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ALTERNATE/MODIFIED BINDERS FOR ASPHALT AIRFIELD PAVEMENTS

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This report documents a laboratory-based research effort to determine the effects of asphalt modifiers and alternate binders on asphalt airfield pavements. The modified binders were tested to determine their potential for reducing pavement deformation distresses, improving rheological properties, reducing asphalt contents, and improving the asphalt pavement's heat-resistant capabilities under jet engine blasts.

An intensive literature search was performed during the first year of the study to gather all of the available information on the modifiers currently available. This information was used to choose 14 test materials, which were tested in the laboratory during the second year of the study. Data resulting from these tests were used to choose the five most promising test materials, which were evaluated further in the third and final year of the study by more detailed laboratory tests.

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All laboratory mix specimens were made with the same aggregate gradations and under as near identical conditions as possible. An AC-20 grade of asphalt cement was chosen as the base asphalt for all modified asphalt blends. Asphalt mix testing consisted of indirect tensile, resilient modulus and unconfined creep-rebound tests. Asphalt binder tests included kinematic viscosity, Brookfield viscosity, penetration, resiliency, and chromatography. 25 to FLD 18

The results of this research study indicate that no single asphalt modifier or alternate binder is capable of providing all of the performance improvements cited by the objectives of this study in every set of field conditions. Nevertheless, this research did reveal a small group of modifiers and alternate binders that consistently rated better in the tests critical to the desired improvements outlined by this study's objectives. Included in this group of top performers are the oxidant, SBS, polyethylene and EVA modifiers as well as the AC-40 and natural lake asphalts. These materials are recommended for use in asphalt airfield pavements in order to improve the pavement's resistance to rutting and other pavement distresses.

EXECUTIVE SUMMARY

A. OBJECTIVE

The main objective of this research project was to determine which asphalt modifiers can significantly reduce permanent deformation distresses in asphalt airfield pavements. These pavement distresses include rutting and shoving. This study also included modifying asphalt binders to improve the rheological properties of the asphalt, substantially or totally replacing the asphalt cement, and improving the asphalt pavement's heat-resistant capabilities to resist heat from high-temperature aircraft engine exhausts.

B. BACKGROUND

Recently, asphalt airfield pavements have suffered extensive damage from rutting and shoving. The causes of these problems have included the increasing volume of aircraft traffic, higher tire pressures, heavier load capacities, and substandard construction materials. These problems are expected to increase unless something is done to improve the performance characteristics of future pavements. Many research programs have been conducted on asphalt modifiers. Most of these have focused on single modifiers or modifier types, but few have attempted to validate their findings in field trials. Furthermore, no documented research program has attempted a comprehensive laboratory analysis of asphalt modifiers in terms of the needs of military airfield pavements. This research program was designed to fill this void.

C. SCOPE

A literature and technology review was done during the first year of the established 3-year time frame. Fourteen modifiers and alternate binders were chosen for initial laboratory testing to comparatively analyze the candidate materials. These initial tests were conducted during the second year of the study and resultant data were used to choose five materials to meet the test objectives of this study. These five test materials were evaluated under a more stringent set of laboratory tests in the third and final year of the study. A comprehensive analysis of all test data and background information gathered was used to reach the conclusions and make the recommendations resulting from this study.

D. METHODOLOGY

It was found that over 200 asphalt modifiers were commercially available. After eliminating all modifiers and alternate binders not designed to resist permanent deformation, the remaining list of materials was used to select the test materials to be evaluated in the first phase of testing. Past performance, the amount of supportive data, and present and future availability were all considered. Based on the results of the initial laboratory tests, five test materials were chosen to be further evaluated.

E. TEST DESCRIPTION

All asphalt mixture tests were performed at the Waterways Experiment Station (WES) using a computer-driven, hydraulic-powered materials testing apparatus designed specifically for this research study. These tests included the indirect tensile, resilient modulus, and unconfined creep-rebound tests. All asphalt binder tests, with the exception of the chromatography analysis, were also conducted at the WES laboratories. The binder tests performed included kinematic viscosity, Brookfield viscosity, penetration, and resiliency. The chromatography analysis was conducted at Clemson University through a cooperative research agreement. Modified asphalt mixture tests and binder tests were conducted in both phases of laboratory tests, with the first phase designed to comparatively analyze or "screen" the test materials, and the second phase designed to analyze the effects of critical testing variables on the most promising test materials.

F. RESULTS

The results of this research program are many-faceted. Of the test methods used, it was evident which tests produced more consistent and more reliable results. Test methods which showed a useful sensitivity to critical changes in material properties were also identified. These discoveries should be valuable to future laboratory research studies. Certainly, the most important discoveries of this research pertain to the modifier materials themselves. Although all test materials showed some improvements in at least one test area, a small group of materials clearly emerged as consistently superior performers during laboratory testing. These materials and their respective test results form the basis for the conclusions and recommendations of this study.

G. CONCLUSIONS

No single asphalt modifier or alternate binder can be expected to outperform all others under all field conditions; however, a small group of modifiers consistently rated higher in the tests critical to the objectives of this study. Included in this group of top performers are the oxidant, SBS, polyethylene and EVA modifiers as well as the AC-40 and natural lake asphalts. These materials and their specific attributes should become the foundation for any future research in this subject area, whether in the laboratory or in the field. The findings of this research should be used by the researchers, designers, and builders of future modified asphalt airfield pavement systems.

H. RECOMMENDATIONS

Under the specific conditions outlined in Section V of this report, four asphalt modifiers and two alternate binders are recommended for use in asphalt airfield pavements to improve the pavement's resistance to rutting and other deformation distresses. These materials include the EVA, polyethylene, SBS, and oxidant modifiers as well as the AC-40 and natural lake asphalts. Further laboratory studies are recommended to extend the knowledge gained from this study. These studies should include investigations into proper mix design procedures, fatigue characteristics and moisture resistance. Also, the findings of this study and any related laboratory studies needs to be validated through field test sections. Finally, the information gained by this and other related research must be carefully documented so that the asphalt modifier user will have access to the latest information available on asphalt modifiers.

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PREFACE

This report was prepared by the US Army Engineer Waterways Experiment Station, Geotechnical Laboratory, 3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199. The work was funded by the Engineering and Services Laboratory of Headquarters Air Force Engineering and Services Center, under Program Element 62207F, Project Number 2673, Task Number 00, Work Unit 07. Funding documents include MIPR N86-28, MIPR N87-5 and MIPR N88-15.

The performance period for this effort was from January 1986 to September 1988. The AFESC/RDCP project officers were Mr Charles Bailey and Ms Patricia Suggs.

This report documents a literature study and laboratory investigation of alternate and modified binders for asphalt airfield pavements when used for the purposes of increasing the pavement's durability and resistance to rutting and fatigue.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). AT NTIS, it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of this project was to conduct research into asphalt binder modifiers and alternate binders, with emphasis on those materials whose primary function is to improve resistance to permanent deformation. More specifically, the Waterways Experiment Station's (WES) Pavement Systems Division was tasked to investigate materials to modify, augment, extend and/or replace conventional asphalt cement binders for the purposes of: (1) substantially or totally replacing the asphalt cement, (2) modifying asphalt cements to increase resistance to rutting from high pressure tires, (3) improving the rheological properties of the asphalt, and (4) improving heat-resistant capabilities for use in pavements subjected to high temperature engine exhausts from new thrust-vectored aircraft.

In a broader sense, this study was designed to strengthen the fundamental knowledge of asphalt modification as it pertains to asphalt airfield pavements. The development of this fundamental knowledge will aid the asphalt modifier user in determining the usefulness of modification techniques for solving particular problems under site-specific conditions. Many of the problems addressed by this study are also applicable to the asphalt road paving arena. Therefore, the findings of this study and other similar research programs, should have an impact on those agencies responsible for the construction, rehabilitation, and maintenance of all types of asphalt pavement systems.

B. BACKGROUND

1. Problem Statement

In recent years, military airfield construction and rehabilitation have become increasingly difficult from a materials design standpoint. Aircraft design changes such as increasing tire pressures and load capacities have been labeled as leading causes of these new design problems because of their contributions to deformation distresses in asphalt-surfaced pavements such as rutting or shoving. Additional design problems are expected as asphalt pavements are exposed to high-temperature exhausts from new thrust-vectored aircraft. Also, the price of asphalt materials has risen

dramatically during the past 20 years, leading to a desire to reduce asphalt contents in pavement systems.

Many years of materials research have proven that asphalt airfield pavements can be designed and constructed (with carefully selected materials and procedures) to provide acceptable performance under these severe loading conditions. However, the increasing costs of construction materials and the non-availability of suitable construction materials for these high-quality pavements have forced many designers to search for viable economic alternatives, such as the use of asphalt modifiers.

The same asphalt pavement problems have also occurred in the asphalt highway systems throughout the world. As these problems became more widespread and obvious, a large number of asphalt modifiers appeared on the civilian market. Reports have been made of extreme to moderate success for some modifiers in the field, while others have had mixed reviews. Nonetheless, it is generally accepted within the asphalt industry that the present modifier technology can solve many deformation problems. However, the use of asphalt modifiers on a full-scale basis seems to be prevented by two factors. First, most of the modifiers available on the current market are new to the industry and therefore do not have a substantial performance history. Second, no clear guidance is available on selecting modifiers for a given set of conditions and performance requirements.

2. Asphalt Modifier History

The concept of modifying asphalt binders and mixtures is not new. In its earliest stages, asphalt modification consisted of mixing two or more asphalt binders of different paving grades from different sources. This practice has continued through the years and often delivers a satisfactory end product. The major problem with this technique, however, lies in the possibility that the asphalt cements will be chemically incompatible (1). This incompatibility cannot always be effectively predicted, and incompatibility can lead to premature asphalt pavement distresses.

The early years of asphalt modification also saw the addition of mineral fillers, extenders, and rubber to traditional asphalt binders in an attempt to improve several mechanical properties. This concept of modifying asphalt binders through the use of additives was met with considerable skepticism, and until recent years saw limited applications. Many of

these early additives were merely waste products from other industries, and with little or no technical support, were marketed as innovative asphalt modifiers.

Several factors have led to the resurgence in the interest in asphalt modification. First, there is a growing perception that asphalt cements have changed, creating changes in construction as well as early field performance (1). The logic behind this theory is based on the fact that new refinery technology extracts more light-end petroleum products from crude oil. These new refinery procedures are thought to significantly alter the chemistry (and the resulting performance characteristics) of today's asphalt cements.

Another reason for the recent growth in asphalt modifier interest involves traffic-related distresses resulting from the escalating traffic demands found on all types of asphalt pavements. Higher volumes of traffic, heavier loads, and increasing tire pressures are characteristics of these traffic-related problems. Increasing traffic demands are found in both civil and military roads and streets, as well as on airfields.

Some other reasons for the growing interest in asphalt modification include:

- The dramatic increase in the cost of asphalt cements as a result of the price increases of crude oil
- Growing economic pressures that lead to thinner pavements and deferred maintenance
- Excess supplies of industrial byproducts and waste materials prompting the idea of converting them to asphalt additives

Although some naturally occurring materials and several industrial byproducts and waste materials continue to be marketed as asphalt modifiers, the trend developing in today's market is toward high-tech, carefully engineered modifiers. Instead of focusing on a single area of desired binder improvement, many of today's asphalt modifiers are designed to improve a number of performance characteristics. Many present asphalt modifier manufacturers offer several different formulations of the same material to cover a broader range of user needs.

All of these technological advancements will undoubtedly lead to more asphalt modifier usage. However, because these advancements and the

number of available modifiers grew substantially in a relatively short time, the asphalt modifier picture became somewhat confusing for the user. Common questions among today's asphalt modifier users include: Which modifier works best for my needs? Which modifiers are compatible with my asphalt cement? Are the claims made for his modifier legitimate?

A great deal of research has been done in an attempt to eliminate some of the confusion surrounding the asphalt modifier industry. Much of this research, however, has been focused on single modifiers or modifier types, and most of the findings remain unvalidated by successful field trials. This research project is aimed at reducing the confusion surrounding current asphalt modifier technology and at answering some of the more prominent asphalt modifier questions in terms of airfield pavements.

3. Current Asphalt Modifier Usage

Today, all forms of paving asphalts are being modified; asphalt cements, emulsions, and cutbacks. The modified binders are being used for fog seals, slurry seals, chip seals, patching mixtures, cold-mixed and hot-mixed mixtures, both dense and open-graded. However, most modified asphalts are currently used in seal coats and dense-graded hot-mixed asphalt mixtures as well as open-graded porous friction courses.

Most of the reasons for using an asphalt modifier relate to some desired "improvement" in the parent asphalt's temperature-viscosity relationship. Terrel and Epps (1) have graphically represented the typical temperature versus viscosity (stiffness) relationships of conventional unmodified and modified asphalt-aggregate mixes. Figure 1 displays these relationships for the temperature range inherent in both the construction period and the service life. Ideally, an asphalt modifier will produce one or more of the following viscosity-temperature alterations: Above about 200°F, the viscosity is lowered to permit better workability during construction. From about 70°F to 175°F (the upper end of the hot weather range), the viscosity is increased to resist rutting and shoving. Below about 40°F, the stiffness of the mix is lower than normal, thus providing better resistance to low-temperature cracking.

C. SCOPE

The scope of this research study included a literature and technology review, two separate phases of laboratory testing on laboratory-produced

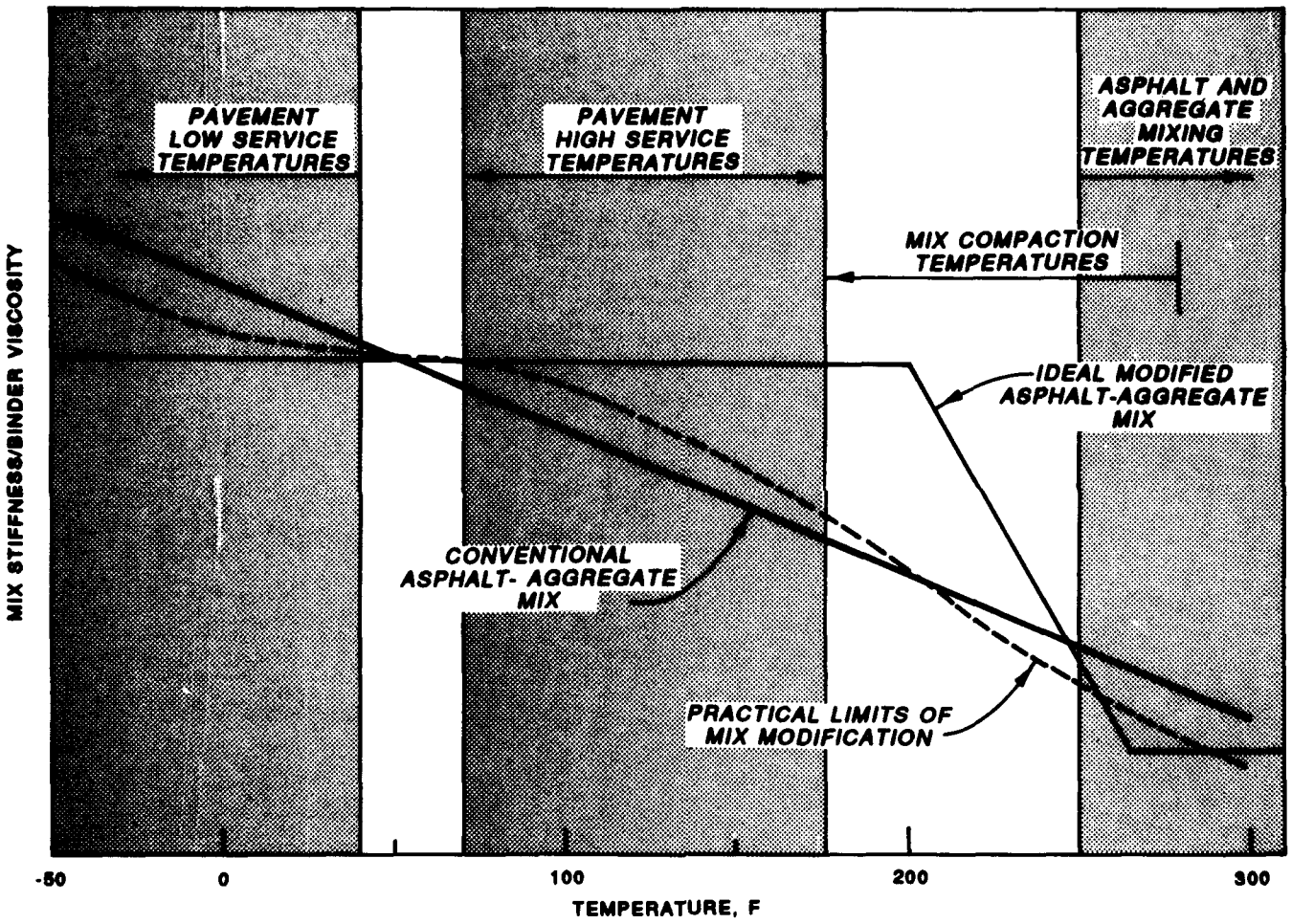

Figure 1. Changes in Mixture Stiffness Obtained by Modification.

samples, and the resulting analysis of the generated data. Both conventional and nonconventional testing procedures were incorporated into the laboratory test plans. Asphalt mix tests performed included the Marshall stability and flow, indirect tensile, resilient modulus, and unconfined creep-rebound tests. Asphalt binder tests performed included kinematic viscosity, Brookfield viscosity, penetration, resiliency, and chromatographic profiles.

The first year of the study was spent gathering information on asphalt modifiers, testing procedures, and jet blast effects on asphalt pavements. The first phase of laboratory tests was conducted in the second year of the study. Initially, 14 modifiers were chosen for testing under the Phase I laboratory test plan, and by comparatively analyzing the resulting data, five test materials were selected for further study in the Phase II laboratory test plan. These five modifiers were determined to be the most promising for use in accomplishing the objectives of this study. Phase II laboratory testing and analysis was carried out and completed in the third and final year of the study. Laboratory tests similar to those of Phase I were conducted with the effects of varying asphalt contents, modifier concentrations, and base asphalt source examined for each of the five test materials. Further information on the materials, testing methods, and the analysis procedures used in this study is detailed throughout the text of this report.

SECTION II

RESEARCH PLAN

A. TECHNOLOGY REVIEW

Because of the magnitude and broad spectrum covered by this project, an intensive technology review plan was initiated at the beginning to cover three areas: (1) the commercial modifiers themselves, (2) the test procedures used to evaluate modified asphalts, and (3) jet blast effects on modified asphalt pavements. This initial phase of the research plan was initiated and completed within the first fiscal year of the project's 3-year time frame.

To assist the project's principal investigator in carrying out this initial phase, a panel of experts in the field of asphalt modifiers was formed to provide outside review and assistance for the duration of the project. This panel consisted of Dr. E. Ray Brown of Auburn University (the project's initial principal investigator), Dr. Jon A. Epps of the University of Nevada-Reno, Dr. Anthony F. Stock of the University of Dundee, Scotland (presently with the B. P. Research Center, Middlesex, G. B.), and Dr. Thomas D. White of Purdue University.

1. Modifiers

Before performing literature searches for information on commercial asphalt modifiers, a general classification system for all of the modifiers on today's market was developed, based on physical and chemical properties of the modifier material. By classifying all of the current asphalt modifiers into categories, the overwhelming list of available materials was initially organized, but most important, it was possible to eliminate those modifier categories that do not improve a mixture's resistance to permanent deformation as a primary function. Improving the asphalt pavement's resistance to permanent deformation was the main objective of this research. The modifier categories remaining for consideration were rubbers, plastics, fillers, hard asphalts, oxidants, and fibers.

The next step in compiling the available information on asphalt modifiers was to generate a data base of "fact sheets" intended to include all modifiers in those categories that were known to improve resistance to permanent deformation. This proved to be more difficult than anticipated,

since many modifiers had gone on and off of the market rather quickly. This lack of information due to limited success was enough to eliminate many modifiers from further considerations. However, fact sheets were drawn up for all modifiers with sufficient background information from the available literature sources. These 19 fact sheets are found in the Appendix of this report.

After all of the available information on the modifier materials was gathered, the project's principal investigator and the advisory panel selected the list of materials to be included in the first phase of laboratory tests. Past performance histories, the amount of supportive data, and the present and future availability were all considered in compiling this list. The final list of modifiers for the first phase of laboratory tests included four rubber products, three plastic products, three types of fillers, two types of hard asphalts, one oxidant, and one fiber material. These modifiers are described later in this section of the report. Generic labels and descriptions are used in lieu of trade names throughout this report to prevent possible implications of direct evaluations of any proprietary products.

2. Testing Procedures

A thorough review of current test methods for evaluating modified asphalts was carried out in the initial technology review to ensure that laboratory testing would provide the most significant data attainable under the given time and funding constraints. Over 30 laboratory testing procedures were evaluated for consideration in this study. These test procedures covered both asphalt binder and asphalt mixture testing methods. Some tests had well-established histories in asphalt materials research, while others were in the development stages. At a meeting held midway through the first year of the project, the principal investigator and project consultants collaborated to identify tests best suited for the project's goals. Also, a preliminary test plan was outlined for the first phase of laboratory tests. This test plan, as outlined later in this section of the report, was subsequently approved by the sponsoring agency, and efforts began to secure the necessary equipment, materials, and supplies for the first phase of laboratory tests.

3. Jet Blast Effects

As part of the project, a study of possible detrimental effects of jet blasts from vectored thrust type aircraft was conducted. There was no attempt to directly correlate structural differences between asphalt pavements modified by the different materials of this study, in that the true effects of thrust-vectored jet blasts are unknown for any type of asphalt pavement at this point. However, as part of his contract duties to the work of this project, Dr. Anthony F. Stock produced the following analysis based on the exhaust characteristics of the F-15 aircraft engines.

Although it is understood that the F-15 aircraft engines are not thrust-vectored, these engines represent the current state of the art in aircraft engine design and therefore best represent the type of engines to be used in future thrust-vectored aircraft. When considering the effects of thrust-vectored jet aircraft engines, three areas of concern are prominent:

a. The possibility of localized heating causing excessive hardening in the binder.

b. The possibility of reduced pavement strength caused by a reduced binder stiffness through significant subsurface heating.

c. The effect of high-speed air or "jet blast" directed onto the pavement surface.

To address the heating effect, the exhaust from a vectored thrust aircraft is considered to be analogous to a pavement heater of the type used for asphalt pavement hot planing and some forms of recycling. The reason for this analogy is to make use of an analysis procedure reported by Carmichael et al (2) which is designed to model the change in pavement temperature with depth resulting from the passage of a heater. This analysis treats the pavement as a semi-infinite solid at a fixed initial temperature, where the temperature above the surface is suddenly changed and maintained at a new and higher temperature. The computer program used to conduct this analysis was run with the following input variables:

a. Data provided by the project officer for the Advanced Technology F-15 Pavement Interaction Study indicated that the temperature at the center of the exhaust plume of the engine at the pavement surface was 540°F. Therefore, this temperature was input as the heat source temperature.

b. Initial pavement temperatures of 32, 70, and 100°F were used to investigate the effects of this parameter.

c. Temperature profiles were calculated after 1, 2, 5, and 10 minutes exposure to the 540°F heat source.

d. Following a preliminary series of calculations, the maximum depth for calculation was set to 3.75 inches to ensure that the full depth of penetration of the heat from the exhaust was computed.

To address the concern of possible localized surface heating on an asphalt pavement, a plot of the rise in surface temperature as a function of time was evaluated from the computer program's output data. This plot is shown in Figure 2 and displays the surface temperature versus time relationship for each of the three initial surface temperatures. The pattern of increase in temperature with time is virtually independent of the initial temperature. Also, the shape of the curve indicates that the surface temperature is continuing to rise, as would be expected. The maximum surface temperature reached after 10 minutes exposure was just below 220°F. Repeated cycles of localized surface heating at this magnitude could lead to premature aging of the binder. Thus, under the most extreme condition investigated, there is some possibility of temperature aging of the asphalt cement on the surface of the pavement. However, this extreme condition is unlikely to occur during the operation of thrust-vectored aircraft. The computations do not consider the cooling effects of wind, which may be significant in many cases.

The use of thrust-vectored aircraft will undoubtedly raise the subsurface temperature of the asphalt pavement. This will, in turn, reduce the stiffness of the pavement layer to some degree and could, therefore, influence the building up of distresses in the pavement. To evaluate the possible limits of this structural heating effect, data were drawn from the computer program output to graphically display the calculated temperature versus depth profiles for exposure times of 1, 2, 5, and 10 minutes. These graphs are presented in Figures 3-6. As would be expected, the greatest depth of penetration of the heating effect occurred at the 10-minute exposure time, reaching a depth of approximately 2.7 inches. In order to present a complete picture of the temperature-depth profiles, the data from Figures 3-6 have been grouped together according to the initial pavement

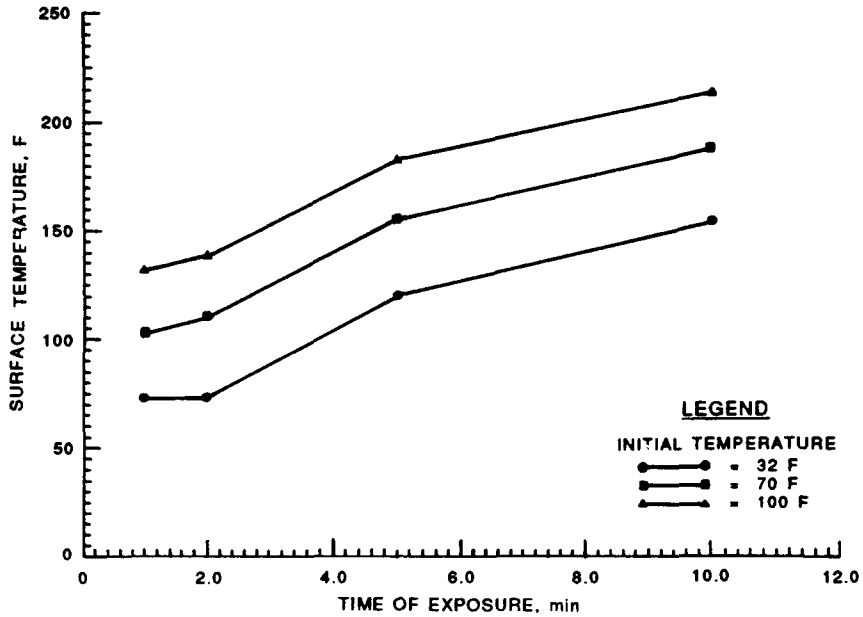

Figure 2. Temperature Profiles as a Function of the Time of Exposure to the Vectored Thrust.

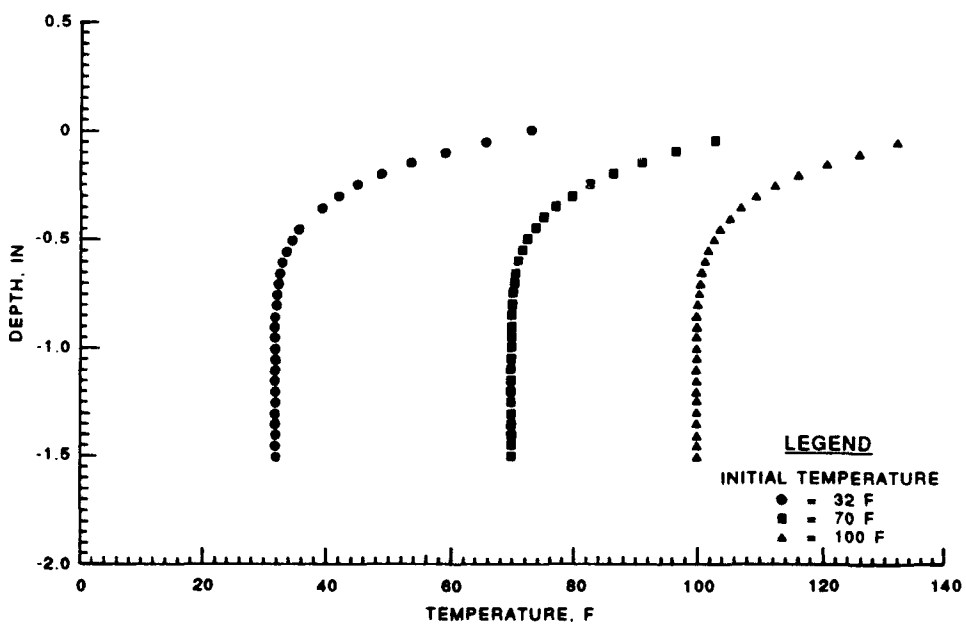

Figure 3. Temperature Profiles as a Function of Depth After 1 minute of Exposure to Vectored Thrust.

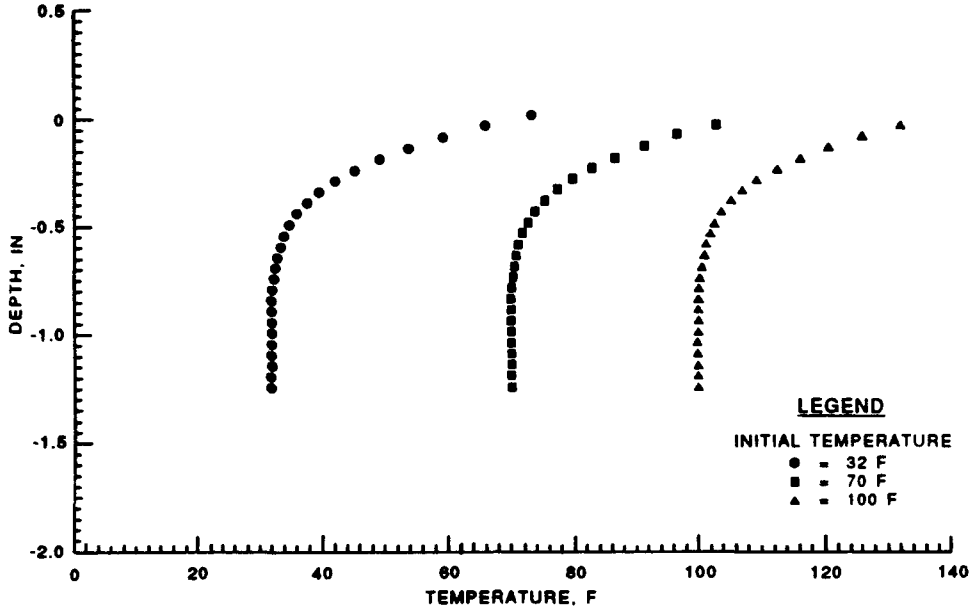

Figure 4. Temperature Profiles as a Function of Depth After 2 minutes of Exposure to Vectored Thrust.

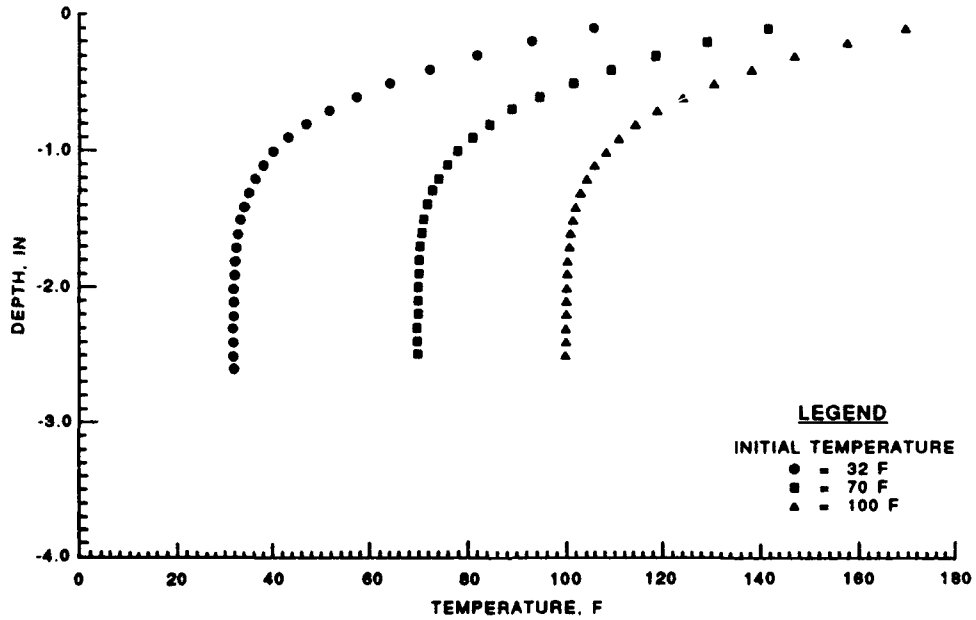

Figure 5. Temperature Profiles as a Function of Depth After Five Minutes of Exposure to Vectored Thrust.

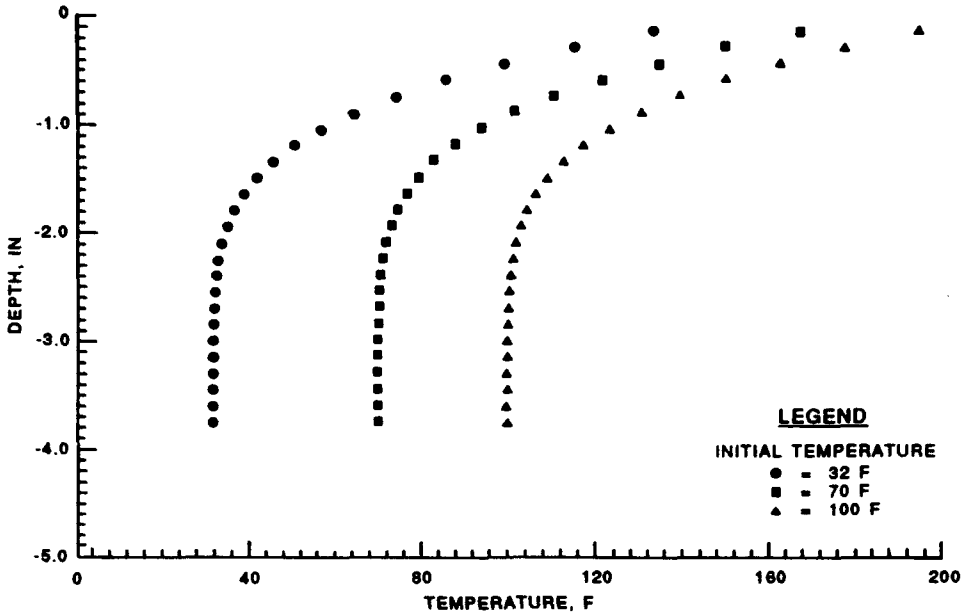

Figure 6. Temperature Profiles as a Function of Depth After 10 minutes of Exposure to Vectored Thrust.

temperature and are presented in this form in Figures 7, 8, and 9. These figures show that there is virtually no difference in the temperature profile after 1 and 2 minutes of exposure. As is the case for surface temperatures, the only scenario that provides for possible structural damage is the 10-minute exposure with high initial pavement temperatures. Since it can be assumed that the actual normal exposure time will be much less than 10 minutes, it should be safe to assume no significant subsurface structural damage to the asphalt pavement should occur under normal operating conditions.

The final consideration in terms of thrust-vectored aircraft is the possibility of erosion of a pavement surface subjected to the blast from these aircraft. It is beyond the scope of this investigation to undertake any tests in relation to this problem; however, an investigation of the literature has revealed that surface erosion under jet blast has been investigated at WES in the past (3). One conclusion states that "Asphaltic concrete will give satisfactory performance under traffic and blast of jet planes, except in areas where afterburner checks are made." It was also noted that with certain aircraft where jet engine blasts are sometimes

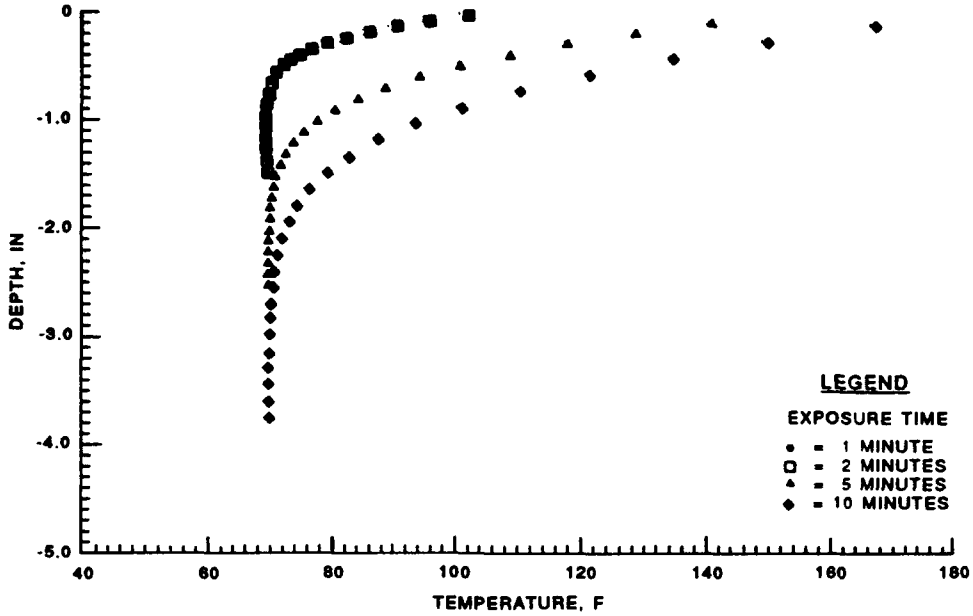

Figure 7. Temperature Profiles as a Function of Depth for an Initial Temperature of 32°F.

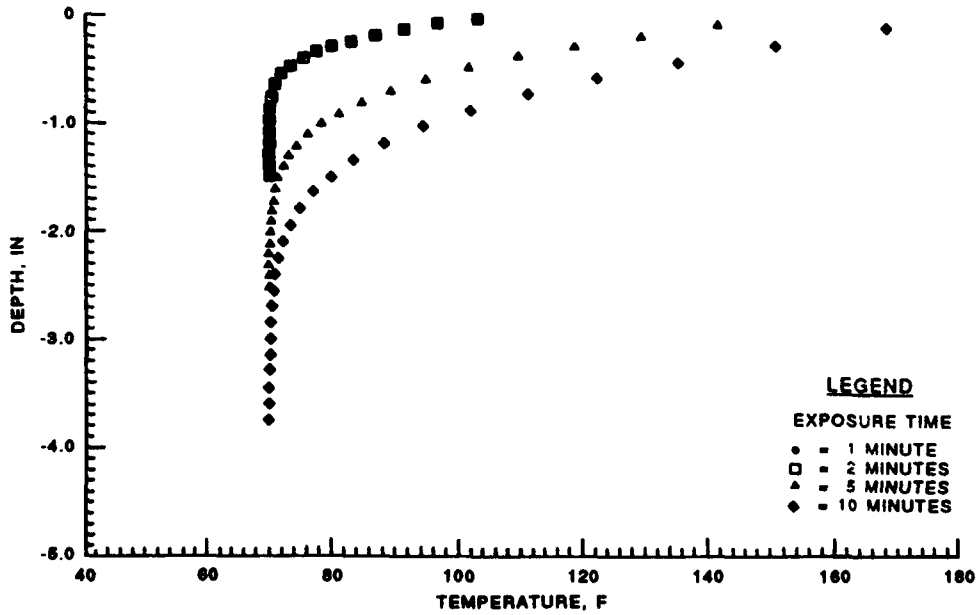

Figure 8. Temperature Profiles as a Function of Depth for an Initial Temperature of 70°F.

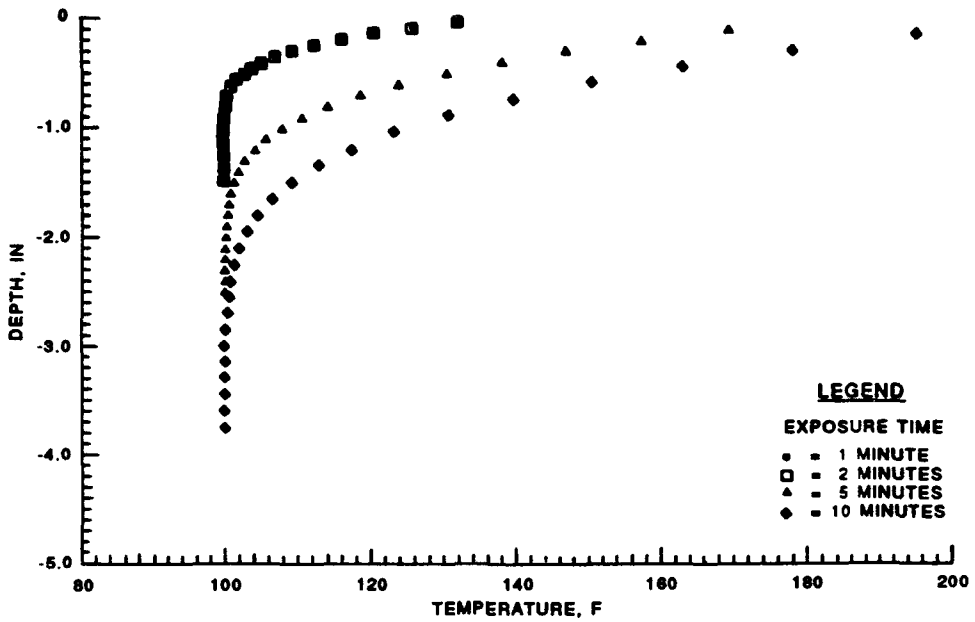

Figure 9. Temperature Profiles as a Function of Depth for an Initial Temperature of 104°F.

aimed more directly onto the pavement surface, minor erosion of surface materials is possible. By assuming that the jet blast forces (i.e. temperature, velocity, etc.) of future thrust-vectored aircraft may exceed those forces of the WES study, there is a definite possibility of surface erosion problems on asphalt pavements subjected to thrust-vectored engine blasts.

B. DEVELOPMENT OF AUTOMATED DATA ACQUISITION TESTING SYSTEM

To more accurately control the laboratory testing and data accumulation throughout the first and second phases of the test program, a state-of-the-art computer operated system was assembled at the WES Materials Research Center Laboratories. This custom-designed system is known as the Automated Data Acquisition Testing (ADAT) System. An overall view of the system is shown in Figure 10. The ADAT System was specifically designed to conduct the three asphalt mix tests chosen for this study. These tests were the indirect tensile, resilient modulus, and creep-rebound tests. Details of these tests and their respective test methods will follow.

Figure 10. Overall View of ADAT System.

The heart of the ADAT system is the MTS electrohydraulic closed-looped material testing system. An arbitrary waveform generator is built into the system to control the loading sequences of the electrohydraulic system. Specimen deformations are measured by electronic linear variable differential transformers (LVDT) and electronic load cells record the test loads. Other automated features of the system include electronic temperature control of the enclosed environmental chamber and real-time color graphics for continual test monitoring.

The ADAT System is built around a 16-bit computer designed to operate as the system's principal measurement and control station. Customized computer programs were implemented for the ADAT System to reduce the operator dependency inherent in most traditional asphalt mix tests in the laboratory. These computer programs control the mechanics, monitoring systems, test data manipulations, and data storage for the three tests conducted on the modified asphalt mix specimens. A single operator controls all testing

variables and monitors test results from the computer's keyboard with simple keystroke commands (Figure 11).

Figure 11. Operator at ADAT System Computer Control Keyboard.

All ADAT system computer programs were designed by members of the Instrumentation Services Division (ISD) at WES.

C. PHASE I LABORATORY TESTS

1. Materials

The following paragraphs give a brief description of the aggregates, binders, and each of the modifiers used in the project's Phase I laboratory testing. As mentioned before, generic descriptions of the modifier materials will be used here and throughout the report in lieu of trade names. The dosage rates and mixing procedures described for each of the modifier materials are based on the modifier manufacturers' recommendations.

a. Aggregates

Both the aggregates and aggregate gradation used in the asphalt mixtures remained the same throughout the laboratory tests. The aggregates were a mixture of a well-graded, crushed Alabama Limestone and 10 percent by weight of Tennessee Valley Sand. A single gradation of this aggregate blend was utilized that fell within the requirements of the US Army and US Air Force standard practice requirements for a 3/4 inch maximum size, high tire pressure blend as prescribed in TM 5-822-8/AFM 88-6. The dry aggregate apparent specific gravity of this blend was 2.80. Table 1 lists the gradation band recommended by TM 5-822-8/AFM 88-6 and the gradation of the aggregates used throughout this project. Figure 12 graphically displays these gradation curves.

TABLE 1. AGGREGATE GRADATION

US Standard Sieve Size	Specification[a] (% Passing)	Gradation Used (% Passing)
3/4 inch	100	100
1/2 inch	82-96	88.2
3/8 inch	75-89	81.7
No. 4	59-73	66.1
No. 8	46-60	53.7
No. 16	34-48	39.8
No. 30	24-38	26.6
No. 50	15-27	20.7
No. 100	8-18	13.9
No. 200	3-6	4.9

[a] From TM 5-822-8/AFM 88-6, Chapters 2 and 9 for 3/4 inch aggregate high tire pressure applications.

b. Asphalt Cement

An AC-20 viscosity graded asphalt cement was chosen as the base asphalt for this laboratory study. A local source of AC-20 asphalt which is refined from a combination of two south Mississippi crudes was selected for use. The asphalt cement was refined from 70 percent Heidelburg-Eucatta-Yellow Creek Crude, while the remaining 30 percent was refined from an Ovett Crude. Table 2 lists the properties of this AC-20 asphalt cement and the AC-40 asphalt cement which is discussed later.

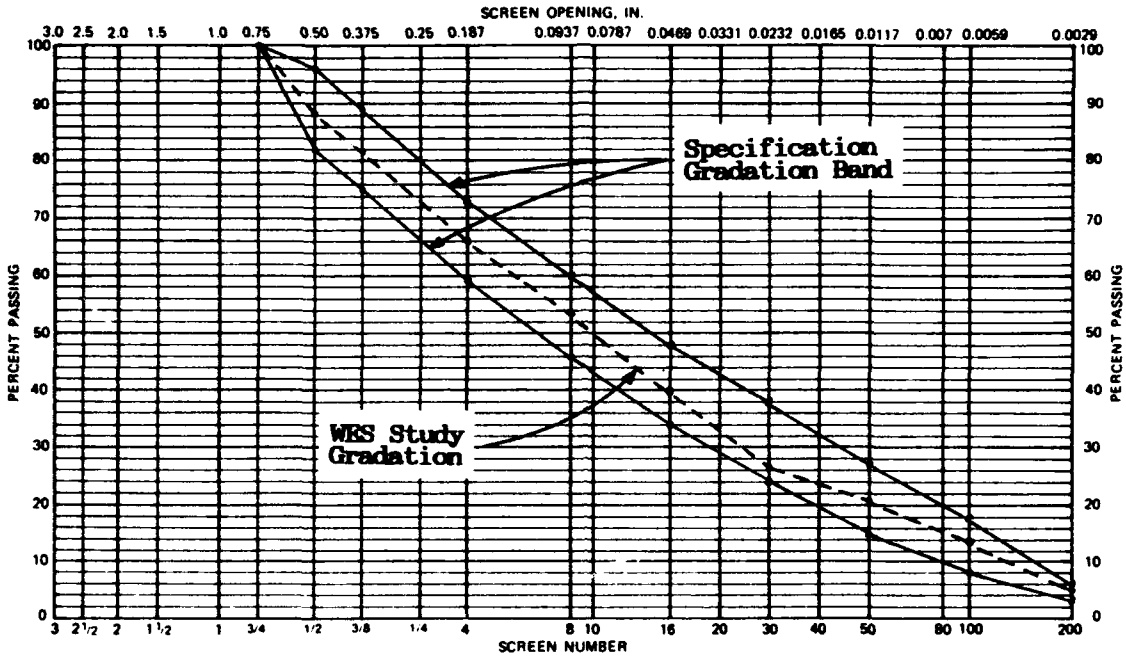

Figure 12. Aggregate Gradation Curves.

TABLE 2. ASPHALT CEMENT PROPERTIES (ASTM D 3381)[6]

Test	AC-20 Results	AC-20 Spec. Limits[a]	AC-40 Results	AC-40 Spec. Limits[a]
Penetration (100g,5 sec,77°F)	85	≥40	39	≥20
Viscosity (abs,140°F,P)	2138	2000 400	3256	4000 800
Viscosity (kin,275°F,cst)	478	≥210	334	≥300
Viscosity (TFO,abs,140°F,P)	4651	≤10000	6562	≤20000
Ductility (TFO,5cm/min,77°F,cm)	150+	≥20	150+	≥10
Specific Gravity	1.037		1.020	

[a] Table 1 of ASTM D 3381

c. Rubber Modifiers

One of the rubber type asphalt modifiers used in this study was a styrene-butadiene-styrene or SBS rubber described as an oil-extended polymer produced in pellet form. This type of rubber is available in other solid forms such as crumb or ground material for easy incorporation into base asphalts at elevated temperatures. The pellet form used in our study was mixed at a dosage rate of 12 percent by total weight of the modified binder to our base AC-20, which had been preheated to 275°F. Thirty minutes of low-speed mixing by a heated paddle mixer was enough to evenly disperse the rubber into the base asphalt.

A styrene-butadiene rubber (SBR) in latex form was also examined in the Phase I testing. The dosage rate of this rubber modifier was 3 percent by total weight of the resulting modified binder. The SBR latex, containing 70.9 percent solids, was mixed for 2 hours and 30 minutes with the base asphalt using a high-speed Hockmeyer F-type disperser blade. Similar special blending equipment may be needed at the asphalt hot-mix plant under field conditions.

Another rubber latex evaluated contained a low modulus, slow-crystallizing polychloroprene homopolymer. A dosage of 2 percent by total weight of modified binder was slowly "dripped" into the base asphalt which was at a temperature of 300°F. This slow addition of modifier to base asphalt allows for the water contained in the latex to evaporate at a controlled rate, as is recommended for field applications. The blend was mixed for 30 minutes at low speed, using the WES laboratory heated paddled mixer.

The final type of rubber examined in the project was a form of ground reclaimed tire rubber. The material contained about 50 percent of its volume ranging from the 100- to 200-mesh sieve sizes with the other 50 percent smaller than the 200-mesh sieve size. The material was made up of nearly equal parts by weight of rubber hydrocarbon, carbon black, and acetone extract with a small amount of ash. Blending was accomplished by heating the base asphalt to 300°F and mixing 10 percent of the ground rubber for 30 minutes using equipment and procedures similar to other blendings done in the WES laboratory.

d. Plastic Modifiers

A thermoplastic copolymer of ethylene and vinyl acetate, commonly referred to as ethylene vinyl acetate or EVA was included in the study. The material was supplied to the WES laboratory in the form of small clear pellets, which were mixed with the base asphalt at a rate of 4 percent by total weight of the modified binder. The base asphalt was preheated to 330°F. Sufficient blending was accomplished using the WES laboratory's low speed paddle mixer with 30 minutes mixing time.

Another plastic studied in the project was a high-melt index type of polyethylene. Because polyethylene is not soluble in asphalt, it was necessary to use the Hockmeyer high-shear blending process to mix the two components. For these tests, 5 percent polyethylene by total weight of modified binder was mixed with the base asphalt at 300°F under high-shear blending conditions for approximately thirty minutes.

The final type of plastic modifier evaluated was a specialized two-component polymer. Because of recent patents granted on this proprietary material, the manufacturer was unwilling to divulge the product's chemical makeup. The first component was mixed at a rate of 7 percent by total weight of modified binder with the 300°F base asphalt using the WES paddle mixer at low speeds. Continuous mixing for approximately 30 minutes allowed the first component to react with the asphalt before adding the second component. A dosage of 4 percent by total weight of the second component was then added to the asphalt mixture, and after another 30 minutes of low-speed blending, the modified asphalt was ready to be blended with the aggregates.

e. Filler Modifiers

Sulphur has an established history as an asphalt modifier through its uses as a mix stiffener and as a partial replacement for the asphalt cement. Because of the strength properties typically gained with a sulphur-modified asphalt mix, sulphur was included in this project under the filler classification. WES used the rock form of yellow sulphur, a common form used in asphalt modification. The sulphur was added in an amount of 40 percent by total weight to the 300°F base asphalt and blended for 30 minutes at low speeds with the standard heated paddle mixer. Careful

control of the mixing temperature was used to avoid release of potentially toxic gases from heated sulphur at temperatures above 325°F.

Lime ($CaOH_2$) is another filler common to the asphalt industry. It has an established history as a good antistripping agent in asphalt pavements and is reported to provide increased mix strengths. A chemical grade hydrated lime was incorporated into the asphalt mixture as a slurry. Lime, in an amount of 1.5 percent by weight of the aggregates, was mixed with water, in a 70/30 weight ratio of water to lime. The lime slurry was then used to coat the cold aggregate which was in turn heated until dry. Finally, the lime coated aggregate was mixed at 275°F with the asphalt cement.

The last of the three fillers chosen for this project was a pelletized form of carbon black. This particular type of microfiller is a mixture of high structure carbon black and high boiling point maltenes oil. The carbon black pellets were blended at the recommended dosage of 15 percent by total weight of the modified binder to the 300°F asphalt cement. A high speed Waring Blender was used to blend the carbon black and asphalt cement. Total mixing time was approximately 30 minutes.

f. Hard Asphalts

Two hard asphalt binders were included in this research project as possible alternate binder materials. One of the materials was a natural lake asphalt refined from crude natural asphalt after it is excavated from the open lake bed source. This asphalt has been known to provide better durability and resistance to deformation in asphalt pavement systems largely due to the naturally occurring mineral matter in the asphalt. The amount of mineral matter, which is volcanic ash, contained in the asphalt normally ranges from 35 percent to 45 percent after refining. The most common use of this asphalt is to mix it in near equal proportions with softer asphalts to achieve the desirable mix qualities resulting from a harder asphalt. In the WES laboratory, the asphalt was simply heated to 300°F, then 45 percent by total weight was mixed with the 300°F base asphalt cement. Approximately 30 minutes of low-speed blending was sufficient to mix the two asphalts.

The other hard asphalt binder tested was an AC-40 grade. This material was refined from a Wilmington Crude originating from the Long Beach,

California area. As with the natural lake asphalt mixture, the AC-40 was mixed with the aggregates under standard procedures after heating the asphalt to 300°F. The properties of this AC-40 asphalt cement are found in Table 2.

g. Oxidant Modifier

The oxidant chosen for this project was one of the few modifier materials with a substantial performance history. This modifier is an oil-based soap containing soluble manganese and a hydrocarbon carrier acting as a dispersant. The modifier was in liquid form and was mixed with the base asphalt cement at 300°F for approximately 30 minutes using the standard laboratory low-speed paddle mixer. A dosage of 2 percent modifier by total weight of the modified binder was used. After mixing the modified asphalt with the aggregates, a 4-hour 280°F oven cure of the loose mix was allowed to simulate the reaction that occurs in the pavement under field construction conditions.

h. Fiber Modifier

A form of polyester fibers specifically designed for asphalt modification was included in the project. The 3/8 inch long fibers were added to the preheated loose aggregates at a dosage rate of 0.3 percent by weight of the aggregates. The aggregate and fiber blend was then mixed with the base asphalt cement at 275°F.

2. Mixture Tests

a. Marshall Mixture Design

The Marshall Mixture Design Procedure, as outlined in Military Standard 620A (4), was used to determine optimum asphalt contents for all modified asphalt mixtures of this study. The optimum asphalt contents determined from this test were used to make the laboratory specimens of the modified asphalt mixtures for all Phase I mix tests. Since the Marshall Mix Design Procedure is currently recognized by all Department of Defense agencies, one can safely assume that this mix design procedure will be the most prominently used in modified asphalt mix designs for airfield projects.

A Model 4C Gyratory Testing Machine (GTM) was used to compact all laboratory specimens. Previous experience with gyratory compaction suggests that laboratory tests, when performed on mixes compacted at stress levels similar to anticipated field traffic conditions, simulate field behavior under traffic (5). Based on these experiences and numerous studies designed to correlate the Marshall hand-hammer compactor with the GTM, all laboratory specimens were compacted with the GTM for this study. The gyratory compactive effort used in this study followed the standard settings prescribed in Military Standard 620A which correlates with 75 blows of the Marshall hand hammer. The 75-blow compactive effort is considered to be the standard for high-tire-pressure designs. The gyratory compactive effort was set at the 200 psi normal stress level, 1-degree gyration angle and 30 revolutions of the compaction apparatus. The asphalt mix specimens produced from this compaction are cores that satisfy the Marshall specimen dimensions of 4 inches in diameter and approximately 2 1/2 inches high. All laboratory mix samples were air cured from 7 to 14 days before testing. Figure 13 shows the WES Model 4C Gyratory Testing Machine and Figure 14 is a schematic of the gyratory compaction process.

As an integral part of the Marshall Mix Design Procedure, the Marshall Apparatus (Figure 15) is used to measure core stability, which is an indicator of mix strength, and the specimen deformation or flow, which is an indicator of mix plasticity. Before testing for stability and flow, the specimens are air-cured and brought to the appropriate testing temperature by a 140°F water bath. Effects of varying the asphalt content are indicated during this test, as several binder contents are used for the test specimens to determine the optimum asphalt content. The effects of the various binders on the Marshall Mix design criteria were not known. As a result, optimum asphalt contents were selected based on 4 percent air voids rather than applying all of the design criteria. The results of these tests are presented and discussed in Section III.

b. Indirect Tensile

The Indirect Tensile Test, as specified by ASTM (6) Method D 4123, was conducted on all Phase I modified asphalt mix specimens to determine the tensile strength of the specimens. This test method is known to be a relatively straightforward strength test which lacks the test

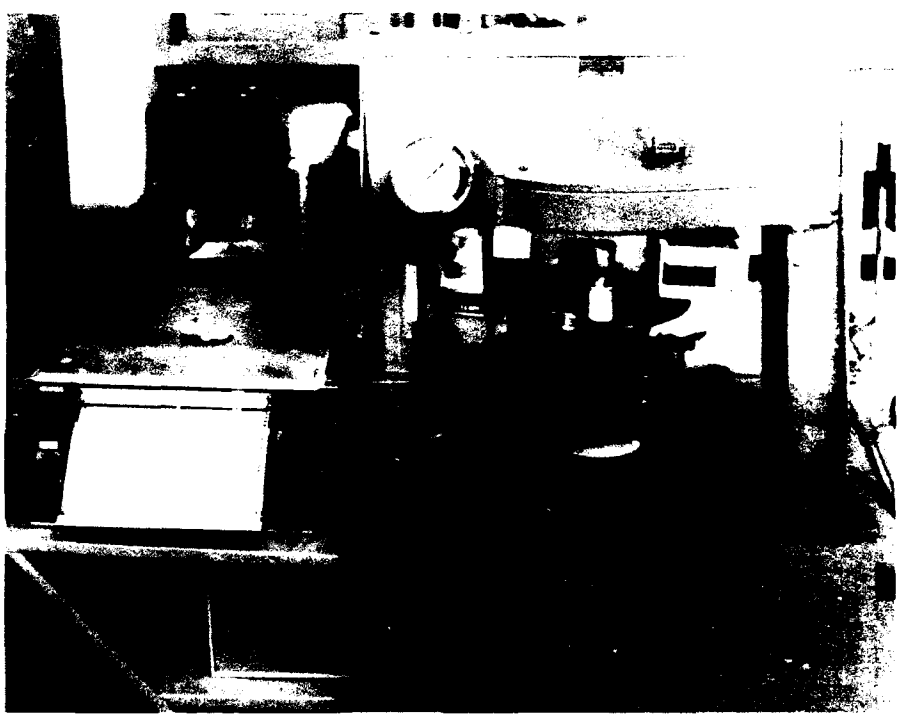

Figure 13. WES Model 4C Gyratory Testing Machine.

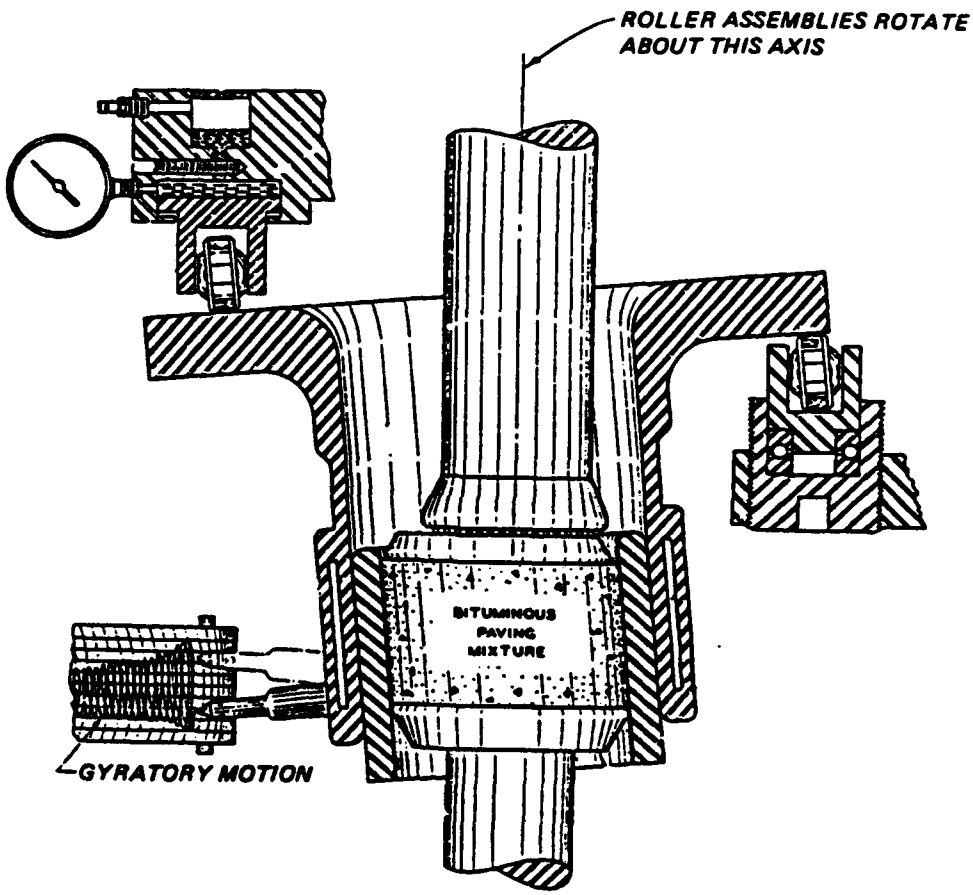

Figure 14. Schematic of Gyratory Compaction Process.

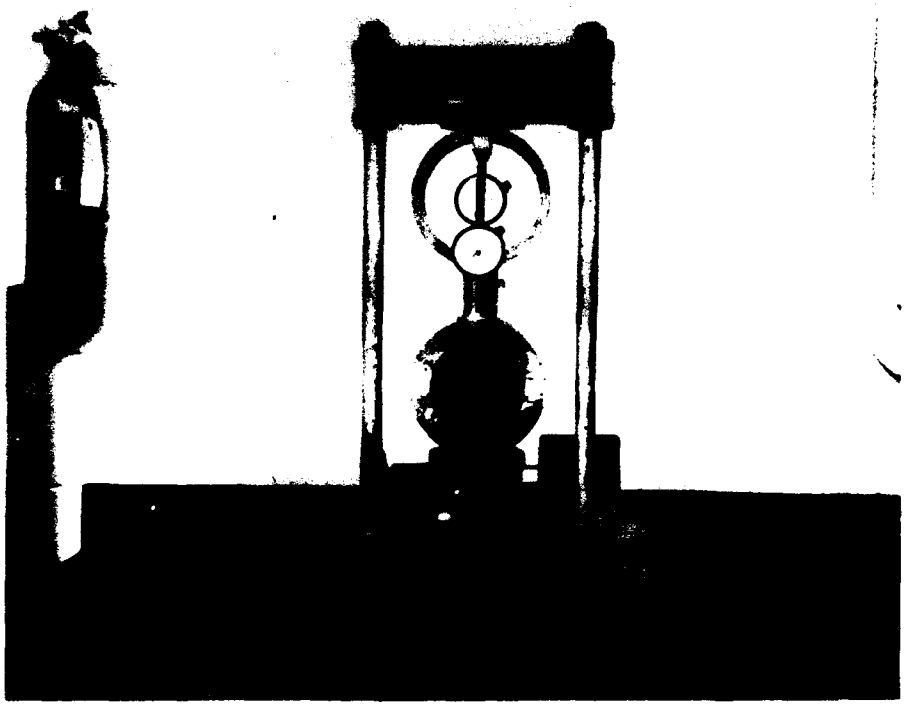

Figure 15. Marshall Apparatus.

input variables that can lead to inconsistent results. The samples were tested at different temperatures to determine the temperature effects on tensile strength. Cured samples were placed in ovens or freezers, as appropriate for the desired test temperature, for a minimum of 24 hours before testing in an environmentally controlled chamber.

Before indirect tensile testing, the specimens were positioned so that the loading plates were parallel and centered on the vertical diametral plane of the specimen. Once the loading device was properly positioned and the ADAT system was readied, a vertical load was applied at a constant deformation rate of 2 inches per minute. This loading continued until specimen failure (Figure 16) and the ultimate load, which was automatically recorded by the ADAT system, was used to calculate the resulting tensile strength. This process was repeated on three test specimens for each of the four designated test temperatures with each modified asphalt

Figure 16. Indirect Tensile Test.

mixture. The test temperatures included in this test were 0°F, 39°F, 77°F and 104°F.

The tensile strength was calculated using the equation given in ASTM D 4123 as follows:

$$\text{Tensile Strength} = 2P/\pi tD \text{ where}$$

where

P = peak load or ultimate applied load required to fail specimen (lb)

t = thickness of specimen (in)

D = diameter of specimen (in)

The results of the Phase I Indirect Tensile Tests are presented and discussed in Section III.

c. Resilient Modulus

The Resilient Modulus, as specified by ASTM Method D 4123, was determined on all Phase I modified asphalt mix specimens. The resilient modulus values derived from this test were used to evaluate the relative quality of the modified asphalt mixtures. Higher resilient modulus values indicate a greater resistance to permanent elastic deformation, which is a desirable trait in asphalt mixtures. Effects of repeated loads and temperature susceptibilities are revealed in this test. Since the test is nondestructive, the specimens recovered after resilient modulus testing were used to conduct other mix tests, thereby saving a considerable amount of time, cost, and effort.

For resilient modulus testing, the 4-inch diameter by 2 1/2-inch high cylindrical specimens are preconditioned at the desired temperature for 24 hours and then positioned between the loading plates in the same fashion as with the indirect tensile strength test. After the horizontal and vertical LVDTs were properly positioned and zeroed, the specimen was ready for testing (Figure 17). Although the equation used to calculate the resilient modulus values in this study requires only the specimen's horizontal deformation, the vertical deformations were measured and recorded for each test for possible future considerations. Before resilient modulus testing, the specimens were preconditioned by applying a repeated Haversine waveform at a reduced load for a period sufficient to obtain a uniform deformation readout. This preconditioning deformation was monitored on the ADAT system's strip chart recorder. After preconditioning, the ADAT system was programmed to perform the resilient modulus test on the specimen under the following conditions: The magnitude of the repeated load was set at 5 to 25 percent of the asphalt mixture's predetermined tensile strength, depending on the test temperature (lower percentage load for higher test temperatures); the load duration was set at 0.1 seconds for all tests, as this time frame is considered to be representative of transient pavement loadings; the loading frequency was set at 1.0 Hz, or 1 cycle per second; a

Figure 17. Resilient Modulus Test.

Haversine waveform was applied by the ADAT system's arbitrary waveform generator as recommended by the ASTM test method.

The ADAT system was programmed to run a ten cycle resilient modulus test and to capture the test data of three loading cycles when signaled by a computer keystroke command. This procedure was implemented so that the system operator could visually monitor the repeated resilient deformations on the strip chart recorder and ensure that the deformations had stabilized before capturing the data that would automatically be converted into the resulting resilient modulus value. In addition to insuring uniform horizontal deformations, the ADAT system monitored the vertical deformations so that no test data were captured when total cumulative vertical deformations became greater than 0.001 inch, as specified in the ASTM standard. When this criterion was exceeded, the computer system warned the operator of the excessive vertical deformation, the test load was reduced, and the test was repeated on the same sample.

Three specimens representing each of the Phase I materials were tested for resilient modulus. Each of these specimens was tested at two positions. After testing at an initial position (0 degrees), the specimen was rotated about the horizontal axis 90 degrees from the original position. As a result of applying this test procedure to the three specimens, a total of six resilient modulus values were determined for each of the four test temperatures (0°F, 39°F, 77°F, and 104°F) representing each of the Phase I materials. The test results reported for these Phase I resilient modulus tests, presented and discussed later in this report, are simply averages of the six values for each material.

The equation used to calculate the resilient modulus values of this study is a modified form of the equation presented in the pertinent ASTM standard. This equation assumes a Poisson's ratio of 0.35 and therefore considers only the measured horizontal deformations. The equation suggested by the ASTM standard involves the use of a measured vertical deformation and the use of this data produced too much variability for the asphalt mixture specimens of this study. In theory, the larger top size aggregate gradations, like the gradation used in this study, produce more variability in the resilient modulus test as compared to specimens containing relatively smaller top size aggregates. The equation programmed into the ADAT system for calculating resilient modulus is:

$$E_{RT} = .62\ P/(t\ \Delta H_T)$$

where

E_{RT} = total resilient modulus of elasticity (psi)

P = applied repeated load (lb)

t = thickness of specimen (in.)

ΔH_T = total recoverable horizontal deformation (in.)

d. Creep-Rebound

A Creep-Rebound test procedure was developed for this project. The test is devised to examine resistance to permanent deformation under severe loads and is an indicator of rutting potential. Equal consideration is given to the reaction of the asphalt mixture during and after intense loading.

Creep tests were performed on three specimens, with each measuring approximately 4 inches in diameter and 2 1/2 inches tall which are

stacked on top of each other. The stacked specimens were first positioned in the environmental chamber between the loading plates. Silicone grease was used to precoat the loading plates in order to minimize the effect of end restraint. Two vertical LVDTs were mounted on the center specimen (see Figure 18 for specimen alignment) and the recorded deformation was taken as the average of the two readings from these measuring devices. A 50-pound preload, approximately 4 psi vertical stress, was applied to the specimen before the application of the actual test load in order to seat the specimen between the loading plates.

Figure 18. Creep Rebound Test.

During testing, a constant load was held for 60 minutes and then released for another 60 minutes for the rebound test phase. The load was measured with an electronic load cell, as with the indirect tensile and resilient modulus tests. Loads and deformations were monitored by the computer system at preselected times during the load application and rebound phase, and simultaneously converted to stresses and strains by the computer system. These stresses and strains were then converted by the ADAT

system's Creep-Rebound program into a creep modulus value for each data point. Data sampling times were set at 1, 2, 4, 8, 15, 30, 60 seconds, and continuing similarity for 60 minutes. At that time, the system was programmed to release the load and continue monitoring the deformation under the same time sequence as for the creep test phase. The creep test was conducted at 77°F and 104°F. Constant loads ranging from 50 to 100 psi vertical stress for the 77°F tests and 20 to 40 psi for the 104°F tests were used. As with other tests run with the ADAT system, all test data were automatically stored in the computer's memory. Figure 19 displays a typical creep-rebound deflection versus time curve.

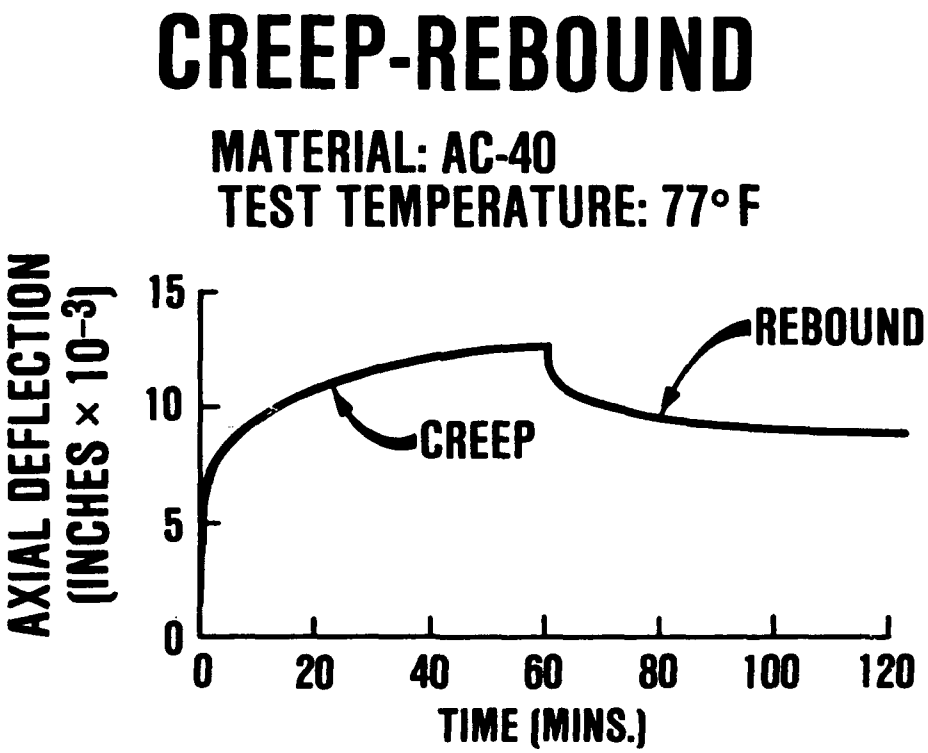

Figure 19. Typical Creep-Rebound Deflection.

The results of the creep-rebound test on asphalt mixtures can be used in a number of ways. First, the amount of axial deformation under loading (creep) indicates the asphalt mixture's resistance to deformation under actual loading conditions. Lower creep values are more desirable.

Second, the amount of recovery from imposed axial deformation (rebound) indicates the asphalt mixture's ability to recover from imposed deformations. Again, higher rebound values are more desirable. Finally, the stress-strain data captured during the creep portion of the test is converted into a creep modulus value which is, in effect, a measure of the asphalt mixture's stiffness. A higher creep modulus or stiffness value is more desirable to minimize permanent deformation. The equation used to calculate the creep modulus values derived from the Creep Rebound test is:

$$E_C = [(S)(H)] / D$$

where

E_C = creep modulus (psi)

S = vertical stress (load/contact area; psi)

H = height of specimen (in)

D = axial deformation (in)

The creep, rebound, and creep modulus values derived from the Phase I tests are presented and discussed later in this report in Section III.

3. Binder Tests

a. Penetration

A penetration test was used in the Phase I testing to indicate changes in the binder's consistency after modification. Penetration values also indicate how brittle an asphalt cement may become at cold temperatures or after aging. More directly, the results of this test were used to evaluate the comparative degree of change in the modified binder's consistency. Depending upon the circumstances, a significant change in binder penetration may or may not be desirable. For instance, in cold weather climates, a significant decrease in binder penetration may result in thermal cracking problems.

The test method and equipment described by the ASTM D 5 standard (6) were used to test samples of the modified asphalts, as well as the base AC-20 and the unmodified AC-40. All binder test specimens were sampled from the same materials used to make the asphalt-aggregate mix specimens and were allowed to cool for 4 hours before testing at 77°F. The results of this test are presented and discussed in Section III.

b. Chromatography

As a component of the asphalt modifier study, Clemson University's Department of Civil Engineering conducted a high-pressure gel-permeation chromatography (HP-GPC) study on the 14 Phase I binder materials. The chromatography testing was carried out in 1987 and coordinated by U.S. Army Major Richard P. Price, a PhD candidate in the Civil Engineering Department. The purpose of Clemson University's study was to determine if a modified asphalt's chromatography data would correlate with any of the more common asphalt tests used today.

Asphalt chromatography reveals certain physical characteristics of a material by analyzing its molecular size distribution. The results of this test are repeatable and can pick up variations in the molecular structure of asphalts. The output derived from a chromatography test is the test material's molecular size distribution, normally displayed as a chromatographic profile. This graphical profile displays the relative proportions of differing molecular sizes that make up a given material. A typical chromatographic profile is shown in Figure 20.

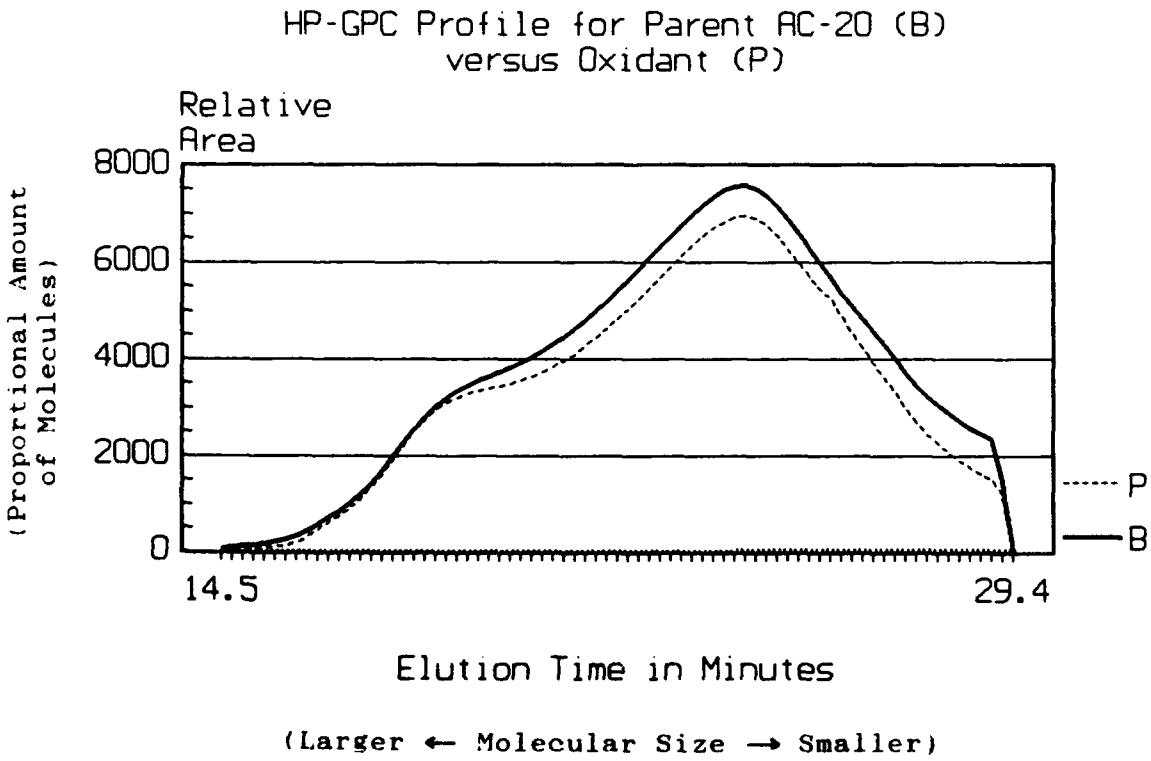

Figure 20. Typical Chromatographic Profile.

An in-depth description of the equipment, test methods, and analysis procedures used for this study will not be presented here, but may be found in Major Price's Dissertation (6) presented to the Graduate School of Clemson University in August of 1988. The pertinent data and conclusions drawn from this study will, however, be presented and discussed in Section III.

D. PHASE II LABORATORY TESTS

1. Materials

Many of the materials used in the Phase I testing were also used in the Phase II tests. However, some new materials were included in the Phase II tests and these material changes are discussed in the following paragraphs.

a. Aggregates

The aggregates and aggregate gradation used in the asphalt mixtures remained the same throughout all Phase I and Phase II laboratory mix tests. This eliminated the aggregate design variable; therefore, all changes in properties could be associated with the binder modification. The aggregate properties and gradation used are described earlier in this section of the report and the gradations are presented in Table 1 and Figure 12.

b. Asphalt Cements

In addition to the local AC-20 asphalt cement refined from Mississippi crudes which was used in all Phase I tests, two additional and different AC-20 asphalts cements (both refined from California crude sources) were included in the Phase II tests. The physical differences are clearly displayed in Table 3 which lists the results of the specification tests for the three asphalt cements, described in ASTM D 3381. These tests are identical to the tests performed on the Phase I AC-20 and AC-40 asphalts (Table 2). For the Phase II coding system adopted, the three base AC-20 asphalt cements used in the Phase II tests were labeled 1, 2 and 3. The asphalt cement 2 was the same asphalt used in the Phase I tests, while the asphalts 1 and 3 were the new asphalt cements. The AC-20 base asphalt 2 is comparatively standard under all of the cited test properties. The asphalt 1 is quite different; 77°F penetration and 275°F viscosity are

TABLE 3. PHASE II BASE ASPHALT CEMENT PROPERTIES.

Test	Spec.[a] Limits	BASE ASPHALT 1	2	3
Penetration (100g,5sec,77°F)	≥40	41	85	80
Viscosity (abs,140°F,P)	2000±400	2247	2138	2104
Viscosity (kin,275°F,cst)	≥210	270	478	407
Viscosity (TFO,abs,140°F,P)	≤10000	3620	4651	6822
Ductility (TFO,5cm/min,77°F,cm)	≥20	150+	150+	61
Specific Gravity		1.014	1.037	1.032

[a] Table 1 ASTM D 3381

significantly lower, and the 140°F viscosity after thin-film oven-aging is lower. The physical differences of the asphalt 3 are evident in both of the thin film oven tests where viscosity is comparatively higher and ductility substantially lower.

c. Modifiers

In June of 1987, all Phase I laboratory testing was completed. A subsequent analysis of the data and review of pertinent information gained from the literature search were carried out to choose five modifiers or alternate binders for further testing in the Phase II test plan. This exercise was carried out by all project consultants and the project's principal investigator. At a meeting held at WES in July 1987, all project consultants, representatives of WES's Pavement Systems Division, and representatives of the U.S. Air Force Engineering and Services Center (sponsoring agency) met to review the Phase I analyses and to choose the five materials to be included in the Phase II work.

Generally speaking, greater emphasis was given to those tests and analyses that better displayed the modified mixture's resistance to rutting and other deformation distress characteristics. Relative cost, availability, and ease of incorporation were also determining factors in selection of Phase II materials. Five materials, representing four of the modifier categories, were selected for further evaluation. In alphabetical order, the modifier materials selected were: AC-40 (hard asphalt), ethylene vinyl acetate (plastic), manganese soap (oxidant), polyethylene (plastic), and styrene-butadiene-styrene (rubber).

2. Mix Variation Matrix Design

The underlying goal of the Phase II test plan was to determine the effects of the selected modifiers on asphalt binders and mixtures. As part of the evaluation, three types of mix variations were chosen to be evaluated. The three mix variables examined were the binder content, modifier content, and asphalt cement source. These factors were considered significant to the performance of mixtures with a modified asphalt binder.

Variations in the amount of binder, whether modified or unmodified, occur in asphalt pavement construction for several reasons. Variations of asphalt contents in mixtures produced and inherent differences in asphalt contents derived by different mix design procedures are two common reasons for binder content variations. More variation should be expected for the modifier content in the binders of future modified asphalt pavement systems. This expected problem is supported by the fact that many modifier dosage levels are presently selected based purely on the manufacturer's recommendations and "engineering judgement." The last mix variable examined was the base asphalt cement source, considered the most critical of the three. Choosing the proper binder for an unmodified asphalt pavement is undoubtedly a critical design element, but when compatibility between asphalt and modifier is considered, using the right asphalt becomes even more important. A test plan was developed to evaluate the effects of each of these three mix variables on the performance characteristics of a modified asphalt pavement.

To effectively and efficiently carry out the Phase II test plan, a mix-variation matrix was developed (Figure 21). This test matrix was designed to provide the data necessary to determine the effects of each mix variable on the modified asphalt mixtures. A coding system was implemented to simplify the labeling of each blend. Letter and number codes were used to identify a test blend's modifier type, asphalt source, binder content, and modifier content. For instance, a test blend consisting of an EVA-modified local AC-20, with an optimum binder content and a lean modifier concentration would be labeled D2YP.

Values of binder content and modifier content for all asphalt 2 modified blends were derived from existing Phase I data. Optimum binder contents for all asphalt 1 and asphalt 3 modified blends were determined by

ALTERNATE/MODIFIED BINDERS FOR AIRFIELD PAVEMENTS
PHASE II TEST MATRIX

MODIFIER	ASPHALT SOURCE	X			Y			Z			BINDER CONTENT / MODIFIER CONTENT
		P	Q	R	P	Q	R	P	Q	R	
A OXIDANT	1					a b					TEST PLAN a
	2		b		a b	a b	a b		b		Brookfield Vis(140,275F) Resiliency (77 F)
	3					a b					Penetration (60, 77 F)
B SBS	1					a b					TEST PLAN b
	2		b		a b	a b	a b		b		Creep Rebound (77,104F) Resilient Mod(0,77,104F)
	3					a b					Ind. Tensile (0,77,104F)
C POLY-ETHYLENE	1					a b					BINDER CONTENT
	2		b		a b	a b	a b		b		X = 0.80 Y Y = OPTIMUM* Z = 1.20 Y
	3					a b					
D EVA	1					a b					MODIFIER CONTENT
	2		b		a b	a b	a b		b		P = 0.80 Q Q = OPTIMUM** R = 1.20 Q
	3					a b					
E AC-20 CONTROL	1					a b					ASPHALT SOURCE
	2		b			a b			b		1 = VALLEY 2 = LOCAL 3 = COASTAL 4 = AC-40
	3					a b					
F AC-40	4		b			a b			b		* Marshall Mix Design ** Manufacturer's

Figure 21. Phase II Test Matrix.

conducting Marshall Mix Designs under the same criteria as those used for all Phase I tests. Optimum modifier contents for these asphalt 1 and asphalt 3 source blends were the same for each respective modifier as used in the Phase I tests. All optimum binder, optimum modifier, asphalt 2 blends (2YQ) required no mix tests, as the existing Phase I data were used to fill these matrix blocks.

3. Mix Tests

The laboratory tests performed on the modified asphalt concrete mix specimens of the Phase II test plan were the same as those performed under the Phase I test plan. However, because of the increased number of blends to be tested, the testing procedures had to be scaled down to a degree that

would allow for all Phase II blends to be tested within the established time and funding constraints. The test plan changes agreed upon by the representatives of the sponsoring agency, WES, and the project consultants were as follows:

- o Remove the 39°F test from the resilient modulus and indirect tensile tests, as this data removal would least effect the temperature analysis of these tests. Also, since this study focuses on preventing rutting, the higher-temperature tests are more criticle to the overall analysis.
- o Reduce the number of replications for all tests from three to two.

In addition to the mix test plan changes listed above, the Phase II test plan called for the test specimens used for the nondestructive resilient modulus test to be used in the indirect tensile test. To validate the long-standing "nondestructive" claim of the resilient modulus test, an analysis was conducted before Phase II testing began. A group of asphalt mix specimens was produced with identical materials and under as nearly identical conditions as possible. One group of specimens was conditioned and tested for resilient modulus, placed back in its preconditioning environment (freezer, ambient air, or oven), then tested for tensile strength. This routine was conducted for two test temperatures, 0°F and 104°F. The other group of mix specimens was simply tested for tensile strength at each of these test temperatures.

A comparative analysis of the resulting data, displayed in Table 4, showed no significant effects on a test specimen's tensile strength when first tested for resilient modulus. This supported the nondestructive claim of the resilient modulus test under the conditions of this study. Therefore, there was no need for separate test specimens when conducting resilient modulus tests and indirect tensile tests at the same temperatures. A 25 percent reduction in time, funding, and effort was then realized by reducing the Phase II mix specimen number from 720 to 540.

4. Binder Tests

a. Penetration

Penetration tests were conducted on the Phase II modified binder blends at two test temperatures, 39°F (4°C) and 77°F (25°C). These

TABLE 4. EFFECT OF RESILIENT MODULUS TEST ON INDIRECT TENSILE SAMPLES.

	Tensile Strength (psi) [average of three]			
	AC-20		AC-40	
	0°F	104°F	0°F	104°F
Tensile Test Only	601.3	46.5	543.6	55.2
Resilient Modulus and Tensile Test	633.0	47.3	528.3	59.4

temperatures are commonly used when the penetration test is to be used to indicate temperature susceptibility properties of the binder. The temperature susceptibility value derived from the penetration data is known as the Pen Index. Simply stated, the greater or more positive the Pen Index number, the less temperature-susceptible the binder should be. The equation used to calculate the Pen Index values for this study is a simplified form of the equation used throughout the industry and is a converted as follows:

$$\frac{20 - PI}{10 + PI} = \frac{50\ (\log P77 - \log P39)}{25°C - 4°C}$$

which reduces to:

$$PI = \frac{8.40 - 10 \log (P77/P39)}{.42 + \log (P77/P39)}$$

where

PI = Pen Index

P77 = Penetration @ 77°F

P39 = Penetration @ 39°F

The test method described in the ASTM D 5-86 standard (6) was followed in conducting both the 39°F and 77°F penetration tests. The equipment used to run the tests was a standard penetrometer with an automatic timer (Figure 22) also meeting the appropriate ASTM specifications. The presentation and discussion of these tests as well as the other Phase II binder tests are presented in Section III.

Figure 22. Penetrometer Used to Conduct Penetration Tests.

b. Resiliency

A Resiliency Test was performed on the Phase II modified binders in a fashion similar to the joint sealant industry's standard test for measuring the resiliency of joint sealant materials. The testing procedures in ASTM D 3883 standard (6) were slightly modified to suit the purposes of this study. The following paragraph summarizes the test procedure used in this study.

Initially, a sample of the asphalt binder is hot-poured into a container similar to that used for the Penetration Test. The specimen is air-cured for 24 hours before testing. The specimen is then conditioned in a 77°F water bath for 1 hour where it will remain throughout the testing. A ball penetration tool is substituted for the needle on a standard penetrometer (Figure 23) and forced into the asphalt specimen until a specified penetration depth is reached (Figure 24). The load on the penetration ball is held for 20 seconds, then released, with only the dead weight of the

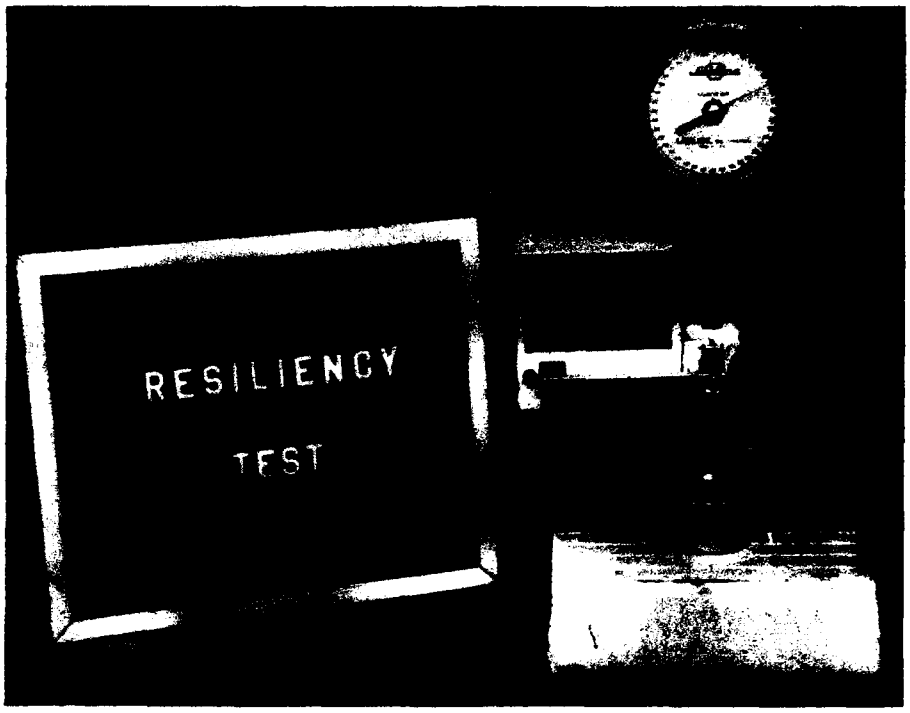

Figure 23. Penetrometer Used to Conduct Resiliency Tests.

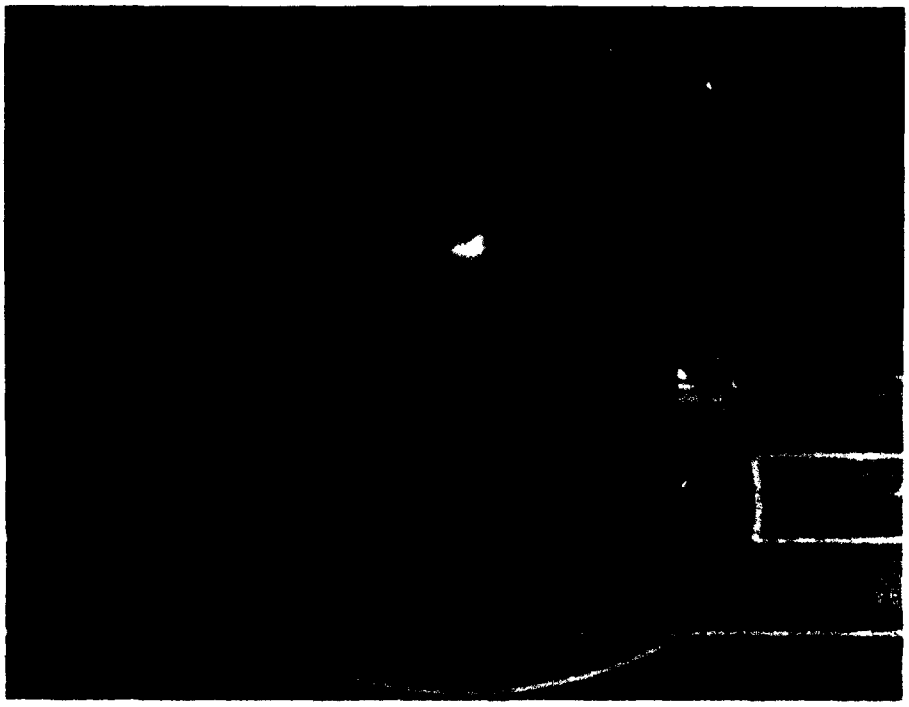

Figure 24. Close-up of Resiliency Test.

penetration ball and loading arm resting on the sample. The resulting elastic deformation recovery is recorded at several time intervals throughout the next 120 seconds. A subsequent percentage recovery versus time plot and, more directly, the final recovery percentage gives an indication of the binder's elastic resilience properties in much the same way as the Creep Rebound Test measures the same properties of an asphalt mixture.

c. Brookfield Viscosity

It was determined during the Phase II test plan development that some sort of binder viscosity measurement would be helpful in the analysis of the effects of the modifiers. However, there were considerations as to the best method for measuring the viscosity of the modified binders. The relatively nonhomogeneous nature of many of the modified binders was predicted to cause problems with some of the more common viscosity test methods. Plugging of viscometer tubes was considered to be one potential problem with the more common kinematic viscosity test.

To avoid the problem of binder inconsistency, a 140°F Brookfield Viscosity Test was conducted on all Phase II binder materials. The test method used was similar to that cited in the ASTM D 2994 standard (6)

Figure 25. Brookfield Viscometer.

which outlines various test methods for rubberized tars. A Brookfield Viscometer, Model LFV (Figure 25) was used to conduct the tests. The Brookfield test differs from other "flow measurement" viscosity tests in that it more or less measures the shear strength of the liquified binder as a small metal spindle slowly spins while immersed in the sample.

There is no direct correlation between Brookfield viscosity and kinematic viscosity or absolute viscosity. The relative changes in Brookfield viscosity were obvious, however, and these changes were used in a comparative analysis to support the modifier effects measured with other tests.

d. Kinematic Viscosity

As stated in the previous discussion of the Brookfield viscosity test, possible problems were predicted with using the standard kinematic viscosity test for testing the modified binders of this study. Nonetheless, two limitations of the Brookfield tests forced an attempt to conduct the kinematic tests on the modified binders. First, since no correlations were found to exist between Brookfield and kinematic viscosities, the usefulness of the Brookfield data became somewhat limited. Second, there was a need to determine temperature susceptibility of the modified binders. One of the most commonly used indicators of temperature susceptibility is the Pen-Vis Number which is derived from kinematic viscosity data.

The test method and equipment described in the ASTM D 2170 standard (6) were used to conduct the 275°F kinematic viscosity tests on all modified binder materials. The three viscometer baths located in the WES laboratories (Figure 26) were used to conduct the tests. Several tests were found to be somewhat distorted by the physical properties of the binder, as predicted, and these considerations will be discussed during the presentation of the test results later in this report.

The following formula was used to calculate the Pen-Vis Numbers (8) by incorporating the results of the 275°F kinematic viscosity test and the 77°F penetration test:

$$\text{Pen-Vis Number} = \text{PVN} = \frac{(-1.5)\ (L - X)}{(L - M)}$$

where

$L = 4.25800 - 0.79674\ [\log (\text{Pen @ } 77°F)]$

$M = 3.46289 - 0.61094\ [\log (\text{Pen @ } 77°F)]$

$X = \log (\text{Kinematic Viscosity @ } 275°F)$

Similar to the interpretation of the Pen Index values, the greater or more positive the PVN value, the less temperature susceptible the binder should be.

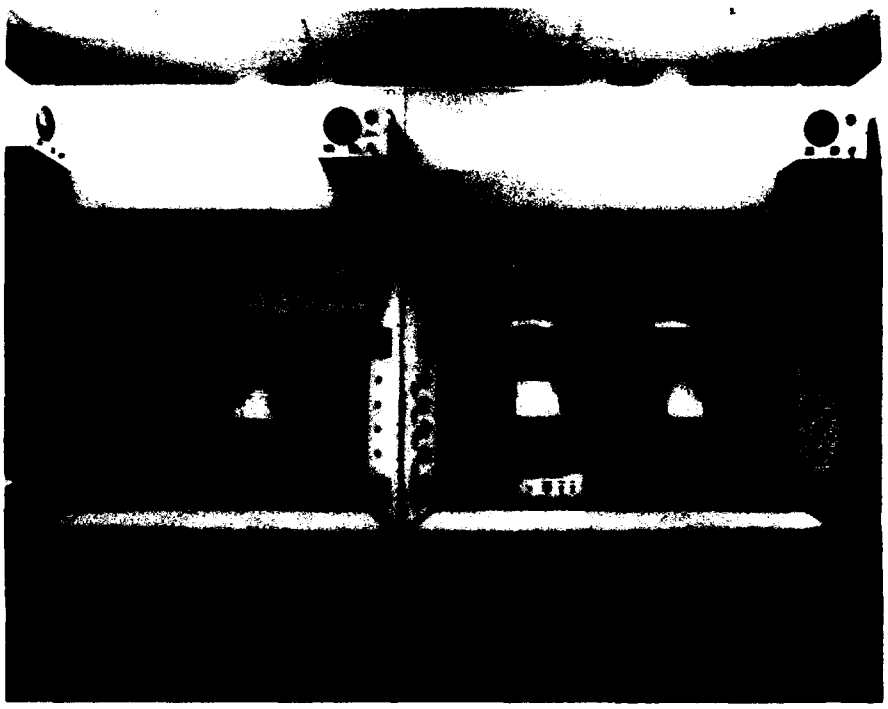

Figure 26. Viscosity Baths Used to Conduct Kinematic Viscosity Tests.

SECTION III

RESULTS

A. DATA ANALYSIS PROCEDURES

A number of approaches were used in analyzing the test results. The different approaches were used individually and combined to provide the evaluation of the modified binders tested.

1. Direct-Magnitude Ranking

In analyzing a group or groups of data, the simplest and most direct method of analysis is to rank the data by magnitude. This method is also useful in grouping data and identifying significant differences between these groups. A direct-magnitude ranking of data will usually answer such questions as "Which one is best?" or "Which ones are different?" With some background history on correlations of laboratory data to field performance, a rough estimate of significance levels may be made. Significance levels may help to answer such questions as "To what extent is this one better?"

Direct-magnitude rankings were performed on most of the Phase I test data and some of the Phase II test data. Since the Phase I test materials were prepared to eliminate many input variables (same base asphalt, aggregates, mix design criteria, etc.), the direct-magnitude ranking analysis effectively displayed the effects of the modifiers. Since the bulk of the Phase II test plan was set up to investigate the effects of several mix variables on only five materials, the ranking analysis was less significant. A few rankings were organized for some of the Phase II binder test data, however.

All magnitude ranking analyses performed on the test results of this study will be presented and discussed later in this section of the report. This type of analysis is of limited value when presented alone. Therefore, additional analyses on the test data were used to supplement the magnitude ranking analysis. This multiple-analysis approach produces test results and conclusions which are much more valid and technically sound.

2. Graphical Analyses

A large number of graphs were produced from all of the differing types of data of this study to allow for a more visual interpretation of

the data. Graphical analyses will often reveal important facets of the test results such as trends and test variable relationships that could otherwise go undetected. The graphical analyses of this study supported many of the project's expected findings but, perhaps more important, displayed many unforeseen data trends and relationships.

Graphical analyses were conducted on practically all sets of data produced by this study. The straightforward design of the Phase I test plan made for relatively easy interpretations of the graphical analyses used to compare the test results of the fourteen test materials. Simple bar graphs and line graphs clearly identified the pertinent trends and relationships in most cases. The inclusion of several test variables and their interactions made the Phase II data more difficult to analyze by graphical methods. The overwhelming number of possible graphical relationships that could be examined from the Phase II test plan made the Phase II graphical analyses time-consuming. Nonetheless, a great deal of information was gained from these analyses.

Many graphs generated from both the Phase I and Phase II data did not reveal any significant findings or were repetitious in the conclusions that could be drawn. Since the presentation and review of these graphs would likely be cumbersome, only a few graphs are presented in this report to represent the types of graphs used in the data analysis.

3. Statistical Analysis

Several statistical analyses were conducted on the groups of data produced from both the Phase I and Phase II data. The purpose of these analyses was to determine which modifiers or modifier groups were significantly different from other modifiers. These analyses were used to support or reject the other analyses of this study. In some cases, significant differences were obvious. In other cases where the differences weren't as obvious, the statistical analysis was needed to highlight and define these significant differences.

All statistical analyses conducted on the data of this study were drawn from a statistical software package known as SPSS/PC+ (9). The first analysis conducted with this package was an analysis of variance to determine if the observed differences between the means of different data populations were true statistical differences. This analysis of variance was

helpful in indicating the existence of one or more significant differences between population means within a given data group. It did not, however, define where the significant differences actually occurred.

To identify those data points found to be significantly different from the other data of a sample population, two types of a multiple comparison procedures were conducted. The two procedures used were the Student-Newman-Kuels (SNK) and the Scheffe Tests. Both procedures used the 95 percent confidence level in determining if group population means were significantly different. Even though the SNK and Scheffe Tests are both multiple-comparison tests conducted at the 95 percent confidence level, they analyze the data in slightly different ways. The Scheffe method treats the data more conservatively and requires larger differences between the means for significance in comparison to the SNK method. Both of these methods were used because of the wide range of variance levels between the different tests of this study.

Since the entire statistical analysis output in hard copy form is several hundred pages long, it will not be presented in that form in this report. A simplified review of the significant differences and where they occurred will, however, be discussed in the presentation and discussion of the test results following in this section of the report.

B. PHASE I RESULTS

In discussing the results and analysis of the Phase I test plan, data from each type of test will be discussed separately at first. Following the presentation and discussion of the individual test results, a compilation of all pertinent Phase I results will be presented and discussed to provide an overall analysis of the data.

1. Marshall Mix Design

The results of the Marshall Mix Design tests relevant to any comparative analysis are presented in Table 5. A quick examination of the optimum asphalt contents derived from the mix design tests reveals little differences between most of the modified mixtures. With the exception of the optimum binder content of the lime-modified mixture being slightly lower and the sulfur-modified mixture being slightly higher, all other modified mixture binder contents are within 0.8 percent asphalt content of each other. Therefore, in using the Marshall Mix Design procedure with the

TABLE 5. PHASE I MARSHALL MIX DESIGN RESULTS.

Test Material	Optimum Asphalt Content (%)	Marshall Stability (lb)	Marshall Flow (.01 in)
Control AC-20	5.0	2160	11
AC-40	4.8	2240	9
Natural Lake Asphalt	5.6	3200	9
Sulfur	6.0	2810	10
Carbon Black	5.4	2460	10
Lime	4.5	2550	11
Ground Rubber	5.4	2040	12
SBR	5.1	2780	10
SBS	5.1	2480	11
Polychloroprene	5.2	2040	11
EVA	4.8	2640	9
Polyethylene	5.0	2570	11
Fibers	5.0	2160	10
Oxidant	4.8	3850	10
Two-Component Polymer	4.9	2080	10

selected design criteria and materials of this study, no significant differences were found in the derived optimum asphalt contents. This theoretically eliminates an economic based decision to choose one of these modifiers over another to realize significant cost savings from reduced asphalt contents.

An analysis of the data taken directly from the Marshall apparatus reveals virtually no differences in the flow values, while fairly significant differences in stability values are evident. Even though all of the stability values are well above the minimum 1800 pounds required for airfield designs, several data groups were identified. The ground rubber, polychloroprene and two-component polymer modified mixtures surprisingly lowered the stability values in comparison with the unmodified mixture, while the fiber-modified and AC-40 mixtures showed very little or no increase in stability.

Another data group, representing a small increase in stability, includes the carbon black, lime, SBS, EVA, and polyethylene-modified mixtures. The next data group, representing a considerable increase in stability, includes the sulfur and SBR-modified mixtures. Finally, the two

modified mixtures that provided for sizeable increases in Marshall stability were the natural lake asphalt and oxidant-modified mixtures with increases of 1040 pounds and 1690 pounds, respectively, over the unmodified AC-20 mixture.

2. Indirect Tensile

The results of the Phase I Indirect Tensile tests are presented in Table 6. The most direct method of analyzing this data was to rank the test materials from the highest tensile strength to the lowest tensile strength for each test temperature. Since asphalt pavement deformation distresses usually occur at higher temperatures, the 77°F and 104°F rankings would be more critical under these circumstances. By dividing the 0°F tensile strength value by the 104°F tensile strength value, a temperature-susceptibility ratio was obtained, whereby larger ratio values indicate a greater temperature susceptibility. The results of these ranking analyses are presented in Table 7. In combining the rankings based on overall performance in the Indirect Tensile tests, several modifier groups were recognized. The natural lake asphalt ranked the highest overall, followed closely by the polyethylene, EVA, oxidant, and AC-40 materials. The next data group included the lime and carbon black modified binders, followed by the polychloroprene, SBR, SBS, and ground rubber modified binders. The last data group, including the sulfur, fiber, and two-component modified binders, were the only materials found that did not improve the overall tensile strength characteristics over the unmodified control AC-20.

The Phase I indirect tensile data was plotted on a temperature versus tensile strength graph so that the resulting modifier curves could be visually analyzed. An example of such a graphical analysis is presented in Figure 27. By comparing the slopes of the curves, temperature susceptibility could be analyzed. Also, the distance separating the curves with respect to the y-axis (tensile strength) indicated a relative degree of improvement in tensile strength over the given range of temperatures. In general, the slopes of the curves were virtually the same at higher temperatures, indicating that the differences in temperature susceptibilities between the modifiers resulted more from low temperature strength values rather that the high temperature values. The only curves which plotted a significant distance above the other curves over most of the temperature range were for the natural lake asphalt and AC-40.

TABLE 6. PHASE I INDIRECT TENSILE TEST RESULTS.

Test Material	Tensile Strength (psi) 0°F	39°F	77°F	104°F
Control AC-20	583.6	345.9	96.7	38.5
AC-40	450.9	445.1	197.7	50.2
Natural Lake Asphalt	600.1	516.5	209.7	60.7
Sulfur	535.1	290.1	91.3	41.9
Carbon Black	605.0	352.3	130.0	47.4
Lime	642.0	401.3	97.8	48.8
Ground Rubber	599.1	349.2	99.3	44.4
SBR	526.5	387.9	131.6	41.3
SBS	476.7	330.0	117.5	48.2
Polychloroprene	630.4	366.0	124.8	43.7
EVA	610.5	391.3	140.9	53.3
Polyethylene	600.3	419.2	156.3	55.0
Fibers	552.4	332.5	82.7	38.9
Oxidant	493.4	386.6	161.9	98.3
Two-Component Polymer	561.6	159.9	97.1	32.1

TABLE 7. PHASE I INDIRECT TENSILE RANKINGS.

Rank	Tensile Strength 0°F	39°F	77°F	104°F	Temperature Susceptibility Ratio
1	Lime	NL Asphalt	NL Asphalt	Oxidant	Oxidant
2	Polychlor	AC-40	AC-40	NL Asphalt	AC-40
3	EVA	Polyethyl	Oxidant	Polyethyl	NL Asphalt
4	Carbon Blk	Lime	Polyethyl	EVA	SBS
5	Polyethyl	EVA	EVA	AC-40	Polyethyl
6	NL Asphalt	SBR	SBR	Lime	EVA
7	Grnd Rubber	Oxidant	Carbon Blk	SBS	SBR
8	CONTROL	Polychlor	Polychlor	Carbon Blk	Sulfur
9	2Comp Poly	Carbon Blk	SBS	Grnd Rubber	Carbon Blk
10	Fibers	Grnd Rubber	Grnd Rubber	Polychlor	Lime
11	Sulfur	CONTROL	Lime	Sulfur	Grnd Rubber
12	SBR	Fibers	2Comp Poly	SBR	Fibers
13	Oxidant	SBS	CONTROL	Fibers	Polychlor
14	SBS	Sulfur	Sulfur	CONTROL	CONTROL
15	AC-40	2Comp Poly	Fibers	2Comp Poly	2Comp Poly

PHASE I INDIRECT TENSILE
Graphical Analysis

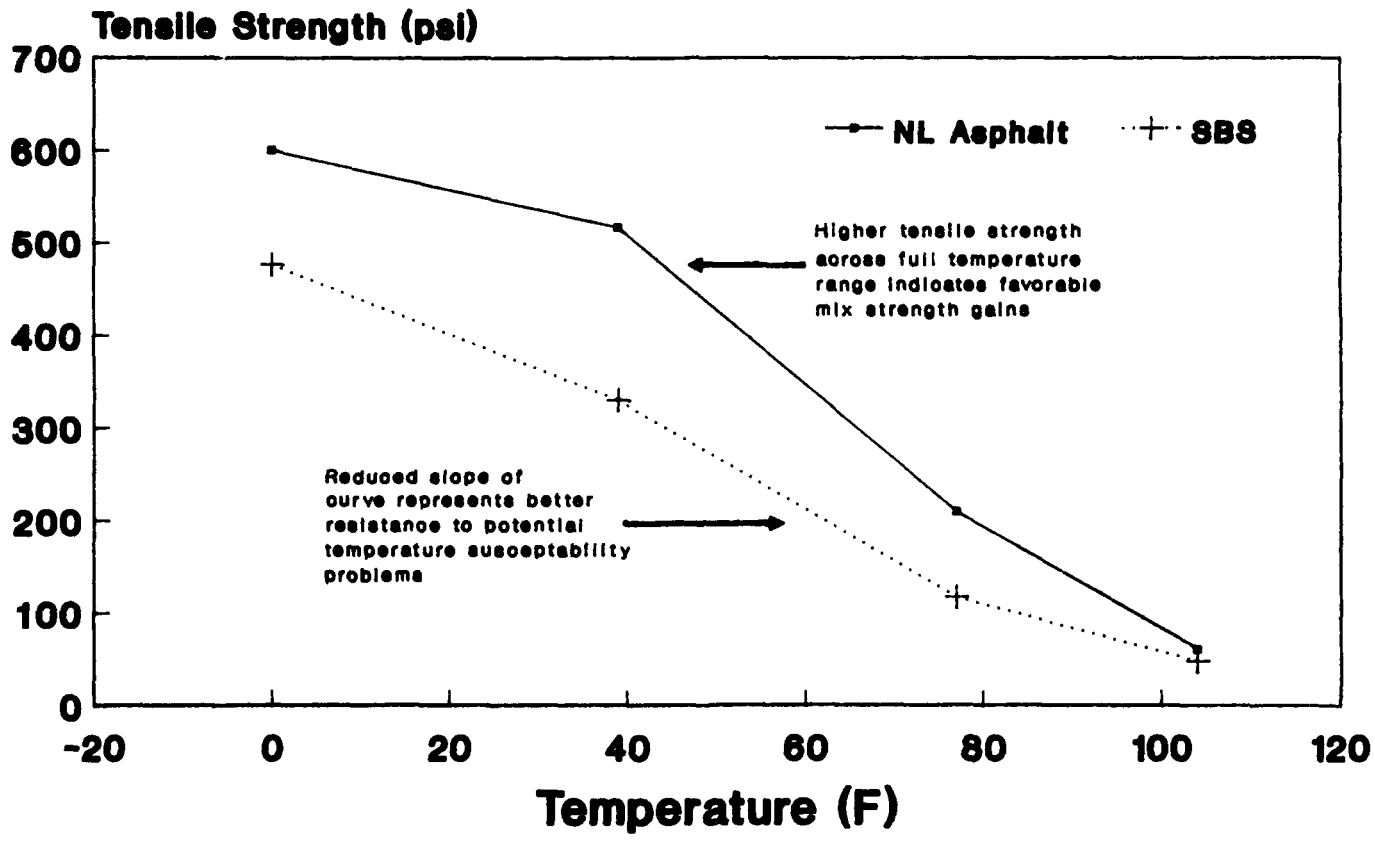

Figure 27. Example of Phase I Indirect Tensile Graphical Analysis.

Since the effect of temperature on tensile strength had already been determined to be relatively uniform, the only statistical analysis conducted on the Phase I Indirect Tensile data was designed to evaluate the effects of the modifiers on the tensile strength at each of the four test temperatures. Those data points found to be significantly different in statistical terms were as follows: At 0°F, the AC-40, SBS, and oxidant materials were significantly lower; At 39°F, the two-component polymer and sulfur materials were significantly lower; At 77°F, the natural lake asphalt and AC-40 materials were found to be significantly higher, while the fiber material was significantly lower; At 104°F, the oxidant and natural lake asphalt were significantly higher and the two-component polymer significantly lower.

3. Resilient Modulus

The results of the Phase I resilient modulus tests are presented in Table 8. Higher modulus values are generally equated with stiffer, more

TABLE 8. PHASE I RESILIENT MODULUS TEST RESULTS.

Test Material	Resilient Modulus (psi) 0°F	39°F	77°F	104°F
Control AC-20	10019511	3149496	328347	97305
AC-40	7694475	8956771	1455688	154087
Natural Lake Asphalt	6164758	2983155	769635	399356
Sulfur	6539716	3440960	1069896	230954
Carbon Black	14292176	2718928	945442	328635
Lime	6327010	4006691	1053338	249985
Ground Rubber	4528393	11326002	1122610	310335
SBR	10700148	2940091	617019	284345
SBS	7633861	1627416	741300	248935
Polychloroprene	21091812	3106965	1930596	201870
EVA	3303198	2452695	436695	167774
Polyethylene	16490165	2584498	621477	202716
Fibers	7660020	2424546	899149	325831
Oxidant	1966176	2859251	432842	171775
Two-Component Polymer	6556570	2728373	621827	144880

rut-resistant asphalt mixes. Since these higher modulus values were more desirable in this study, a ranking analysis at each test temperature was conducted in the same manner as the initial indirect tensile data analysis.

Likewise, an analysis of temperature susceptibility was conducted by dividing a material's 0°F modulus value by its 104°F modulus value and subsequently ranking the entire list of resulting ratios. As was the case for the Indirect Tensile data, the 77°F and the 104°F data is considered to be more critical as these temperatures better represent the pavement temperature range where deformation distresses are likely to occur. The results of the resilient modulus ranking analyses are found in Table 9.

TABLE 9. PHASE I RESILIENT MODULUS RANKINGS.

Rank	Tensile Strength 0°F	39°F	77°F	104°F	Temperature Susceptibility Ratio
1	Polychlor	Grnd Rubber	Polychlor	NL Asphalt	Oxidant
2	Polyethyl	AC-40	AC-40	Carbon Blk	NL Asphalt
3	Carbon Blk	Lime	Grnd Rubber	Fibers	Grnd Rubber
4	SBR	Sulfur	Sulfur	Grnd Rubber	EVA
5	CONTROL	CONTROL	Lime	SBR	Fibers
6	AC-40	Polychlor	Carbon Blk	Lime	Lime
7	Fibers	NL Asphalt	Fibers	SBS	Sulfur
8	SBS	SBR	NL Asphalt	Sulfur	SBS
9	2Comp Poly	Oxidant	SBS	Polyethyl	SBR
10	Sulfur	2Comp Poly	2Comp Poly	Polychlor	Carbon Blk
11	Lime	Carbon Blk	Polyethyl	Oxidant	2Comp Poly
12	NL Asphalt	Polyethyl	SBR	EVA	AC-40
13	Grnd Rubber	EVA	EVA	AC-40	Polyethyl
14	EVA	Fibers	Oxidant	2Comp Poly	CONTROL
15	Oxidant	SBS	CONTROL	CONTROL	Polychlor

A plot of modulus versus temperature for the Phase I data illustrates the data scatter predominantly found in the 0°F and 39°F tests. Since this data scatter created curves of erratic slopes and no discernible trends, the usefulness of the 0°F and 39°F data was greatly reduced. This deduction makes the 0°F, 39°F, and temperature-susceptibility rankings suspect, and therefore left only the 77°F and 104°F rankings useful in the overall Phase I resilient modulus data analysis. In combining the results of the 77°F and 104°F rankings, only three test materials fell into a data group separate from all other materials. The two-component polymer and oxidant modified materials were significantly below the other test materials, and the unmodified control mixture had the least favorable overall

performance in the resilient modulus tests. Thus, all modifiers and alternate binders improved the resilient modulus characteristics to some degree in the Phase I tests.

Since the data scatter of the 0°F and 39°F Resilient Modulus tests made these data unsuitable for a statistical analysis, only the 77°F and 104°F data were input to the statistical program. Although the data scatter of the 77°F data is much less in comparison to the 0°F and 39°F data, it was enough to eliminate all 77°F data points from being considered significantly different from any other 77°F data point. The 104°F data turned out to be quite uniform statistically, therefore no data were found to be significantly different once again.

4. Creep-Rebound

Table 10 includes the results of the Phase I creep-rebound tests. The creep modulus values reported are the modulus values measured at the end of the 1-hour creep loading phase. Likewise, the rebound percentages of this table are the final rebound percentages measured at the end of the 1-hour rebound phase of the test. An important consideration in relation to the modulus and rebound data of both test temperatures is the applied creep load. In an attempt to eliminate testing variables, all test materials were initially tested at 50 psi loads at 77°F and 20 psi loads at 104°F. For some test materials, the resulting axial deformations were relatively small to the point of significantly distorting the resulting modulus and rebound results. An increase in creep load of 33 to 50 percent caused these materials to deflect to a point which yielded consistent modulus and rebound results, as observed in the test replications. One material, the oxidant modified mixture, required a 100 percent increase in test loads to obtain consistent results. When these increased loads were applied to the materials which gave small deformations at the initial loads, the majority of the materials failed in shear. This trial and error testing led to the conclusion that it was impossible to produce valid creep data with identical creep loads for all materials. This fact made it necessary to factor in the varying creep loads as well as temperature when analyzing the modulus and rebound data.

Since the creep modulus value is an indicator of mix stiffness, higher modulus values are generally desirable to decrease rutting

TABLE 10. PHASE I CREEP-REBOUND TEST RESULTS.

Test Material	[77°F] Load (psi)	Modulus (psi)	Rebound (%)	[104°F] Load (psi)	Modulus (psi)	Rebound (%)
Control AC-20	50	40582	33.0	20	15250	60.2
AC-40	50	30909	30.2	20	34421	35.8
Natural Lake Asphalt	75	80412	26.0	30	31064	34.2
Sulfur	75	52009	18.9	30	38893	19.8
Carbon Black	75	53013	20.9	30	22213	26.8
Lime	75	43321	23.3	30	24529	30.9
Ground Rubber	75	58962	42.5	30	13909	30.2
SBR	75	49503	24.0	20	22480	45.3
SBS	75	53560	25.8	30	27968	23.5
Polychloroprene	50	42623	29.7	20	19402	25.8
EVA	75	75479	30.6	30	29272	27.7
Polyethylene	75	46398	21.6	30	37936	37.6
Fibers	50	23645	36.1	20	11449	44.7
Oxidant	100	192759	15.6	40	47580	40.0
Two-Component Polymer	75	54778	34.2	20	22330	30.2

potential. The percent rebound is a measure of the test material's elastic and viscoelastic recovery properties; therefore, higher rebound values are more desirable. Based on these premises and disregarding the creep loads, Table 11 displays a ranking analysis of the modulus and rebound data. By factoring in the creep loads, several materials separate themselves in terms of overall performance in the creep rebound tests. The oxidant, EVA, natural lake asphalt, ground rubber, two-component polymer, and SBS modified materials performed exceptionally well at 77°F, with only the AC-40 and fiber modified materials performing below the unmodified control AC-20. At 104°F, the oxidant, polyethylene, and natural lake asphalt performed exceptionally well, while only the fiber-modified material performed below the AC-20 control.

By comparing the 77°F data with the 104°F data, several temperature related trends were observed. These observed relationships were as follows: The AC-40 and polyethylene materials performed significantly better overall at the higher test temperature. The ground rubber and two-component polymer materials performed much worse overall at the higher test temperature. The rebound (elastic recovery) characteristics of the oxidant modified material were much better at the higher test temperature.

TABLE 11. PHASE I CREEP-REBOUND RANKINGS.

Rank	[77°F] Modulus	[77°F] Rebound	[104°F] Modulus	[104°F] Rebound
1	Oxidant	Grnd Rubber	Oxidant	CONTROL
2	NL Asphalt	Fibers	Sulfur	SBR
3	EVA	2Comp Poly	Polyethyl	Fibers
4	Grnd Rubber	CONTROL	AC-40	Oxidant
5	2Comp Poly	EVA	NL Asphalt	Polyethyl
6	SBS	AC-40	EVA	AC-40
7	Carbon Blk	Polychlor	SBS	NL Asphalt
8	Sulfur	NL Asphalt	Lime	Lime
9	SBR	SBS	SBR	Grnd Rubber
10	Polyethyl	SBR	2Comp Poly	2Comp Poly
11	Lime	Lime	Carbon Blk	EVA
12	Polychlor	Polyethyl	Polychlor	Carbon Blk
13	CONTROL	Carbon Blk	CONTROL	Polychlor
14	AC-40	Sulfur	Grnd Rubber	SBS
15	Fibers	Oxidant	Fibers	Sulfur

The creep rebound testing at only two test temperatures did not lend itself to any useful graphical analyses. Also, without enough supportive data on the true effects of test loads on the creep modulus and resulting percent rebound, there was no way to statistically normalize the data in a way that would eliminate the creep load variable. This, in turn, eliminated the usefulness of a statistical analysis on the creep rebound data.

5. Penetration

The results of the Phase I penetration tests are presented in Figure 28. The materials are ranked from the harder or stiffer materials (low penetrations) to the softer materials (high penetrations) on the graph. This allows for a visual comparison and contrast of the separate modifiers and data groups.

An increase in binder stiffness is normally expected of a modifier or alternate binder proposed to increase a mixture's resistance to deformation distresses. As displayed in Figure 28, this is the case for most of the Phase I test materials. Not surprisingly, leading this group of materials are the two hard asphalts of this study. The reduction in 77°F penetration for these materials could be considered excessive for paving

Phase I Penetration Test

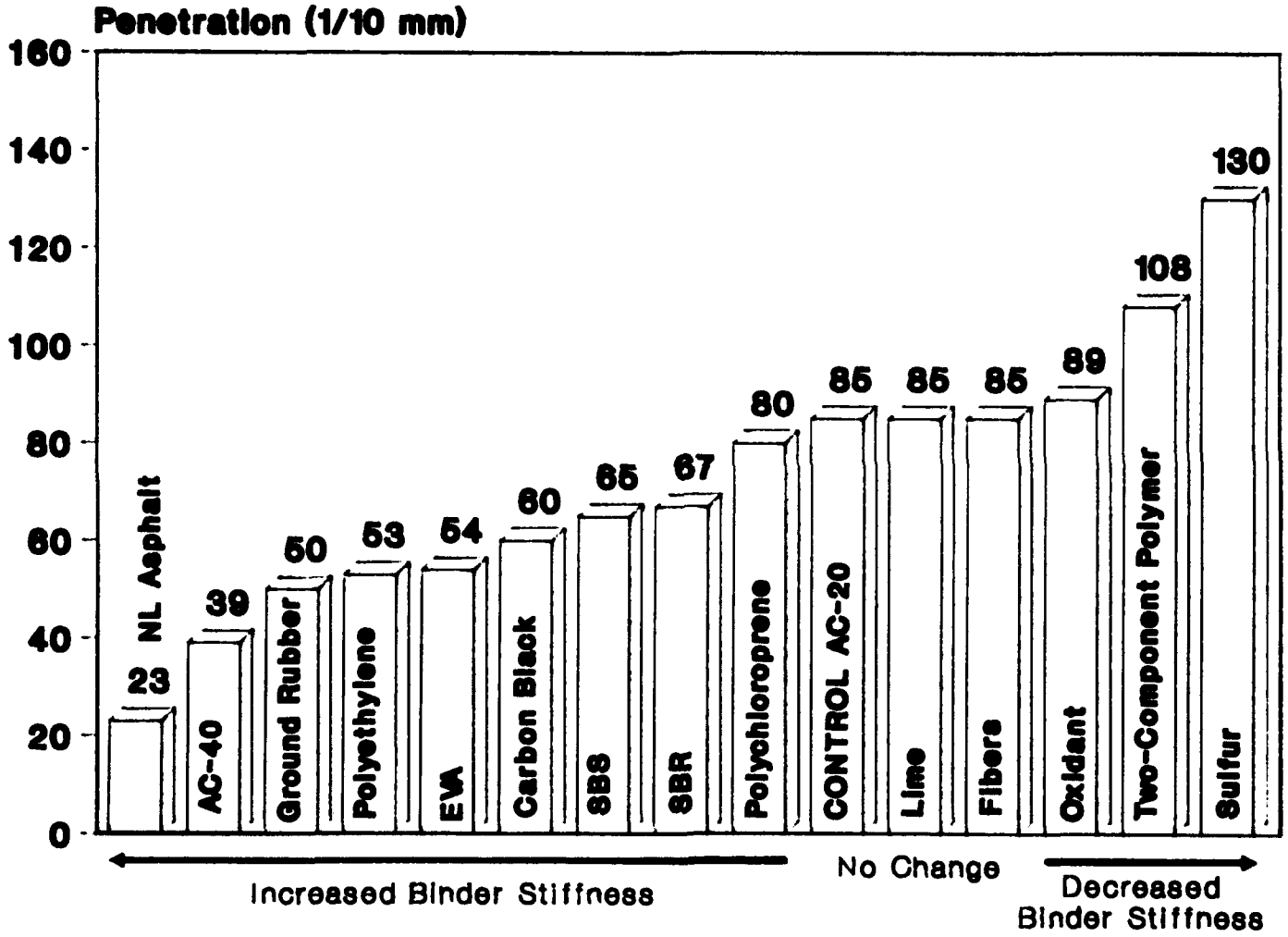

Figure 28. Phase I 77°F Penetration Test Results.

asphalts, as they do not meet the minimum penetration requirements of the appropriate ASTM (6) standard (D 3381, Table 2), which requires a minimum penetration of 40 for the hardest grade cited in Table 2. The rubber and plastic modifier materials make up most of the remaining materials which produced small to moderate increases in binder stiffness. The carbon black filler material was the only modifier outside of the plastic and rubber categories to fall into this data range.

Two modifier materials did not change the binder stiffness as it is described by the 77°F penetration tests. The lime additive did not change the penetration value simply because it was not added to the asphalt mixture through the binder, but rather as a slurry added to the aggregates before mixing with the binder. The lime was intended to react with the asphalt primarily at the asphalt/aggregate interface and, therefore, never really changed the physical properties of the asphalt binder as a whole. Similarly, the fiber additive did not change the penetration of the control asphalt because the fiber modification was designed to only disperse the fibers as evenly as possible throughout the mass of the asphalt-aggregate mixture, not to become a partner with the asphalt in a "semihomogeneous" modified binder system. During the test, unless the penetration needle touched a number of fibers embedded in the binder, an unlikely scenario, the penetration value would be unchanged.

Three test materials were found to increase the 77°F penetration over the unmodified control AC-20. Under the objectives of this study, this may be considered undesirable. A discrepancy between the guidelines of the penetration test and the curing needs of the modified material is a likely explanation for the unexpected penetration increase of two of the test materials. It is entirely possible that the oxidizing reaction of the oxidant modifier and the crystallization reaction of the sulfur and asphalt mixture were not allowed to be completed by the curing requirements of the penetration test, thus distorting the results. The reasons for the increased penetration of the two-component polymer modified binder are unknown, but were reflected in the relatively unsatisfactory performance in the other Phase I tests for this material.

6. Chromatography

The chromatography analysis of this study performed at Clemson University on the majority of the Phase I test materials was directed towards investigating correlations between standard asphalt binder and mix tests and the various outputs of a chromatographic analysis. A comparative analysis of the chromatographic profiles did, however, provide additional insight into the differences between the modified binders on the molecular level. Known relationships between chromatography data and field performance characteristics were also applied to the analysis of the chromatography data.

Because of the physical limitations of the chromatography equipment used, the larger particles of the three filler materials and the fiber material could not be effectively tested. Also, it was discovered that the mobile phase of the technique used substantially dissolved the active ingredient of the oxidant modifier, rendering the resulting profile useless for comparative analysis. The remaining nine materials were tested and analyzed in groups according to the pre-established physical categories, which were hard asphalts, rubbers, and plastics. The resulting chromatographic profiles of these material groups are presented in Figures 29 through 31. The test material codes found in Table 12 are used with each of these graphs.

In analyzing the chromatographic profiles, the differences between the modifier or alternate binder curves and the control AC-20 curve are examined across the full range of molecular sizes. Greater consideration is typically given to the large molecular size portion of the profiles, which is found along the left side of the graph's x-axis. Generally speaking, a greater amount of large molecular size materials, up to a reasonable limit, is known to increase a binder's strength properties (7). An excess of this limit may actually reduce the binder's strength properties, however. Also, excessive large molecular size material has been shown by Jennings (10) to indicate a potential for low-temperature cracking. In practically all cases of the comparative analysis between the chromatographic profiles of this study, the significant differences were found in the large molecular size range. This can be attributed to the fact that this range recognizes the addition of various high-molecular-weight polymers typical of asphalt modifiers and the varying amounts of large molecular size

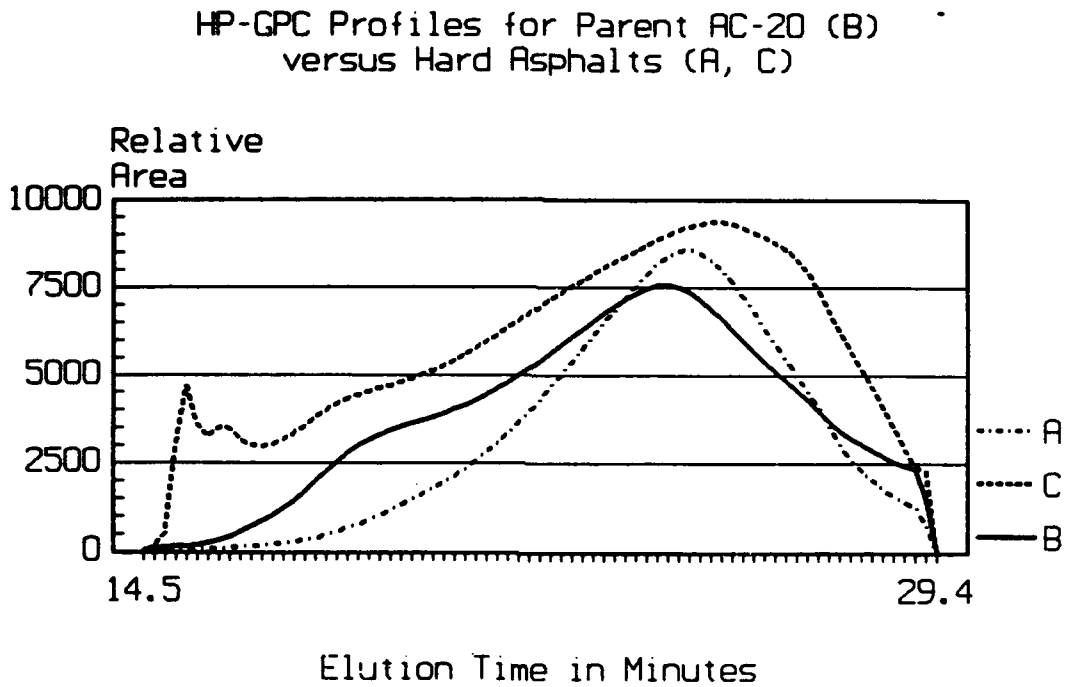

Figure 29. Hard Asphalts Chromatographic Analysis.

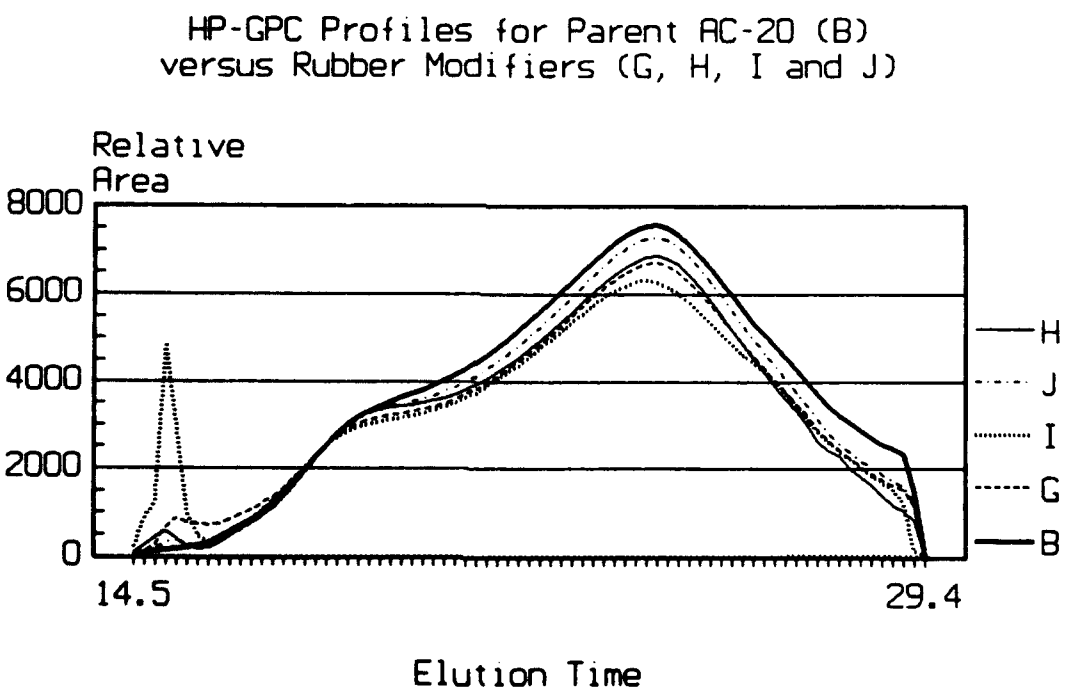

Figure 30. Rubber Modified Asphalts Chromatographic Analysis.

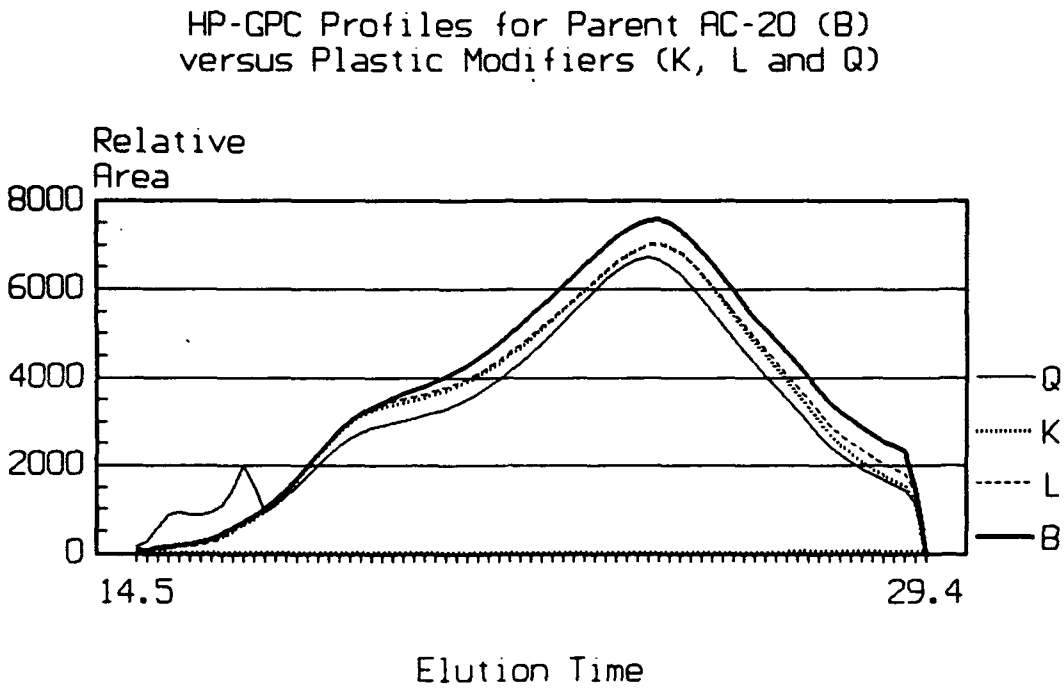

Figure 31. Plastic Modified Asphalts Chromatographic Analysis.

TABLE 12. PHASE I CHROMATOGRAPHY TEST MATERIAL CODES.

Code	Material	Category
A	AC-40	Hard Asphalt
B	CONTROL AC-20	CONTROL
C	Natural Lake Asphalt	Hard Asphalt
G	Ground Rubber	Rubber
H	SBR	Rubber
I	SBS	Rubber
J	Polychloroprene	Rubber
K	EVA	Plastic
L	Polyethylene	Plastic
Q	Two-Component Polymer	Plastic

materials, such as the asphaltenes. Since the test materials of this study were chosen primarily for their ability to increase the binders' and resulting mixtures' resistances to permanent deformation, the analysis looked for some marked increase in the large molecular size range of the profile with limited distortion of the remainder of the curve.

As shown in Figure 29, three distinctively different chromatographic profiles were produced from the two hard asphalts and the control AC-20. In comparing the large molecular size fractions, the natural lake asphalt profile displays a considerable increase in the largest measurable molecular size over the AC-40 and control AC-20. The physical makeup of the natural lake asphalt makes this difference expected; however, the lower amount of large molecular materials in the AC-40, as compared to the control AC-20, was not expected. These results may help to explain the unexpected reduction in low temperature tensile strength, resilient modulus, and 77°F creep modulus of the AC-40 test mixtures as compared to the control AC-20 test mixtures. The vast differences in the large molecular size range are reflected in the remaining portions of the profile curves for this data group.

The chromatographic profiles of the rubber modifiers (Figure 30) display an interesting similarity between each of the four rubber modifier materials. Each of the profiles show an increase of a specific large molecular size range and remain more or less proportionally the same in comparison with the control AC-20. This suggests that each of these four modifiers are altering the molecular size distribution of the modified binder at almost the exact same point. The only difference is the amount of this particular molecular size addition. In terms of the chromatography analysis, they are modifying the asphalt in the same way, only in differing degrees. Following the premise that increasing the amount of large molecular size materials can increase the binder's strength properties, Figure 30 suggests that the SBS modifier should have a greater effect than the other three rubber modifiers. This theory is supported in the Phase I mix test data in the high-temperature tests; therefore, in the case of the rubber modifier analysis, the strength gains proposed by the significant increases in the large molecular size proportions are only realized at higher temperatures. For this study, the higher temperatures are considered the most critical in terms of resistance to permanent deformation

distresses. Therefore, this analysis reflected positively for the SBS modifier.

Figure 31 is a display of the chromatographic profiles of the three plastic modifiers and the control AC-20. The EVA and polyethylene profiles were virtually indistinguishable from each other and from the control AC-20, while the two-component polymer profile was significantly different in the large molecular size range. These profiles indicate that the EVA and polyethylene are both slight additions of a single high-molecular-weight polymer while the two-component polymer modifier adds a much greater level of two different high-molecular-weight polymers. Since the two-component polymer modified materials did not perform as favorably as the other two plastic modifiers in the Phase I mix tests, the theory that a higher amount of large-molecular-size materials transmits to better strength properties is not supported in the plastic modifier analysis. It is possible that either the amount of large-molecular-size materials was too high for the two-component polymer or the polymer materials themselves did not react as favorably with the parent AC-20 as did the polymers of the other two plastic modifiers.

7. Comprehensive Results

At the conclusion of all Phase I testing, there was an immediate need to combine the results of all tests into a comprehensive analysis. The main reason for this need was to reduce the list of test materials to a number which could be thoroughly analyzed in the Phase II test plan. Before the final selection of the Phase II test materials, the Phase II test plan was designed to evaluate five modifiers or alternate binders in addition to the three control AC-20 asphalts. It then became the responsibility of the project's principal investigator and team of consultants to use the Phase I test results and the information gained during the literature review to select five test materials for Phase II testing.

No particular selection criteria or analysis procedures were given to the three project consultants when they were asked to choose the five Phase II test materials. By allowing each member of the Phase II test material selection panel to independently rank the test materials, alternative ways of ranking were permitted and possible prejudices in the selection process were eliminated. At a project meeting held at WES in July of

1987, the project principal investigator, all project consultants, and representatives of WES's Pavement Systems Division and the sponsoring agency met to review the independent Phase I data analyses and agreed upon the five test materials that would be included in the Phase II test plan. The analyses previously presented in this section of the report represent the bulk of the analyses used by the selection panel in making its final selections.

Even with independent analysis and selection procedures, the "best five" lists of each selection panel member were surprisingly similar. It was acknowledged that many of the test materials had merit in one or more of the test areas, but it was clear that a small group consistently outperformed the other materials. One material of this group, the natural lake asphalt, was eliminated from future consideration because of its limited commercial availability. The remaining five materials chosen for inclusion in the Phase II test plan included a hard asphalt, a rubber modifier, the oxidant modifier, and two plastic modifiers. In alphabetical order, these materials are: AC-40, EVA, oxidant, polyethylene, and SBS.

The remaining rubber modifiers and the lime and carbon black fillers followed the leading five materials in overall performance, displaying slight to moderate improvements. The fiber modifier showed no significant improvement over the unmodified AC-20 control. The sulfur and two-component polymer modified mixtures were the only two materials that actually performed worse overall in comparison to the unmodified AC-20 control under the Phase I test plan.

C. PHASE II RESULTS

As was the case for the Phase I data, the test results and analyses of each Phase II test method will be discussed separately. Following the presentation and discussion of all Phase II test methods, an overall analysis of the Phase II test results will be presented. This overall analysis will provide the basis for many of the conclusions and recommendations resulting from this study.

Each of the Phase II test blends represents varying levels of four mix-design elements: modifier type, base asphalt source, binder content, and modifier content. For this reason, each of the Phase II test blends is described by a four-character code with each character identifying one of

the four design elements. Since all of the Phase II data will be presented based on these four digit codes, the test matrix used to derive these codes (Figure 21) may be referenced for the Phase II data tables.

1. Marshall Mix Design

The pertinent results of the Marshall Mix Design tests conducted on the Phase II modified asphalt mixtures are presented in Table 13. Mix design tests were conducted on each of the four modified blends for both of the new base asphalts (1 and 3) as well as the unmodified new asphalt mixtures (E1YQ and E3YQ). As a result, a total of 10 mix design tests were conducted under the Phase II test plan. The data presented in Table 13 for all mixtures containing the original 2 base asphalt (2YQ) and the unmodified AC-40 (F4YQ) were taken from the Phase I test results. The only mix design variable that could be analyzed from the data besides the modifier type is the base asphalt source.

TABLE 13. PHASE II MARSHALL MIX DESIGN RESULTS.

Blend	Optimum Asphalt Content (%)	Marshall Stability (lb)	Marshall Flow (.01 in)
A1YQ	4.6	4300	11
A2YQ	4.8	3850	10
A3YQ	4.9	3500	10
B1YQ	4.9	2400	10
B2YQ	5.1	2480	11
B3YQ	4.6	2440	11
C1YQ	5.1	2325	10
C2YQ	5.0	2570	11
C3YQ	5.0	2240	9
D1YQ	4.5	1970	11
D2YQ	4.8	2640	9
D3YQ	4.8	2400	10
E1YQ	4.9	1900	11
E2YQ	5.0	2160	11
E3YQ	4.8	1850	9
F4YQ	4.8	2240	9

A comparative analysis of the optimum asphalt content results reveals a slight sensitivity to asphalt source for three of the four modifiers. The polyethylene (type C) blends were virtually unchanged by varying the asphalt source. Although the oxidant, SBS, and EVA modified blends had variances of about the same amount, no distinct pattern resulted from these tests. This means that, for the modifiers of this study, the unknown reactions between the modifier and the base asphalt seem to govern the resulting optimum asphalt content rather than the mix design properties of the base asphalt alone. In the overall analysis, however, there appears to be no significant differences between the optimum asphalt contents of any of the modified asphalt blends in Table 13.

With the exception of the oxidant (type A) blends, the asphalt 2 blends produced mixes of slightly higher Marshall stabilities in comparison with the asphalt 1 and asphalt 3 blends. This sensitivity to asphalt source was slightly more pronounced with the oxidant and EVA-modified blends. Usually, however, the Marshall stabilities of the modified mixtures mirrored the relative stabilities of the unmodified mixtures. Therefore, in contrast to the effects of varying base asphalts on the optimum asphalt content, the relative change in the Marshall stability of a modified asphalt mixture seems to be uneffected by any reaction between the modifier and base asphalt. The stabilities generally increased by about the same percentage over the unmodified stabilities within a single modifier group, regardless of the varying base asphalt source. Virtually no significant differences were detected in the Marshall flow values of the various modified mixtures.

2. Indirect Tensile

The results of the Phase II indirect tensile tests are presented in Table 14. The test methods and equation used to derive this data are the same as those described earlier in this report for the Phase I indirect tensile tests. Each data point represents the average of two replicate tests, as is the case for the Phase II resilient modulus and creep rebound data.

To analyze these data, numerous graphs were constructed to evaluate the effects of each of the three mix variables (asphalt source, binder content, and modifier content) which would, in turn, help to determine the

TABLE 14. PHASE II INDIRECT TENSILE TEST RESULTS.

Blend	Tensile Strength (psi)		
	0°F	77°F	104°F
A1YQ	478.8	427.9	204.8
A2XQ	479.4	187.4	97.9
A2YP	547.0	187.6	95.1
A2YQ	493.4	161.9	98.5
A2YR	507.9	209.2	105.9
A2ZQ	520.6	180.1	89.9
A3YQ	546.1	233.4	81.8
B1YQ	685.5	169.1	34.2
B2XQ	523.3	119.1	36.4
B2YP	601.8	115.2	43.7
B2YQ	476.7	117.5	48.2
B2YR	543.0	98.4	41.1
B2ZQ	624.7	110.0	33.1
B3YQ	603.7	142.0	41.4
C1YQ	537.4	285.2	46.5
C2XQ	593.6	131.8	44.9
C2YP	608.9	164.9	45.7
C2YQ	600.3	156.3	55.0
C2YR	650.3	164.8	46.5
C2ZQ	651.9	126.1	47.5
C3YQ	606.2	179.7	40.6
D1YQ	505.3	258.4	37.2
D2XQ	561.8	127.1	46.0
D2YP	641.8	170.9	53.7
D2YQ	610.5	140.9	53.3
D2YR	597.5	151.7	52.7
D2ZQ	633.3	146.4	49.5
D3YQ	599.4	172.7	44.2
E1YQ	414.2	245.4	36.3
E2XQ	570.1	96.9	30.5
E2YQ	583.6	96.7	38.5
E2ZQ	605.0	109.6	32.2
E3YQ	584.3	137.5	30.5
F4XQ	513.5	210.1	50.8
F4YQ	450.9	197.7	50.2
F4ZQ	596.7	206.5	55.3

effects of modification. Also, the statistical analyses described earlier for the Phase I data analysis were conducted with this Phase II tensile strength data. The results of the graphical analysis of this data will be discussed first, with a discussion of the statistical analysis to follow.

In analyzing the varying effects of the three mix variables, graphs such as those in Figures 32-34 were constructed for each modifier as well as the control AC-20 mixtures. The effects of varying the asphalt source were determined by first identifying the fact that the asphalt 1 produced significantly lower tensile strengths at 0°F and higher tensile strengths at 77°F than the other asphalt sources when unmodified. Three of the four modified blends produced the same trends of tensile strength versus temperature with only the SBS rubber modified blend significantly changing the asphalt source/temperature relationships. The SBS modifier caused the asphalt 1 blend to test significantly higher at 0°F and at the same level as the other two asphalts at 77°F and 104°F.

Except for the SBS modified blends no significant changes in tensile strength were caused by varying the binder content in the control AC-20 mixtures at any of the three test temperatures. For the SBS modified tensile strength data at 0°F, the lean binder mixture tested significantly higher than the other two binder content levels, with the rich binder mixture testing significantly higher than the optimum content binder mixture. No significant changes were examined at the other two remaining test temperatures for the SBS-modified blend.

The results of examining the effects of varying modifier contents were similar to previous results. The SBS-modified blend was again the only modifier group to produce any significant changes in tensile strength at any of the three test temperatures. At 0°F, the rich modifier content blend produced significantly higher tensile strengths than the other two modifier content blends, while the lean modifier content blend tested significantly higher than the optimum modifier content. No significant changes in tensile strength were found to exist at the two other test temperatures for the SBS-modified blend.

The statistical analysis performed on the Phase II Indirect Tensile data produced statistical data groups for each of the three mix variables at each test temperature. These data groups are presented in Table 15 and were used to support the findings of the graphical analysis. The

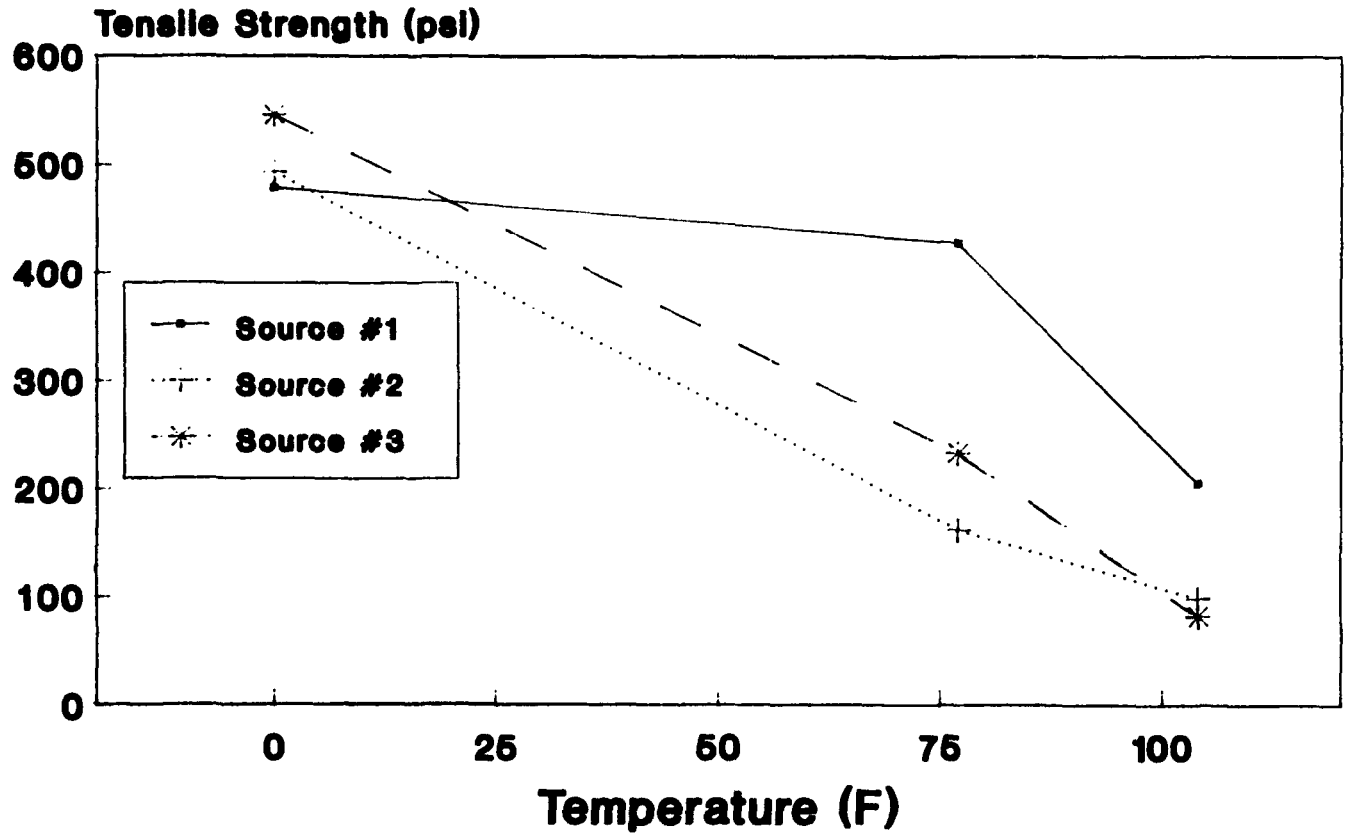

Figure 32. Indirect Tensile Curve of Oxidant Modified Mixture with Varying Asphalt Source.

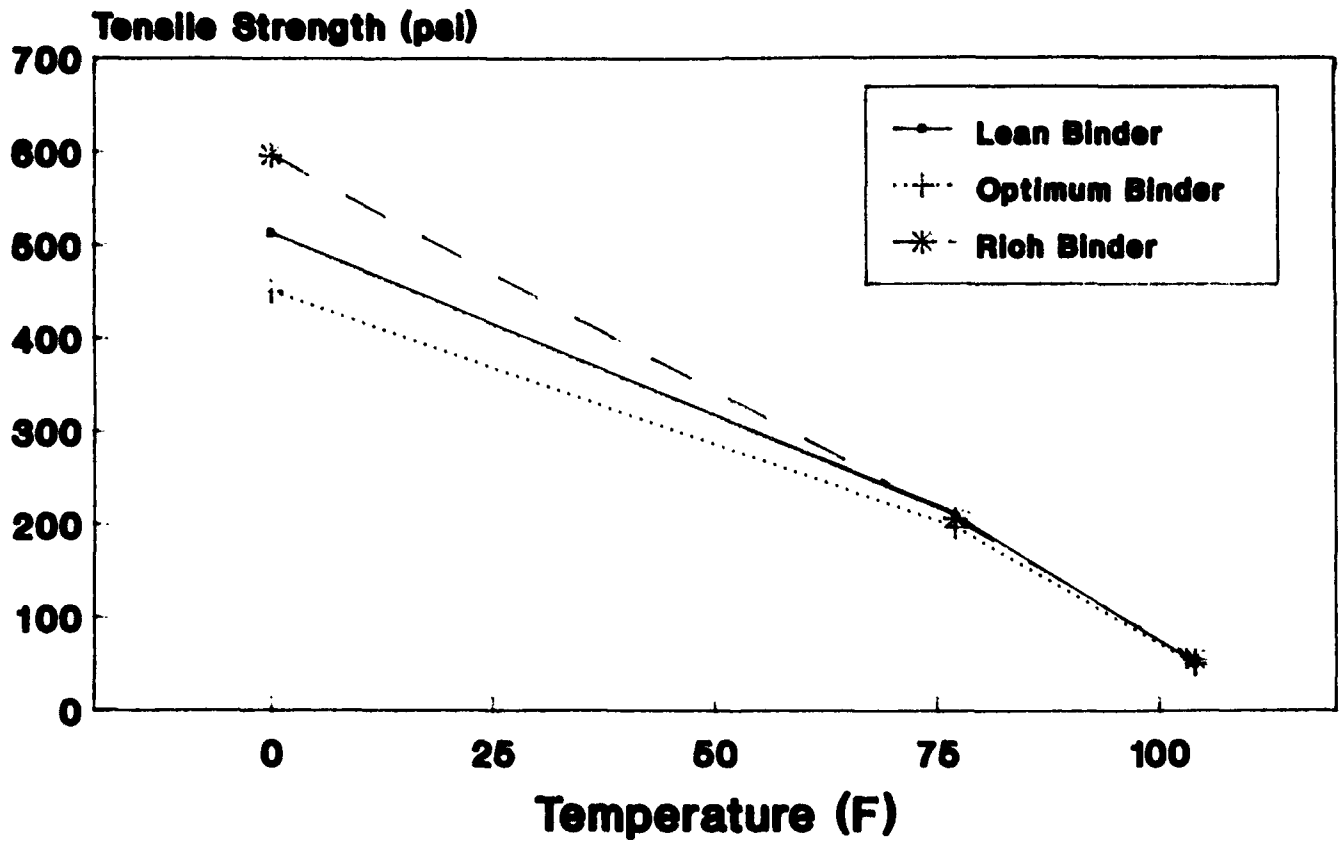

Figure 33. Indirect Tensile Curve of AC-40 Mixture with Varying Binder Content.

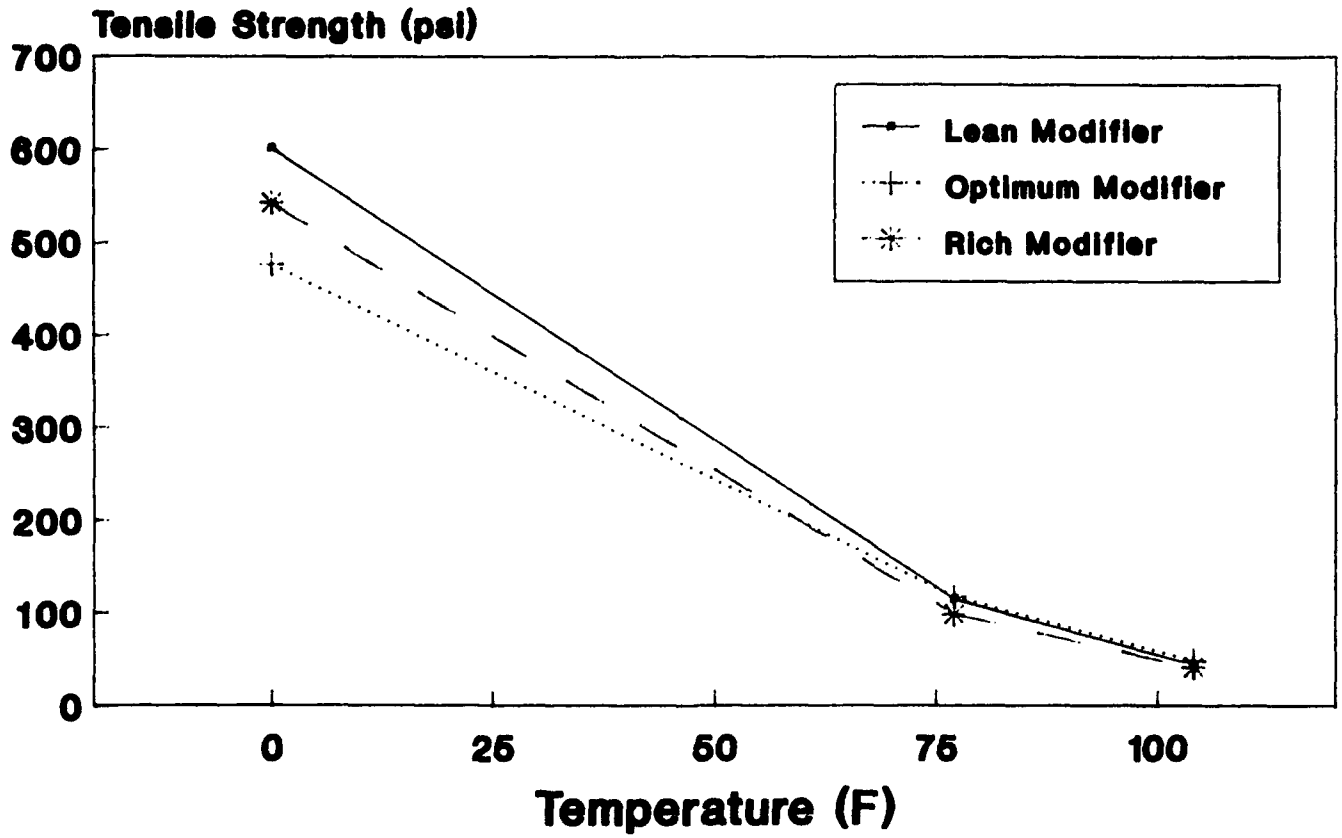

Figure 34. Indirect Tensile Curve of SBS Modified Mixture with Varying Modifier Content.

TABLE 15. PHASE II INDIRECT TENSILE STATISTICAL DATA GROUPINGS.

Modifier	Temp (°F)	Statistical Data Groups: Varying Asphalt Source	Varying Binder Content	Varying Modifier Content
Oxidant	0	None	None	None
	77	1 > 3 > 2	lean,rich>opt.	rich>lean,opt.
	104	1 > 2 & 3	None	None
SBS	0	1 > 3 > 2	rich>lean,opt.	None
	77	1 > 3 > 2	None	None
	104	2 > 3 > 1	opt.>lean,rich	None
Poly-ethylene	0	2 & 3 > 1	None	None
	77	1 > 3 > 2	opt.>lean,rich	None
	104	2 > 1 > 3	None	None
EVA	0	2 & 3 > 1	None	None
	77	1 > 3 > 2	None	lean>rich>opt.
	104	2 > 3 > 1	None	None
Control AC-20	0	2 & 3 > 1	None	NA
	77	1 > 3 > 2	None	NA
	104	2 & 1 > 3	opt.>rich,lean	NA
AC-40	0	NA	rich>lean,opt.	NA
	77	NA	None	NA
	104	NA	opt.>lean,rich	NA

Note: NA = Not Applicable ">" = significantly greater than
"&" and "," = no significant difference

statistical analysis typically identified more significant changes within a data group than the visual interpretations of the graphs.

By the standards of the statistical analysis of this study, the effects of varying the asphalt source were much more pronounced than the effects resulting from the other two mix variables. At 0°F, the asphalt 2 and asphalt 3 blends grouped higher than the asphalt 1 blends for the polyethylene, EVA, and control AC-20 mixtures. The order was reversed for the SBS-modified blend and no significant differences were identified for the oxidant-modified blend at 0°F. At 77°F, the asphalt 1 blends tested significantly higher than the other blends, while the asphalt 3 source blends tested significantly higher than the asphalt 2 blends for all modifier groups. At 104°F, the asphalt 2 blends tested higher than the

other asphalt source blends in all cases except for the oxidant-modified blend which had the asphalt 1 blend rating the highest of the three.

The statistical analysis of varying the binder content at 0°F revealed only two modifier groups which produced significantly different results. For the SBS-modified and AC-40 blends, the rich binder content blends tested significantly higher than the other binder content blends. At 77°F, again only two modifier groups showed significant levels of sensitivity to varying the binder content. The optimum binder content blend tested significantly lower for the oxidant modifier and significantly higher for the polyethylene-modified mixture. At 104°F, the optimum binder content blend tested significantly higher for the control AC-20, SBS, and AC-40 blends while the other modifier groups showed no significant effects from varying the binder content.

Only two modifier/temperature data groups were identified, based on varying the modifier content. At 77°F, the oxidant-modified blend with a rich amount of modifier tested significantly higher than the other modified content blends. Also at 77°F, the lean modifier content EVA blend tested higher than the optimum modifier content blend.

Finally, a statistical analysis of the optimum blends of each modifier was conducted for each test temperature to determine which modifiers performed best in terms of higher tensile strengths at each respective test temperature. At 0°F, the EVA, polyethylene and control AC-20 blends grouped statistically higher than the oxidant, SBS and AC-40 blends. At 77°F, the statistical groupings from highest to lowest are: oxidant and polyethylene; EVA; SBS; AC-20 control. At 104°F, the statistical groupings from highest to lowest are: oxidant; polyethylene, EVA, AC-40 and SBS; AC-20 control.

3. Resilient Modulus

The results of the Phase II resilient modulus tests are presented in Table 16. The test methods and equation used to derive these data are the same as those used for the Phase I resilient modulus tests. Graphical and statistical analyses were conducted with these data in a fashion similar to those described earlier for the Phase II indirect tensile data. Figures 35-37 represent three of the many graphs constructed and analyzed for the data.

TABLE 16. PHASE II RESILIENT MODULUS TEST RESULTS.

Blend	Resilient Modulus (psi)		
	0°F	77°F	104°F
A1YQ	9181040	6157942	746185
A2XQ	6721657	1884460	813472
A2YP	19252025	1720437	1115805
A2YQ	6327010	1053838	249985
A2YR	8841332	2988134	848708
A2ZQ	2262507	3033353	418633
A3YQ	3631382	976988	303570
B1YQ	4228737	839797	122200
B2XQ	6782760	725830	182754
B2YP	3768130	553840	306239
B2YQ	6164758	769635	399356
B2YR	4504007	581452	135779
B2ZQ	9229707	494890	102919
B3YQ	5226030	1551597	193554
C1YQ	15653367	1564208	258665
C2XQ	7011567	894010	740258
C2YP	8433410	834296	208099
C2YQ	14292176	945442	328635
C2YR	7527342	778444	239823
C2ZQ	7822025	589145	212091
C3YQ	6760830	670817	139434
D1YQ	9514486	1650330	207463
D2XQ	7582202	775104	192948
D2YP	12319342	1393175	242120
D2YQ	6539716	1069896	230954
D2YR	9574702	1196282	204187
D2ZQ	10156247	563458	176758
D3YQ	17783007	1333418	202003
E1YQ	7022342	1340755	154399
E2XQ	10499750	570061	132328
E2YQ	10019511	328347	97305
E2ZQ	5970397	653848	98672
E3ZQ	7099995	836712	182853
F4XQ	20856300	1703542	469874
F4YQ	7694475	1455668	154087
F4ZQ	12929300	1394655	212702

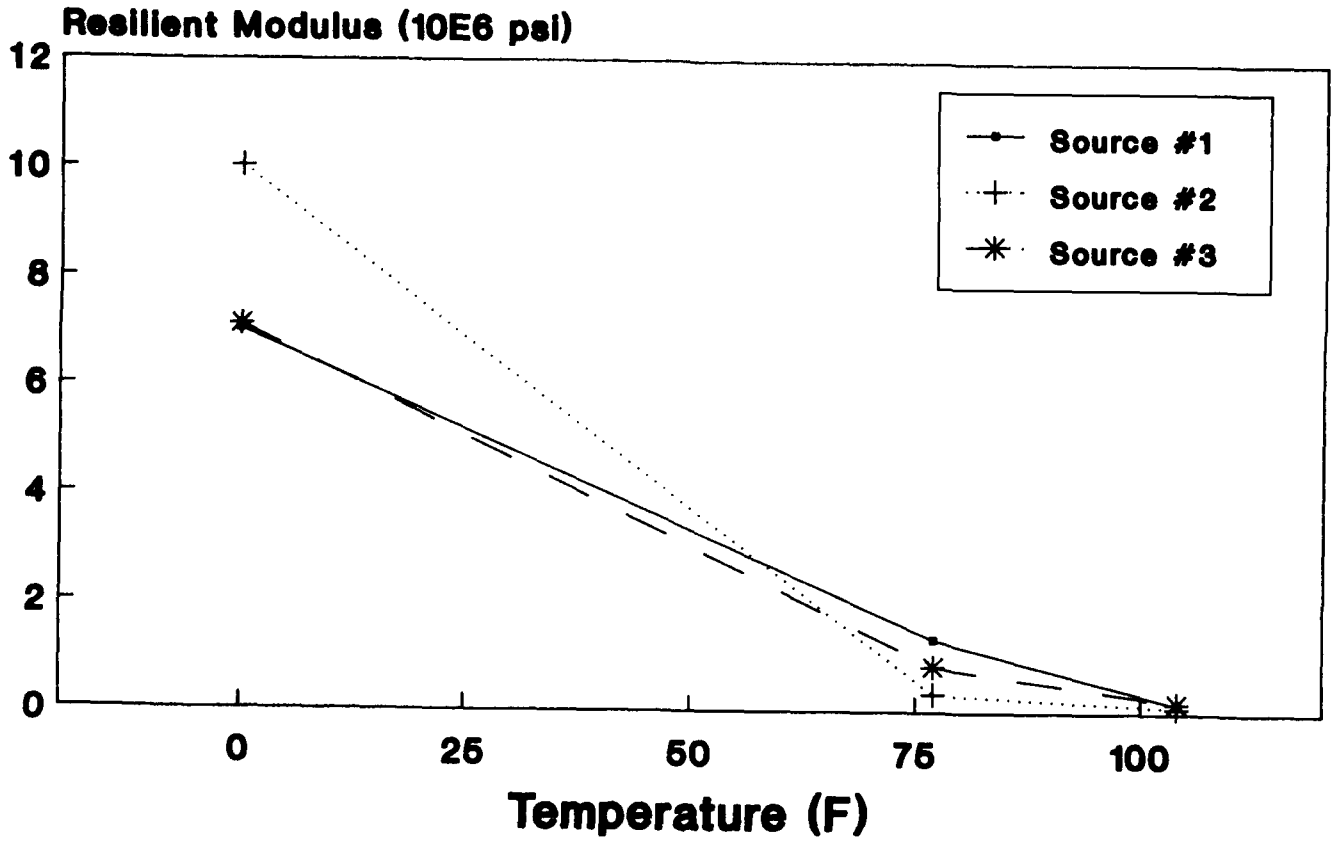

Figure 35. Resilient Modulus Curves of Control AC-20 Mixture with Varying Asphalt Source.

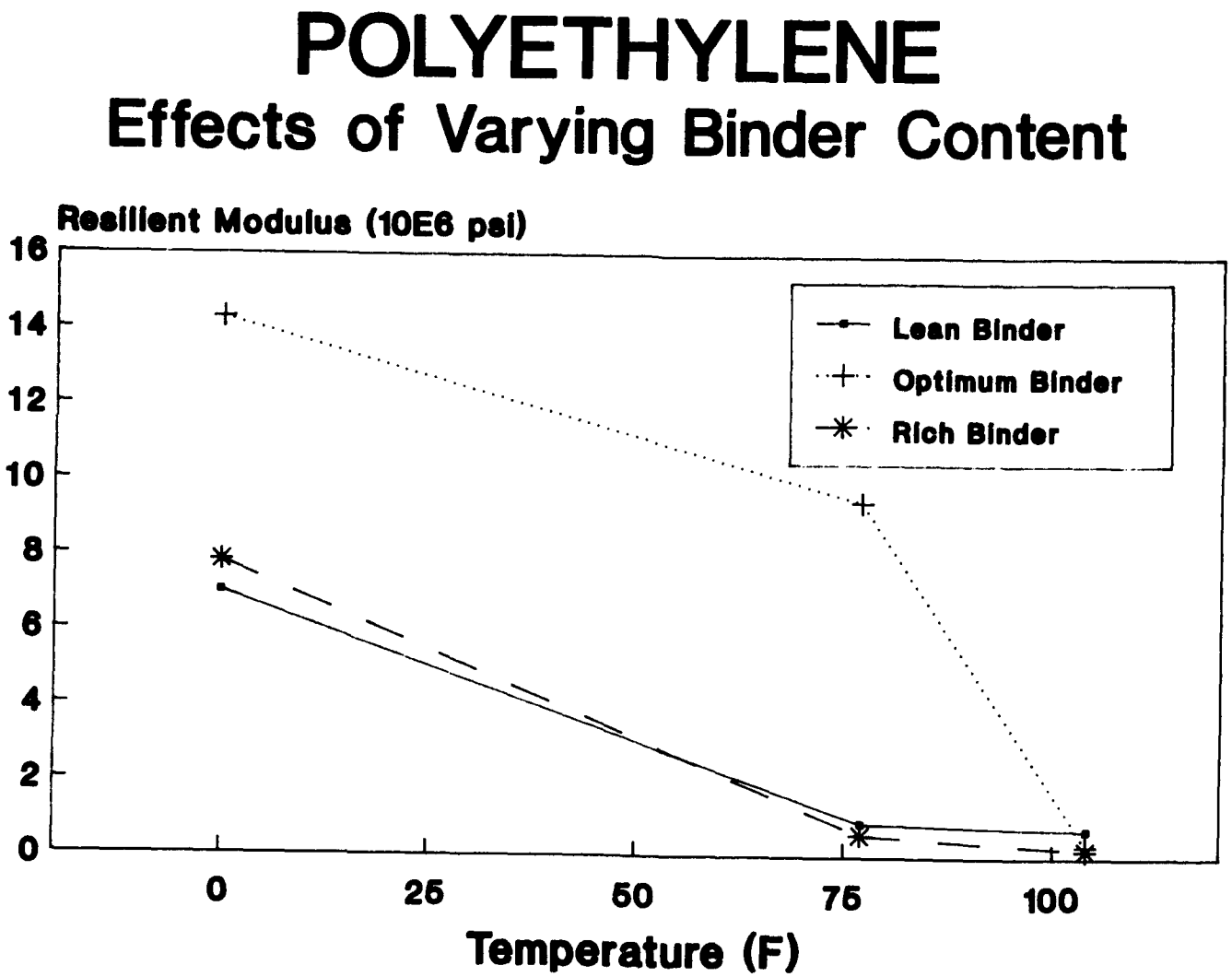

Figure 36. Resilient Modulus Curves of Polyethylene-Modified Mixture with Varying Binder Content.

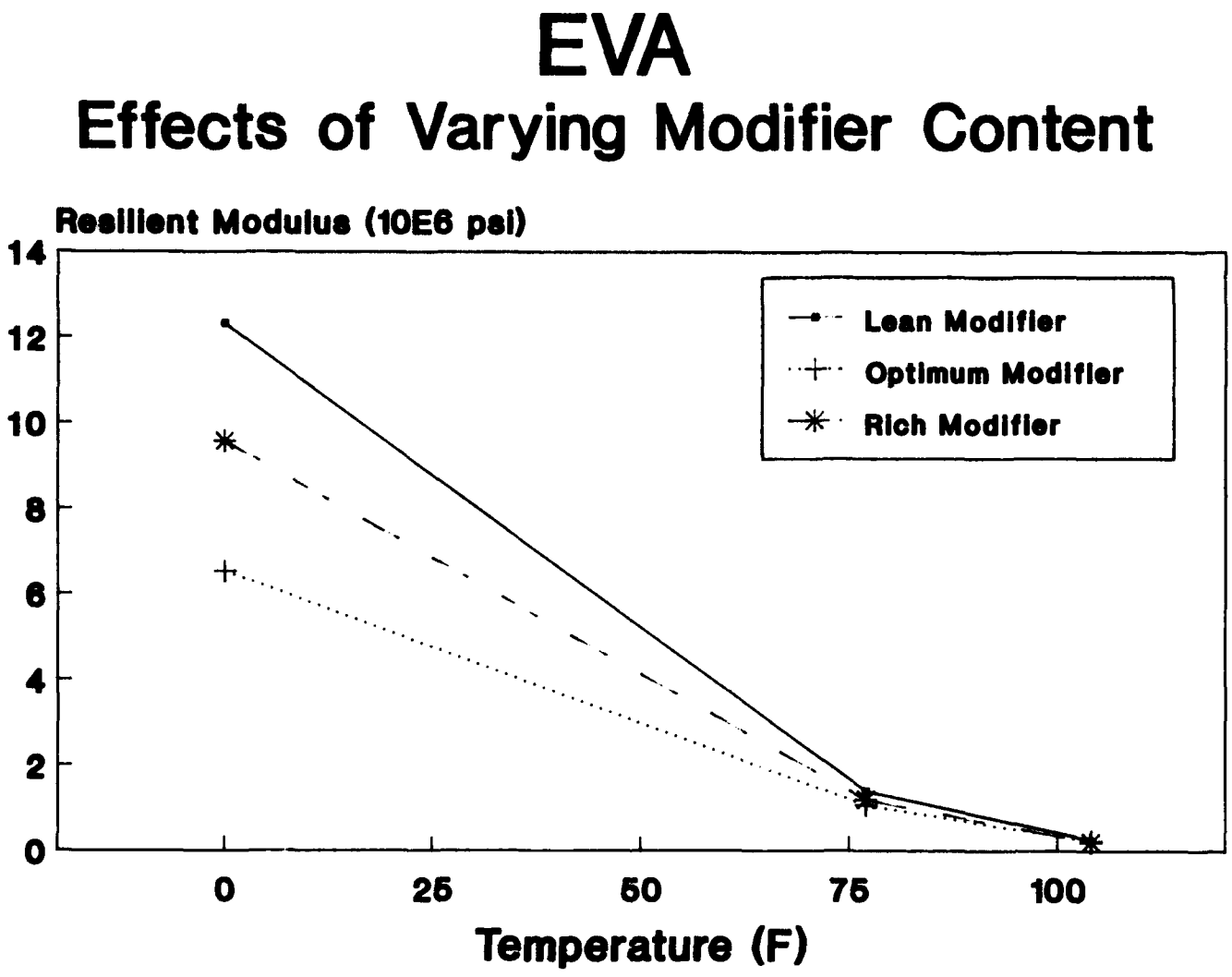

Figure 37. Resilient Modulus Curves of EVA-Modified Mixture with Varying Modifier Content.

In graphically analyzing the effects of each mix variable on resilient modulus, the results varied at all test temperatures and no patterns or trends were detected. Therefore, rather than discussing each of the individual graphical analyses, Table 17 summarizes the effects of the mix variables for each modifier blend at each test temperature. Since a higher resilient modulus is generally more desirable in an asphalt mixture, those blends which plotted higher or greater, as noted in Table 17, are considered to be the better blends.

TABLE 17. RESULTS OF PHASE II RESILIENT MODULUS GRAPHICAL ANALYSIS.

		Statistical Data Groups		
Modifier	Temp (°F)	Varying Asphalt Source	Varying Binder Content	Varying Modifier Content
Oxidant	0	1 > 2 > 3	lean,opt.>rich	lean>opt.,rich
	77	1 > 2 & 3	rich>lean>opt.	rich>lean>opt.
	104	1 > 2 & 3	lean>rich>opt.	lean>rich>opt.
SBS	0	None	rich>lean,opt.	rich>lean,opt.
	77	3 > 1 & 2	lean,opt.>rich	lean>opt.,rich
	104	2 > 1 & 3	opt.>lean,rich	None
Poly-ethylene	0	1 & 2 > 3	opt.>lean,rich	opt.>lean,rich
	77	1 > 2 & 3	lean,opt.>rich	None
	104	1 & 2 > 3	lean,opt.>rich	None
EVA	0	3 > 1 & 2	rich>lean,opt.	lean>rich,opt.
	77	1 > 2 & 3	opt.,lean>rich	None
	104	None	None	None
Control AC-20	0	2 > 1 & 3	lean,opt.>rich	NA
	77	1 > 2 > 3	rich>lean,opt.	NA
	104	1 & 3 > 2	lean,opt.>rich	NA
AC-40	0	NA	lean>rich>opt.	NA
	77	NA	None	NA
	104	NA	lean>rich>opt.	NA

As was expected, the considerable amount of data scatter between replicate test values of resilient modulus had a significant impact on the subsequent statistical analysis. Since the statistical analyses of this study considered the variances of the replicate test values that make up the reported averages, the resulting statistical data groups were almost

always eliminated. Of the 48 statistical analyses conducted for the resilient modulus data, only nine data groups contained data that significantly differed from the other data within the subset being analyzed.

The lack of data trends detected from the graphs and statistical data groups from the statistical analyses probably resulted from the significant amount of data scatter with the resilient modulus results. This eliminates most correlations between resilient modulus and the other test results of this study and reduces the confidence level of using the resilient modulus results in the overall analysis. This point will be accounted for in the discussion of the comprehensive Phase II results, found later in this report.

4. Creep Rebound

The results of the Phase II creep rebound tests are presented in Table 18. The test methods and equation used to derive this data are the same as those described earlier in this report for the Phase I creep rebound tests. Also, the methods used to analyze the data are the same as those used in the Phase I Creep Rebound data analysis.

One test variable that made the creep data somewhat difficult to analyze was the test load. The Phase I blends (denoted as the 2YQ blends in Table 18) were loaded to produce maximum deflections without failure in order for the differing material responses to be more recognizable. Uniform loading conditions were impossible during these Phase I tests, as some test materials failed at a given load, while others deformed very little at the same load. This problem was further accentuated in the Phase II tests, where it was found that only a low test load would work for all blends of a particular modifier. Since the test load value is a part of the creep modulus equation and a higher test load results in a higher creep modulus, the loading variances were considered in the Phase II creep data analysis.

Two sets of data were drawn from the Phase II creep data for analysis. The first data group was the creep modulus, which is interpreted to be a measure of a mixture's resistance to permanent deformation. A higher creep modulus value is more desirable. The second data group analyzed was the creep rebound values. These values are interpreted to measure a mixture's recoverable elasticity properties after severe loading conditions. Higher rebound percentages are more desirable.

TABLE 18. PHASE II CREEP REBOUND TEST RESULTS.

Blend	Load (psi)	[77°F] Modulus (psi)	Rebound (%)	Load (psi)	[104°F] Modulus (psi)	Rebound (%)
A1YQ	40	98501	23.6	30	37529	30.8
A2XQ	40	55977	24.9	20	24537	27.3
A2YP	40	69069	22.3	20	34288	26.8
A2YQ	100	192759	15.6	40	47580	40.0
A2YR	40	76762	29.9	20	38587	34.8
A2ZR	40	51814	20.4	20	40477	32.1
A3YQ	40	68994	32.9	20	46794	30.7
B1YQ	40	45800	36.1	20	33429	40.0
B2XQ	40	39335	28.4	20	25564	38.4
B2YP	40	54661	39.0	20	34144	34.2
B2YQ	75	53560	25.8	30	27968	23.5
B2YR	40	46787	40.5	20	29669	32.6
B2ZQ	40	41309	19.5	20	78848	50.0
B3YQ	40	37780	29.8	20	30098	56.8
C1YQ	40	59409	31.1	20	26829	37.4
C2XQ	40	36601	20.1	20	24827	43.6
C2YP	40	60980	38.8	20	23898	44.5
C2YQ	75	46398	21.6	30	37936	37.6
C2YR	40	53045	23.4	20	33389	59.7
C2ZQ	40	44391	27.8	20	25808	32.7
C3YQ	40	49792	34.4	20	27871	41.1
D1YQ	40	16893	15.2	20	24395	42.2
D2XQ	40	48701	20.5	20	40843	35.5
D2YP	40	39805	31.8	20	27055	25.5
D2YQ	75	75479	30.6	30	29272	27.7
D2YR	40	61570	29.2	20	28186	31.0
D2ZQ	40	54262	37.7	20	37529	36.2
D3YQ	40	58585	26.7	20	23225	35.3
E1YQ	40	33403	21.2	15	17006	29.1
E2XQ	40	30708	25.2	10	34886	25.2
E2YQ	50	40582	33.0	20	5250	60.2
E2ZQ	40	33973	33.4	20	24244	33.7
E3YQ	40	20901	57.5	15	31137	31.7
F4XQ	40	22813	29.1	20	14259	23.0
F4YQ	50	30909	30.2	20	34421	35.8
F4ZQ	40	58274	42.2	20	26508	35.1

To graphically analyze the Phase II creep data, numerous graphs were constructed similar to those represented by Figures 38-43. These graphs related the effects of the three Phase II mix variables, the mix temperature, and the modifier itself. Once again, the results were varied and few patterns or trends were recognized. Tables 19 and 20 display the results of the graphical analyses for the modulus and rebound data, with the greater values considered more desirable in both tables.

Because of the data scatter of the Phase II creep data, the statistical analyses identified only those data points considerably different from the others within a given data group. This helped to identify those test blends which performed significantly better or worse in a more distinctive manner than the graphical analysis. These few statistically significant data groups are discussed in the following paragraphs.

Only three data groups were identified as significantly different by the statistical analysis of the creep modulus with varying asphalt source. The asphalt 3 blend tested significantly higher at 104°F for the unmodified AC-20 blend and the oxidant modified blend. The EVA-modified asphalt 1 blend rated significantly lower at 77°F. In the statistical analysis of varying the asphalt source on creep rebound at 77°F, the asphalt 1 blend rated significantly lower with the EVA blend. Also at 77°F, the asphalt 3 blend rated significantly higher with the oxidant and lower in the unmodified AC-20 mixture. At 104°F, the oxidant modified asphalt 2 blend produced a significantly higher rebound value while the EVA-modified asphalt 1 blend produced a significantly lower rebound value. For the unmodified AC-20 at 104°F, the asphalt 2 blend rebounded significantly higher.

The statistical analysis of the effects of varying the binder content on the creep modulus revealed five significant data groups. The rich blend rated significantly higher at 77°F for the AC-40 mixture and higher at 104°F for the oxidant, SBS, and control AC-20 mixtures. The optimum binder content oxidant blend rated significantly higher at 77°F. Four significant creep rebound data groups were identified in the binder content analysis. The rich binder content blends produced higher rebound values with the EVA and AC-40 blends at 77°F, as well as the polyethylene modified blend at 104°F. Also, the optimum binder content blend of the control AC-20 produced a significantly higher creep rebound at 104°F.

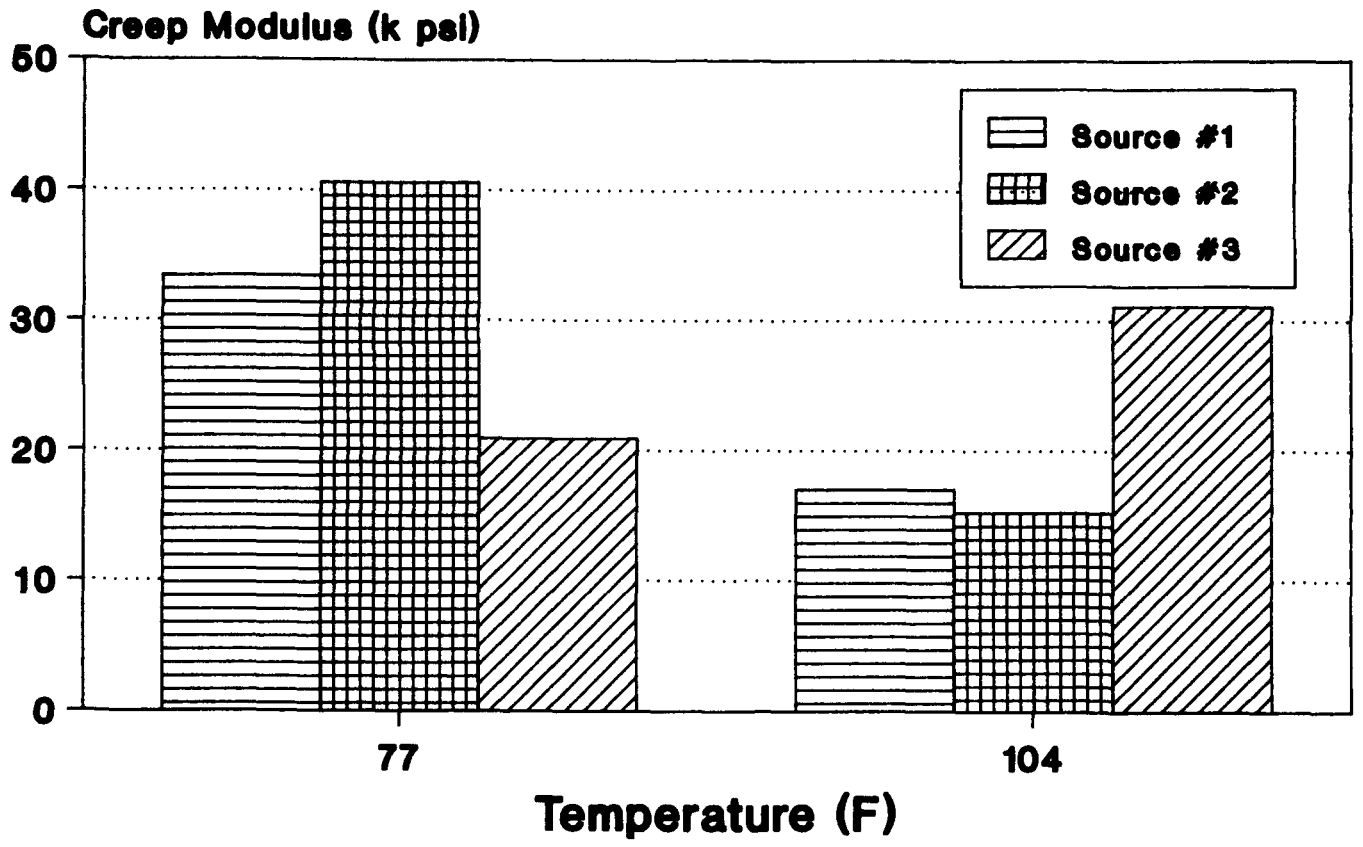

Figure 38. Creep Modulus Graph of AC-20 Control Mixture with Varying Asphalt Source.

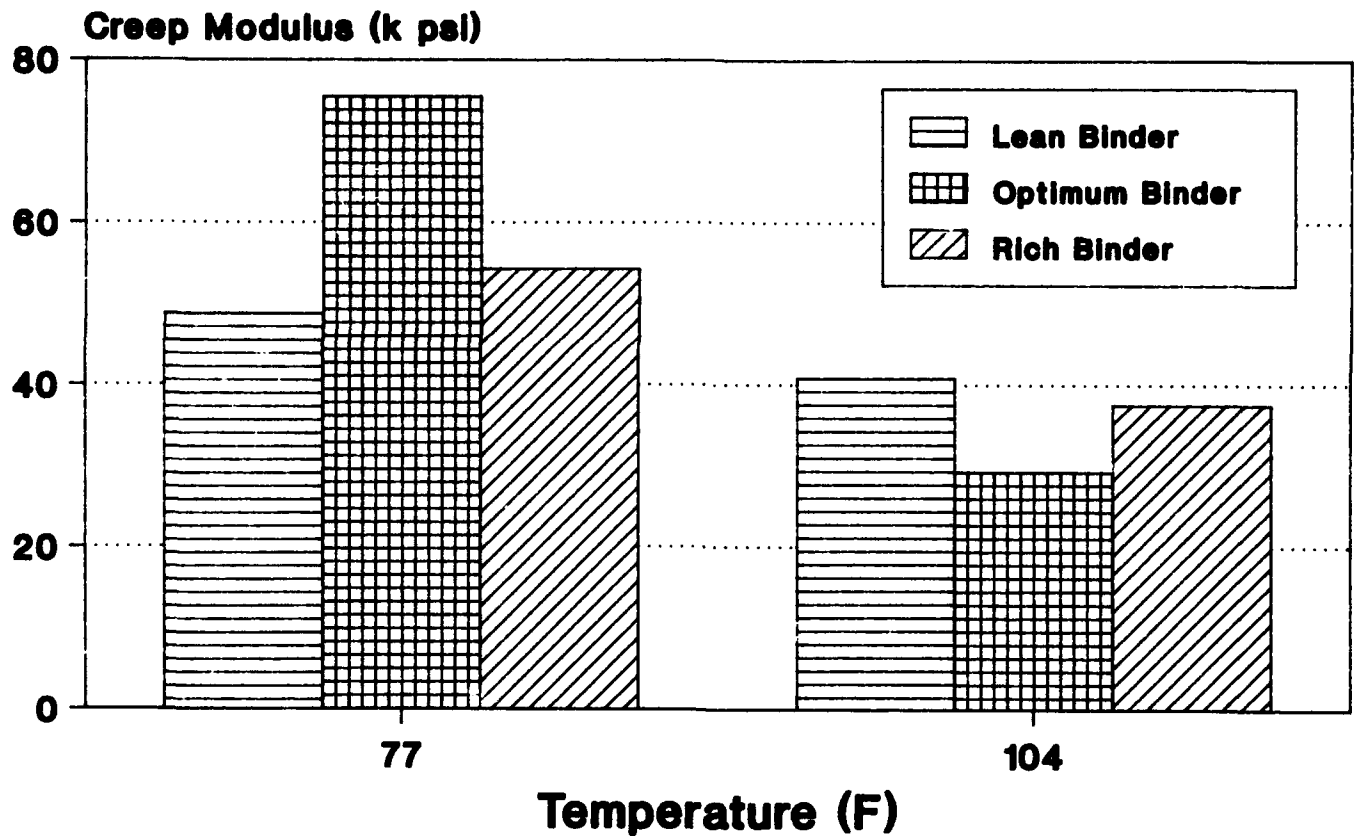

Figure 39. Creep Modulus Graph of EVA-Modified Mixture with Varying Binder Content.

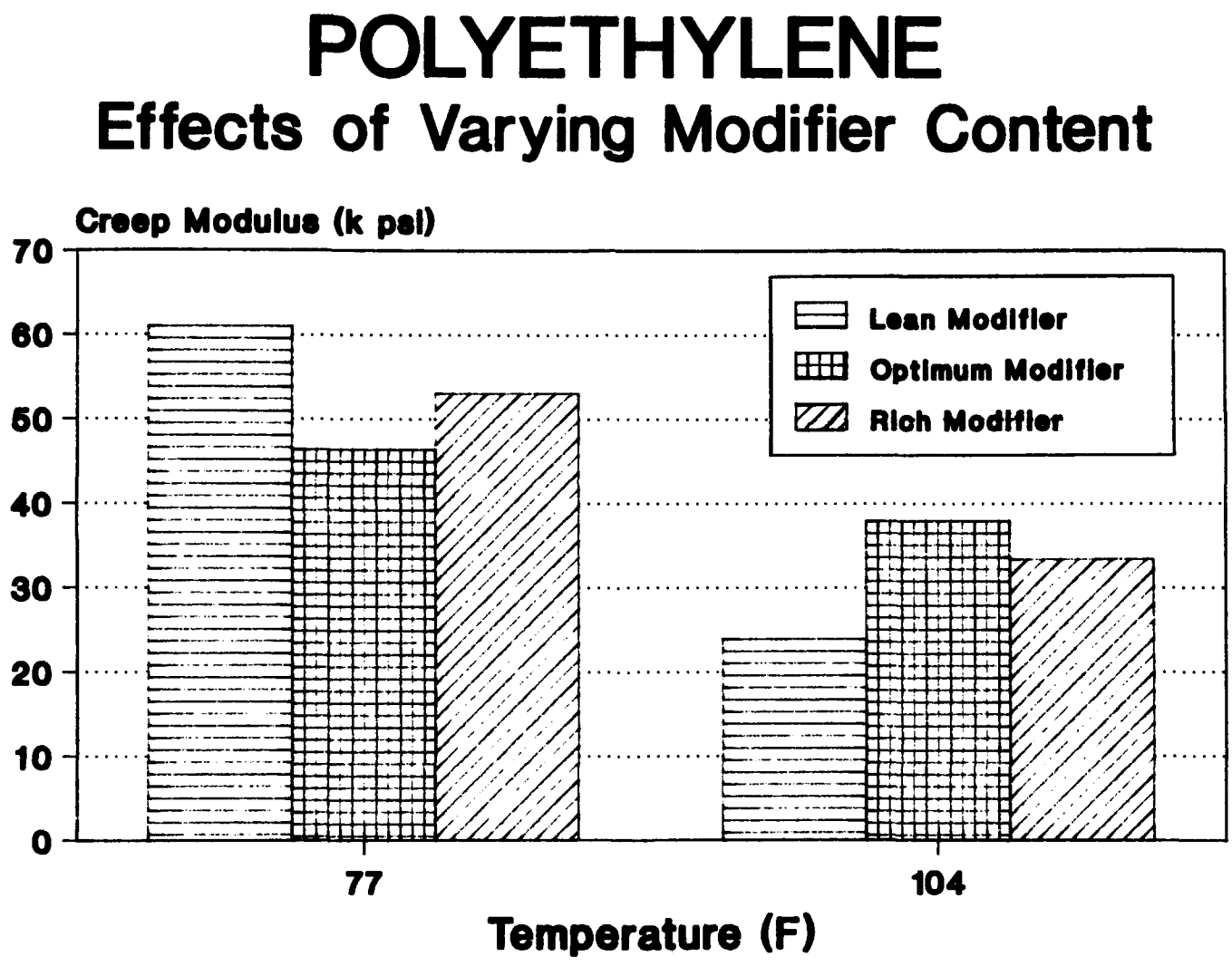

Figure 40. Creep Modulus Graph of Polyethylene-Modified Mixture with Varying Modifier Content.

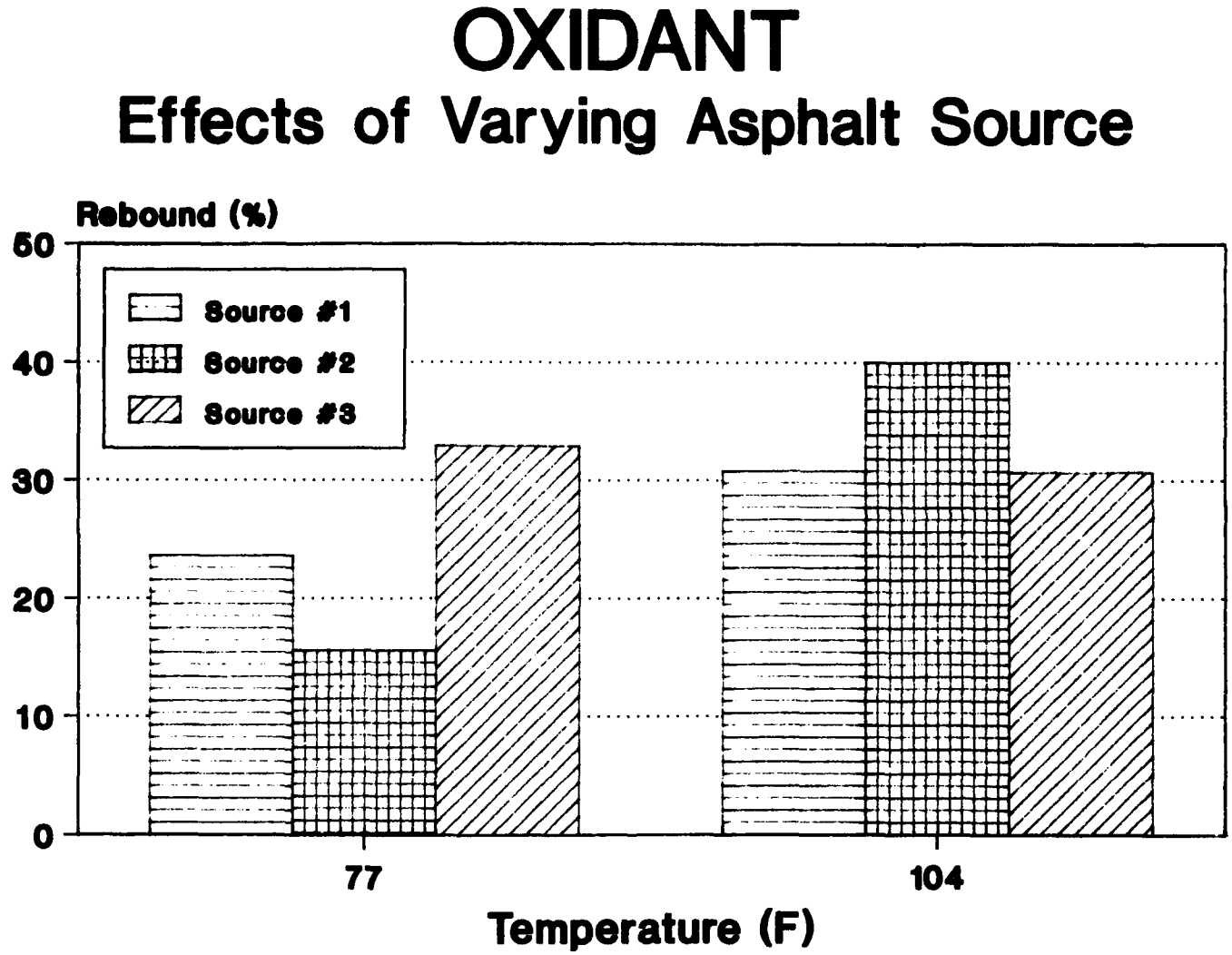

Figure 41. Creep Rebound Graph of Oxidant-Modified Mixture with Varying Asphalt Source.

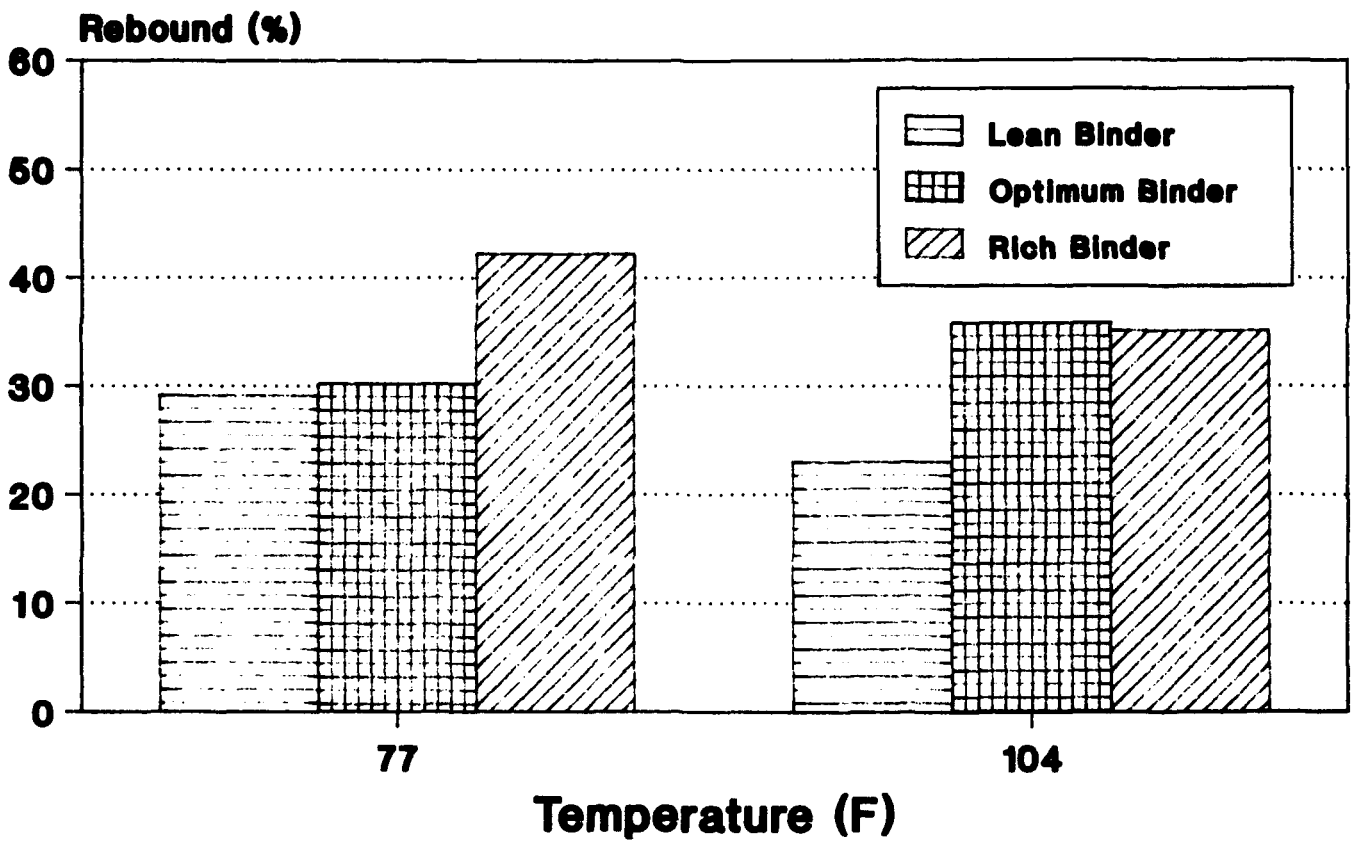

Figure 42. Creep Rebound Graph of AC-40 Mixture with Varying Binder Content.

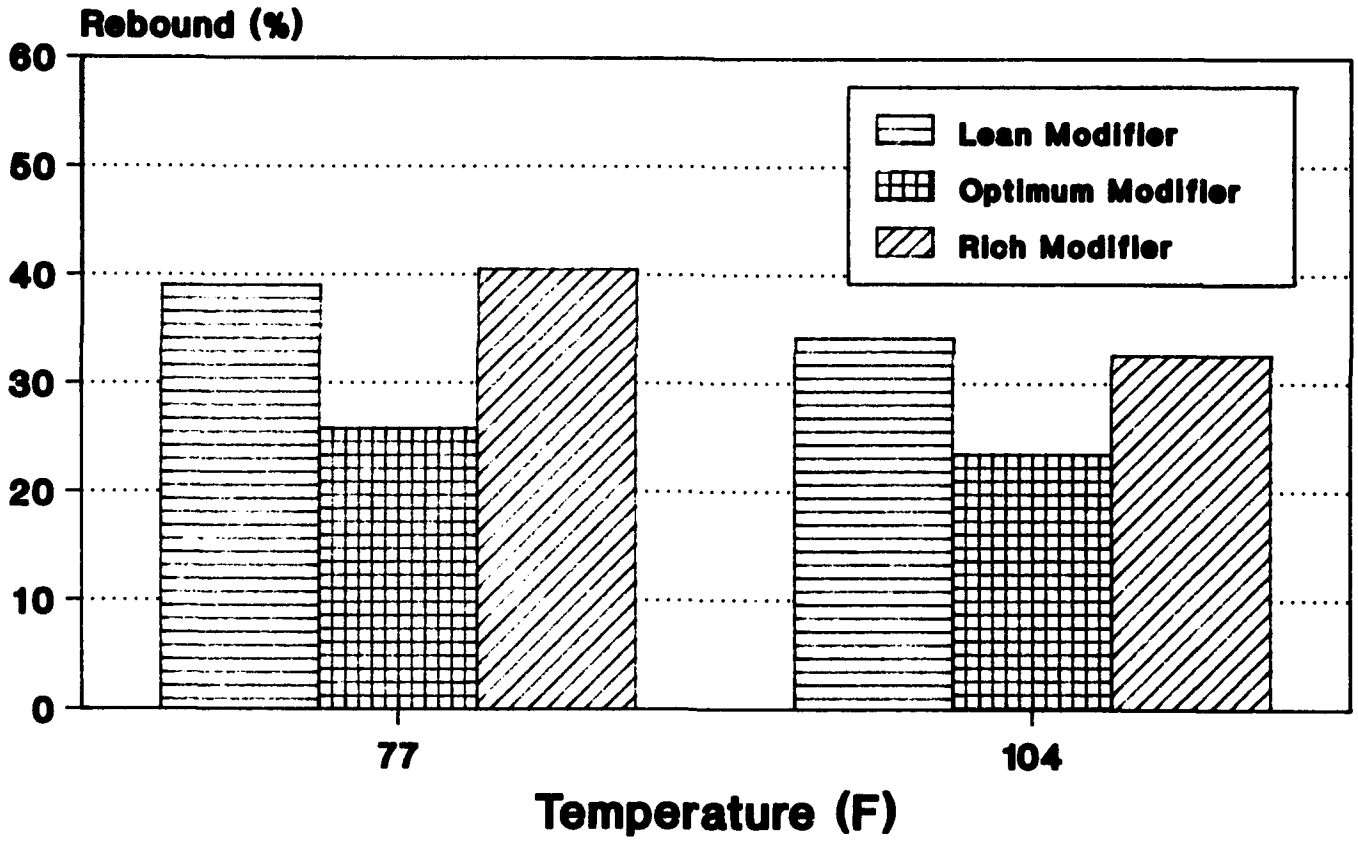

Figure 43. Creep Rebound Graph of SBS-Modified Mixture with Varying Modifier Content.

TABLE 19. RESULTS OF PHASE II CREEP MODULUS GRAPHICAL ANALYSIS.

Modifier	Temp (°F)	Statistical Data Groups: Varying Asphalt Source	Varying Binder Content	Varying Modifier Content
Oxidant	77	2 > 1 & 2	opt.>lean,rich	opt.>lean,rich
	104	2 & 3 > 1	opt.,lean>rich	opt.>lean,rich
SBS	77	1 & 2 > 3	None	None
	104	None	rich>lean,opt.	None
Poly-ethylene	77	1 > 3 > 2	None	lean>rich>opt.
	104	None	None	rich>lean,opt.
EVA	77	2 & 3 > 1	None	opt., rich>lean
	104	None	lean,rich>opt.	None
Control AC-20	77	1 & 2 > 3	None	NA
	104	3 > 1 & 3	lean>rich,opt.	NA
AC-40	77	NA	rich>lean,opt.	NA
	104	NA	opt.>rich,lean	NA

TABLE 20. RESULTS OF PHASE II CREEP REBOUND GRAPHICAL ANALYSIS.

Modifier	Temp (°F)	Statistical Data Groups: Varying Asphalt Source	Varying Binder Content	Varying Modifier Content
Oxidant	77	3 > 1 > 2	None	rich>lean>opt.
	104	2 > 1 & 3	opt.>rich,lean	opt.>rich>lean
SBS	77	1 > 3 > 2	lean,opt.>rich	lean,rich>opt.
	104	None	rich>lean,opt.	lean,rich>opt.
Poly-ethylene	77	1 & 3 > 2	rich>lean,opt.	lean>opt.,rich
	104	None	None	rich>lean,opt.
EVA	77	2 & 3 > 1	rich>lean,opt.	None
	104	None	None	None
Control AC-20	77	3 > 1 & 2	None	NA
	104	2 > 1 & 3	opt.>lean,rich	NA
AC-40	77	NA	rich>lean,opt.	NA
	104	NA	opt.,rich>lean	NA

No significant effects on the creep modulus were caused by varying the modifier content, according to the statistical analysis. Three data groups were identified as being significantly different for the creep rebound and varying modifier content analysis. The optimum modifier content of the SBS blend rebounded significantly less at 77°F. For the polyethylene-modified blend, the lean modifier content rebounded significantly more at 77°F and the rich modifier content blend rebounded significantly higher at 104°F.

Finally, a statistical analysis was conducted to rate the modifier groups based on their performances at each test temperature. At 77°F, the modifier groups ranked in the following order, from best to worse, based on the creep modulus data: oxidant; EVA; SBS, polyethylene, and control AC-20; AC-40. No modifiers were significantly different at 77°F, as evaluated by the creep rebound data analysis. Likewise, no modifier groups rated significantly higher or lower under the creep modulus analysis at 104°F. In the creep rebound analysis at 104°F, the unmodified AC-20 rated significantly higher and the SBS modified blend rated significantly lower.

5. Penetration

The results of the Phase II penetration tests are presented in Table 21, which includes the results of the other Phase II binder tests. The Phase II analysis of the penetration data consisted of combining the 39°F and 77°F penetration values into a penetration index (found in Table 22), and then evaluating the effects of varying the asphalt source and modifier content on this "pen-index" or "PI" number. A discussion of the penetration index and the equation used to calculate it is found earlier in this report. As it is used in this study's analysis, the penetration index is an indicator of a binder's temperature susceptibility where a larger PI indicates less temperature susceptibility and hence better field performance.

The pen-index values were evaluated graphically as shown in Figures 44 and 45. Figure 44 shows the effects of varying the asphalt source on the modified binder's pen-index values. In all cases, the index values of the modified binders approximated the index values of the unmodified control AC-20. The asphalt 2 rated best, followed by the asphalt 3 and then the asphalt 1. The EVA blend did little to improve the pen-index

TABLE 21. PHASE II BINDER TESTS RESULTS.

Blend	Penetration (39°F)	Penetration (77°F)	Brookfield Viscosity (cP) (140°F)	Brookfield Viscosity (cP) (275°F)	Kinematic Viscosity (275°F, cSt)	Resiliency Rebound (%)
A1YQ	15	54	515000	740	244	-21.6
A2YP	38	78	204500	1150	441	-15.1
A2YQ	44	81	497500	1350	452	-15.4
A2YR	40	82	350000	950	438	-18.1
A3YQ	40	90	273000	750	382	-47.0
B1YQ	21	58	*	2975	908	2.0
B2YP	35	56	*	0250	1330	40.0
B2YQ	38	54	*	5650	2124	45.0
B2YR	37	49	*	4150	4198	60.0
B3YQ	30	51	*	3600	1812	47.0
C1YQ	7	26	550000	9500	672	3.0
C2YP	22	51	715000	5275	1596	0.0
C2YQ	26	51	532500	8200	2106	3.7
C2YR	21	44	795000	9700	3233	7.0
C3YQ	20	49	060000	8950	1558	7.0
D1YQ	10	35	278000	1275	426	0.0
D2YP	28	53	672500	2375	1117	13.0
D2YQ	37	48	942500	2300	1250	22.0
D2YR	29	47	280000	1850	1324	23.0
D3YQ	23	46	560000	950	943	20.0
E1YQ	11	40	755000	1575	270	-13.2
E2YQ	64	85	657500	2250	478	-13.0
E3YQ	33	80	582500	2175	407	-16.0
F4YQ	7	35	700000	1700	334	-9.0

* Binder too viscous to test.

TABLE 22. PHASE II BINDER TEMPERATURE-SUSCEPTIBILITY PROPERTIES.

Blend	Penetration Index (PI)	Pen-Vis Number (PVN)
A1YQ	2.91	-1.55
A2YP	7.21	-0.36
A2YQ	8.39	-0.28
A2YR	7.22	-0.31
A3YQ	6.32	-0.41
B1YQ	4.63	0.34
B2YP	10.19	0.83
B2YQ	12.00	1.42
B2YR	13.25	2.22
B3YQ	9.37	1.13
C1YQ	2.73	-0.78
C2YP	6.05	0.96
C2YQ	7.68	1.34
C2YR	7.00	1.72
C3YQ	5.57	0.88
D1YQ	3.07	-1.18
D2YP	8.07	0.51
D2YQ	13.64	0.55
D2YR	10.02	0.61
D3YQ	7.48	0.13
E1YQ	2.85	-1.66
E2YQ	13.20	-0.14
E3YQ	5.66	-0.45
F4YQ	1.26	-1.49

values over those of the control AC-20 with only slight improvements for the asphalt 2 and asphalt 3 blends. The oxidant and polyethylene blends did not significantly improve the asphalt 1 and asphalt 3 blends, and substantially reduced the pen-index of the asphalt 2 blend. The SBS blend, which was the most favorably ranked as a result of this analysis, improved the pen-index values of the asphalt 1 and asphalt 3 blends considerably while only slightly reducing the asphalt 2 blend's pen-index.

Figure 45 displays the effects of varying the modifier content on the binder's penetration index. Very little change was caused by varying

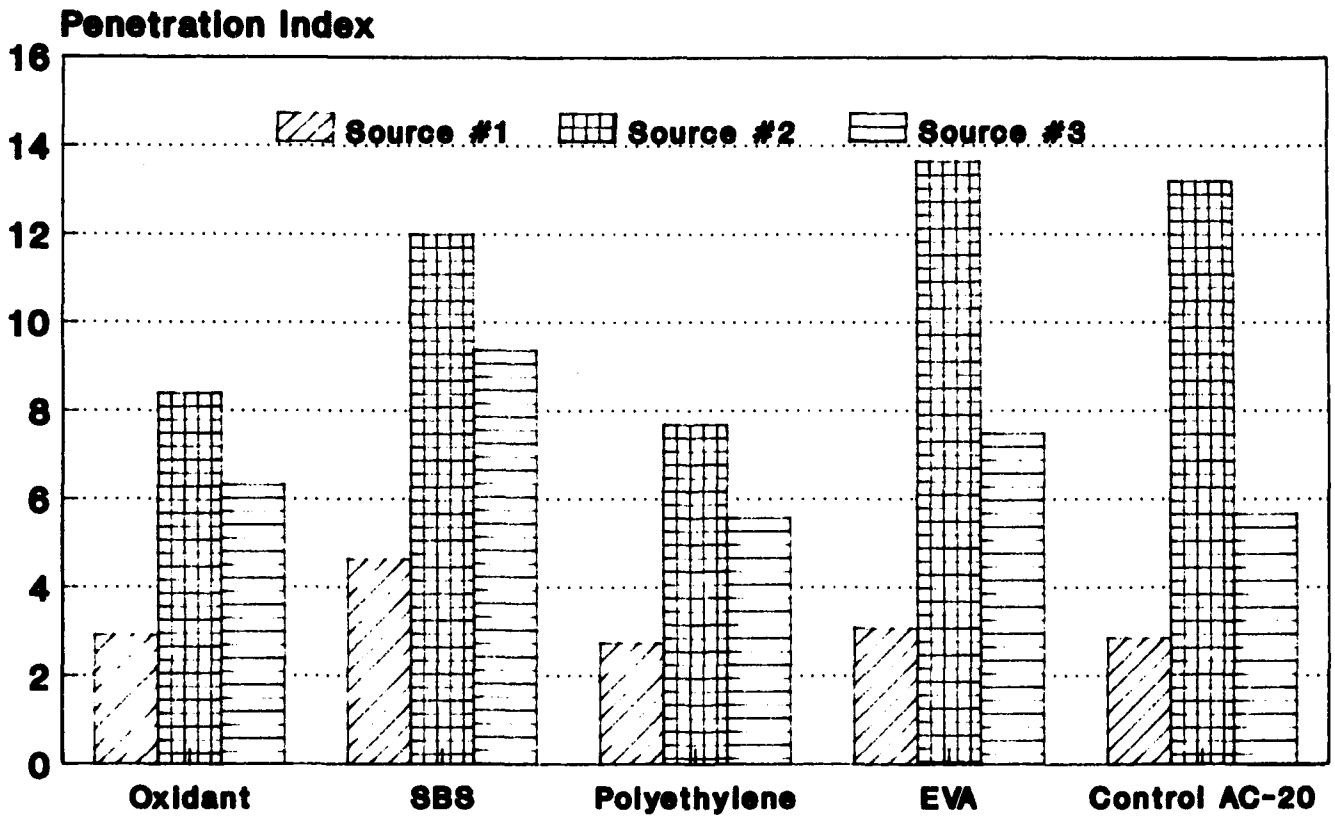

Figure 44. Graph of Penetration Index with Varying Asphalt Source.

PENETRATION INDEX
Effects of Varying Modifier Content

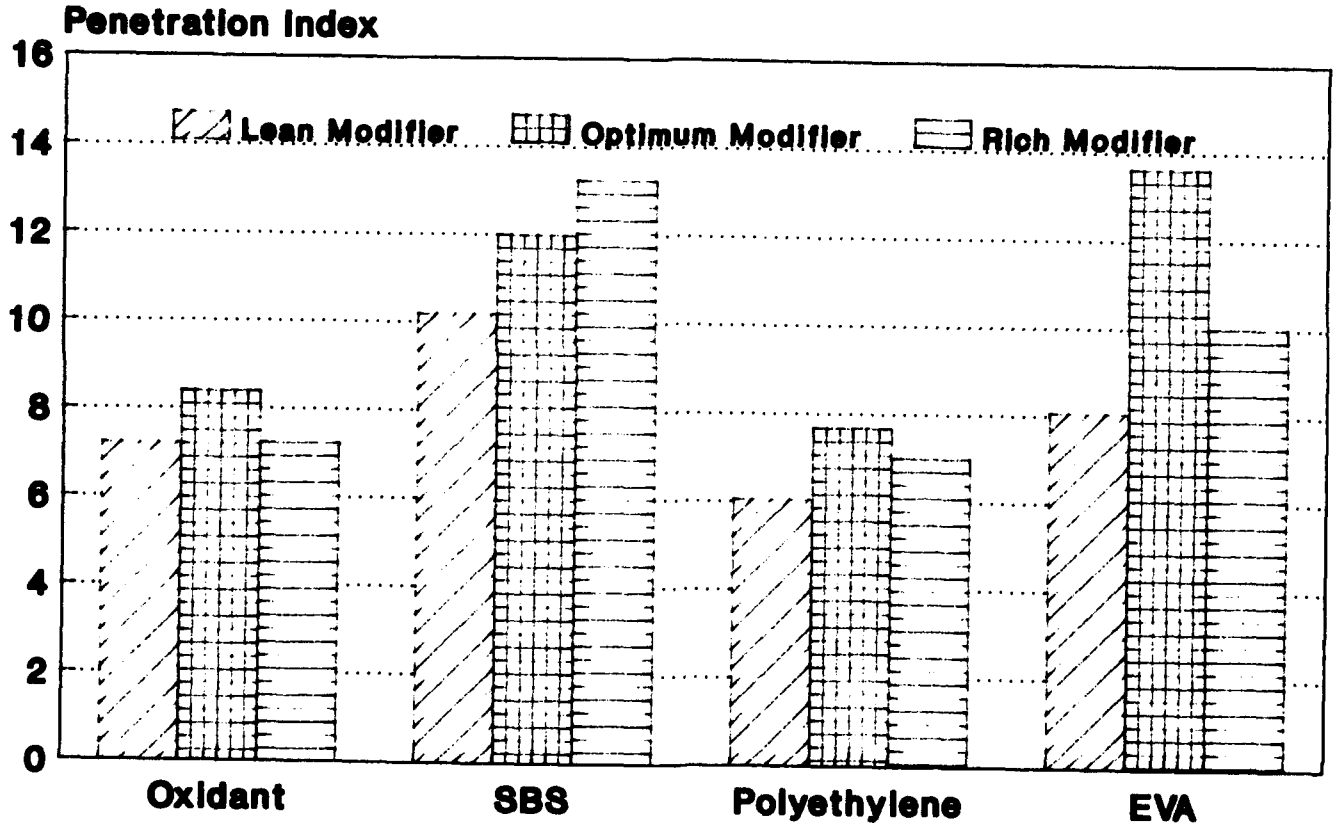

Figure 45. Graph of Penetration Index with Varying Modifier Content.

the modifier content in all cases except for the EVA blend where the optimum modifier content blend was significantly higher than the lean and rich blends. In the overall analysis of this graph, the SBS and EVA blends rated marginally higher than the oxidant and polyethylene blends.

As was expected, the penetration index of the AC-40 asphalt rated well below those of the modified AC-20 blends and the control AC-20. The penetration index of the AC-40 asphalt was, however, reasonably good in comparison to normal AC-40 pen-index values.

6. Brookfield Viscosity

The results of the Phase II Brookfield viscosity tests are presented in Table 21. The intention of conducting the Brookfield viscosity test was to insure that at least some form of viscosity data would be reported in the Phase II binder analysis, as it was feared that the modified binders would be unsuitable for testing under the more standard viscosity tests, such as the kinematic (ASTM D 2170-85, Ref 6). The resulting data scattered badly, however, making the usefulness of the Brookfield viscosity data limited.

Because of the high viscosity of all of the test materials at 140°F, the resulting Brookfield viscosity data at this temperature were of little value. At 275°F, however, the test results did represent the general changes in viscosity caused by varying the asphalt source, modifier content, and modifier type. The asphalt 1 and asphalt 3 blends produced significantly lower viscosities in comparison to the asphalt 2 blends for all test materials except for the polyethylene, where no viscosity change was observed by varying the asphalt source. The only significant effects on viscosity caused by varying the modifier content were found in the lean modifier blends of the SBS and polyethylene test materials. The SBS lean modifier blend had a significantly higher Brookfield viscosity and the lean blend of the polyethylene material had a significantly lower Brookfield viscosity.

The polyethylene blend increased the Brookfield viscosity the most with the viscosity increase of the SBS blend close behind. The EVA modifier had virtually no effect on the binder's Brookfield viscosity and the oxidant modifier actually reduced the Brookfield viscosity in comparison to

the control AC-20. Surprisingly, the AC-40 asphalt tested at or below the viscosity level of the control AC-20 at 140°F.

7. Kinematic Viscosity

As mentioned in the preceding discussion of the Brookfield viscosity results, the kinematic viscosity test was excluded from the original test plan because of expected problems with highly viscous modified binders. The limited usefulness of the Brookfield data forced an attempt to run the 275°F kinematic viscosity test, however, and the results were surprisingly consistent between replicate test values. Therefore, the kinematic viscosity test results, included in Table 21, were incorporated into the Phase II binder analysis.

An evaluation of the viscosity results to determine the overall effects of each modifier type on the kinematic viscosity revealed close similarities to those of the Brookfield viscosity analysis. The SBS and polyethylene materials increased the kinematic viscosity by the greatest amount and the EVA modifier moderately increased the kinematic viscosity. The oxidant modifier did not alter the kinematic viscosity in comparison to the control AC-20, and the AC-40 asphalt again tested below the control AC-20.

To make the kinematic viscosity results more useful, the viscosity data were used in conjunction with the 77°F penetration data to develop Pen-Vis numbers (PVN), calculated using the equation and methods discussed earlier in this report. The PVN is an indicator of temperature susceptibility just as the Pen-Index values are. The PVN values of the Phase II binders are given in Table 22.

In a manner similar to the Pen-Index analysis, two graphs were constructed to visually analyze the effects of varying asphalt source, varying modifier content, and modifier type on the binder's temperature susceptibility characteristics. The graphs for the PVN analysis are represented by Figures 46 and 47. PVN values near zero, both positive and negative, are common and the more positive values are usually more desirable as they indicate less temperature susceptibility.

Figure 46 displays the effects of varying the asphalt source on each of the test materials' Pen-Vis number. In all cases, the asphalt 1 blend rated the poorest of the three asphalt sources. With the SBS, polyethylene and EVA blends, the only blends to show significant improvements

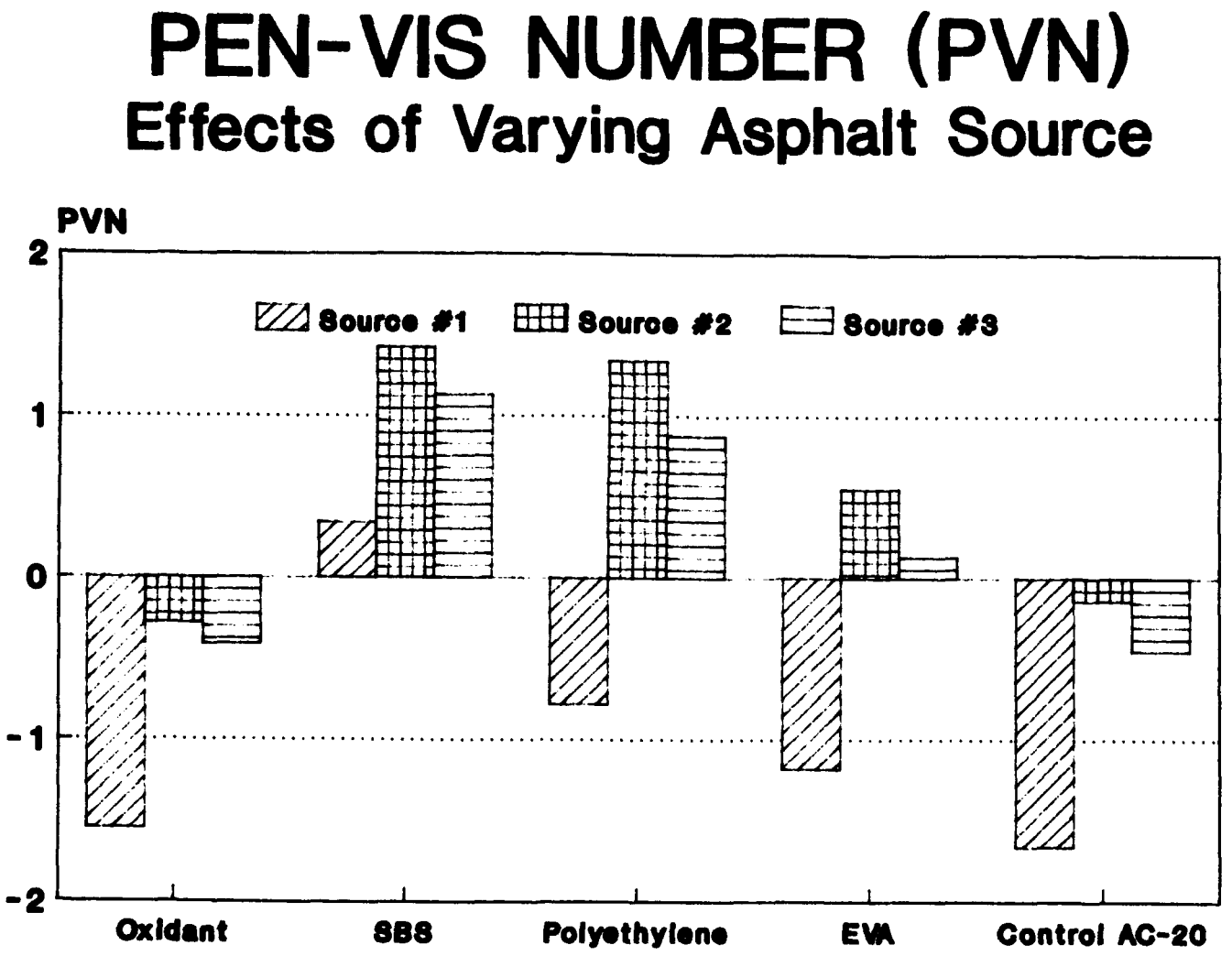

Figure 46. Graph of Pen-Vis Number with Varying Asphalt Source.

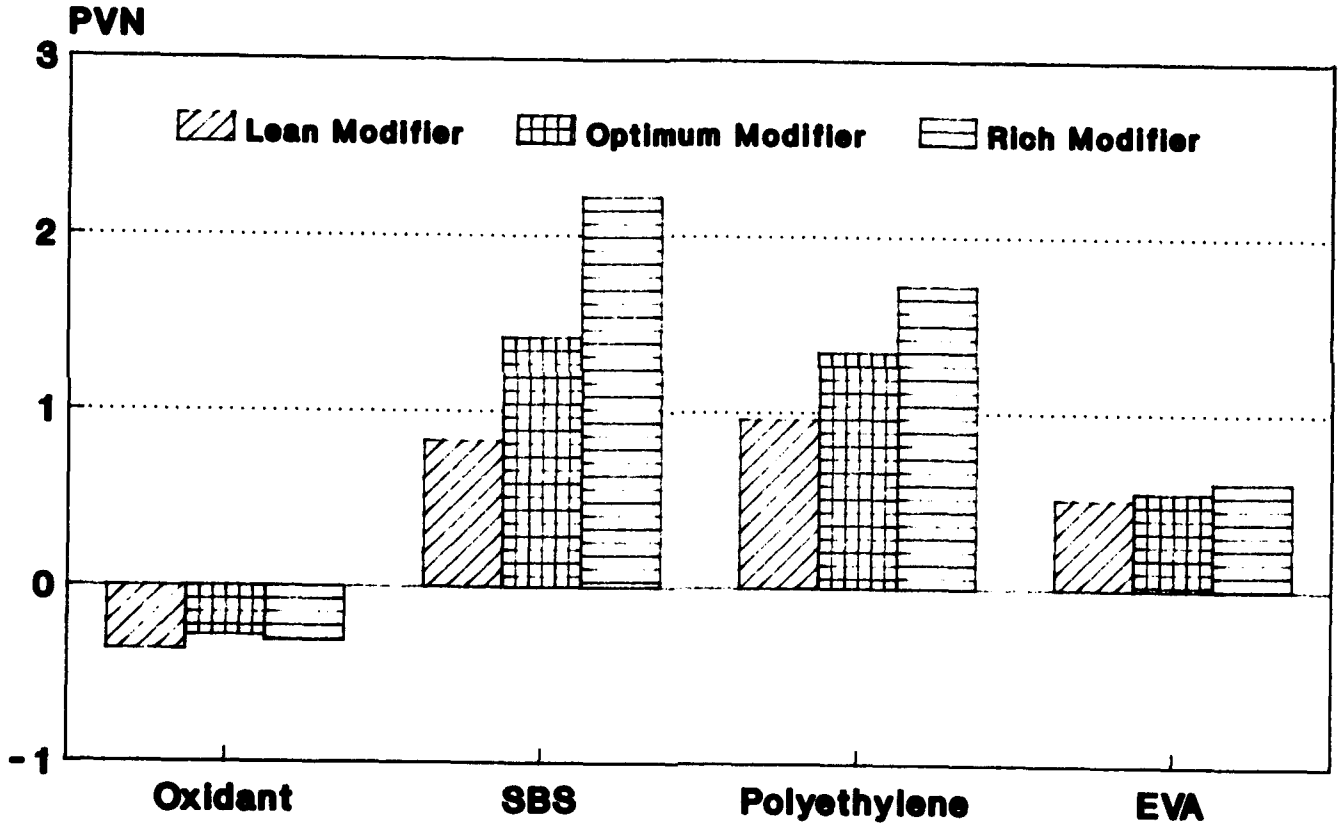

Figure 47. Graph of Pen-Vis Number with Varying Modifier Content.

in PVN response, the asphalt 2 blend rated slightly higher than the asphalt 3 blend. In the overall analysis, the SBS modifier produced the best PVN improvements, followed closely by the substantial improvements produced by the polyethylene modifier. The EVA modifier showed slight improvements in PVN response, while the oxidant modifier produced virtually no change to the PVN in comparison to the control AC-20.

Figure 47 displays the effects of varying the modifier content on the PVN of each test material. No effects on PVN were caused by varying the modifier content with the oxidant and EVA modified blends. With both the SBS and polyethylene blends, the orders of PVN magnitude from best to worst were rich, optimum, and lean modifier contents. In the overall analysis of the four modifier types, the ranking from most improved to least improved PVN was once again SBS, polyethylene, EVA and oxidant.

8. Resiliency

The most useful information from the resiliency test is the final rebound percentage. This is a measure of the binder's retained elasticity properties after loading, similar to the creep rebound being a measure of an asphalt mixture's retained elasticity properties after loading. With both tests, a higher percent rebound represents better elastomeric properties and is more desirable in preventing permanent deformations in asphalt pavements.

The elastic responses, or percent rebounds, derived from the Phase II resiliency tests are presented in Table 21. The positive values of percent rebound indicate the percentage of the total deflection caused by the applied load which was recovered after the load was released. This measurement was taken at a specified time after the load was released. The negative values of percent rebound are for those test materials which continued to deflect under the dead weight of the loading device after the applied load was released.

In analyzing the overall effect of the modifiers, it was fairly easy to determine which modifiers performed the best under the conditions of this test. The SBS material performed the best by far and the EVA material also performed considerably better than the control AC-20. The polyethylene-modified binder performed slightly better than the control

AC-20, while the oxidant material and the AC-40 asphalt showed no improvements over the unmodified AC-20.

To evaluate the effects of varying the asphalt source and modifier content on the resiliency percent rebound, Figures 48 and 49 were constructed and analyzed. Figure 48 displays the effects of varying the asphalt source on each test material's resiliency rebound. The asphalt 1 blend tested significantly lower for the SBS and EVA modified blends and the oxidant-modified asphalt 3 blend tested significantly lower than the other two asphalt source blends. The polyethylene and control AC-20 blends showed no significant effects caused by varying the asphalt source. In the overall analysis of this graph, the SBS modifier rated highest, followed by the EVA modifier and then the polyethylene. The improvements promoted by these modifiers were more pronounced for the asphalt 2 and asphalt 3 blends. The oxidant modifier rated below the control AC-20 primarily as a result of decreasing the percent rebound of the asphalt 3.

Figure 49 displays the effects of varying the modifier content on each test material's resiliency rebound. The rich modifier blend rebounded better than the optimum modifier blend, which in turn rebounded better than the lean modifier blend in all cases (but in differing degrees). The overall ranking order, from best or highest percent rebound to lowest was SBS, EVA, polyethylene and oxidant.

9. Comprehensive Results

Table 23 is a compilation of all modifier rankings resulting from the Phase II tests and analyses. These rankings take into account the effects of each of the examined mix variables, the test temperatures, and the significance level of data variances. This table should be interpreted with a knowledge of the properties measured by each of the tests, and the extent to which each of these tests may be applied to a particular field performance problem. Simple rankings of this nature do not display the magnitude of the difference between one test material and another within a given test property, an important element in this laboratory data analysis. These considerations and all other important details will be discussed in the conclusions of this study, found in Section IV.

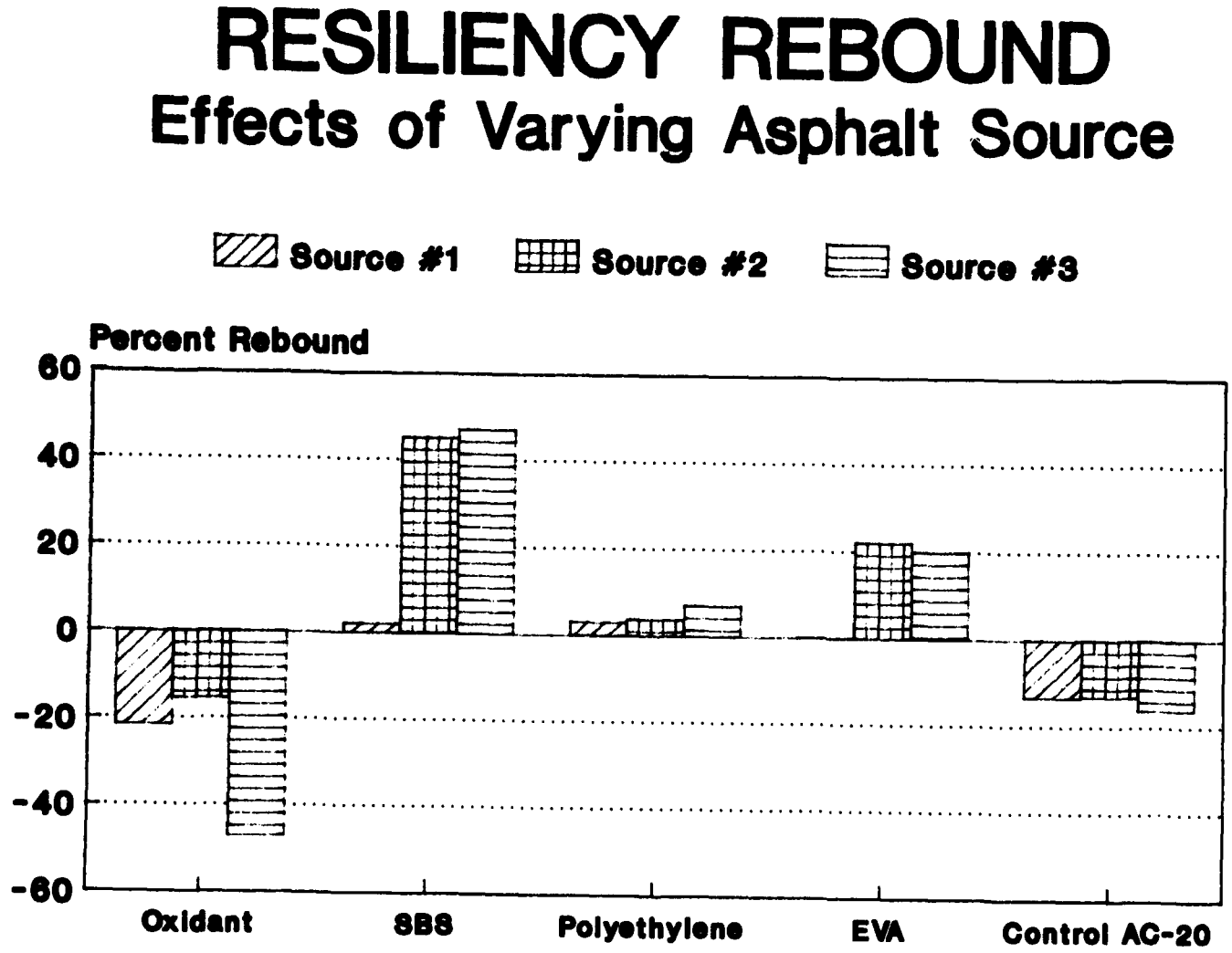

Figure 48. Graph of Resiliency Rebound with Varying Asphalt Source.

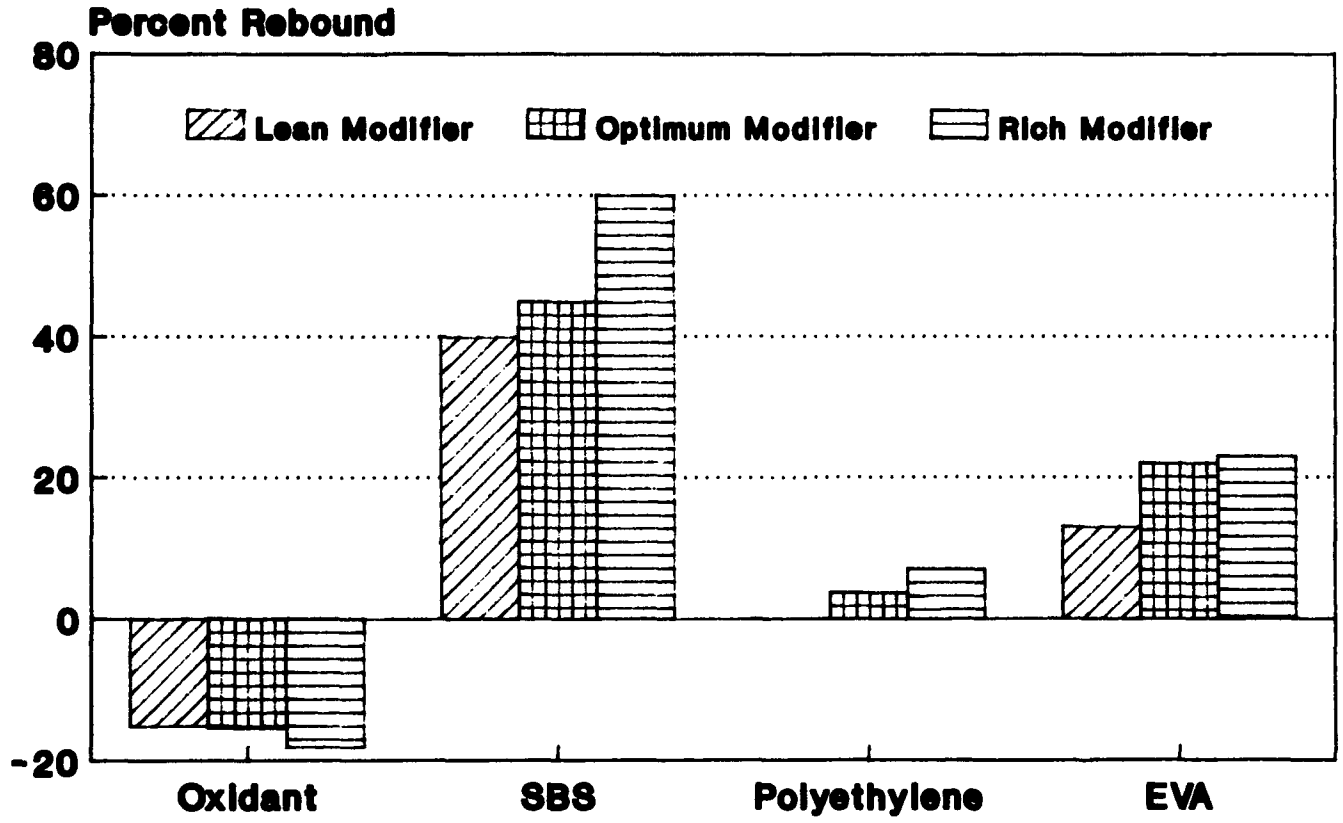

Figure 49. Graph of Resiliency Rebound with Varying Modifier Content.

TABLE 23. COMPREHENSIVE RANKINGS OF PHASE II TEST RESULTS.

Test	Oxidant	SBS	Polyethylene	EVA	Control	AC-40
Marshall Stability	1	2	2	2	6	5
Tensile Str.						
0°F	4	4	1	1	1	4
77°F	2	5	2	4	6	1
104°F	1	2	2	2	6	2
Resilient Mod.						
0°F	2	6	2	2	2	1
77°F	6	3	3	1	3	1
104°F	1	2	2	2	6	2
Creep Modulus						
77°F	1	3	4	2	4	6
104°F	*	*	*	*	*	*
Creep Rebound						
77°F	*	*	*	*	*	*
104°F	2	6	2	2	1	2
Pen Index	3	1	3	2	5	6
Pen-Vis Number	4	1	2	3	4	6
Resiliency	4	1	3	2	4	4

* No significant variance between results of any test materials

Note: The 1 - 6 rankings of this table represent a "best" to "worse" rank.

SECTION IV

CONCLUSIONS

No one asphalt modifier or alternate binder would be expected to outperform all others under all field conditions. The results of this laboratory study supported this fact by highlighting comparative strong points and weak areas for each test material involved in the laboratory tests. Certainly, some of the performance characteristics described by the results of this study are more critical than others. As mentioned earlier in the discussion of the test data, some of this study's test results should be considered more reliable than others. Because of these and many other considerations, there is no single, simple way to determine which modifier is best.

Since each of the Phase II test materials were selected because of its optimum performance during the Phase I tests, these five test materials would be expected to give the best field performance in terms of the needs prescribed by the objectives of this study. Therefore, the following discussions of predicted field performance will be limited to the five Phase II test materials.

A. OXIDANT

The oxidant modifier used in this study seems to be sensitive to several critical mix design elements. The optimum modifier and binder content mixes tended to perform much better than the lean and rich mixes in the critical tests. Also, it is possible that the oxidant modifier would amplify the field performance problems inherent in many asphalts of relatively high viscosity and high-temperature susceptibility.

As indicated by the comprehensive rankings in Table 23, the oxidant modifier does have a great deal of potential as a mix stiffener when properly designed and mixed. These improvements are more prominent at elevated temperatures, which is where this reaction is more favorable to an asphalt mixture's performance in preventing deformation distresses. In climatic regions where the temperature susceptibility of the binder is critical, however, the oxidant modifier would seem to have the potential to promote thermal cracking problems.

B. SBS

The SBS rubber modifier proved to be the best test material by a large margin in terms of the Phase II binder tests and analyses. This would indicate that the SBS modified binder should do a good job of improving the base asphalt's temperature-susceptibility characteristics. An asphalt modifier that increases the resulting mixture's strength properties, while improving the binder's temperature susceptibility properties provides a highly desirable combination of improvements. All too often, mix strength properties and binder temperature susceptibility are tradeoffs in asphalt modifications.

Although the binder test results for the SBS modifier were excellent and the mix tests favorable, many of the Phase II mix variable analyses indicate that the results could have been better. Several Phase II test results indicate that the selected optimum asphalt content may have been slightly low for optimum performance in the tests. This would have a greater impact on the mix test results, as most of the comparative analyses between the modifiers for these tests were based on the optimum asphalt content blends.

C. POLYETHYLENE

The polyethylene modifier was one of the two consistently superior performers of this study. Sizable improvements in the mix strength properties, indicated by the laboratory tests, were gained across the entire temperature range investigated. The temperature susceptibility of the binder was also significantly improved, as indicated by the Pen Index and Pen-Vis numbers derived from the Phase II binder tests.

The polyethylene-modified blends were less sensitive to all three of the Phase II mix variables as a whole when compared to most of the modifiers of this study. This bodes well for this modifier's predicted field performance, as the mix design variances investigated by the Phase II tests were well within the variances that commonly occur in most field applications.

D. EVA

The EVA modifier was the second of the two modifiers which were consistently superior throughout the Phase II tests. As with the polyethylene

modifier, the significant level of improvement in the modified mix strength properties was evident for the entire temperature range investigated. Likewise, the sizable improvements in the modified binders's temperature susceptibility properties were near the same level as that of the polyethylene-modified binder.

The EVA-modified asphalt mixtures proved to be relatively less sensitive to each of the three Phase II mix variations. This was more evident at the higher test temperatures. Because the EVA modifier improves mix strengths and binder properties, while reducing mix variation sensitivity, this modifier would seem suitable for a larger variety of field applications and climatic conditions.

E. AC-40

As stated earlier in this report, the main reason for including an unmodified AC-40 asphalt in the study was to determine if the modification of an AC-20 asphalt created a binder with properties similar to an unmodified asphalt of higher viscosity. Indeed, in many of the Phase I tests, the AC-40 asphalt performed as well as or better than many of the modified AC-20 asphalts. Since an AC-40 asphalt would typically be less expensive and not as complicated to design with compared to most modified AC-20 asphalts, it could be chosen as the best alternative over the modified AC-20 asphalt. For these reasons, the AC-40 asphalt was included in the Phase II test plan to compare with the Phase II test materials.

The Phase II tests indicate that a good quality AC-40 asphalt will provide mix strength gains over an unmodified AC-20 mixture comparable to the gains produced by many of the modifiers. The elastic properties and temperature-susceptibility characteristics of the binder are substantially worse in comparison to the modified AC-20 binders and even when compared to the unmodified AC-20 asphalts. Nevertheless, in warmer climates and where the elastic properties are not as critical for the pavement in question, a good quality AC-40 asphalt could provide satisfactory results when attempting to build a pavement resistant to permanent deformation distresses.

SECTION V

RECOMMENDATIONS

The following recommendations are made, based on the results of this research study.

A. MATERIALS

1. The EVA and polyethylene modifiers are recommended for use in modifying asphalt cements to substantially increase resistance to rutting and other deformation distresses, while at the same time improving the rheological properties of the asphalt. These improvements are realized more at elevated temperatures, but are also evident at lower pavement temperatures. A considerable amount of technical support and continued material research is available from the leading manufacturers of both of these asphalt modifiers, providing a sound technical future for these materials.

2. The SBS modifier is recommended for use in modifying asphalt cements to moderately increase resistance to rutting and other deformation distresses when a substantial decrease in the binder's temperature susceptibility is also desired. This combination of desired material improvements will likely occur more so in climatic regions of comparatively high-temperature variances between the summer and winter months.

3. The oxidant modifier is recommended for use in modifying asphalt cements to substantially increase the mixture's resistance to rutting and other deformation distresses. Its use may be more appropriate in regions with comparatively mild winter temperatures. Considerable care must be taken to insure proper proportioning and design of oxidant-modified asphalt pavements to prevent problems such as premature pavement cracking caused by excessive binder hardening.

4. An AC-40 asphalt is recommended as an alternative to using a modified binder of a lower viscosity grade only when economics prevent the use of the modified binder. AC-40 binders can be expected to be more temperature-susceptible than unmodified AC-20 asphalts, therefore, their use should be limited to climatic regions with mild winter temperatures and comparatively low temperature variances between the summer and winter months.

5. The only test material found that could effectively replace a sizable portion of the asphalt cement in an asphalt mix was sulfur. The overall laboratory performance of the sulfur-modified mixture was below that of the unmodified AC-20 mixture according to the Phase I analysis of this study. Therefore, sulfur-modified mixtures are not recommended for consideration under the objectives of this study.

6. The natural lake asphalt is recommended for use as a viable additive to AC-20 and lower viscosity graded asphalt cements for the purpose of increasing an asphalt mixture's resistance to rutting and other deformation distresses. This material's sole source availability could cause logistics and economic considerations that would limit its widespread use, however. The limited Phase I data indicate that a natural lake asphalt-modified AC-20 would have less temperature susceptibility and better cold-temperature properties than most hard asphalts. This limited binder data would need to be extended before the use of a natural lake asphalt-modified binder is proposed for any asphalt airfield construction.

B. OTHER RECOMMENDATIONS

1. Further research is needed into proper mix design procedures for asphalt modifiers and alternate binders. Besides the normal design elements, these new mix design procedures need to include test methods for determining the proper amount of modifier to add to the binder.

2. Additional laboratory studies should be conducted on the most promising modifiers identified by this research study. Tests which determine fatigue characteristics and moisture resistance of the modified asphalt mixes should be included in these future studies.

3. Perhaps the most important step in validating the findings of this study and any related laboratory studies would be to construct and evaluate a field test section made of modified asphalt mixtures. This test section should be used to evaluate the most promising modifier materials identified by this study.

4. The knowledge gained by this and other asphalt modifier research programs needs to be documented in a fashion that will allow the asphalt modifier user to properly design, test and construct modified asphalt

pavement systems. This documentation would include standardized mix design procedures and test methods as well as standard practice manuals for the construction and maintenance of modified asphalt pavement systems.

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APPENDIX

Modifier Fact Sheets

MATERIAL: Mineral Filler

DESCRIPTION:

Mineral filler is defined as material nominally passing the Number 200 Sieve and is used in some amount in all asphalt mixtures. The filler may occur naturally in the mixture from the crushing or breakdown of the parent rock or may be a commercial filler. Some commercial fillers include lime, cement, sulfur and carbon black. Material costs vary considerably from location to location and, for this reason, are not discussed here.

There are several sources for most fillers used in production of asphalt concrete. Carbon Black can be purchased from the following source:

Cabot Corporation
Concord Road
Billerica, Massachusetts 01821
(617) 663-3455

AREAS OF APPLICATION:

Fillers have been shown to provide a number of advantages when used in asphalt concrete. Some of the uses include:

1. Some amount of filler is needed to obtain sufficient mixture stability.
2. Some fillers are used to improve the mixture's resistance to the adverse effects of water.
3. An increase in filler normally produces a lower optimum asphalt content, thereby resulting in a reduction in mixture cost.
4. Some fillers seem to produce a stiffer mixture at higher temperatures but do not greatly stiffen the mixture at lower temperatures.

PHYSIOGRAPHIC FACTORS:

Mineral fillers are added to an asphalt mixture during production at the asphalt plant. Equipment is needed to store commercial fillers and to accurately add these fillers to the mixture. Care must be taken when using sulfur since the addition of sulfur to asphalt at high temperatures can give off a toxic gas.

DISCUSSIONS AND RECOMMENDATIONS:

The filler used in most asphalt mixtures is filler obtained from crushing the parent rock or filler occurring naturally with the parent rock. The quality of some of the naturally occurring materials is unsatisfactory, therefore, these poor materials should not be used in the production of

asphalt concrete. The fillers obtained from the crushing of rock and the better quality naturally occurring fillers are used in moderation to produce asphalt concrete. These fillers, which are primarily used to meet aggregate gradation requirements, help to insure satisfactory performance. In most cases, these fillers are not available in sufficient quantity to market. Commercial fillers are available and can be used to provide a better quality mixture in some cases.

Sulfur has been investigated for use as a filler and as an asphalt extender. It has shown some benefit when used as a filler. The addition of sulfur does increase the stiffness of asphalt concrete at high temperatures which should reduce permanent deformation under traffic. The addition of sulfur does increase the stiffness at low temperatures which could present a cracking problem.

A number of test sections have been constructed using sulfur mixtures. These sections have been constructed in Texas and Nevada, as well as within many other states. These test results have generally supported the findings in the laboratory that the addition of sulfur filler does result in a stiffer asphalt concrete.

Some disadvantages of the use of sulfur include cost, low-temperature properties, and safety. Sulfur is now relatively expensive and the use of sulfur filler results in an overall increase in mix cost. The use of sulfur or other fillers requires a storage silo and equipment for feeding the material from the silo to the plant.

Some cracking has been observed in test sections using sulfur filler; however, the permanent deformation has been reduced. The asphalt cement selected for use can be modified, if necessary, to reduce low-temperature cracking.

Safety can be a problem when mixing sulfur with asphalt cement. If overheated, a toxic gas is produced that can endanger personnel on the job. The danger is greater when sulfur is added to the asphalt cement before being fed into the asphalt plant. When sulfur is used as a filler, all materials are mixed in the pugmill or drum (for drum mix plant), thus minimizing the danger.

Lime has normally been used in asphalt mixtures to improve resistance to adverse effects of water. In this case, the lime does provide for higher stability but that is not typically the intended purpose. Because of the higher stability, the use of lime should result in reduced permanent deformation.

Carbon Black has been used to increase the stiffness of asphalt concrete to reduce permanent deformation. Tests have shown that carbon black does not adversely affect the low-temperature properties of asphalt concrete and the high temperature properties are improved. Carbon Black has been used in a number of test sections to evaluate its performance.

SUMMARY:

Carbon Black and Sulfur appear to be the fillers that have the best chance of producing an asphalt concrete mixture that will support high tire pressures without permanent deformation and that will not tend to crack excessively at low temperatures.

REFERENCES:

YAO and C. L. Monismith, "Behavior of Asphalt Mixtures with Carbon Black Reinforcement," Proceedings of the Association of Asphalt Paving Technologists, Vol 55 (1986), pp. 564-585.

D. W. Gilmore, R. D. Cottman, and J. A. Scherocman, "Use of Indirect Tension Measurements to Examine the Effect of Additives on Asphalt Concrete Durability," Proceedings of the Association of Asphalt Paving Technologists, Vol 53 (1984), pp. 495-524.

D. A. Anderson and J. P. Tarris, "Characterization and Specification of Baghouse Fines," Proceedings of the Association of Asphalt Paving Technologists, Vol 52 (1983), pp. 88-120.

W. Akili, "On the Use of Sulphur in Sand-Asphalt Application," Proceedings of the Association of Asphalt Paving Technologists, Vol 52 (1983), pp. 561-584.

P. S. Kandhal, "Evaluation of Sulphur Extended Asphalt Binders in Bituminous Paving Mixtures," Proceedings of the Association of Asphalt Paving Technologists, Vol 51 (1982), pp. 189-221.

MATERIAL: Fiber Pave

MANUFACTURER:

Hercules Incorporated
Hercules Plaza
Wilmington, Delaware 19894
(302) 594-6500

NATIONAL DISTRIBUTOR:

Fiberized Products, Inc.
P.O. Box 217
Hilliard, Ohio 43026
(Ohio only) (614) 771-1133
1-800-822-9140

DESCRIPTION:

Fiber Pave is a short-length polypropylene fiber designed for use as an asphalt reinforcement. This nonhazardous fiber has been engineered to increase the pavement service life of conventional highway paving, patching, crack sealing, and seal coating applications.

AREAS OF APPLICATIONS:

When used in asphalt hot mixes, Fiber Pave is added to the hot mix asphalt mixture and not the binder, prior to entry into the plant. Typically, 0.3 percent Fiber Pave is added by total weight of hot asphalt mixture. Fiber Pave may also be added to asphalt cement and used for joint and crack sealing as well as in membranes for reflective crack control.

PHYSIOGRAPHIC FACTORS:

Fiber Pave is supplied in ready-to-use polyethylene bags in weight increments that will accommodate individual plant capacities. Plants producing 2-ton batches should order bags containing 12-pounds, 3-ton batches, 18-pounds, etc. These bags should be stored in dry covered areas to prevent moisture damage.

Fiber Pave can be mixed by either batch- or drum-mixing processes. When using a batch plant, the fibers are added through the pugmill access door or onto the filled weight hopper. Good dispersion of the fibers is obtained by a 10 second dry mix followed by the usual 35-second wet mix. The asphalt inlet temperature should not exceed 300°F and aggregate temperatures should not exceed 290°F, as the fibers will soften or melt. When using a drum-mix plant, a special feed system designed by Hercules should be used. This feed system

delivers the fibers at a metered rate consistent with the production rate chosen by the plant. Essentially, fiber is added into a hopper and conveyed by belt at a metered rate onto a conveyor that dumps into the recycle opening.

When hauling the mixture, keep it hot (250-285°F). For long hauls, it is suggested to use double-covered foamboard insulation applied to the side walls of the truckbed. Standard paving equipment can be used without modification for laydown. The mixture may be difficult to rake.

DISCUSSIONS AND RECOMMENDATIONS:

When using Fiber Pave in hot asphalt mixtures, modifications in mix design methods are not needed. It may be necessary to increase the percentage of bituminous binder (nominally 0.3 percentage points) over that of a standard mix to accommodate the fiber surface area. The property improvements claimed by the manufacturer include:

1. Improved resistance to shoving, rutting and raveling.
2. Improved resistance to aggregate segregation.
3. Improved resistance to induced reflective cracking.
4. Improved Marshall stability.

Research has indicated that the use of these fibers in hot mixes produce more of the improvements dealing with lateral stresses and strains (i.e., shoving, reflective cracking, etc.) rather than those dealing with vertical stresses and strains (i.e., rutting).

SUMMARY:

Fiber Pave is a polypropylene fiber used as an additive to several types of asphalt pavement applications, including asphalt hot mixes. Technical support from the manufacturer and limited field experience is available to the user to support the use of this asphalt modifier.

REFERENCE:

Terrel, Ronald A. and Epps, Jon A., "Asphalt Modifiers - A Users Manual for Additives and Modifiers in Asphalt Pavements," Draft Report for the National Asphalt Pavement Association, 1988.

MATERIAL: Trinidad Natural Asphalt

SUPPLIER:

Dr. Ing D. Knobig
Trinidad Asphalt Corporation of America
One Stone Place
Bronxville, NY 10708
(914) 793-5100
(212) 324-2858

DESCRIPTION:

Trinidad Natural Asphalt (TNA), sometimes called Trinidad Lake Asphalt, is refined from a crude natural asphalt lake located in Trinidad. In its crude form, it is a complex emulsion of water, gas, bitumen and mineral and vegetable matter. The refined products, sometimes known as Epure´ have the following composition and properties

Bitumen Soluble in CS_2	53-55%
Mineral Matter (Ash)	36-37%
Insoluble Organic matter	8-11%
Specific Gravity	1.4
Softening Point	94-97
Penetration	1.5-4

AREAS OF APPLICATION:

Use of TNA as an additive improves impermeability, resistance to deformation, skid resistance, fatigue and overall durability.

PHYSIOGRAPHIC FACTORS:

TNA is usually supplied in its refined form in disposable drums, each weighing about 500-pounds (227 kg) although it is available fluxed to some standard road building viscosities. The first stage in using TNA is to heat it until it is sufficiently fluid to pump. After this, it can be handled for blending and/or mixing as if it is a conventional asphalt cement. Robust and well-maintained equipment is recommended as the high mineral content present in TNA can lead to accumulations and blockages in pipe work. The minerals can also accelerate wear, particularly in pumps and bearings. TNA suppliers may recommend equipment on request.

DISCUSSIONS AND RECOMMENDATIONS:

TNA has been in use in highway construction in England since 1840 and in North America since 1870. It has been used successfully to provide good and durable skid-resistant characteristics in many heavily trafficked roads and has been included in specifications for surfacing materials on principal highways in Great Britain. TNA has also been used successfully in New York, New Jersey and Virginia on very heavily trafficked sections of highways where access for maintenance is very difficult. While there is no quantitative data on resistance to permanent deformation, it is reported that overlays made from mixes including TNA have not needed maintenance after 9 years of service, when conventional overlays have been replaced after 2 years. TNA blends have also been used for surfacing several major bridges in both the USA and the UK. Further reports of good performance under arduous traffic conditions have come from Hong Kong, Finland, Germany, Japan and Austria. Successful applications have been reported at several civil airports, notably La Guardia, Munich-Rein, Bremen, Copenhagen and Luxembourg, and at Pterdsfeld and Bremgarten military airfields.

Claims for improved fatigue performance are based upon an unpublished consultants report from the University of Maryland.

SUMMARY:

TNA is such a well-established additive that it tends to be overlooked. There are many and strong claims for its efficiency in reducing deformation based on experience, although little quantitative data is available to support these.

MATERIAL: Chemkrete

SUPPLIER:

LBD Asphalt Products Company
P.O. Box 158
Deer Park, Texas 77536-0158
(713) 479-6384

DESCRIPTION:

Chemkrete is an oil-based soap containing soluble manganese. When mixed with asphalt cement and allowed to cure in thin films in the presence of oxygen, it modifies the asphalt by causing an increased viscosity and, in some cases, a reduced temperature susceptibility. A hydrocarbon carrier is used as a dispersant for the soluble manganese soap.

AREAS OF APPLICATION:

The liquid modifier is added to a liquid asphalt cement.

Major applications of this product are for thick overlays and thick asphalt concrete sections associated with new construction.

PHYSIOGRAPHIC FACTORS:

The modifier is added to the asphalt cement at the refinery or in storage. An asphalt concrete constructed with the modified asphalt will exhibit increased strength and decreased temperature susceptibility properties if allowed to cure. Improved resistance to stripping by water is also evident.

DISCUSSIONS AND RECOMMENDATIONS:

The Lubrizol Company purchased the technology from Chemkrete in 1982 and established Chemkrete Technologies, Inc. In 1986, the Chemkrete Technologies, Inc. name was changed to LDC (Lubrizol Development Company). Since 1982, changes were made in the additive and softer asphalts treated at lower dosage levels have been used.

Field trial sections placed before 1982 hardened excessively and developed transverse and block cracking patterns during the first few winters of service. Improved performance of field trial sections has been obtained with the newer formulations. Reflection cracking and some tenderness problems have been noted on these new sections.

In 1983, a university research program was initiated by Lubrizol at five institutions. Results are given below.

1. Temperature susceptibility of the treated asphalt cement is reduced.
2. Temperature susceptibility of mixtures containing the treated asphalt is reduced.
3. Improved resistance to low temperature cracking and improved high temperature stability is expected.
4. Improvements in water sensitivity is predicted with boiling tests but not freeze-thaw types of tests.

SUMMARY:

Overall performance of field trial sections has been less than desirable. New formulations of the modifier have improved performance. Improved resistance to permanent deformation is suggested by the available research data.

REFERENCES:

Kennedy, T. W. and Epps, J. A., "Engineering Properties of Manganese-Treated Asphalt Mixtures," paper presented at TRB, January 1985.

Maulthrop, J. G. and Higgins, W. A., "Manganese-Modified Asphalt Pavements--A Status Report," paper presented at TRB, January 1985.

Kennedy, T. W. and Anagnos, J. N., "Engineering Properties and Moisture Susceptibility of Manganese-Treated Asphalt Mixtures," Research Report CT-1, Center for Transportation Research, University of Texas, July 1984.

Eichborn, C. Tung, Y. K., Andreae, J. and Epps, J. A., "Characterization of Chemkrete-Treated Asphalt Mixtures," Department of Civil Engineering, University of Nevada-Reno, June 1984.

Petersen, J. C., Plancher, H. and Miyake, G., "Fundamental Studies of the Curing of Chemkrete-Modified Asphalt," Final Report, Western Research Institute, University of Wyoming, January 1985.

Anderson, D. A., "Physical Properties of Aged Manganese-Treated Asphalt Cements," Final Report, Nittany Engineers and Management Consultants, Inc., April 1985.

Haas, R. and Steele, L., "Laboratory Evaluation of Low-Temperature Stiffness Characteristics and Resilient Moduli of Chemkrete-Modified Asphalt Mixes," University of Waterloo, December 1984.

"Chemkrete Status Report," FHWA Demonstration Projects Program, May 1983.

MATERIAL: Ductilad D1000

SUPPLIER:

LBD Asphalt Products Company
P.O. Box 158
Deer Park Texas 77536-0158
(713) 479-6384

DESCRIPTION:

Ductilad D1000 is a liquid modifier and when used in dosages of 2 to 4 percent by weight of asphalt cements prevents age-hardening of the asphalt cement. The modifier has a lower viscosity than asphalt cement.

AREAS OF APPLICATION:

Ductilad D1000 is a modifier for use in asphalt cements used in seal coats and asphalt concrete in hot, desert climates to reduce age hardening of asphalt binders.

PHYSIOGRAPHIC FACTORS:

The modifier is added to the asphalt at 2 to 4 percent by weight of asphalt. Improved ductility of the treated asphalt cement at 77°F after the California Tilt-Oven Durability Test is evident from test results. Improved resistance to hardening as measured by the viscosity increase at 140°F and the California test is also evident from test results.

Accelerated laboratory curing tests performed on compacted asphalt concrete samples indicate better resistance to age hardening without affecting initial stability values.

DISCUSSIONS AND RECOMMENDATIONS:

The laboratory data available for this product are quite limited because it is relatively new to the asphalt modifier market. To date, only one small field test section has been placed in Ohio. This material does seem to have merit as an antioxidant, but is not designed to control permanent deformation.

SUMMARY:

Resistance to age hardening results from the use of this product. Limited information is presently available.

REFERENCE:

"Ductilad D1000--An Additive to Inhibit Age-Hardening of Asphalt Cement," Chemkrete Technologies, Inc., January 1986.

MATERIAL: Aqua-Shield

SUPPLIER:

LBD Asphalt Products Company
P.O. Box 158
Deer Park Texas 77536-0158
(713) 479-6384

DESCRIPTION:

Aqua-Shield is a family of amine based liquid anti-strip products designed for use in hot-mix asphalt paving mixtures. It is a heat-stable product.

AREAS OF APPLICATION:

Aqua-Shield is a modifier for dense and open-graded asphalt concrete mixtures. Potential applications also include chip seals.

PHYSIOGRAPHIC FACTORS:

Aqua-Shield Antistrip additives are available in bulk tank car or tank truck or in 55 gallon drums.

The modifier is added to the asphalt cement at 0.5 percent by weight of the asphalt cement. The modifier can be added at either the refinery or terminal or at the mixing site. In-line injection type mixing is recommended to insure thorough and complete dispersion in the asphalt cement.

Water sensitivity tests performed according to the Lottman procedure show improved resistance to the action of water. The product performed as good as 1 percent slurried lime on several aggregates. The product cost is less than slurried lime.

DISCUSSIONS AND RECOMMENDATIONS:

This is a new Chemkrete product with only limited laboratory data available. The product is not suitable for the control of permanent deformation.

SUMMARY:

Improved resistance to the action of water results from the use of this modifier. Limited information is presently available.

REFERENCE:

"Aqua-Shield Products Group-Aqua-Shield AS4115 Anti-Strip Agent," Chemkrete Technologies, Inc., January 1986.

MATERIAL: Kling Beta

SUPPLIER:

SCANROAD, Inc.
Box 7677
Waco, Texas 76714
1-800-345-3749

DESCRIPTION:

Kling Beta-LV-(HM) and Beta-2550-(HM) are amine-based liquid chemicals that are heat stable antistripping agents specially designed to prevent stripping of asphalt from aggregate when used in hot-mixed systems.

AREAS OF APPLICATION:

Kling Beta is designed for use in hot-mixed dense and open-graded asphalt concrete mixtures. Potential applications include seal coats.

PHYSIOGRAPHIC FACTORS:

The modifier is added to the asphalt cement at a rate of 0.25 to 1.0 percent by weight of asphalt. The modifier can be added to the asphalt by either mechanical agitation, pump circulation of the storage tank or by injection into the asphalt loading line, followed by recirculation through the truck by-pass system to allow for proper mixing.

DISCUSSIONS AND RECOMMENDATIONS:

This product has been marketed for several years but little technical information is available in the United States. Several state DOTs have approved the product as an antistrip additive.

SUMMARY:

Improved resistance to the action of water results from the use of this modifier. Limited information is presently available.

REFERENCE:

"Kling Beta-LV-(HM) and Kling Beta-2550-(HM)," ScanRoad Information, ScanRoad, Nobel Industries, Sweden.

MATERIAL: Ground-Reclaimed Rubber

SUPPLIER:

Various companies produce ground rubber and current information such as availability and suppliers may be obtained from:

Asphalt Rubber Producers Group
Suite 106
3336 N. 32nd Street
Phoenix, Arizona 85018
(602) 955-1141

DESCRIPTION:

Ground reclaimed rubber is generally produced from used automobile tires and has been used as an asphalt additive since the mid-1960s. The material may be raw (unprocessed) and is labeled "reclaimed" or when processed, may be labeled "recycled" rubber.

This material consists chiefly of vulcanized SBR or polyisoprene reinforced with carbon black and is ground so that the particle gradation is less than the Number 10 sieve. It is generally known as asphalt rubber when added to asphalt in quantities ranging from about 15-25 percent by weight. The rubber is added to the asphalt in the field at elevated temperatures and the blend results in an elastic, highly viscous and tacky asphalt binder.

AREAS OF APPLICATION:

These binders have seen the most use in seal coat construction and "Stress Absorbing Membranes" (SAM) in lieu of conventional asphalts. The intent has been to utilize their elastomeric nature to absorb and dissipate stress within the membrane, thus reducing reflective cracking. The binders have also been used in "Stress-Absorbing Membrane Interlayer" (SAMI) applications on old pavements before overlaying with hot mix asphalt.

Although more limited, the use of asphalt rubber as a binder in hot mix asphalts is growing. These asphalt rubber mixtures are promoted as having: more flexibility, slower aging, less raveling, extended construction seasons, and more resistance to rutting and shoving.

PHYSIOGRAPHIC FACTORS:

Reclaimed rubber is generally available in one or more forms from the supplier:

1. Dry granules, available in bags.

2. Premixed with oil-based extenders, available in drums or tank cars.
3. Preblended with asphalt usually in special tank cars and/or distributor trucks.

The application or addition of rubber should be at the direction of the supplier for a particular system. Granulated rubber is often added to the hot aggregate. Preblended asphalt rubber must be heated in a manner similar to that for asphalt cement, but usually at some higher temperature. Depending upon the system, hot-mix asphalt temperatures will range from 325 to 390°F. Hot mix asphalt facility modifications may include bins and feeders for dry granules and perhaps a dedicated tank and pump for hot asphalt rubber blends.

Construction procedures should be similar to those for hot mix asphalts, but with the same level of compaction, higher voids may be expected. Mixing, laydown, and compaction temperatures may be higher.

DISCUSSIONS AND RECOMMENDATIONS:

Widespread use of asphalt rubber has faltered because of high capital equipment costs necessary to produce the asphalt rubber, relatively high construction costs, and uncertain opinions on their effectiveness. Until the factors that influence the cost of these materials change, the possible applications of reclaimed ground rubber in asphalts will remain limited.

SUMMARY:

In summary, mixtures containing reclaimed ground rubber have been used extensively for:

1. Hot mix asphalts, both dense and open graded.
2. Stress absorbing membranes.
3. Crack sealing.
4. Seal coats.

REFERENCE:

Terrel, Ronald A. and Epps, Jon A., "Asphalt Modifiers - A Users Manual for Additives and Modifiers in Asphalt Pavements," Draft Report for the National Asphalt Pavement Association, 1988.

MATERIAL: Downright

SUPPLIER:

DOW Chemical USA
Specialty Chemicals Department
Midland, Michigan 48674
David Wolfe

DESCRIPTION:

DOW manufacturers several Styrene/Butadiene Rubber latexes for use in asphalt cements and emulsions. HM-100L latex is used with asphalt cements, AE-200L latex is used with anionic asphalt emulsions and CE-3000L latex is used with cationic asphalt emulsions.

AREAS OF APPLICATION:

HM-100L is used in asphalt cements for use in dense- and open-graded asphalt concrete. AE-200L and CE-300L are used in asphalt binders for chip seal coats, cold patching materials, crack fillers, and slurry seals.

PHYSIOGRAPHIC FACTORS:

The SBR latex modifiers are used in quantities ranging from 2 to 5 percent rubber solids by weight of asphalt cement for hot mix applications. Concentration ratios between 2 and 5.5 percent latex by weight of emulsion are recommended for cold applications.

The SBR latex is normally added at the hot mix plant with special blending equipment. The product has been added at the refinery but heat stability problems may result.

The SBR latex can be added to emulsions in storage. High shear pumps should be avoided when handling the latex.

Improved high-temperature viscosity and mixture stiffness results with the use of the modifier. Improved low-temperature ductility, penetration, and mixture stiffness have been noted.

DISCUSSIONS AND RECOMMENDATIONS:

DOW has sponsored research at the University of Nevada-Reno and the University of Wyoming since 1984. Binder tests and mixture test results are available but not published. Some improvement in the high- and low-temperature performance is suggested from these laboratory test results. Field test results indicate that improved resistance to rutting is possible. The product has the potential to help control permanent deformation.

SUMMARY:

Improved temperature susceptibility results with the use of these latex modifiers.

REFERENCES:

"Improving Asphalt's Low-Temperature Properties and Durability with Downright Latexes," DOW Chemical, USA.

MATERIAL: Kraton

SUPPLIER:

Shell Development Company
Westhollow Research Center
P.O. Box 1380
Houston, Texas 77082
(713) 493-7757

DESCRIPTION:

Kraton is described as a Thermoplastic Rubber (TR). The title is general and describes a family of block copolymers based on styrene and either butadiene or isoprene which are produced for a wide range of industrial applications as well as for use in blending with bitumen.

AREAS OF APPLICATION:

Blends of Kraton and bitumen are recommended for a very wide range of uses in the paving industry. It is claimed that Kraton will reduce permanent deformation, and increase fatigue life; characteristics which make it ideal for use in wearing courses and thin overlays. Improved durability and reduced postconstruction compaction suggest its use in porous friction course materials. As a stress-absorbing membrane it can absorb horizontal crack mouth movements of several millimeters, maintain elastic characteristics over a wide range of temperatures, adhere efficiently to the old surface, and be placed successfully in thin layers. Surface treatments are enhanced by better initial chip retention and tensile properties and an extended range of use.

PHYSIOGRAPHIC FACTORS:

The Kraton products are usually supplied in pellet form. The pellets are bagged and supplied in quantities of approximately 1-ton on a shrink-film wrapped pallet.

The manufacturers of Kraton indicate that the product does not present any unacceptable hazard when used in accordance with normal safe handling procedures adopted in the industry.

The following specific recommendations are made by the supplier with regard to processing:

1. Avoid inhalation of fumes and vapors from the hot rubber compound.
2. Prevent skin contact with hot rubber compound surfaces.

3. Observe the safety regulations for the chemicals used in rubber processing.

Care is necessary with regard to the selection of mixing equipment. The mixing temperature should not exceed 365°F and the blending time should be as short as possible, with sufficient time to dissolve the TR as completely as possible in the bitumen. Mixing is easiest if the pellets are preground into a fine powder. The modest shearing action of a paddle mixer may be adequate depending on the type of bitumen. Immersion mixers with serrated rotors and agitators give the best results because of their high rotation speed and the cutting action of the teeth.

Addition of Kraton is usually recommended in quantities of 12 to 14 percent by mass of the total binder.

DISCUSSIONS AND RECOMMENDATIONS:

Kraton is claimed to improve nearly all aspects of the performance of bituminous paving mixes. There is a relatively large volume of supporting data derived from laboratory tests. However much of this work has been directed towards supporting the use of Kraton as an additive in roofing mixes. To date, no information is available concerning the performance of blends in highway applications other than in surface treatments.

SUMMARY:

The manufacturers claims are based on relatively extensive laboratory studies. However the lack of data from full scale trials in highway mixes is not particularly encouraging. These data will likely be developed with the development of field studies in the near future.

MATERIAL: Neoflex

SUPPLIER:

Pavement Technologies, Inc.
15042 NE 40th Street, Suite 201
Redmond, Washington 98052
Tel: 206-883-6860
Telex: 323680(PaveTech)

DESCRIPTION:

Neoflex is a cationic latex-modified bitumen-based emulsion, supplied as a ready-made liquid binder.

AREAS OF APPLICATION:

Neoflex is used as the binder in single-surface treatments to restore skid resistance and drainage in urban streets and on the pavements of primary and secondary road systems. It is also used as the binder in double surface treatments when a high degree of wear resistance and surface drainage is required.

PHYSIOGRAPHIC FACTORS:

Neoflex is handled in the same way as a conventional asphalt emulsion. It is applied by spraybar in a manner which is also largely conventional. In the European trials, it was usually applied at a rate of about 2 ks/m^2, though two trials at a rate of 1.6 kg/m^2 have been completed successfully.

DISCUSSIONS AND RECOMMENDATIONS:

The particular advantages claimed for Neoflex are:

1. It provides good immediate strength even when applied under adverse conditions.
2. It does not require that either the underlying surface or the chippings added subsequently be dry in order to obtain a successful treatment.
3. It does not penetrate the asphalt substrate and therefore will not contribute to any potential fattening problems.

Several trials of Neoflex were carried out in Europe in 1980. They were recorded as performing satisfactorily in 1983. Not much of the data in the literature relates to measurements of the performance of Neoflex under traffic. It is therefore impossible to be certain of its performance in a North American environment.

SUMMARY:

The manufacturer's claims are supported by a limited number of trials carried out in Europe. While it is likely that it would function successfully in the United States, a strong recommendation should await further successful data.

MATERIAL: Neolastic

SUPPLIER:

Pavement Technologies, Inc.
15042 NE 40th Street, Suite 201
Redmond, Washington 98052
Tel: 206-883-6860
Telex: 323680(PaveTech)

DESCRIPTION:

Neolastic is a cationic thermoplastic co-polymer modified bitumen-based emulsion. It is supplied as a ready-made liquid binder.

AREAS OF APPLICATION:

Neolastic is used as a binder in single- or double-chip seal treatment on either flexible or rigid pavements carrying heavy traffic. It is also used in maintenance of primary and secondary road system pavements carrying medium or high densities of traffic. Neolastic products also have uses in a preventative maintenance for heavily trafficked highways.

PHYSIOGRAPHIC FACTORS:

Neolastic is handled in the same way as a conventional asphalt emulsion. It is applied by spraybar in a manner which is also largely conventional. In the European trials, it was usually applied at a rate of about 2 kg/m^2, though two trials at a rate of 1.6 kg/m^2 have been completed successfully.

DISCUSSIONS AND RECOMMENDATIONS:

The particular advantages claimed for Neolastic are:

1. It provides good immediate strength, even when applied under adverse conditions.
2. It does not require that either the underlying surface or the chippings added be subsequently dry to obtain a successful treatment.
3. It does not penetrate the asphalt substrate, therefore, and will not contribute to any potential fattening problems.

Several trials of Neolastic were carried out in Europe in 1980. They were recorded as performing satisfactorily in 1983. There are very little data in the literature relating to measurements of the performance of Neolastic under traffic. It is therefore impossible to be certain of its performance in a North American environment.

SUMMARY:

The manufacturers claims are supported by a limited number of trails carried out in Europe. While it would probably function successfully in the United States, a strong recommendation should await further successful data.

MATERIAL: Neoprene

SUPPLIER:

E. I. DuPont de Nemours and Company, Inc.
Polymer Products Department
Barley Mill Plaza
Kirk Mill Building
Wilmington, Delaware 19898
1-800-441-7111

DESCRIPTION:

Neoprene is a rubber additive composed of elastomeric chloroprene polymers. There are several types of this asphalt modifier available, including both dry and latex forms. The more common latex form is an off-white liquid containing 45 to 60 percent solids.

AREAS OF APPLICATION:

Four to 6 percent wet weight (2 to 3 percent dry weight) of Neoprene is typically added to asphalt emulsions or to asphalt cement to achieve desired physical properties. However, the effectiveness of the Neoprene is dependent upon its compatibility with the crude source. This can be determined by pretesting.

PHYSIOGRAPHIC FACTORS:

Bulk shipments of Neoprene are made in tank car, tank truck, and collapsible rubber tanks. Shipments are also made in 55-gallon drums by freight car and/or truck. Latex samples are packaged and shipped in one gallon or five gallon "Cubitainers."

Latexes should be stored within a temperature range of 55- 88°F which may require insulation of the storage tank and transfer lines. Latexes thicken as the temperature falls and will coagulate irreversibly upon freezing. This will occur when the temperature goes below 32°F unless the latex contains a freeze/thaw stabilizer or a freezing point depressant.

Neoprene latexes do not require constant agitation to maintain uniform dispersion of the polymer particles. However, prolonged standing causes slight settling of the particles in some types of Neoprene latex. It is good practice to stir the latex periodically. Mixing for about ten minutes every day using a slow speed (e.g., 25 RPM) agitator should be sufficient. For most latexes, which can coagulate under high shear, it is desirable to select as low a pump speed as practical.

The preferred method of mixing is with the hot asphalt cement. For asphalt emulsions, Neoprene has been successfully added to the soap solution before emulsification. DuPont is currently experimenting with adding Neoprene to the pug mill or drum mixer and has not yet determined the effectiveness of this mixing process.

DISCUSSIONS AND RECOMMENDATIONS:

Neoprene is the country's oldest commercial synthetic rubber. The reasons for this fact are found in the technical and marketing support given to this product by its parent company, DuPont. A relatively large amount of technical research has been focused on Neoprene and the producers of this modifier have responded to this research by upgrading the Neoprene formulation through the years. This modifier has a promising future with applications covering a broad spectrum of asphalt pavement technologies. As with many asphalt modifiers, the degree of physical property improvement is dependent upon the compatibility of Neoprene with the parent asphalt.

SUMMARY:

Neoprene latex, when compatible with the asphalt crude with which it is mixed, has been found to improve:

1. Temperature susceptibility (as measured by PVN, PI, and low temperature penetration).
2. High-temperature viscosity (as measured by absolute and kinematic viscosity).
3. Durability (as measured by toughness and tenacity before and after TFOT).
4. Chip retention.

REFERENCE:

Terrel, Ronald A. and Epps, Jon A., "Asphalt Modifiers - A Users Manual for Additives and Modifiers in Asphalt Pavements," Draft Report for the National Asphalt Pavement Association, 1988.

MATERIAL: Olexobit

SUPPLIER:

Deutch B. P.

(British Petroleum, GERMANY)

DESCRIPTION:

Olexobit is a blend of asphalt cement and a polymer based on an Ethyl-Propo-Diene monomer (E.P.D.M.). It is supplied as a ready-made binder, and may be described, generically, as a rubberized asphalt.

The quantity of additive in the bitumen is regarded as proprietary information by the supplier.

AREAS OF APPLICATION:

Olexobit is used as a binder for high-grade paving applications in West Germany. Its most common use is as the binder of Gussasphalt mixes, which are subject to heavy traffic. Alternative formulations of Olexobit are also produced for roofing applications and for emulsification for use in surface treatments.

PHYSIOGRAPHIC FACTORS:

No detailed information is available, but it is probable that Olexobit is handled in a manner which is similar to conventional materials.

DISCUSSIONS AND RECOMMENDATIONS:

Olexobit has been in use in Germany since about 1970 and since it is still in use, it would appear to be reasonable to assume that it is successful. However its use does not appear to have spread into other European countries, let alone into other continents.

It has been used in comparative trials in the United Kingdom. These trials have been based on Hot Rolled Asphalt, the mix most commonly used for surfacing heavily trafficked roads in the United Kingdom. As yet, no results are available on the data accumulated from these field trials.

SUMMARY:

The manufacturers do not attempt to give this product a high profile. However, the fact that it is still in use some 18 years after its initial introduction supports a view that it provides the type of service required from it.

MATERIAL: Sealgum

SUPPLIER:

Pavement Technologies, Inc.
15042 NE 40th Street, Suite 201
Redmond, Washington 98052
Tel: 206-883-6860
Telex: 323680(PaveTech)

DESCRIPTION:

Sealgum is a cold laid, rough textured, waterproof, latex modified binder-based micro-asphalt concrete. The binder is in the form of an emulsified latex-modified asphalt. The mix has a high filler content to maximize its waterproofing characteristics and minimize the risk of bleeding.

AREAS OF APPLICATIONS:

Sealgum is recommended for use in urban streets, parking lots, industrial areas, and school yards. It is also recommended for surfacing emergency stopping lanes and parking areas, and as a new wearing course on asphalt stabilized base courses. Surfacing of damp, compacted sand/gravel base courses is possible after curing. Airfield runways and taxiways can be resurfaced with Sealgum and it is suitable for the maintenance of rural pavements under rapid, medium and high density traffic.

PHYSIOGRAPHIC FACTORS:

The material is proportioned, mixed, and placed directly onsite by a single batch or continuous machine. A special mechanical spreader is incorporated in the machine which can operate on pavements of any width. The machine is claimed to be capable of covering up to 25,000 yd^2 of surface per working day. Light compaction is recommended if the newly treated surface is to receive some traffic. Sealgum sets rapidly, allowing a treated pavement to be reopened to traffic very quickly.

DISCUSSIONS AND RECOMMENDATIONS::

Sealgum is offered as an alternative to surface treatments by slurry seal and by thin hot mix overlays.

The advantages claimed over slurry seals are:

1. More durability.
2. Greater skid resistance.
3. Better leveling and finishing characteristics.
4. Thicker and more flexible surfacing.

The advantages claimed over thin hot mix overlays are:

1. Simplification of detailing in the region of joints with shoulders.
2. Localized treatment is possible (e.g., in wheel track ruts).
3. Improved adhesion to existing pavement surface.
4. Since only light compaction is required, the risk of disruption to underground utilities is minimized.
5. The equipment can readily adjust to the variable cross section of old surfaces.

SUMMARY:

Sealgum appears to be a mix based on the latex-modified binder Neoflex produced by the same company for use in simple surface treatments. No data is currently available to verify the advantages claimed for the mix. No improvement in the resistance to permanent deformation have been claimed for this material.

MATERIAL: Pliopave

SUPPLIER:

Pliopave is produced by the Goodyear Tire and Rubber Company of Akron, Ohio. It is still being produced and marketed, but not for use as an additive to liquid asphalts.

DESCRIPTION:

Pliopave is a latex rubber that can be added to liquid asphalts.

AREAS OF APPLICATION:

Pliopave is used as an additive to liquid asphalt to improve the performance of asphalt pavement systems.

PHYSIOGRAPHIC FACTORS:

Pliopave is normally added to asphalt binders at a rate of 3 to 5 percent by weight. If the rubberized asphalt is to be used for joint sealing, as much as 10 percent rubber may be added to the asphalt binder.

Rubberized asphalt can be used in chip seals, slurry seals, fog seals, plant-mix seal coats, and asphalt concrete; and is applied in the same manner as if conventional asphalt was being used as the binder. The mix temperature, climatic conditions, etc., should be the same as for conventional paving types. Rubberized asphalt should not be confused with rubberized tar. Rubberized asphalt is not fuel-resistant.

DISCUSSIONS AND RECOMMENDATIONS:

During the last few years, rubberized asphalt has been used as the binder for a number of paving jobs. After evaluating many of these jobs, some paving engineers have concluded that no benefit is gained by the use of rubberized asphalt, while others have concluded that performance will be improved substantially. It is believed that as wider application and construction experience are gained, the ratio of good performing jobs to bad performing jobs will increase.

The greatest potential for asphalt treated with Pliopave appears to be in the construction of thin lifts such as slurry seals, chip seals, and sand mixes. Rubberized asphalt increased the asphalt's ability to bond to and hold aggregate intact, thereby reducing such distresses as raveling and edge cracking.

When Pliopave is added to an asphalt binder, the binder becomes less temperature-susceptible; in other words, rubberized asphalt is harder than

conventional asphalt at higher temperatures and is softer than conventional asphalt at lower temperatures. Since it is harder than conventional asphalt at higher temperatures, bleeding is not normally a problem. Field projects have shown that chip seals when constructed with this material have very few bleeding problems.

The biggest problem in using rubberized asphalt is the expense. Whenever used, the initial cost of the job is increased over that for conventional asphalt; however, the savings in maintenance costs and the increased pavement life often justify the use of this material.

Some literature has indicated that rubberized asphalt outperforms conventional asphalt for approximately 1 to 2 years, depending on the pavement type. After this time the deterioration in the rubberized asphalt is much more rapid than that for the conventional asphalt. It is felt that a properly designed and constructed rubberized asphalt pavement type (thin layers) will perform longer and with less maintenance than a pavement type constructed with conventional asphalt.

SUMMARY:

Generally, Pliopave does improve the quality of asphalt binder. When Pliopave is added to asphalt, the asphalt will be less temperature-susceptible, will have stronger bond to aggregate, and will be less susceptible to bleeding. Additionally, maintenance costs of many pavement types will be reduced; however, initial costs will be greater.

SPECIFIC REFERENCES:

Fish, G. W., "Pliopave Experimental Project Construction and Materials Report," Research Report No. 179, Florida Department of Transportation, October 1973.

Hughes, C. S., "Minimization of Reflection Cracks Installation Report - 1973," VHRC 73-R16, Virginia Highway Research Council, October 1973.

GENERAL REFERENCES:

"South Dakota Chip Seal Coat Study," Physical Research Section, South Dakota Department of Highways, 1967.

"Agoura Test Section," Report No. M&R43038, Materials and Research Department, California Division of Highways.

Carey, Donald E., "A Laboratory Evaluation of Rubber-Asphalt Paving Mixtures," Research Report No. 79, Louisiana Department of Highways, June 1974.

MATERIAL: Diapoly-K

SUPPLIER:

J. H. Diamond Company, Inc.
701 Lake Avenue
Lake Worth, Florida 33460
(Florida only) (305) 582-7161
1-800-582-7161

DESCRIPTION:

Diapoly-K is a two-component polymer that is specifically designed for use as an additive to asphalt cements for varying uses in asphalt pavement systems. No information is available as to the chemical make-up of this proprietary material.

AREAS OF APPLICATION:

Diapoly-K is marketed as an additive to asphalt cements for a wide variety of pavement applications including hot mixes and chip seals.

PHYSIOGRAPHIC FACTORS:

The addition of the two polymer components of Diapoly-K to asphalt cements is a relatively simple process. Typical polymer loadings range from five to twenty percent by weight, depending upon the application and characteristics of the parent asphalt. The two polymer components are labeled Component A and Component B. Component A is a solid crumb material which will liquify at 150 degrees F. Component B is a viscous, gold colored transparent liquid which will flow at room temperature. Both polymer components are considered non-temperature susceptible in terms of weight loss and chemical breakdown.

Irregardless of the total polymer dosage level, the addition of the two components is on the order of about two to one, Component A to Component B. Component A is added to heated and liquified asphalt cement and the resulting mixture is stirred at low speeds for a minimum of five minutes before adding Component B. After Component B is added to the hot asphalt cement, the modified mixture is blended for an additional five minutes before blending with the aggregate.

DISCUSSIONS AND RECOMMENDATIONS:

At the time of this writing, very few field tests of this material had been conducted. This limits the knowledge of shelf life, bulk-blending

procedures, and most important, field performance. Research has proven that this material is sensitive to varying properties of the parent binder, as is the case for most asphalt modifiers.

Limited laboratory testing of Diapoly-K has indicated the potential usefulness of this polymer modifier. Further research and field trials are recommended for this material before any full-scale applications are considered.

SUMMARY:

Diapoly-K is a relatively new product on the asphalt modifier market. Limited laboratory research has indicated that there are improvements in asphalt behavior that could be gained by using this polymer material. Among the possible improvements cited by these laboratory tests are:

1. Decreased high and low temperature susceptibility.
2. Decreased binder hardening due to hot mix plant processing and in-place aging.
3. Increased resistance to stripping from water intrusion.
4. Increased tensile strengths of mixtures.
5. Better mixing and coating of aggregates.

REFERENCE:

Ruth, Byron E. and Tia, Mang, "Preliminary Evaluation of Polymer-Modified Paving Grade Asphalt Cements," Report prepared for J. H. Diamond Company, Inc., September 1985.

M[illegible]RIAL: Novophalt

SUPPLIER:

Murray Jelling
21 Spring Hill Road
Roslyn Heights, New York 11577
(516) 621-0060

DESCRIPTION:

Novophalt is a pre-blended mixture of polyethylene and asphalt cement.

AREAS OF APPLICATION:

Novophalt is used to obtain improved resistance to deformation and increased stiffness in many types of asphalt mixtures.

PHYSIOGRAPHIC FACTORS:

The Novophalt process usually involves the addition of about 7 percent by weight of polyethylene to asphalt cement. Because polyethylene is not soluble in asphalt, it is necessary to use a high shear mixer to blend the two components.

After prolonged storage, the asphalt cement and polyethylene will separate, with the polyethylene rising to the top. If the blend is stored at high temperatures for a period of days, high shear mixing will be required to eliminate the separation. However, continuous or frequent low shear mixing is sufficient to maintain a homogeneous blend.

DISCUSSIONS AND RECOMMENDATIONS:

The Novophalt process was developed primarily as a means of disposing of waste polyethylene in Europe.

The Transport and Road Research Laboratory (TRRL) in Great Britain has evaluated Novophalt in the laboratory, and to a limited extent, in the field. This program concluded that Novophalt is capable of conferring substantial improvements in stiffness and resistance to permanent deformation, but also indicated that significantly increased control is probably necessary in order to achieve the improvements.

Several full-scale trials have been built in Europe; the earliest being constructed in 1977. The limited information available from these trials indicates that they are performing satisfactorily and show improved resistance to deformation.

SUMMARY:

Novophalt appears to provide improved resistance to deformation; however, it does require greater care in processing than do conventional asphalt mixes.

MATERIAL: Polybilt, Escorene, EVA

SUPPLIER:

Exxon Chemical Company
13501 Katy Freeway
Houston, Texas 77079-1398
(713) 870-6771

DESCRIPTION:

Polybilt, which is also referred to in the literature as Ethylene Vinyl Acetate (EVA), is a thermoplastic copolymer of ethylene and vinyl acetate. It is supplied as small solid pellets which are sometimes described as "tear drops."

AREAS OF APPLICATION:

Polybilt is used as an additive to asphalt hot mixes to improve resistance to deformation, increase mix stiffness and to improve the workability of the mixture.

PHYSIOGRAPHIC FACTORS:

EVA products are normally added to asphalt binders at a rate of 2 to 5 percent by weight. Good homogeneous blends can be obtained with low shear mixes if the following practices are adopted:

1. Mix at 320 to 356°F.
2. Add EVA progressively for more uniform mixing.
3. Use a mixer which will create splash or that draws a vortex. (This is to negate the effect of EVA's low specific gravity.)
4. Circulate a blend which has been kept in hot static storage to eliminate concentration gradients that may form with time.

EVA can withstand temperatures up to 444°F without degradation, but prolonged storage at temperatures above 392°F is not recommended. Degradation leads to the formation of acetic acid, which emits a vapor that acts as an irritant to people who come into contact with it. The acid can also cause metal corrosion over prolonged periods.

DISCUSSIONS AND RECOMMENDATIONS:

Most of the development of the use of EVA copolymers as additives in asphalt has taken place in Europe.

Extensive laboratory studies carried out by the Transport and Road Research Laboratory (TRRL) in England have indicated that the copolymer reduces temperature-susceptibility, increases resistance to deformation except

at low temperatures and very short loading times, increases the elastic response after an imposed strain, does not have a detrimental effect on compaction, and can reduce the effects of aging in an oven.

EVA copolymers can be manufactured to a wide range of vinyl acetate contents and molecular weights. An EVA containing 18 percent vinyl acetate with a molecular weight of about 16,000 is a good compromise. However, it is possible that EVA copolymers with different compositions may be advantageous for some applications. Exxon Laboratories are currently developing these various compositions, and they are expected to be on the market in the near future.

Limited field trials indicated that EVA modified mixes could be too soft to roll at conventional temperatures, but that the difficulty could be overcome by decreasing the rolling temperature. The TRRL judged the field experiments to be extremely promising.

SUMMARY:

The manufacturer's claims appear to be supported by the TRRL's laboratory studies. It is particularly relevant that the claim to improve resistance to permanent deformation is supported.