or State	Agency	Response
Idaho	DOT	Supplier's proprietary information
Quebec	DOT	Supplier's proprietary information
Sweden	VTI	?
Sweden	Nynas	Penetration Grade from 80 to 200
Norway	Road Adm.	Supplier's proprietary information
Finland	Neste Oil	Penetration Grade 200
Finland	VTT	Penetration Grade 160/220
Switzerland	EMPA	?
Saskatchewan	City of Regina	Penetration Grade 150/200 or 200/300
Japan	Ohbayashi Road Co.	Penetration Grade 60-80

- Are these grades designed a) especially polymer modification in mind, b) for general use?

Country or State	Agency	Response
Idaho	DOT	Supplier's proprietary information
Quebec	DOT	Both
Sweden	VTI	?
Sweden	Nynas	?
Norway	Road Adm.	Supplier's proprietary information
Finland	Neste Oil	Especially for polymer modification
Finland	VTT	Especially for polymer modification
Switzerland	EMPA	?
Saskatchewan	City of Regina	Both
Japan	Ohbayashi Road Co.	Supplier's proprietary information

- Do you conduct chemical analysis on the base asphalts that are modified? If yes, which tests?

Country or State	Agency	Response
Idaho	DOT	No
Quebec	DOT	No
Sweden	VTI	?
Sweden	Nynas	Yes, TLC-FID
Norway	Road Adm.	?
Finland	Neste Oil	Yes, TLC-FID
Finland	VTT	?
Switzerland	EMPA	?
Saskatchewan	City of Regina	?
Japan	Ohbayashi Road Co.	Yes, TLC-FID

Polymers

- Which polymers and specific grades have you used?

Country or State	Agency	Response
Idaho	DOT	Supplier’s proprietary information
Quebec	DOT	SBS, SB, SBR
Sweden	VTI	?
Sweden	Nynas	SBS
Norway	Road Adm.	?
Finland	Neste Oil	SBS
Finland	VTT	SBS
Switzerland	EMPA	?
Saskatchewan	City of Regina	?
Japan	Ohbayashi Road Co.	SBS

- Based on your experience, what is the optimal range for the polymer content? Specify for each polymer used, if it varies.

Country or State	Agency	Response
Idaho	DOT	Supplier’s proprietary information
Quebec	DOT	Standard 3%, special cases 6%
Sweden	VTI	?
Sweden	Nynas	4 – 6%
Norway	Road Adm.	?
Finland	Neste Oil	Supplier’s proprietary information
Finland	VTT	3 – 7%
Switzerland	EMPA	?
Saskatchewan	City of Regina	?
Japan	Ohbayashi Road Co.	2 - 7%

- Which polymers and specific grades you will use in the future?

Country or State	Agency	Response
Idaho	DOT	No plan to specify
Quebec	DOT	Same as currently
Sweden	VTI	?
Sweden	Nynas	Same as currently
Norway	Road Adm.	?
Finland	Neste Oil	SBS
Finland	VTT	?
Switzerland	EMPA	?
Saskatchewan	City of Regina	Don’t know yet
Japan	Ohbayashi Road Co.	Don’t know yet

APPENDIX C

QUESTIONNAIRE RESPONSES

		Idaho[1] For Hot Climates	Utah[2]	California[2]	Wyoming[2]	Montana[2]	AASHTO-AGC-ARTBA[3]		Finland[1]	CEN Nordic Proposal[1]
	Unit	AASHTO Type II-B	PBA 20	PBA 6b	Spec #1	Type 1	I-A	II-A	KB65	PMB 70/150-65
Suggested Polymer Content	%		3							
Suggested Polymer		SBR					SBS, SB	SBR		
Original Binder										
Fraass	°C									Min -17
Penetration, 4°C, 200g/60s	1/10mm				Min 25	Min 25	Min 40			
Penetration, 25°C	1/10mm	Min 70	40-120		50-75	65-100	100-150	Min 100	80-160	70-150
Softening Point	°C				Min 60	Min 65	Min 43		Min 60	Min 65
Viscosity, 60°C	Poise	Min 1600	1800-3600	Min 2000	Min 3000		Min 1000	Min 800		
Viscosity, 135°C	cSt	Max 2000	500-1500	Max 2000	Max 2000	700-2000	Max 2000	Max 2000		

---

[1] Attached with the Questionnaire.

[2] Collected from various projects.

[3] AASHTO-AGC-ARTBA Joint Committee, Subcommittee on New Highway Materials, Task Force 31 Report, "Guide Specifications, Polymer-modified Asphalt." Grades recommended in cold service conditions.

APPENDIX C

QUESTIONNAIRE RESPONSES

		Idaho[1] For Hot Climates	Utah[2]	California[2]	Wyoming[2]	Montana[2]	AASHTO-AGC-ARTBA[3]		Finland[1]	CEN Nordic Proposal[1]
	Unit	AASHTO Type II-B	PBA 20	PBA 6b	Spec #1	Type 1	I-A	II-A	KB65	PMB 70/150-65
Viscosity, 180°C	mm2/s								Max 500	
Ductility, 4°C	cm	Min 50						Min 50		
Toughness, 25°C	in- lbs	Min 110						Min 75		
Tenacity, 25°C	in- lbs	Min 75						Min 50		
Elastic Recovery, 25°C	%									Min 75
Elastic Recovery, 5°C	%								Min 25	
Storage Stability, Softening Point, Top-Bottom	°C				Max 4		Max 4		Max 25	Max 5
Storage Stability, Penetration, 25°C, Top-Bottom	1/10mm									Max 12

---

[1] Attached with the Questionnaire.
[2] Collected from various projects.
[3] AASHTO-AGC-ARTBA Joint Committee, Subcommittee on New Highway Materials, Task Force 31 Report, "Guide Specifications, Polymer-modified Asphalt," Grades recommended in cold service conditions.

APPENDIX C

QUESTIONNAIRE RESPONSES

		Idaho[1] For Hot Climates	Utah[2]	California[2]	Wyoming[2]	Montana[2]	AASHTO-AGC-ARTBA[3]		Finland[1]	CEN Nordic Proposal[1]
	Unit	AASHTO Type II-B	PBA 20	PBA 6b	Spec #1	Type 1	I-A	II-A	KB65	PMB 70/150-65
Force Ratio, 4°C, 5cm/min, 30cm elongation					Min 0.3					
Cohesion, 5°C (TT or FD)	J/cm2									Min 5
RTFOT or TFOT Residue		RTFOT or TFOT	RTFOT	RTFOT	RTFOT	RTFOT	RTFOT	RTFOT or TFOT		RTFOT or RFT
Penetration, 4°C, 200g/60s	1/10mm		Min 30		Min 15	Min 20	Min 20			
Softening Point	°C		57							
Penetration Ratio, 25°C	%		Min 50							Min 50
Increase in Softening Point	°C									Max 12

---

[1] Attached with the Questionnaire.

[2] Collected from various projects.

[3] AASHTO-AGC-ARTBA Joint Committee, Subcommittee on New Highway Materials, Task Force 31 Report, “Guide Specifications, Polymer-modified Asphalt,” Grades recommended in cold service conditions.

APPENDIX C

QUESTIONNAIRE RESPONSES

		Idaho[1] For Hot Climates	Utah[2]	California[2]	Wyoming[2]	Montana[2]	AASHTO-AGC-ARTBA[3]		Finland[1]	CEN Nordic Proposal[1]
	Unit	AASHTO Type II-B	PBA 20	PBA 6b	Spec #1	Type 1	I-A	II-A	KB65	PMB 70/150-65
Drop in Softening Point	°C									Max 6
Viscosity, 60°C	Poise	Max 8000		Min 5000				Max 4000		
Viscosity, 135°C	cSt			Min 275						
Viscosity Ratio, 60°C			Max 2.5	Max 4						
Viscosity Ratio, 135°C			Max 2.5							
Mass Loss	%			Max 0.6						
Ductility, 4°C	cm	Min 25	Min 50					Min 25		
Ductility, 25°C	cm			Min 60						
Toughness, 25°C	in-lbs	NA	Min 150							
Tenacity, 25°C	in-lbs	NA	Min 100							

---

[1] Attached with the Questionnaire.

[2] Collected from various projects.

[3] AASHTO-AGC-ARTBA Joint Committee, Subcommittee on New Highway Materials, Task Force 31 Report, "Guide Specifications, Polymer-modified Asphalt," Grades recommended in cold service conditions.

APPENDIX C

QUESTIONNAIRE RESPONSES

		Idaho[1] For Hot Climates	Utah[2]	California[2]	Wyoming[2]	Montana[2]	AASHTO-AGC-ARTBA[3]		Finland[1]	CEN Nordic Proposal[1]
	Unit	AASHTO Type II-B	PBA 20	PBA 6b	Spec #1	Type 1	I-A	II-A	KB65	PMB 70/150-65
Elastic Recovery, 25°C	%				Min 70		Min 45			Min 60
Storage Stability, Softening Point, Top-Bottom	°C		+-3							
On residue from Pav at 100°C or from Tilt Oven at 113°C for 36 hours										
Stiffness, SSD	MPa		Max 300							
m-value, SSD			Min 0.3							

---

[1] Attached with the Questionnaire.

[2] Collected from various projects.

[3] AASHTO-AGC-ARTBA Joint Committee, Subcommittee on New Highway Materials, Task Force 31 Report, “Guide Specifications, Polymer-modified Asphalt,” Grades recommended in cold service conditions.