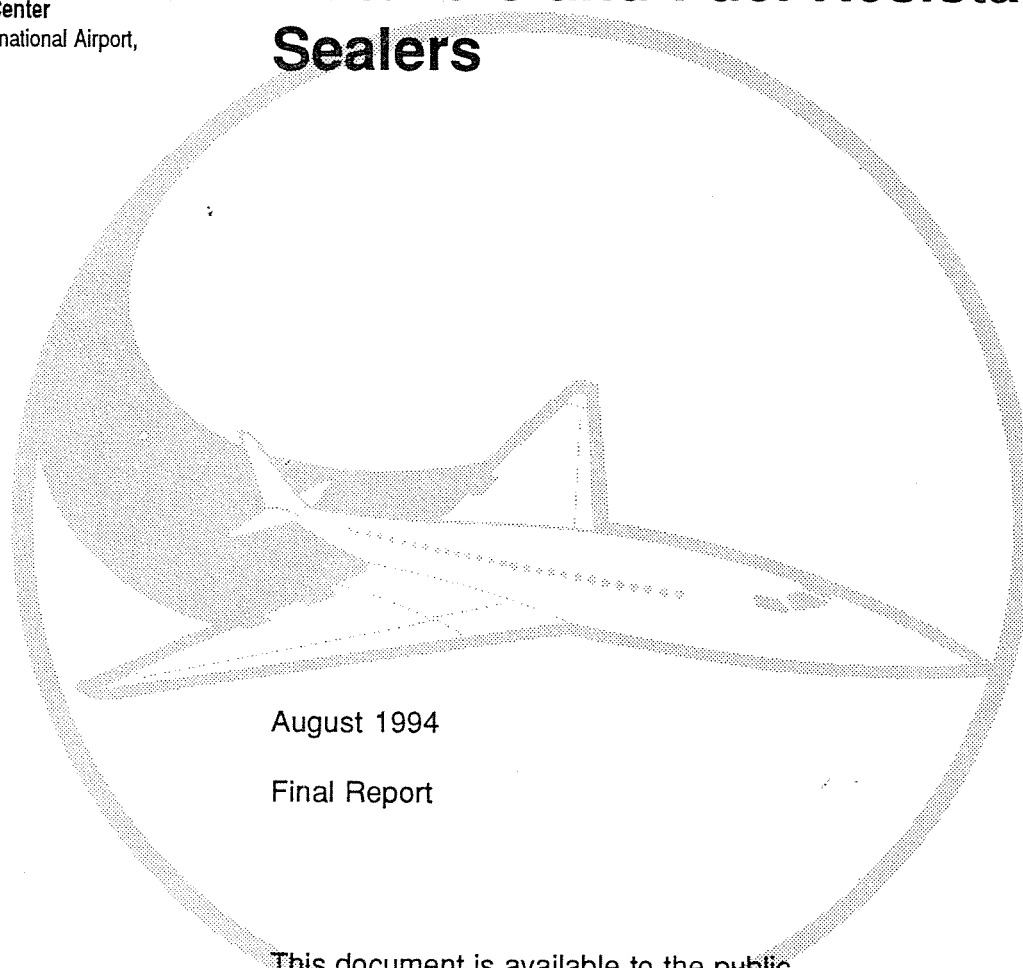


DOT/FAA/CT-94/78
DOT/FAA/RD-93/30

FAA Technical Center
Atlantic City International Airport,
N.J. 08405

Additives in Bituminous Materials and Fuel-Resistant Sealers



August 1994

Final Report

This document is available to the public
through the National Technical Information
Service, Springfield, Virginia 22161.



U.S. Department of Transportation
Federal Aviation Administration

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the objective of this report.

1 Report No DOT/FAA/CT-94/78 DOT/FAA/RD-93/30		2 Government Accession No		3 Recipient's Catalog No	
4 Title and Subtitle Additives in Bituminous Materials and Fuel-Resistant Sealers				5 Report Date August 1994	
				6 Performing Organization Code	
7 Author(s) Gary L. Anderton, Laurand H. Lewandowski				8 Performing Organization Report No	
9 Performing Organization Name and Address US Army Engineer Waterways Experiment Station Geotechnical Laboratory 3909 Halls Ferry Road Vicksburg, MS 39180-6199				10 Work Unit No (TRAIS) DTFA01-90 Z-02069	
				11 Contract or Grant No	
12 Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City International Airport, NJ 08405				13 Type of Report and Period Covered Final Report August, 1993	
				14 Sponsoring Agency Code ARD-200	
15 Supplementary Notes The US Army Engineer Waterways Experiment Station conducted this study as part of the Inter-Agency Agreement Project "Durability Criteria for Airport Pavements."					
16 Abstract This report provides a matrix of information on the current state-of-the-art of commercially available additives for bituminous materials and fuel-resistant sealers. Included in this report is a brief history of these types of additives, the results of an airport field survey, descriptions of seven airport site visits, and detailed discussions of a series of laboratory tests used to physically and chemically characterize these additives. A literature search was conducted throughout the study in order to provide the latest information on each reported additive. The information gained from the literature search, field survey, site visits, and laboratory analyses was used to develop an additives database containing informative profiles of each additive. The database is presented in hard copy as an appendix of this report, and is also presented in a user-friendly computerized database as a supplement to this report.					
17 Key Words Additives Asphalt Bituminous Materials Chromatography Fuel-Resistance Modifers Pavements Seal Coat Spectroscopy			18 Distribution Statement No restrictions. This document and the supporting computerized database are available to the public through the National Technical Information Service, Springfield, Virginia 22161		
19 Security Classif (of this report) Unclassified		20 Security Classif (of this page) Unclassified		21 No of Pages 170	
22 Price					

PREFACE

This report was sponsored by the US Department of Transportation, Federal Aviation Administration (FAA) under Inter-Agency Agreement No. DTFA01-90-Z-02069, "Durability Criteria for Airport Pavements." The study was performed by the Pavement Systems Division (PSD), Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, during the period October 1990 to July 1993. Dr. A. McLaughlin was the FAA Technical Monitor.

This study was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, GL; Dr. G. M. Hammitt II, Chief, PSD; and Mr. T. W. Vollor, Chief, Materials Research and Construction Technology Branch, PSD. PSD personnel engaged in the laboratory testing included Messrs. Bill Dorman, Rogers Graham, and Dr. L. H. Lewandowski. Mr. R. S. Walker, PSD, designed and constructed the additives database. The project's Principal Investigator was Mr. G. L. Anderton. This report was written by Mr. Anderton and Dr. Lewandowski.

The Director of WES during the preparation and publication of this report was Dr. Robert W. Whalin. The Commander and Deputy Director was COL Bruce K. Howard, EN.

TABLE OF CONTENTS

INTRODUCTION.....	1
BACKGROUND.....	1
OBJECTIVE.....	1
SCOPE.....	1
HISTORY OF BITUMINOUS ADDITIVES.....	2
FIELD SURVEY.....	3
ADDITIVES IN BITUMINOUS MATERIALS.....	3
ADDITIVES IN FUEL-RESISTANT SEALERS.....	11
SITE VISITS.....	12
HOUSTON HOBBY AIRPORT.....	12
HOUSTON INTERCONTINENTAL AIRPORT.....	14
DALLAS/FORT WORTH INTERNATIONAL AIRPORT.....	16
OAKLAND PONTIAC AIRPORT.....	17
BISHOP INTERNATIONAL AIRPORT	19
CAPITOL CITY AIRPORT.....	20
DETROIT CITY AIRPORT.....	21
LABORATORY ANALYSIS.....	24
BACKGROUND.....	24
Gel Permeation Chromatography (GPC).....	24
Fourier Transform Infrared (FTIR) Spectroscopy.....	25
EXPERIMENTAL PROCEDURE.....	26
Materials.....	26
Experimental Methods.....	26
Fourier Transform Infrared Spectroscopy.....	26
Interpretation of FTIR-ATR Spectra.....	31
Gel Permeation Chromatography.....	32
Dynamic Mechanical Analysis.....	35
RESULTS AND DISCUSSION.....	35
Analysis of Infrared Spectra.....	35
Analysis of Gel Permeation Chromatography.....	36
ADDITIVE VALIDATION METHODS.....	37
ADDITIVES DATABASE STRUCTURE.....	43
SUMMARY OF SHRP ASPHALT MODIFICATION RESEARCH.....	44
BACKGROUND.....	44
MATERIALS.....	44

SIGNIFICANT TEST RESULTS.....	45
Aging.....	45
Permanent Deformation.....	45
Stripping.....	46
Fatigue and Thermal Cracking.....	46
SUPERPAVE TM MIX DESIGN SYSTEM.....	47
CONCLUSIONS.....	48
RECOMMENDATIONS.....	49
REFERENCES.....	50
APPENDIX A: INFRARED SPECTRA.....	A1
APPENDIX B: GEL PERMEATION CHROMATOGRAPHS.....	B1
APPENDIX C: ADDITIVES DATABASE.....	C1

LIST OF FIGURES

1	BITUMINOUS ADDITIVES SURVEY QUESTIONNAIRE.....	4
2	FUEL-RESISTANT SEALER SURVEY QUESTIONNAIRE.....	5
3	REASONS FOR USING BITUMINOUS ADDITIVES.....	9
4	AIRFIELD PAVEMENT AREAS USING BITUMINOUS ADDITIVES.....	9
5	BITUMINOUS ADDITIVE RATINGS.....	10
6	FUEL-RESISTANT SEALER ADDITIVE RATINGS.....	10
7	HOUSTON HOBBY RUNWAY 17-35 SURFACED WITH NOVAPHALT.....	13
8	HOUSTON HOBBY TAXIWAY FOXTROT SURFACED WITH NOVAPHALT.....	13
9	PAVEMENT GROOVES ON HOUSTON HOBBY RUNWAY 17-35.....	14
10	HOUSTON INTERCONTINENTAL RUNWAY 14R-32L TREATED WITH PDC.....	15
11	VISUAL APPEARANCE OF PDC-TREATED (LEFT) AND UNTREATED (RIGHT) ASPHALT CONCRETE RUNWAY AT HOUSTON INTERNATIONAL AIRPORT.....	16
12	FUEL-RESISTANT SEALER TEST SECTION AT DFW AIRPORT.....	17
13	MODERATE LOSS OF FUEL-RESISTANT SEALER ON DFW PARKING LOT.....	18

LIST OF TABLES

1	AIRPORT PAVEMENTS WITH ADDITIVES.....	6
2	AIRPORT PAVEMENTS WITH NO ADDITIVES.....	8
3	ADDITIVES FINGERPRINTED FOR THE DATABASE.....	28
4	ADDITIVES IN DATABASE WHICH WERE NOT FINGERPRINTED.....	29
5	POLYSTYRENE NARROW MOLECULAR WEIGHT STANDARDS FOR GPC SYSTEM NUMBER 1.....	33
6	POLYSTYRENE MOLECULAR WEIGHT STANDARDS FOR GPC SYSTEM NUMBER 2.....	34
7	MOLECULAR WEIGHT CALCULATIONS FOR BLOCK COPOLYMERS.....	36
8	DATABASE STRUCTURE.....	43
9	SHRP MODIFIER CODES.....	45

INTRODUCTION

BACKGROUND

This study was conducted as one of six research areas under the research project entitled "Durability Criteria for Airport Pavements." Each of these studies was performed by the U.S. Army Engineer Waterways Experiment Station for the Federal Aviation Administration (FAA).

There has been an increasing interest in the use of additives in bituminous materials and fuel resistant sealers in recent years. This current interest is due in part to increasing occurrences of premature flexible pavement failures resulting from heavier airplanes, higher tire pressures, and increased traffic counts. In response to this interest, a great many additive materials have been introduced on the market representing a wide range of chemical compositions. These additive materials range from carefully engineered polymers to slightly refined industrial waste products. Most of these materials remain unproven in terms of full scale airfield pavement field trials.

A previous research study on bituminous additives was conducted at WES and reported on by the author in 1990¹. This study was conducted for the U.S. Air Force and focused on additives which were reported to reduce deformation distresses. Other recent studies on bituminous additives have generally investigated only one or a few additives at once and were directed towards the highway pavements community. The lack of proven data on the majority of the available additives prompted the FAA to identify the research need addressed by this study.

OBJECTIVE

The study reported herein provides a matrix of information on the current state-of-the-art of commercially available additives for bituminous materials and fuel-resistant sealers. This matrix includes information gained from existing literature, results of a field survey questionnaire, selected site visits, and the results of a laboratory analysis. This report is to be used as a source for new FAA specifications and as a basis for further research and verification.

SCOPE

The scope of the study included a review of the available literature, a field survey questionnaire, seven field inspections of airports with additives in use, and a laboratory analysis of the available materials designed to determine the components and chemical composition of each additive. The results of the study are presented and discussed as individual components within this report. The information gained for each additive is also summarized in separate additive profiles listed in an additive database. This database is presented in hard copy in this report and in a computerized database format provided as a supplement to this report.

HISTORY OF BITUMINOUS ADDITIVES

Additives for bituminous materials and fuel-resistant sealers have been around for many years, but they never have enjoyed full acceptance by the pavements industry. Additives used to improve the stripping resistance of asphalt concrete mixtures were experimented with in the 1920's. The use of reclaimed rubber in asphalt mixtures took place as early as the 1940's. Mineral fillers and extenders were also experimented with in these early years of asphalt modification. The concept of asphalt additives has always had its skeptics, and until recent years saw limited applications in the field.

From the early 1980's, the art of bituminous additives has grown considerably in the numbers and variety of products available. The recent growth of the bituminous additive industry has been attributed to several factors, including:

- a) Increasing traffic demands on today's flexible pavements (higher traffic counts, higher tire pressures, heavier loads).
- b) Economic pressures (increasing material and construction costs, desire for thinner pavements, deferred maintenance).
- c) Perception that asphalt cement quality is being reduced by new refining techniques.
- d) Excess supplies of industrial by-products and waste materials which may be used as bituminous additives.

Even though some naturally occurring materials and several industrial by-products and waste materials continue to be marketed as bituminous additives, the trend developing in today's market is toward high-technology, carefully engineered additives. Instead of focusing on a single area of desired binder improvement, many of today's bituminous additives are designed to improve several pavement performance characteristics. Also, many of today's additive manufacturers offer several different formulations of the same additive to cover a broader range of user needs.

FIELD SURVEY

In March of 1991, 200 survey questionnaires were sent to airport agencies throughout the United States. These questionnaires were designed to help determine the field experiences related to bituminous and fuel-resistant sealer additives on civil airports. The questionnaire pertaining to the bituminous additives is shown in Figure 1. The questionnaire addressing the fuel-resistant sealer additives is shown in Figure 2. Both questionnaires were mailed in the same survey package.

Of the 200 surveys sent out, 107 were returned, resulting in a 54 percent response rating. Several of the returned questionnaires were used to describe more than one airport. For the 131 airports described by the returned questionnaires, 62 airports reported no additives in use and 69 airports reported that they did have some type of additive in their current airfield pavement systems. Forty-five of these 69 airports had bituminous additives and 29 airports had fuel-resistant sealer additives. The 69 airports reporting additive usage are listed in Table 1, and the 62 airports reporting no additives in use are listed in Table 2. A breakdown of the most revealing information gained from the survey is shown in Figures 3 through 6.

ADDITIVES IN BITUMINOUS MATERIALS

Figure 3 displays the survey results pertaining to the users' reasons for using bituminous additives. Pavement cracking (59%) was the most significant failure mode which prompted the use of bituminous additives. The most prominent type of cracking cited in the survey responses was thermal (33%). Pavement deterioration by stripping (23%) and raveling (11%) were two other failure modes cited as significant reasons for using bituminous additives. The survey results indicated that permanent deformation by shoving (8%) and rutting (0%) were not critical failure modes on flexible airfield pavements. These survey results may be used as an indicator of the most significant flexible airfield pavement failure modes, giving direction to future research in this field.

Figure 4 indicates which airport bituminous pavement areas are being modified with asphalt cement additives. Runway pavements (58%) dominate this category with approximately three times the volume as that of both the taxiway (20%) and apron (19%) pavement areas. A few airports (3%) cited access roads containing bituminous additives. These results indicate that future efforts in developing bituminous additives for airport pavements should concentrate more on those materials which are suited for runways.

When asked to rate the performance of the bituminous additives in use, the survey respondents seemed very pleased with the performance of these modified pavement systems (Figure 5). It should be noted that these performance ratings are generally for relatively new pavements. The pavements containing bituminous additives cited in this survey ranged from 1 to 11 years old, with an average age of 3.2 years. True pavement performance ratings should include a full life history, and there are virtually no airport pavements in existence which could be used for such a life cycle analysis.

Asphalt Cement Additives

1. Do you have any pavements constructed using asphalt cement additives?
Yes_____ No_____ (If No, skip to question No. 9)
2. Is any construction history of these pavements (construction dates, plans, drawings, laboratory test results, mix designs, etc.) available? Yes_____ No_____
3. Are maintenance records available on these pavements showing types of maintenance and when maintenance was performed? Yes_____ No_____
4. Have pavement evaluations or conditional surveys been performed on these pavements? Yes_____ No_____
5. Are traffic history data (types and frequency of aircraft movements) available for these pavements? Yes_____ No_____
6. What mode(s) of pavement failure (was/were) the most significant in the decision to use an asphalt cement additive? (If more than one failure mode was considered, rate according to significance, where 1 = highest, 2 = next highest, etc.)

Permanent Deformation

Rutting_____

Shoving_____

Other_____

Cracking

Fatigue_____

Thermal_____

Reflective_____

Other_____

Deterioration

Raveling_____

Stripping_____

Other_____

7. Would you rate the performance of your asphalt additive pavement(s) as:

Excellent?_____

Fair?_____

Good?_____

Poor?_____

Comments: _____

8. General information on your asphalt additive uses:

Additive Name/Type	[Pavement Use]				Approximate Surface Area	Construction Date
	Runway	Taxiway	Apron	Other		
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____

9. Do you anticipate any projects with asphalt cement additives during 1991?
Yes_____ No_____

FIGURE 1. BITUMINOUS ADDITIVES SURVEY QUESTIONNAIRE

Fuel-Resistant Sealer Additives

1. Do you have any pavements surfaced with fuel-resistant sealers containing one or more special additives? Yes_____ No_____
(If No, skip to question No. 8)
2. Is construction history of these seal coat applications (construction dates, application rates, laboratory test results, etc.) available? Yes_____ No_____
3. Are traffic history data (types and frequency of aircraft movements) available for these sealed pavements? Yes_____ No_____
4. How many years of service life were you expecting from the seal coat(s) before construction? _____yrs.
5. Judging from current conditions, how many years of service life do you expect from the seal coat(s)? _____yrs.
6. Would you rate the performance of your fuel-resistant sealer(s) with additives as:
Excellent?_____ Fair?_____ Good?_____ Poor?_____
Comments:_____
7. General information on your fuel-resistant sealers with additives:

Additive-Seal Coat Type	[Pavement Use]			Approximate Surface Area	Construction Date
	Apron	Hanger	Other		
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
8. Do you anticipate any projects with fuel-resistant sealers containing additives during 1991? Yes_____ No_____

FIGURE 2. FUEL-RESISTANT SEALER SURVEY QUESTIONNAIRE

TABLE 1. AIRPORT PAVEMENTS WITH ADDITIVES (CONT'D)

<u>Airport Location</u>	<u>Hot-Mix Asphalt Additive</u>	<u>Fuel-Resistant Sealer Additive</u>
Phoenix, AZ	Ground Rubber	Latex Rubber
Oakland, CA	Ground Rubber	
Palm Springs, CA	Butonal NS-175	
San Francisco, CA		Polytar/Promak
Colorado Springs, CO	Butonal NS-175	
Denver, CO	Neoprene/Fiberpave	
Pueblo, CO	Anti-Strip/Styrelf	
Washington, DC (Dulles)	ACCRA 2000	Promak/Grip-Flex
Washington, DC (Nat'l)	Neoprene	
Tallahassee, FL		Latex Rubber
Nero Beach, FL		Grip-Flex
Fort Wayne, IN		Latex Rubber
Lafayette, LA		Latex Rubber
Adrian, MI	Ultrapave	
Alma, MI	Ultrapave	
Bay City, MI	Ultrapave	
Beaver Island, MI	Rubr-Road	
Benton Harbor, MI	Ultrapave	Ultrapave
Cadillac, MI	Ultrapave	
Calumet, MI	Ultrapave	
Detroit, MI	Rubr-Road/Ultrapave	
Escanaba, MI	Ultrapave	Ultrapave
Flint, MI	Ultrapave	
Freeland, MI		Ultrapave
Houghton Lake, MI	Ultrapave	
Iron Mountain, MI	Ultrapave	Ultrapave
Ironwood, MI		Ultrapave
Jackson, MI	Ultrapave	
Kalamazoo, MI	Ultrapave	
Lansing, MI	Ultrapave	Ultrapave
Manistee, MI	Ultrapave	
Menominee, MI	Ultrapave	
Mt. Pleasant, MI	Ultrapave	
Muskegon, MI	Rubr-Road/Ultrapave	Ultrapave
Negaunee, MI	Ultrapave	Ultrapave
Ontonagon, MI	Ultrapave	
Owosso, MI		Ultrapave
Port Huron, MI	Ultrapave	
Sault Saint Marie, MI	Ultrapave	
Three Rivers, MI	Ultrapave	
Traverse City, MI	Ultrapave	
Minneapolis-St. Paul, MN	Fiberpave	
Jefferson City, MO		Latex Rubber
Greensboro, NC	Neoprene	
Bismark, ND	Latex Rubber	

TABLE 1. AIRPORT PAVEMENTS WITH ADDITIVES (CONCL'D)

<u>Airport Location</u>	Hot-Mix Asphalt <u>Additive</u>	Fuel-Resistant Sealer <u>Additive</u>
Lincoln, NE		Dynatex Latex
Omaha, NE	Polypropylene Fibers	
Newark, NJ	Trinidad Natural Asp.	
Albuquerque, NM	Lime	Mu-Mix
Santa Fe, NM	Styrelf	
Las Vegas, NV	Lime/Butonal NS-175	
Newark, NJ	Rubr-Road	
New York, NY (LaGuardia)	Trinidad Natural Asp.	
New York, NY (JFK)	Trinidad Natural Asp./ Rubr-Road	
Findlay, OH		Grip-Flex
Portland, OR		Latex Rubber
Salem, OR	Pave Bond BA2000	
Middletown, PA		Latex Rubber
Pittsburgh, PA	Novaphalt	
Myrtle Beach, SC		Co-polymer Latex
Childress, TX		Ductilad D1002
Dallas/Ft. Worth, TX		Grip-Flex
Houston, TX (Inter.)		Pavement Dressing Conditioner
Houston, TX (Hobby)	Novaphalt	
Salt Lake City, UT	Neoprene/Butonal NS-175	
Madison, WI		Latex Rubber
Casper, WY	Anti-Strip/Latex Rbr.	Latex Rubber
Cheyenne, WY	Latex Rubber	
Jackson, WY	Anti-Strip/Latex Rbr.	Mu-Mix

TABLE 2. AIRPORT PAVEMENTS WITH NO ADDITIVES

Fairbanks, AK	St. Louis, MO
Mobile, AL	Great Falls, MT
Montgomery, AL	Charlotte, NC
Burbank, CA	Winston Salem, NC
Los Angeles, CA	Fargo, ND
San Diego, CA	Grand Forks, ND
San Jose, CA	Lincoln, NE
Weatherford, CN	Concord, NH
Dover, DE	West Lebanon, NH
New Castle, DE	Atlantic City, NJ
Clearwater, FL	Reno, NV
Jacksonville, FL	Falconer, NY
Orlando, FL	Cincinnati, OH
Atlanta, GA	Cleveland, OH
Augusta, GA	Columbus, OH
Honolulu, HI	Oklahoma City, OK
Des Moines, IA	Philadelphia, PA
Mason City, IA	Columbus, SC
Boise, ID	Greer, SC
Chicago, IL	Sioux Falls, SD
Savoy, IL	Nashville, TN
South Bend, IN	Knoxville, TN
Wichita, KS	Abilene, TX
Franfort, KY	Austin, TX
Lexington, KY	San Antonio, TX
Louisville, KY	Norfolk, VA
Baton Rouge, LA	Richmond, VA
Shreveport, LA	Huntington, WV
Portland, ME	Laramie, WY
Baltimore, MD	
Minneapolis, MN	
Rochester, MN	
Kansas City, MO	

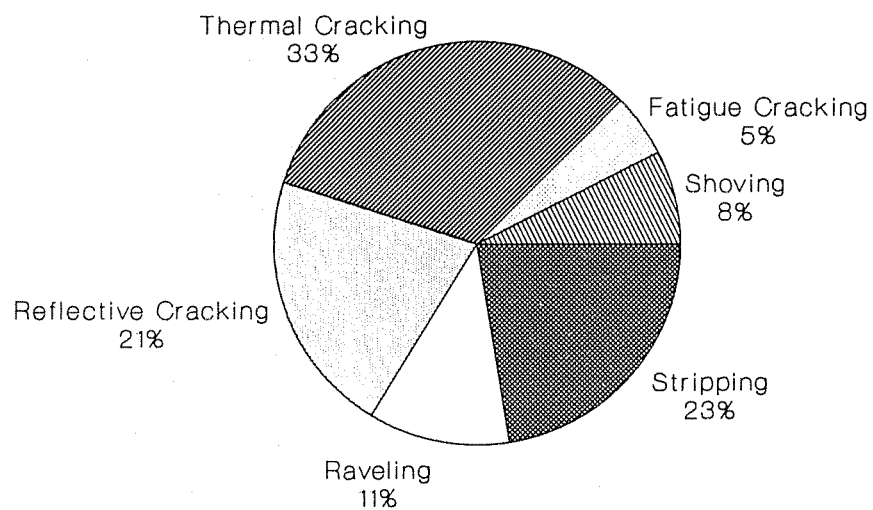


FIGURE 3. REASONS FOR USING BITUMINOUS ADDITIVES

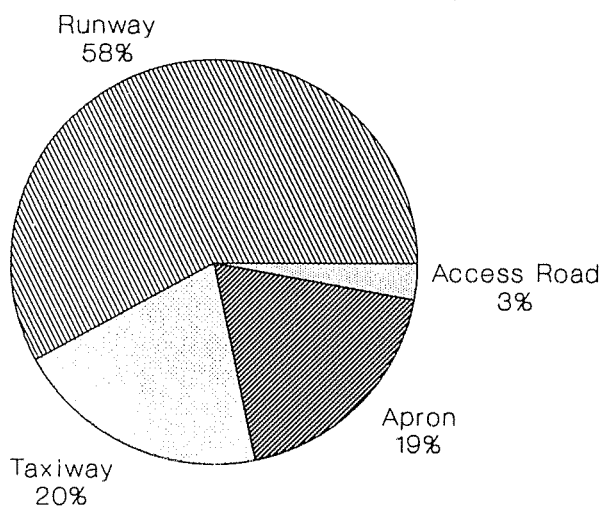


FIGURE 4. AIRFIELD PAVEMENT AREAS USING BITUMINOUS ADDITIVES

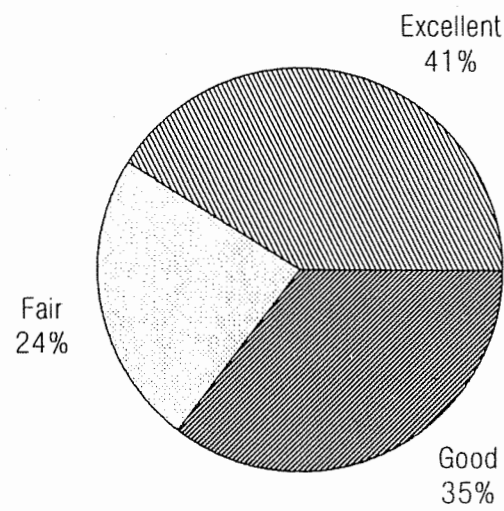


FIGURE 5. BITUMINOUS ADDITIVE RATINGS

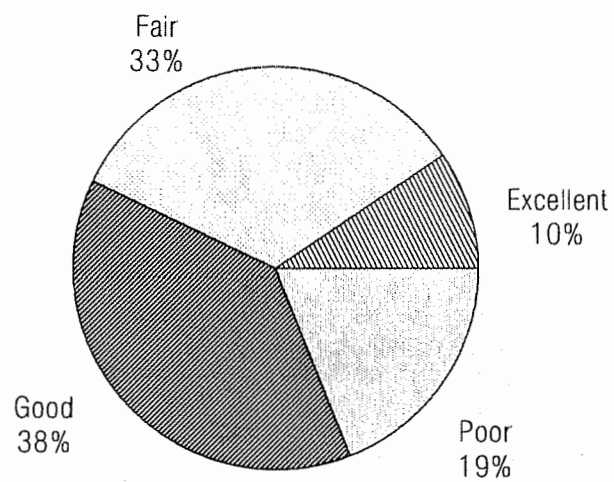


FIGURE 6. FUEL-RESISTANT SEALER ADDITIVE RATINGS

ADDITIVES IN FUEL-RESISTANT SEALERS

The survey results on additives in fuel-resistant sealers indicate that these additives are enjoying less success in the field when compared to bituminous additives. The survey results displayed in Figure 6 show that the majority of fuel-resistant sealer additive users rate their additive's performance as either good (38%) or fair (33%). Also, more survey respondents rated their additive's performance as poor (19%) than excellent (10%).

Additional survey data indicated that almost all of these modified fuel-resistant sealers were being used on parking apron areas. Almost all of the modified fuel-resistant sealers cited in the survey responses were latex rubber modified coal tar materials. When the users were asked what they had originally expected as a design life of their fuel-resistant sealer, the answers ranged from three to 15 years with an average of 6.7 years. When asked how long the modified fuel-resistant sealers were expected to last based on their current condition, the responses again ranged from three to 15 years, but the average was 5.9 years. This means that on the average, the fuel-resistant sealers with additives in current use were predicted to last about 88 percent of their originally expected life span.

SITE VISITS

In 1991 and 1992, site visits were made at seven different airports to observe in-service pavements constructed with bituminous and fuel-resistant sealer additives. The selected airports varied in additive type, traffic type, climate, age of pavements, and user needs. The descriptions of each site are presented separately in the following paragraphs.

HOUSTON HOBBY AIRPORT

One of the four major runways at Houston Hobby Airport is surfaced with a polyethylene-modified asphalt concrete mixture. This runway was reconstructed with the modified asphalt concrete mixture in March 1989 and is shown in Figure 7. The runway 17-35 reconstruction project followed a successful trial section of the same material constructed on a Houston Hobby taxiway in 1986. The taxiway test section (Figure 8) used approximately 500 tons of the polyethylene-modified asphalt concrete in a 5-in. thick surface course. The test section had successfully carried daily traffic and early indications were that the pavement performance was significantly improved. The polyethylene-modified asphalt cement used in these pavements is known as Novaphalt.

Reconstruction of Runway 17-35 at Houston Hobby began with removing the top 4-in. of the runway's center section for the full length of the runway. An asphalt rubber stress absorbing membrane interlayer (SAMI) was first placed in this milled "keel" section to retard any potential reflective cracking from propagating upwards from the existing pavement structure. The milled section was then filled with an intermediate layer of polyethylene-modified asphalt concrete and compacted. Finally, the entire runway was overlaid with 3-in. of the polyethylene-modified asphalt concrete mixture.

Local engineers at Houston Hobby continually quantify the performance improvements of the polyethylene-modified asphalt pavements by comparing their physical appearance to that of the adjacent unmodified asphalt pavements. These pavement performance benefits include: reduced temperature susceptibility, better crack resistance, increased flexural fatigue life, and reduced rutting. An unexpected benefit in using polyethylene-modified asphalt concrete as a surface mixture is that the modified mixture can be saw-cut grooved and exhibit a significantly reduced level of raveling during and after the grooving process. This reduces the chances of foreign object damage (FOD) to aircraft. It was also noted at Houston Hobby that the grooves cut in the polyethylene-modified runway surface were not closing up in the wheel paths during the summer months as many times occurs with traditional asphalt concrete pavements. This results from the increased stability of the polyethylene-modified asphalt concrete mixture. The grooved section of Houston Hobby Runway 17-35 is shown in Figure 9.

Engineers representing the City of Houston are very pleased with the performance of the polyethylene-modified asphalt concrete pavements at Houston Hobby Airport. The airfield at Ellington Air Force Base near Houston is scheduled to be turned over to the city in 1992. Based on the successes at Houston Hobby, city engineers plan on rehabilitating the airfield pavements

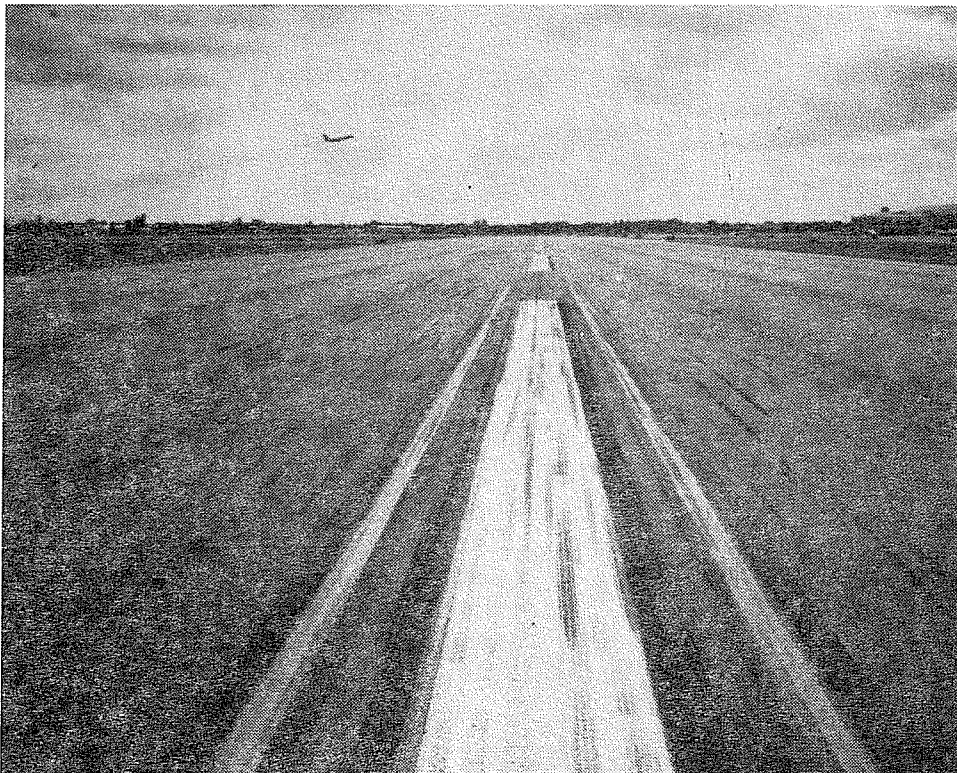


FIGURE 7. HOUSTON HOBBY RUNWAY 17-35 SURFACED WITH NOVAPHALT

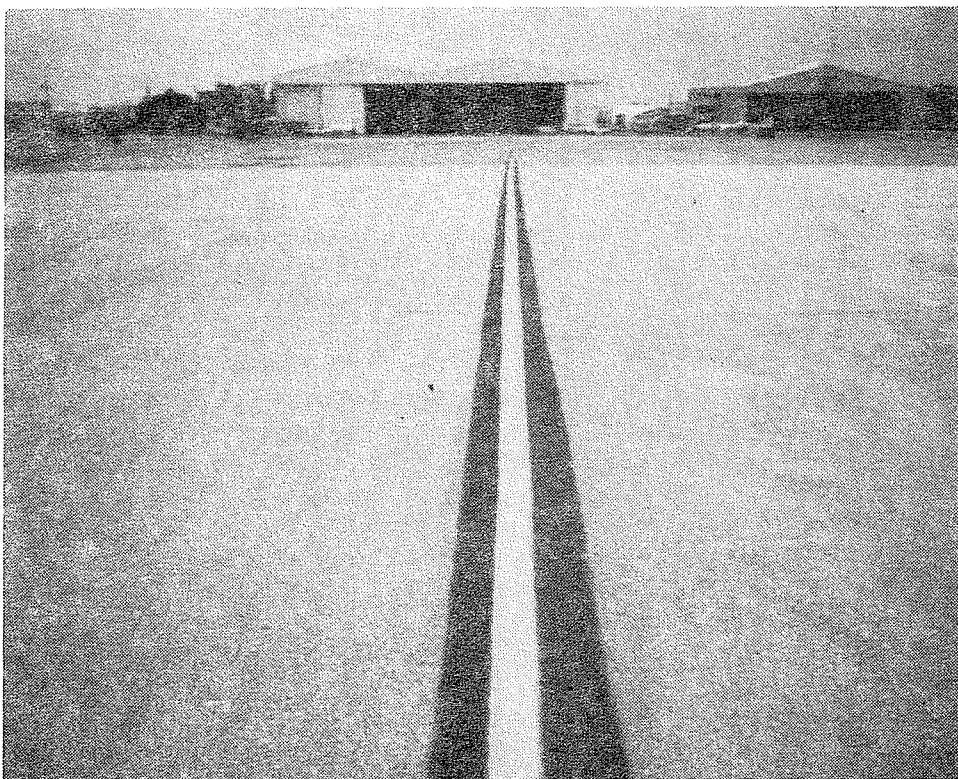


FIGURE 8. HOUSTON HOBBY TAXIWAY FOXTROT SURFACED WITH NOVAPHALT

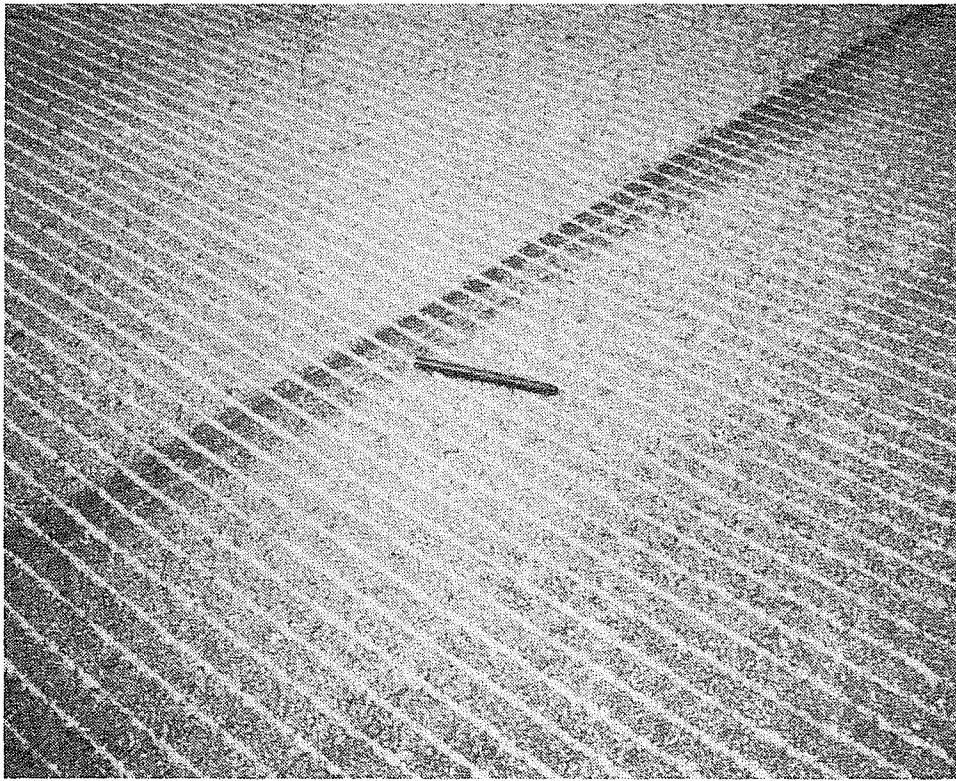


FIGURE 9. PAVEMENT GROOVES ON HOUSTON HOBBY RUNWAY 17-35

at Ellington with 6-in. of the polyethylene-modified asphalt concrete as soon as possible.

HOUSTON INTERCONTINENTAL AIRPORT

Two asphalt concrete runways at Houston Intercontinental Airport have recently been treated with a coal tar based asphalt rejuvenator known as Pavement Dressing Conditioner (PDC). This material was used to extend the life of the asphalt concrete runways by replenishing many of the desirable binder properties such as ductility and viscosity which are lost over time due to environmental age-hardening. The coal tar oils used in this surfacing material provide an additional benefit by protecting the pavement against fuel spills and other petroleum based products.

At Houston Intercontinental, 6000-ft. of Runway 14R-32L were treated with a 0.065 gal/sq yd application of PDC in September 1989. This surface-treated runway is shown in Figure 10. Due to the success of the Runway 14R-32L project, a second runway at Houston Intercontinental was treated with PDC in June 1991. This second application was on 10,000-ft of Runway 9-27, with an application rate of 0.07 gal/sq yd. The cost of the PDC applications on both of these runways was approximately 0.75 \$/sq yd. The additional cost of de-rubberizing and removing the old paint markings before PDC application and then applying new paint markings after PDC application were reported to be between 0.25 and 0.30 \$/sq yd.

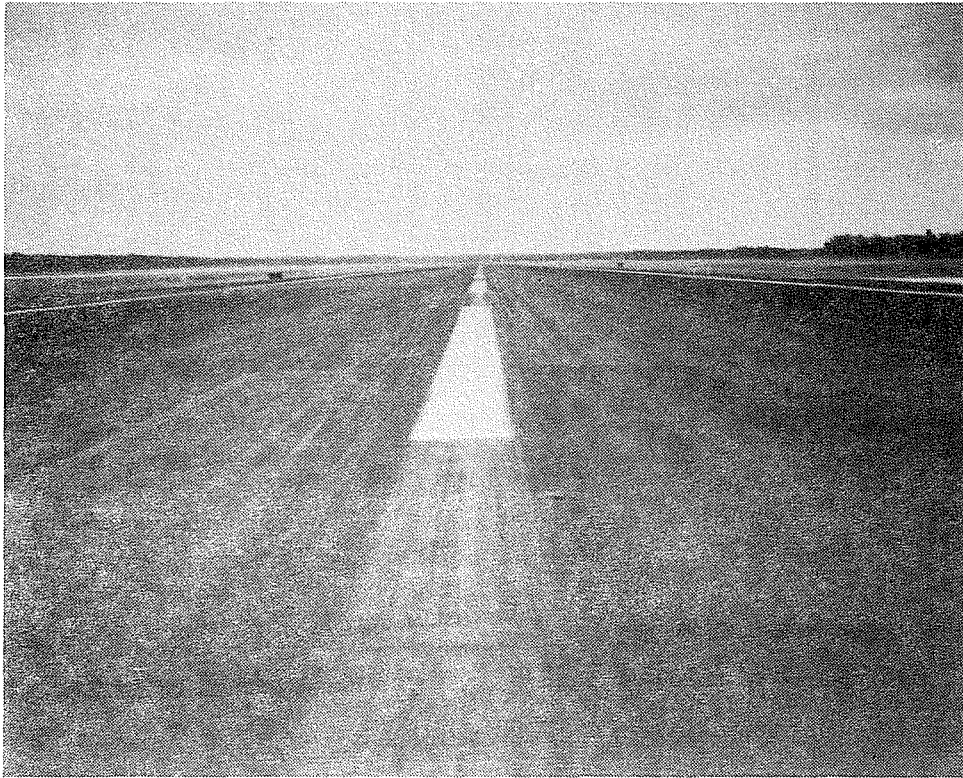


FIGURE 10. HOUSTON INTERCONTINENTAL RUNWAY 14R-32L TREATED WITH PDC

The PDC treatment usually penetrates the asphalt concrete surface to a depth of 1/2 to 1-1/2-in., depending upon the voids characteristics of the asphalt concrete at the surface. Besides softening or rejuvenating the asphalt cement at the surface, the PDC treatment helps to heal existing small surface cracks. The application of PDC can reduce the loss of fine aggregates from the pavement surface, thereby reducing the risk of FOD. A PDC treatment produces the appearance of new asphalt where the existing pavement has the bleached appearance of older asphalt concrete surfaces (Figure 11). All of these benefits can be counteracted by an overdose of PDC, which in some circumstances could over-soften the pavement surface causing it to be unstable under traffic.

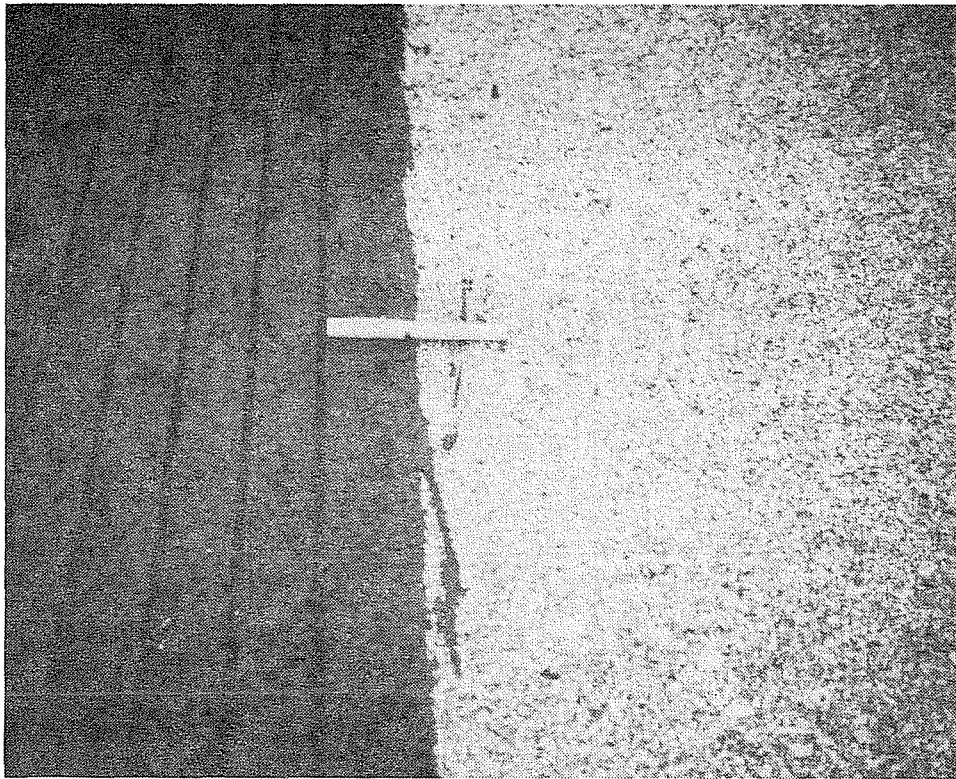


FIGURE 11. VISUAL APPEARANCE OF PDC-TREATED (LEFT) AND UNTREATED (RIGHT) ASPHALT CONCRETE RUNWAY AT HOUSTON INTERCONTINENTAL AIRPORT

DALLAS/FORT WORTH INTERNATIONAL AIRPORT

A site visit at Dallas/Fort Worth (DFW) International Airport was made in December 1992 to observe several applications of modified fuel-resistant sealer materials. Airport pavement engineers at DFW have evaluated several fuel-resistant sealer materials since 1987 in hopes of finding a material suitable for asphalt concrete shoulders surrounding most of the PCC airport pavements. As of December 1992, no fuel-resistant material used at DFW had proven itself suitable for full-scale application on the airport pavement shoulder areas.

One of the pavement areas at DFW used to evaluate the fuel-resistant sealers was an asphalt concrete shoulder off of Apron 2W (Figure 12). At the time of the site visit, there were two separate test sections of different coal-tar based sealers on this shoulder area. One section had the same Pavement Dressing Conditioner (PDC) material as previously described at Houston Intercontinental Airport. The PDC treated section was three years old at the time of the site visit. Another test section on this shoulder had a 1-1/2 year old Polytar treated section. Polytar is a thermoplastic coal-tar based material which was reformulated and marketed under the trade name Grip-Flex beginning in 1992. Neither of these test section areas had shown any signs of premature aging or cracking problems, but local engineers reported that more time was needed before any judgement would be made on these sections.

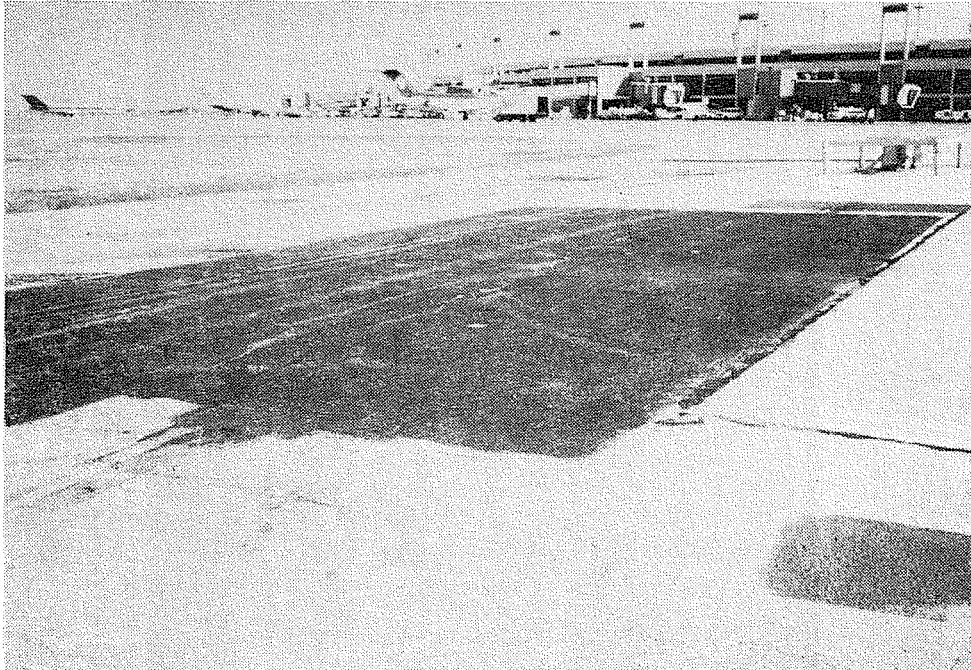


FIGURE 12. FUEL-RESISTANT SEALER TEST SECTION AT DFW AIRPORT

Three automobile parking lots at DFW had also been treated with the Grip-Flex surface sealant. At the time of the site inspection, one parking lot treatment was about five years old, one was about three years old, and the newest surface treatment was 1-1/2 years old. Although the newest sealer material appeared to be holding up, there was evidence that the routine parking lot oil spillage was wearing away the surface material (Figure 13). The loss of the surface treatment was much more evident on the three year old section where large chunks of the surface material were lost after the material had cracked and lost its bond with the asphalt concrete (Figure 14).

It should be noted that although the preliminary results of the DFW Grip-Flex trials seem unfavorable, there have been other airport applications using this material which seem to have been successful (see other airport locations for Grip-Flex in Appendix C). The reason for this discrepancy was unknown.

OAKLAND PONTIAC AIRPORT

A latex rubber modified porous friction course (PFC) runway pavement was observed at Pontiac, Michigan in May 1993. The modifier used at this site was a styrene-butadiene rubber (SBR) latex marketed under the trade name Ultrapave. The modified PFC material was placed in 1986 as a 1-in.-thick surfacing over a dense-mix asphalt leveling course on Runway 27L-9R, which was approximately 8600 ft long and 150 ft wide.



FIGURE 13. MODERATE LOSS OF FUEL-RESISTANT SEALER ON DFW PARKING LOT

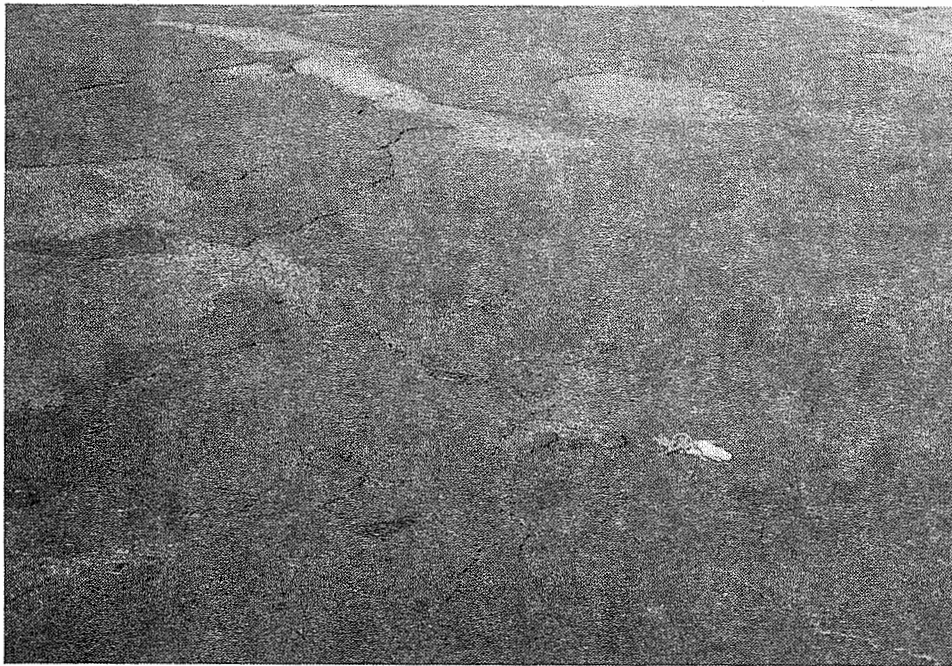


FIGURE 14. SEVERE DETERIORATION OF FUEL-RESISTANT SEALER ON DFW PARKING LOT

Local airport authorities reported that PFC pavements were used at Oakland Pontiac and at other Michigan airports to increase skid resistance during inclement weather. A SBR latex modified binder was used in these PFC pavements to allow for more binder in the mix, thus increasing durability. For a PFC pavement in such a harsh climate, the observed runway at Oakland Pontiac Airport appeared to be in good condition (Figure 15). Much of the surface binder had worn away and a marginal amount of cracking was observed. The surface voids appeared to have been plugged with the sand used by the airport maintenance crews during deicing operations. Although this pavement appeared to be in its final stages of service life, the local airport authorities were pleased with its performance, and it seems likely that the SBR additive was at least partly responsible for this pavement's success.

BISHOP INTERNATIONAL AIRPORT

Two latex rubber modified PFC surfaced runways at Bishop International Airport in Flint, Michigan were observed in use in May 1993. These two runways, RW 18L-36R and RW 9L-27R, were originally portland cement concrete (PCC) surfaced and both were overlaid with the SBR latex (Ultrapave) modified PFC material in 1983. One of the runway ends of RW 18L-36R was extended in 1991 and surfaced with the same SBR latex modified PFC material. A leveling course of dense-graded asphalt concrete was placed between the PCC and PFC layers on all of these pavement areas.



FIGURE 15. MINOR CRACKING IN LATEX RUBBER MODIFIED
PFC RUNWAY AT OAKLAND PONTIAC AIRPORT

The 1983 PFC pavements had an appearance similar to those of the 1986 PFC pavements at Oakland Pontiac Airport; much of the surface voids appeared to be filled with sand and fine aggregate. Both runways had various amounts of transverse and longitudinal reflection cracks from the underlying PCC pavements. The local airport authorities were pleased with the performance of these ten year old PFC pavements, however.

The 1991 PFC surfaced runway extension was in noticeably better condition than the 1983 PFC pavements (Figure 16). The surface aggregates were well coated with binder and the void structure appeared to be much more open. The airport authorities at Bishop International seemed to have found a successful formula for an effective PFC surfacing.

CAPITOL CITY AIRPORT

Two latex rubber modified pavement applications were observed at Capital City Airport in Lansing, Michigan in May 1993. Runway 10R-28L was resurfaced in 1988 with an Ultrapave modified asphalt concrete layer in order to deter the thermal cracking problems common in this area. This runway appeared to be performing well with only minor cracking observed (Figure 17).



FIGURE 16. LATEX RUBBER MODIFIED PFC RUNWAY AT BISHOP INTERNATIONAL AIRPORT



FIGURE 17. LATEX RUBBER MODIFIED RUNWAY (RIGHT) AT CAPITOL CITY AIRPORT

A large section of the Southeast Ramp at Capitol City Airport was sealed with an Ultrapave modified coal tar emulsion seal coat in 1992. Local airport authorities choose the latex rubber modified emulsion in order to increase the sand loadings in the slurry seal mixture, thereby increasing thickness and durability under traffic. The seal coat on this airport loading ramp did appear to be sufficiently thick, but moderate to severe shrinkage cracking was found throughout the entire seal coat area (Figure 18). Cracking of this nature is one of the most common complaints with coal tar based seal coats. The cause of the premature cracking at this site was speculated to have been caused by an early application of the seal coat over a new asphalt concrete surfacing before the surfacing had sufficiently cured.

DETROIT CITY AIRPORT

Two runways at Detroit City Airport in Michigan, which were surfaced with a latex rubber modified asphalt concrete, were observed in May 1993. The latex rubber additive used in both runways was a SBR latex material known as

RUBBER-ROAD. Runway 15L-33R was resurfaced with the SBR modified asphalt concrete in 1988 and Runway 7L-25R was resurfaced in 1992 with this material. Both runway pavements had transverse grooves cut in them to improve skid resistance (Figure 19).

Detroit City Airport authorities reported that the SBR latex additive had become a standard item in their asphalt concrete pavements to deter thermal cracking. The two modified asphalt runways appeared to be structurally sound, with minor cracking observed on the five year old runway surfacing. The airport authorities were reported to be somewhat disappointed in the performance of the transverse grooves on the runways and are considering a SBR latex modified PFC overlay in the near future to increase skid resistance.

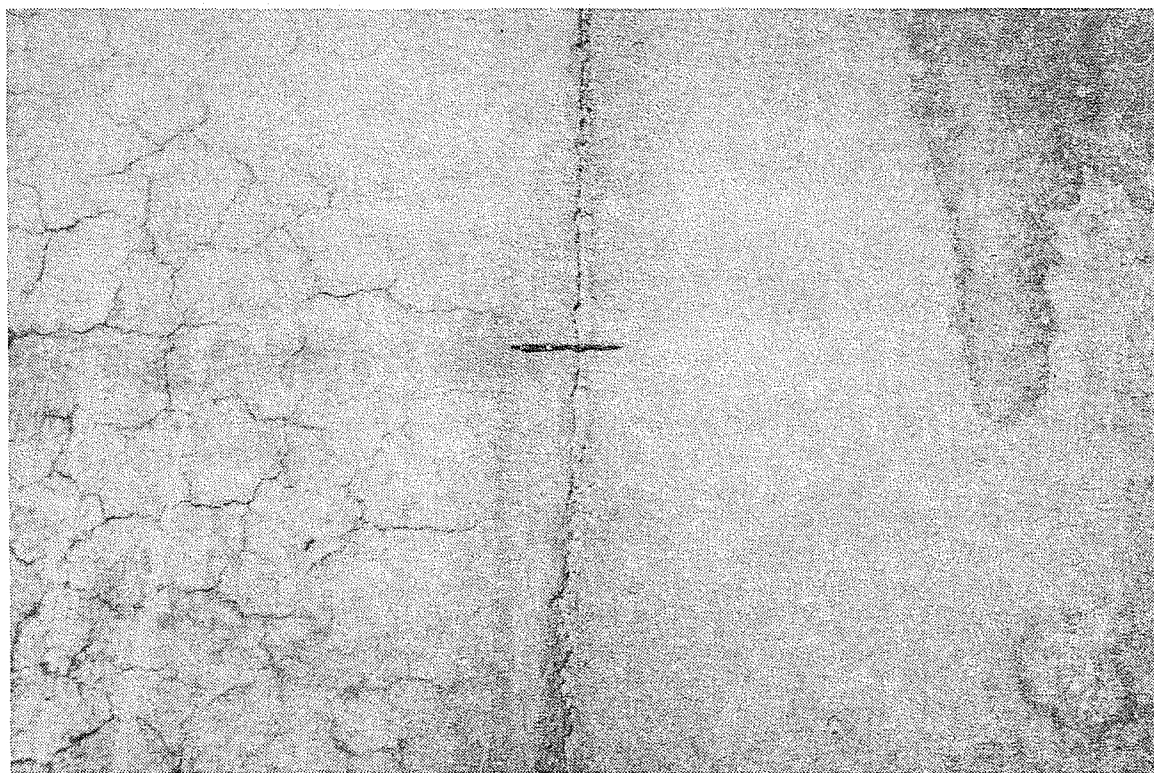


FIGURE 18. SHRINKAGE CRACKING OF LATEX RUBBER MODIFIED FUEL-RESISTANT SEAL COAT (LEFT) AT CAPITOL CITY AIRPORT



FIGURE 19. TRANSVERSE GROOVES CUT IN LATEX RUBBER MODIFIED
RUNWAY PAVEMENT AT DETROIT CITY AIRPORT

LABORATORY ANALYSIS

BACKGROUND

The two methods used in this report for characterizing additives used in bituminous material and fuel-resistant sealers for airfield pavements are Gel Permeation Chromatography (GPC) and Fourier Transform Infrared Spectroscopy (FTIR). A literature survey of these two methods was performed with respect to analyzing bituminous materials and additive modified bituminous materials.

Gel Permeation Chromatography (GPC)

The GPC technique was introduced in 1963 by Moore² for determining the molecular weight distribution of polymers. This method consists of dissolving a sample in appropriate solvent, usually tetrahydrofuran (THF), and injecting the solution into a series of columns. These columns are made up of porous beads which are swollen by the carrier solvent and contain numerous small pores. As the sample travels through the columns, the smaller molecules are temporarily trapped in these pores and take longer to pass through the columns. Once the sample eludes from the column, it is detected by either an ultra-violet absorbance detector or differential refractometer detector. A chromatograph is then produced, which is a plot of absorbance or percent concentration detected versus the time it took each sample fraction to elude through the column, commonly called the retention time.

Altgelt³ was the first to use GPC to study bituminous materials. He fractionated asphaltene molecules using GPC and determined their molecular weight distributions. Since there is not an established relationship between the asphalt molecule's hydrodynamic volume and molecular weight, a molecular size distribution rather than a molecular weight distribution is obtained. Richman⁴ obtained molecular size distributions of three different polymers and detected differences between the various asphalt fractions. Bynum and Traxler⁵ used GPC to analyze asphalts before and after service in pavements. They found that the chromatographs varied depending on the crude source and method of processing.

More recently GPC has been used as a quantitative tool in trying to relate asphalt structure to properties and performance. Jennings⁶ related the area of the chromatograph eluting first from the column (the first third of the area under the curve, denoted as the large molecular size area) to the rutting occurring in asphalt pavements. He also prescribed the limits in which asphalt cements will perform well by their percent of large molecular size, medium molecular size and small molecular size portions. Work also has been performed by dividing the area under the chromatograph into fourths and eighths⁷ and relating these to physical properties such as viscosity, penetration, and specific gravity. Price⁸ divided the chromatograph into ten sections and used analysis of variance to relate the areas under the chromatograph to physical properties of additive modified bituminous materials.

Recent work has centered around altering the parameters of the GPC experimental technique to study the change in the asphalt binder's

chromatograph. [REDACTED] developed a technique called "ultra-fast GPC" where the sample run time is cut down from forty-five minutes to ten minutes. This was done using a high flow rate (3.5 ml/min) and high concentration (7 w/v%). Using this method, he was able to separate the aggregate molecules from the smaller molecular sized disperse phase. Pribanic¹⁰ used a Photo Diode Array Detector to look at the three-dimensional plots of various asphalt binders. She was able to separate the asphalt binders into three distinct groups based on their plots. This separation correlated with some properties such as penetration viscosity number and asphaltene content. Branthaver et. al.¹¹ used GPC to study the relationship between various fractions of asphalt binders and their rheological properties. They found excellent correlation between tan delta values and the ratio of the areas in the chromatographic bimodal distributions.

Although extensive work has been performed in studying bituminous materials using GPC, little work has been done on examining the effects of additives, specifically polymers on the molecular size distribution. Extensive characterization of polymers has been performed and is routinely used in quality control in processing plants. A detailed review of GPC in characterizing polymers is beyond the scope of this review and the authors recommend several references for further information.¹²⁻¹⁵

Fourier Transform Infrared (FTIR) Spectroscopy

FTIR is a valuable tool in evaluating the complex chemical nature of hydrocarbon based materials. FTIR was developed in the 1970's and has replaced dispersive systems in almost all mid-infrared applications. FTIR works on the principle that most organic compounds absorb energy in the infrared region. When an infrared beam of radiation passes through a sample in transmission, the covalent bonds of different functional groups absorb energy at certain characteristic frequencies. The amount of energy absorbed versus frequency is called a spectrum. This spectrum is sometimes referred to as a fingerprint.

Beitchman¹⁶ first used Infrared Spectroscopy to relate several absorption bands to the durability of asphalt binders. Petersen¹⁷⁻¹⁹ has performed extensive research into the quantitative evaluation of the chemical species making up virgin and aged asphalt binders. By using selective solvents and reagents, he was able to determine the concentrations of 2-quinolones, ketones, anhydrides, carboxylic acids, sulfoxides, and esters. FTIR has also been used in the investigation of the structure of asphaltenes²⁰, and the evaluation of the hot-mix aging process²¹.

Several methods have been developed for determining modifier content in asphalt binders using FTIR. Button²² developed a method for determining the content of polyethylene in Novophalt using a specular reflectance technique. He used the ratio of the absorbances of the carbonyl group and the carbon-carbon double bond versus weight percent polymer to produce a calibration curve with an excellent linear relationship. A method has also been developed by the Texas State Department of Highway and Public Transportation²³ for determining the concentration of SBR-latex in bituminous materials. They selected the ratio of the aromatic ring bending at 965 cm^{-1} to the carbon-

hydrogen bending at 1375 cm^{-1} . A calibration curve was then developed for Goodyear Latex modified Cosden AC-10 asphalt binder. Shell Development Company²⁴ has also developed a method for measuring the amount of Kraton SBS-latex in the asphalt binder.

A systematic method is required to determine the content of polymer or other additives in the asphalt binder. Several possible techniques will be suggested in this report.

EXPERIMENTAL PROCEDURE

Materials

The additives selected for this project were collected from various manufacturers and distributors. These additives were then divided into several categories based on their chemical structure and physical appearance. The first group consisted of Block Copolymers which had an as-received form of either pellet or crumb. The second group was made of liquid-based, more specifically, latex-based polymers. The final category consisted of nonhomogeneous hydrocarbon materials that did not fit into the other two categories. Table 1 shows all the additives fingerprinted in the database. Table 2 shows all the other additives which were included in the database, but no samples were obtained for fingerprinting. A total of 38 additives were entered into the database.

Experimental Methods

Several experimental methods were employed in the physical and chemical fingerprinting of the additives. The primary methods used in this study were Fourier Transform Infrared Spectroscopy using the Attenuated Total Internal Reflectance (FTIR-ATR) and Gel Permeation Chromatography (GPC). Some discussion of Dynamic Mechanical Analysis is also included.

Fourier Transform Infrared Spectroscopy

The spectra of the additives were obtained using FTIR-ATR. This method is one of the few methods available to analyze opaque materials in both the liquid and solid states. The most common sampling technique used on polymers is a thin film in the transmission mode. This method was not feasible for running opaque materials. FTIR-ATR provided the quickest method to obtain an accurate chemical fingerprint of the material.

To prepare the additives for FTIR-ATR analysis, they were dissolved in toluene at elevated temperatures ($110\text{--}140^{\circ}\text{F}$) to ensure complete dissolution in the solvent. For the latex polymers, they were first oven dried for 24 hours at 60°C and then put into solution. The solution was then poured onto the internal reflectance element (IRE) and allowed to evaporate. A Zinc-Selenide IRE was used for all of the block copolymers and latex polymers, while a Germanium IRE was used for the totally absorbing opaque samples and the additive content determinations. After approximately 10-15 minutes, a thin film of polymer appeared on the IRE.

Next, the sample/IRE was placed in the sample compartment. After allowing the sample compartment to equilibrate for 100 seconds with purged dry air, analysis begins. An infrared beam of energy is directed internally between the IRE/sample interface (Figure 20). When the angle of incidence is great enough, an evanescent wave enters the sample and is absorbed by the various chemical functional groups in the sample. The spectrum gives the amount of energy absorbed with respect to the different wavenumbers. The final spectrum was obtained when the spectrum of the sample was ratioed against the background (no sample on the IRE).

TABLE 3. ADDITIVES FINGERPRINTED FOR THE DATABASE

Modifier Name	Manufacturer	Chemical Name
<u>Block Coploymers</u>		
Polybilt 103S	Exxon	Ethylene/(Vinyl) Acetate
Polybilt 151		
Polybilt 152		
Polybilt 503		Ethylene/Ethyl Acrylate
Kraton D1101	Shell	Styrene/Butadiene/Styrene
Kraton G1650M		Styrene/Ethylene/Butylene* */Styrene
Elvax Resin	DuPont	Ethyl(Vinyl) Acetate
Vestoplast-S	VP-S Company	Ethylene/Propylene/Butylene
<u>Polymer Latexes</u>		
Neoprene 735A	DuPont	Polychloroprene
Neoprene 654		
Ductilad D1000	Lubrizol	Poly(alkenyl ester sulfide) Liquid based styrene polymer
Ductilad D1002		
RUBR-ROAD	RUBR-ROAD Inc.	Styrene/Butadiene Latex
<u>Miscellaneous</u>		
Trinidad Natural Asphalt	Trinidad Asphalt Corp.	Natural Asphalt
Novophalt	Novophalt America	Low-Density Polyethylene
Gilsonite	American Gislomite Company	Natural Hydrocarbon Resin
Rosphalt 50	Royston Labs	Styrenic Additive

TABLE 4. ADDITIVES IN DATABASE WHICH WERE NOT FINGERPRINTED

Modifier Name	Manufacturer	Chemical Name
<u>Block Copolymers</u>		
Styrelf	Elf Asphalt	Styrene/Butadiene
<u>Polymer Latexes</u>		
Downright	Dow Chemical USA	Styrene/Butadiene Latex
Sealgum	Pavement Technologies	Latex Modifier
Pliopave	Goodyear Tire and Rubber	Latex Modifier
Butonal NS 175 Butonal NS 198 Butonal NS 120 Butonal NS 117 Butonal NS 134	BASF	Styrene/Butadiene Latex
Ultrapave	Textile Rubber and Chemical	Styrene/Butadiene Latex
<u>Miscellaneous</u>		
Microfil	Cabot	HAF Carbon Black
Mineral Filler	Cabot	Mineral Filler
Fiberpave	Hercules Inc.	Short-Length Polypropylene Fibers
Aqua-Shield	LBD Asphalt Products Co.	Amine-Based
Reclaimed Rubber	ARPG	Amine-Based
Kling-Beta	Scanroad, Inc.	Reclaimed Tire
Plusride	Pavetech Corp.	Scrap Tire
Bonifibers	Kapejo, Inc.	Polyester Fibers
Petroflex	GFC Materials	Polyethylene Terephthalate Fibers
Grip-Flex	Elastic Materials, Inc.	Coal-Tar Emulsion Polypropylene Fibers

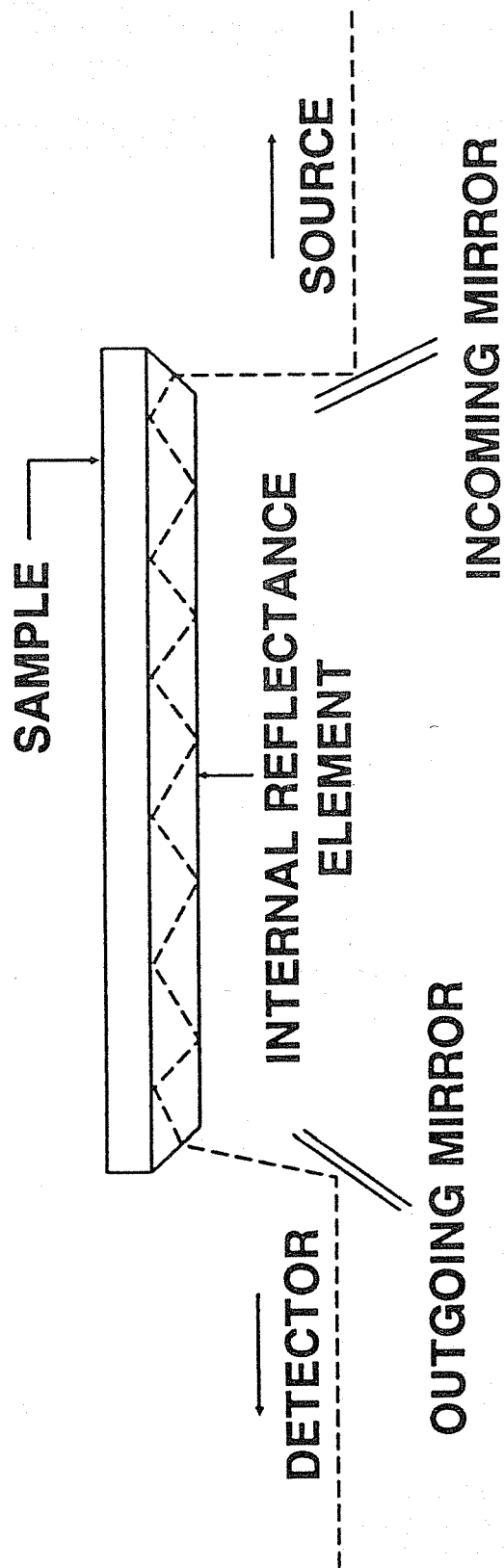


FIGURE 20. SCHEMATIC OF FTIR-ATR SAMPLING TECHNIQUE

All spectra were obtained using a Nicolet 510P FTIR System controlled by an IBM PS2 Workstation with Nicolet PC/IR software. The measuring parameters included a resolution of 4 cm^{-1} and 32 scans. A Deuterium Triglyceride Detector was used to collect the infrared energy leaving the sample compartment. These spectra were then stored on 3.5 inch floppy disk for later analysis.

In order to develop a calibration curve for determining modifier content in polymer-modified asphalt binders, several modifiers were mixed with an AC-20 asphalt binder. The weight percent of additive selected was 0, 3, 5, 7, and 10%. The additives and AC-20 were blended in a low-shear mixer for 45 minutes at 177°C . The results are discussed in the additive validation methods section of this report.

Interpretation of FTIR-ATR Spectra

The interpretation of infrared spectra is somewhat of an art. There are two approaches that can be used in defining spectra: obtain a known spectrum and assign bands to each of the possible functional groups or obtain the spectrum of an unknown and identify the material based on the characteristics' group frequencies found in the spectrum. The philosophy used in this report is the latter one. Once the spectrum of the unknown additive was taken, each peak was then identified according to its frequency. In this section, a brief explanation on how to interpret infrared spectra will be given.

An infrared spectrum consist of bands of different relative intensities and peak shapes absorbing at different frequencies. The strength of the peak is only made relative to the strongest (highest absorbing) band in the spectrum. Peaks are usually classified as very strong, strong, medium, weak and very weak. The breadth of the peak is usually described as sharp, or broad. The key factor in determining the chemical functional group is the frequency or wavenumber in which the peak appears. An extensive table is included in Appendix A listing all of the absorption frequencies of commonly observed functional groups. Further information on the interpretation of infrared spectra can be found in several texts.²⁵⁻²⁷

Another important part of infrared spectroscopy is that according to Beer's Law, the absorbance is related to the concentration of a specific bond at a given frequency in the sample by the equation listed below.

$$A = alc$$

where:

- A = Absorbance (cm^{-1})
- a = Molar Absorptivity ($\text{L mol}^{-1}\text{ cm}^{-2}$)
- l = Cell Pathlength (cm)
- c = Concentration (mol L^{-1})

Since the molar absorptivity and pathlength are known, the absorbance is measured from the spectrum and the concentration of the specific bond group can then be calculated from the above relationship.

Gel Permeation Chromatography

The other primary method used in fingerprinting the modifiers was Gel Permeation Chromatography (GPC). Two different systems were used to analyze the additives, due to the high temperature requirements (>80°C) and solvent system required for the Block Copolymers.

The first system included a Waters 150C GPC with a refractive index detector. The samples were dissolved in Trichlorobenzene (TCB) and then a 250 microliters of .1% (w/v) sample solution in TCB was injected into the system. A flow rate of 1.2 ml/min and run time of 45 minutes were used. A Jordi Gel Mixed Bed Column (10 mm ID x 50 cm long) was used. All the chromatographic runs were monitored at a sensitivity of 64 and a scale factor of 50. A small amount of antioxidant N-phenyl-2 naphthylamine was added to the solution to prevent degradation of the polymers at high temperature.

The system was calibrated using polystyrene standards. Table 5 and Figure 21 show the polystyrene standard's retention times and the calibration curve, respectively.

Once the chromatographs were obtained, the curve was then integrated with a Waters Associates Data Module. The Number Average Molecular Weight (M_n), Weight Average Molecular Weight (M_w), Z-Average Molecular Weight (M_z) and the Polydispersity were obtained for the block copolymers. The statistical molecular weight averages are calculated using the following equations:

$$\sum M_i N_i / N_i = M_n \quad \sum M_i^2 N_i / M_i N_i = M_w \quad \sum M_i^3 N_i^2 / M_i^2 N_i^2 = M_z \quad M_w / M_n = \text{Dispersity}$$

where M_i is the molecular weight of the i species and N_i is the number of moles for that molecular weight species.

The second GPC system was used for the low temperature additives which were soluble in THF at room temperature. These tests included additives from both the latex polymer and miscellaneous groups. The system included a 595 Waters Programmable HPLC Pump in series with a U6K Injector and 484 Tunable UV Absorbance Detector. This system was controlled by a Waters System Interface Module connected to a computer containing Waters 820 Baseline software. The samples were dissolved in THF and then a 25 microliter of .1% (w/v) sample solution in THF was injected into the system. The samples were run at 40°C in THF at 1 ml/min for 30 minutes. Waters Styragel 1000^oA, 500^oA, and 100^oA columns were used. All of the chromatographic runs were monitored at a UV wavelength of 254 nanometers. A sensitivity of 32 and a scale factor of 20 were used.

This system was calibrated using narrow molecular weight standards ranging from 500 to 1,000,000 grams/mole. Table 6 and Figure 22 show the standard's retention times and calibration curves, respectively.

TABLE 5. POLYSTYRENE NARROW MOLECULAR WEIGHT STANDARDS
FOR GPC SYSTEM NUMBER 1

Standard #	Retention Time (minutes)	Log Molecular Weight
1	9.30	7.698
2	9.70	7.477
3	10.50	7.000
4	10.62	6.925
5	12.32	6.133
6	13.22	5.898
7	14.32	5.548
8	16.20	4.995
9	17.25	4.633
10	19.22	4.004
11	20.82	3.447
12	22.25	2.724
13	24.40	1.963

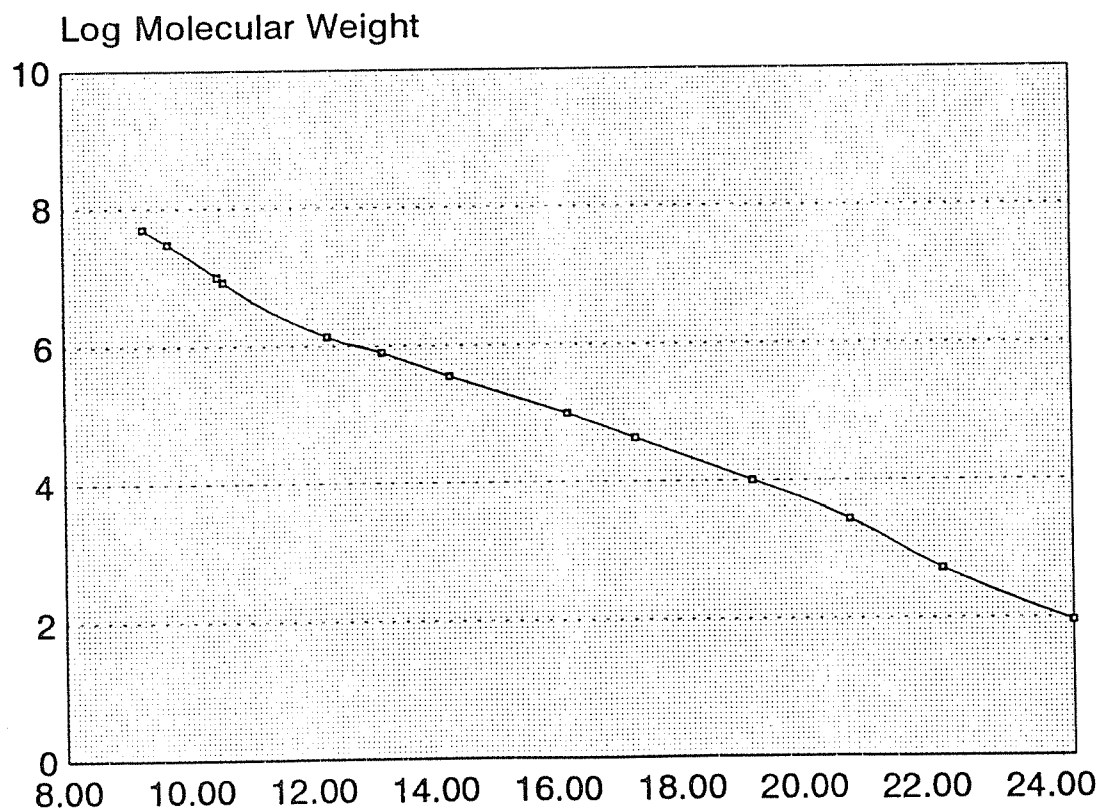


FIGURE 21. CALIBRATION CURVE FOR GPC SYSTEM NUMBER 1.

TABLE 6. POLYSTYRENE MOLECULAR WEIGHT STANDARDS FOR GPC SYSTEM NUMBER 2

Standard #	Retention Time (minutes)	Log Molecular Weight
1	12.94	6.037
2	13.22	5.851
3	13.64	5.550
4	14.38	4.984
5	15.28	4.579
6	16.01	4.292
7	17.99	3.746
8	19.01	3.474
9	20.30	2.939
10	20.73	2.699

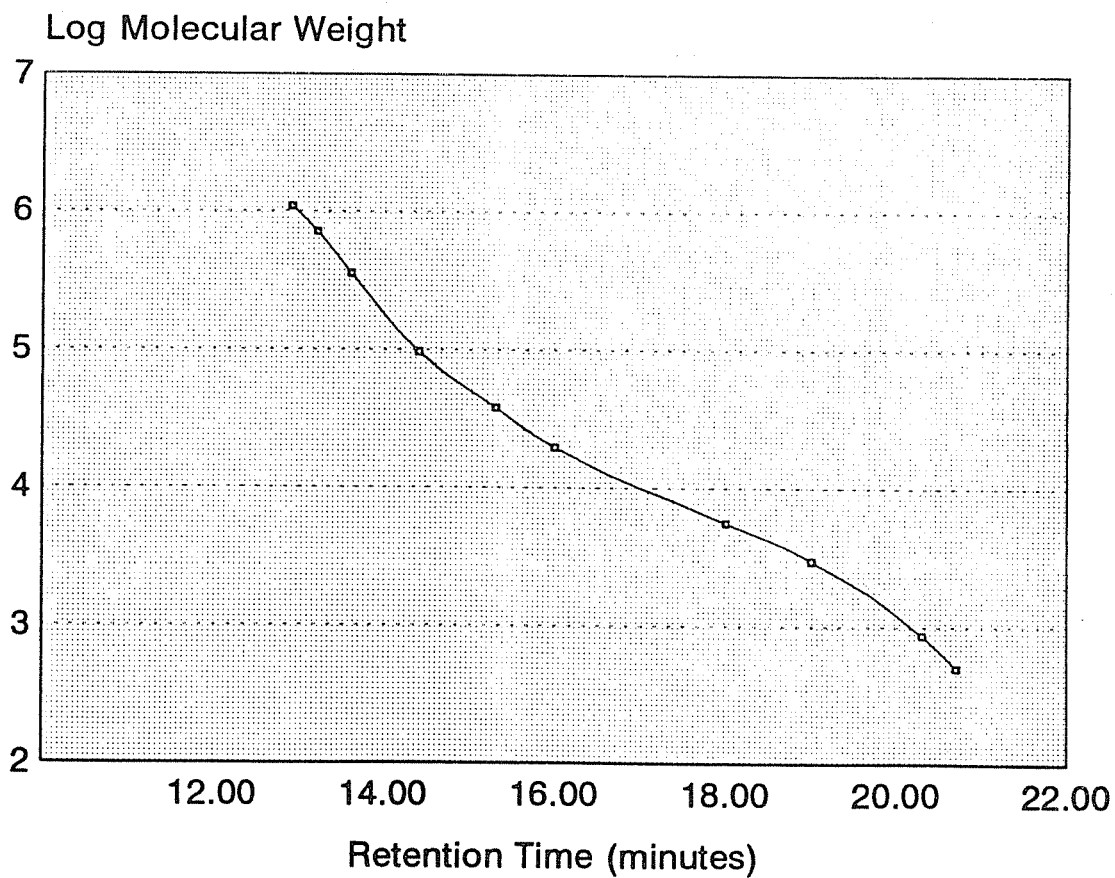


FIGURE 22. CALIBRATION CURVE FOR GPC SYSTEM NUMBER 2

Another method was also proposed as a novel way to fingerprint additives. This method consisted of using the GPC in conjunction with a Photo Diode Array Detector (PDA). With the PDA, a combination of information is obtained on the size distribution and UV spectrum of the sample. Trinidad Natural Asphalt was examined using this technique. The eluted material from the column was detected over the range 240-500 nanometers. The resulting 3-dimensional plot of absorbance versus retention time versus wavenumbers gives a unique perspective of the material.

Dynamic Mechanical Analysis

Dynamic Mechanical Analysis (DMA) was also performed on several of the polymer-modified asphalt binders. Using a Bohlin VOR Rheological System, samples were placed between parallel plates having a diameter of 25 mm and a gap spacing of 2-3 mm. A frequency sweep was first performed to determine the linear viscoelastic region for the modified asphalt binder. Next, another sample was placed in the parallel plate geometry and run through the oscillation mode with a frequency range of .01 to 10 Hertz and a strain of .00861 microstrain units. From the test, a plot of either complex viscosity (n^*), or stored modulus (G') versus frequency was obtained. The complex viscosity (n^*) is the dynamic analog to the static viscosities commonly used to test bituminous materials. G' is a measure of the stiffness of a material, while G'' measures the dissipating processes occurring during flow. It was believed that the dynamic mechanical response of various weight percent modified asphalt binders could be related to the additive content. The results are discussed in the modifier validation method section of this report.

RESULTS AND DISCUSSION

Analysis of Infrared Spectra

FTIR-ATR spectra of all the fingerprinted additives along with a table of peak assignments can be found in Appendix A. Each of these spectra and correlating tables is also contained in a supplemental computer database. Instructions for using this computer program are detailed later in this report.

Several important characteristics were noted when fingerprinting the various additives. The majority of the additives had bands which were distinctively different than those observed for normal bituminous material. For example, all of the ethylene vinyl acetate copolymers had peaks at 1740 cm^{-1} , 1240 cm^{-1} , and 1020 cm^{-1} from the characteristic C=O and C-O stretching, respectively. The Trinidad Natural Asphalt showed strong, broad absorbance at 3414 cm^{-1} and anhydride related peaks at 1768 cm^{-1} , 1722 cm^{-1} , and 1033 cm^{-1} , which make it distinguishable from every other additive in the database. Also the aromatic structure of the Kraton copolymers is very apparent above 3000 cm^{-1} . All of the peaks which distinguish that additive from unmodified asphalt cement are annotated with an asterisk in the spectral correlation tables in Appendix A.

Analysis of Gel Permeation Chromatography

Gel Permeation Chromatography was performed on a majority of the additives which were fingerprinted by FTIR-ATR. Appendix B contains the chromatographs of the analyzed samples. As stated in the experimental procedure, two different GPC systems were employed.

The statistical analysis of the block copolymers run through GPC System 1 are displayed in Table 7.

TABLE 7. MOLECULAR WEIGHT CALCULATIONS FOR BLOCK COPOLYMERS

Sample	$M_n \times 10^3$	$M_w \times 10^3$	$M_z \times 10^3$	Dispersity
Polybilt 103S	32.1	67.0	115.0	2.09
Polybilt 151	30.1	74.0	144.0	2.46
Polybilt 152	38.1	114.0	291.0	2.98
Polybilt 503	45.5	266.0	1137.0	5.85
Kraton D1101	106.0	122.0	142.0	1.15
Elvax 150W	29.0	95.1	346.0	3.29
Vestoplast-S	12.5	59.9	280.0	4.80

It is apparent from the table that there is quite a variation in the statistical molecular weights for the different additives. Several visible differences include the high number-average molecular weight for Kraton D1101 and the high dispersity for Vestoplast-S and Polybilt 503. This method could ideally be used to determine the type of additive, but it only gives the molecular weight and no indication of chemical structure. Although little research has been performed, the chemical structure of the additive is believed to play an important role in the performance of the modified asphalt binder.

Chromatographs were also collected for some of the additives. Since these additives consist of more than one type of component, it was impossible to obtain an accurate molecular weight measurement. The chromatographs do show different characteristic size distributions, but these can be affected as much by the additives as they can by the experimental procedure. One promising observation is the use of the PhotoDiode Array Detector (Figure B-13). This method could be used to fingerprint each additive and should receive further attention.

Since Gel Permeation Chromatography only shows the molecular size or weight distribution, it does not elucidate on the chemical structure. This method was not included in the computer database because it was not considered an ideal fingerprinting technique.

ADDITIVE VALIDATION METHODS

As the use of additives becomes more common in the asphalt paving industry, methods are going to be required to verify the amount and type of additive added to the asphalt concrete mixes. Two methods are proposed in this section to measure the amount of additive in the asphalt binder: Fourier-Transform Infrared Spectroscopy using the Attenuated Total Internal Reflectance Accessory (FTIR-ATR), and Dynamic Mechanical Analysis (DMA).

FTIR-ATR provides a quick and easy method for accessing the additive content in the asphalt binder. This method can also be used, as discussed previously, to identify the different binders. The only drawback with this method is that a calibration curve must first be established for that additive/asphalt binder blend. One possible testing scenario is given below.

Polybilt modifier 152 was blended with an AC-20 asphalt binder in the following weight percent additive: 0, 3, 5, 7, 10%. FTIR-ATR spectra were then taken of each blend. Figure 23 shows the spectrum of all the different weight percent modifier AC-20s. In order to remove procedural differences (i.e. depth the IR beam penetrates into the sample) from one run to the next, a ratio of two peaks was used to measure the amount of the modifier. The peak at 1738 cm^{-1} was used to represent the modifier and the smaller band at 1600 cm^{-1} for the asphalt binder.

The calibration curve of the ratio of the absorbances of the peaks versus weight percent modifier are displayed in Figure 24. The plot shows a linear relationship with a correlation coefficient of .9952. If this method is to be used to validate mix designs, it is suggested that ten to twelve points be used to statistically describe the relationship.

The other validation method employed the Dynamic Mechanical Analyzer to measure the change in the dynamic properties in shear with different additive contents blended with an AC-20 asphalt binder. This method has the added advantage that the Strategic Highway Research Program is already promoting the use of the DMA for performance-based specification testing.

Using the parallel plate testing geometry, the samples were run through increasingly larger rates of shear at constant strain and temperature. A plot of the results is shown in Figures 25 and 26. By taking the lowest point ($\omega = .02\text{ Hz}$) on each of these curves and plotting it versus weight percent additive, a semi-logarithmic relationship was obtained (Figures 27 and 28) between the mechanical properties and the degree of modification. The modified binders displayed an excellent semi-logarithmic relationship, but the unmodified binder had substantially lower dynamic properties. This method shows some promise as a quality control test method.

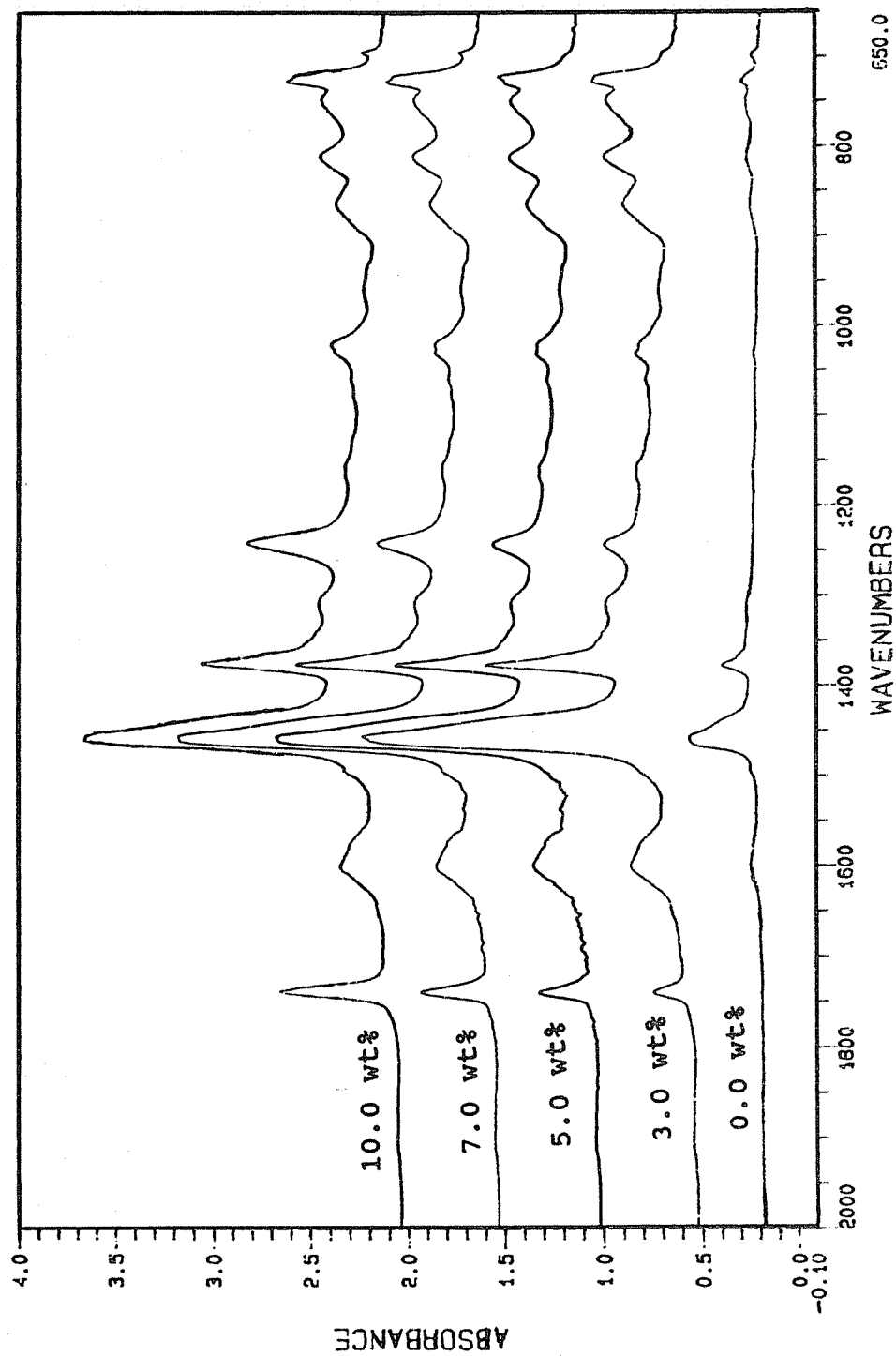


FIGURE 23. FTIR SPECTRA OF THE VARIOUS WEIGHT PERCENTS OF POLYBILT 152 MODIFIED AC-20

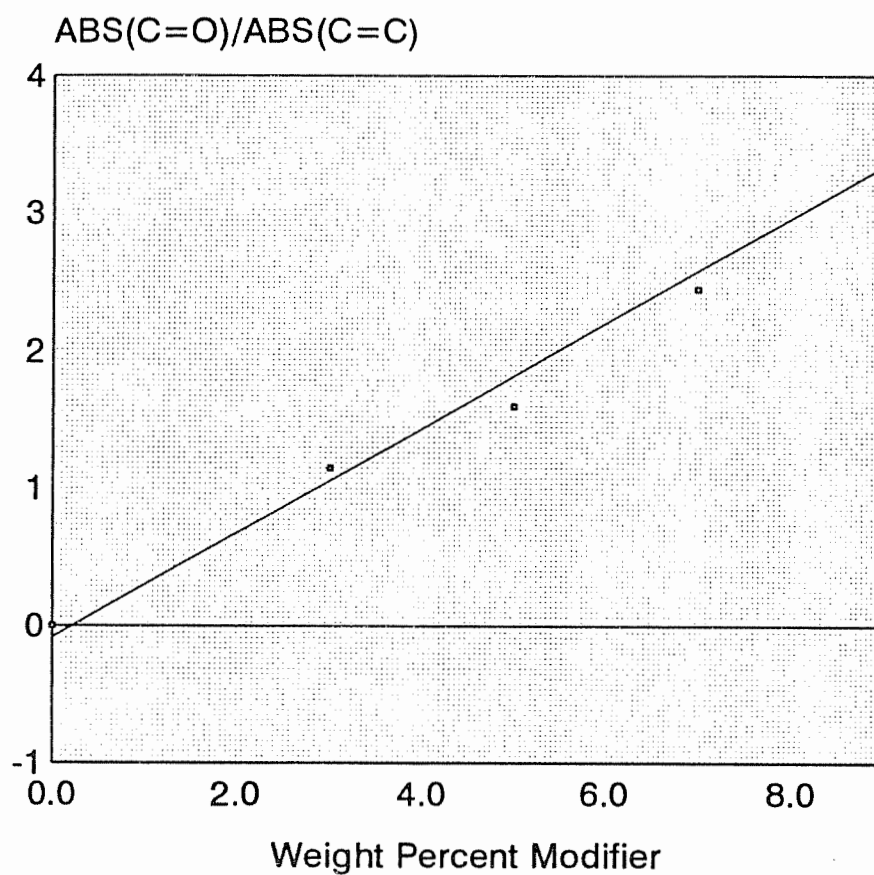


FIGURE 24. CALIBRATION CURVE OF ABSORBANCE RATIO VERSUS
WEIGHT PERCENT ADDITIVE

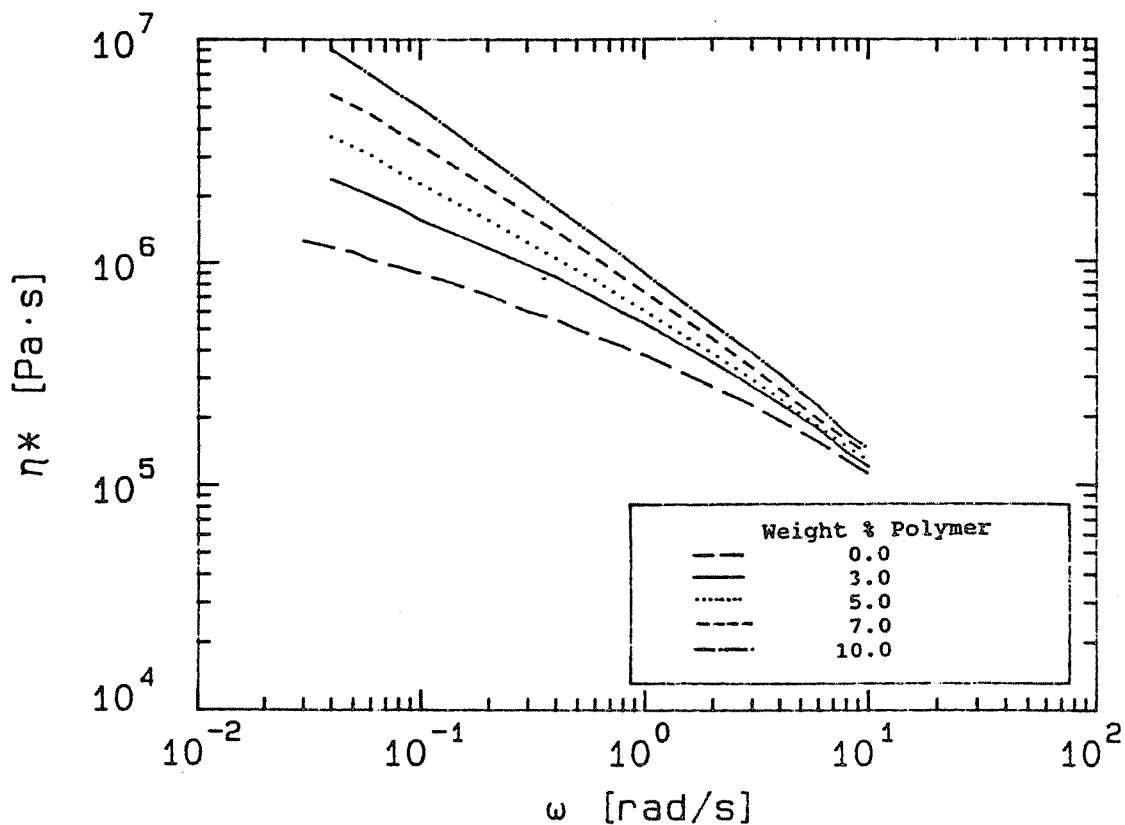


FIGURE 25. A PLOT OF THE LOG COMPLEX VISCOSITY (η^*) VERSUS FREQUENCY (ω) FOR VARIOUS WEIGHT PERCENT POLYBILT 152 MODIFIED AC-20

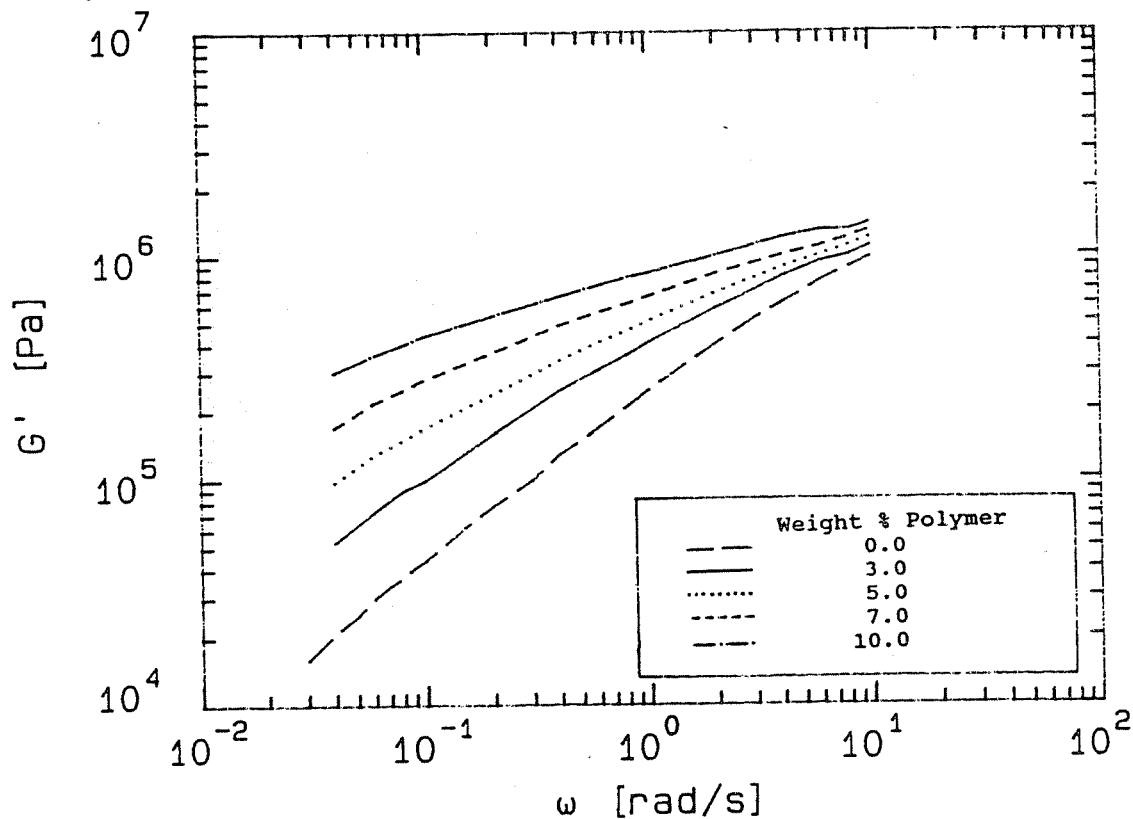


FIGURE 26. A PLOT OF LOG STORAGE MODULUS (G') VERSUS FREQUENCY (ω) FOR VARIOUS WEIGHT PERCENT POLYBILT 152 MODIFIED AC-20

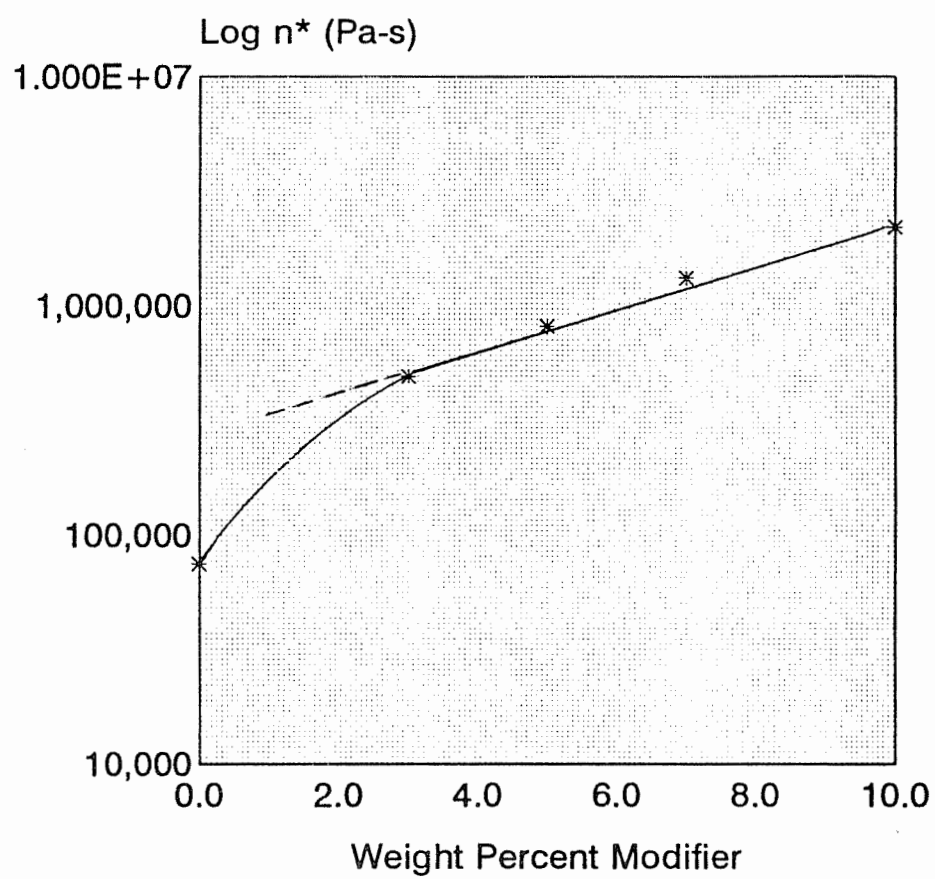


FIGURE 27. A PLOT OF LOG COMPLEX VISCOSITY (η^*) VERSUS WEIGHT PERCENT ADDITIVE

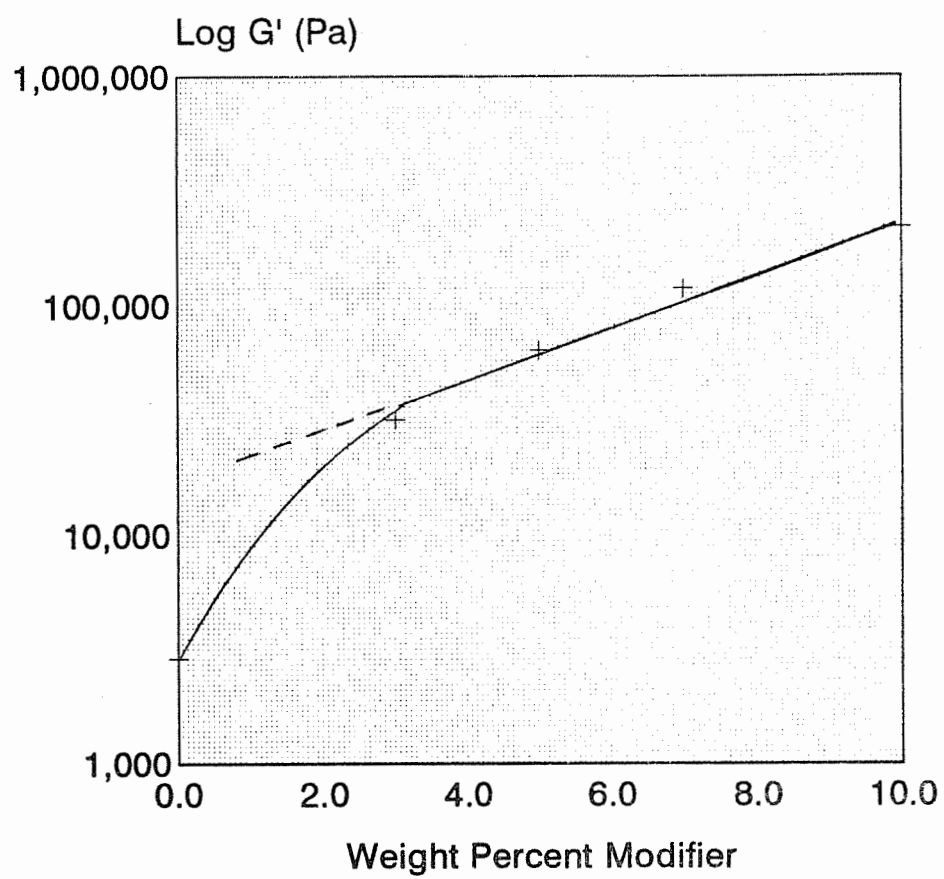


FIGURE 28. A PLOT OF LOG STORAGE MODULUS (G') VERSUS WEIGHT PERCENT ADDITIVE

ADDITIVES DATABASE STRUCTURE

A computer program (ADD.EXE) was written to assist the user in selecting possible additives for bituminous materials and fuel-resistant sealers for airfield pavements. The program requires no special software or hardware to run, although a VGA monitor is recommended for the Spectrometer graphics portion. The following paragraphs briefly describe the program's capabilities.

There are two key elements to the program. First, there is the database section used to store text information about each additive, and secondly, there is a graphics section for viewing the additive's FTIR Spectrum. The following table summarizes the type of information stored in the ADD.EXE database:

TABLE 8. DATABASE STRUCTURE

Name	Trade name of additive
Type	Common additive classification
Supplier	Possible sources for additive
Spectrum File	Data file name that holds line data for plotting FTIR spectrum
Description	Brief description of additive
Uses/Additive Info	Describes what the additive is used for
Field Applications	Describes where the additive has been used in the field

This database information is stored for each additive and allows the user to change, add, or update any information, as well as adding any future additive files to the database.

The graphics section of the database is accessed by pressing key 'F7 - View Spectrum'. This function loads the graphics portion of the ADD.EXE program, and gives the user a look at the FTIR Spectrum line graph for each additive. Not all additives have a corresponding plot and if no plot is available, then pressing 'F7' has no effect and the field 'Spectrum File Name' will display 'NONE'.

To install the program, create a subdirectory on the hard drive called ADD, then copy the file ADDPAC.EXE from the floppy into that subdirectory. Run ADDPAC.EXE to uncompress the files. Run ADD.EXE to start program. The ADD.EXE program is designed to be very user friendly and it requires no special instructions to operate. The program will operate with minimal memory and requires less than 1/2 Megabyte of disk space. Valid keystrokes are always located at the bottom of the screen, and help screens will try to answer any unresolved questions.

SUMMARY OF SHRP ASPHALT MODIFICATION RESEARCH

BACKGROUND

The Strategic Highway Research Program (SHRP) was a highly focused, five year, \$150 million research program which operated as a unit of the National Research Council from 1988 through 1992. SHRP was authorized by Section 28 of the Surface Transportation and Uniform Relocation Assistance Act of 1987. The work of SHRP was generally divided into four research areas: 1) asphalt, 2) concrete and structures, 3) highway operations, and 4) pavement performance.

Part of SHRP's Asphalt Program was designed to select modified asphalt systems with varying levels of documented performance which would in turn be used to evaluate and develop test methods suitable for developing performance based specifications. It was these performance based test methods, criteria, and specifications that were the main focus of SHRP's Asphalt Program for the future of the highway pavements industry.

At the time of this report's writing, no single report on SHRP's Asphalt Modification Study had been published. However, a number of technical reports detailing findings of specific research areas within the Asphalt Modification Study were available in draft form. The following paragraphs of this section of the report summarize the significant results and conclusions of these SHRP documents.

MATERIALS

The asphalt modifiers evaluated by SHRP were selected to create asphalt concrete mixtures with varying levels of pavement performance. The base asphalt cements and the aggregates were also selected and designed to provide a wide range of mixture qualities. The underlying purpose for evaluating these asphalt modifiers was not necessarily to determine the best modifiers available, but to determine the appropriate test methods and criteria for modified asphalt mixtures in terms of predicted pavement performance.

Special codes were used throughout the SHRP literature to identify specific modifier types. Phase I efforts of the SHRP Asphalt Modification Study focused on the selection of modifiers based on industry survey results and literature reviews. The Phase II portion of the SHRP study is where most of the comparative laboratory testing took place and where most of the resulting SHRP reports were produced from. The modifier codes referenced in these SHRP reports and the modifier types they represent are listed in Table 9.

TABLE 9. SHRP MODIFIER CODES

Code	Modifier Type
M401	Styrene-butadiene-styrene
M409	Antistripping Agent (liquid)
M412	Fibers
M413	Antistripping Agent (solid)
M414	Antistripping Agent (solid)
M415	Organic Filler
M416	Softer Grade Asphalt Cement
M417	Reclaimed Rubber

SIGNIFICANT TEST RESULTS

The laboratory tests evaluated in the SHRP Asphalt Modification Study focused on predicting pavement performance in terms of five major deficiencies:

- a) Aging.
- b) Permanent Deformation.
- c) Water Damage (Stripping).
- d) Thermal Cracking.
- e) Fatigue Cracking.

All laboratory tests were conducted on asphalt concrete mixtures with varying qualities of asphalt cement and aggregates. Three quality grades (good, intermediate, poor) of asphalt cement and aggregates were evaluated.

Aging

One of the major conclusions of the laboratory study was that any laboratory test of permanent deformation, thermal cracking, or fatigue cracking should be performed on laboratory aged samples in order to correlate with field performance. SHRP researchers have specified a laboratory aging procedure which uses a traditional Thin Film Oven Test (TFOT) combined with a new Pressure Aging Vessel (PAV) to accomplish this. The laboratory aging equipment and test procedures are detailed in at least two SHRP reports^{28,29}.

Permanent Deformation

A Wheel Tracking Device, developed by SWK Pavement Engineering, Ltd. in Nottingham, England, was used to evaluate the permanent deformation characteristics of four selected modified asphalt concrete mixtures. This device seemed to provide a suitable rutting predictor model. Test results specific to the four selected asphalt modifiers were as follows:

- a) M401 improved the performance of all asphalt concrete mixtures.
- b) M412 improved the performance of the asphalt concrete mixture produced with the "poor" quality asphalt cement.
- c) M415 had little or no effect on any of the asphalt concrete mixtures.
- d) M416 increased the rutting in all asphalt concrete mixtures tested, except for the mixture containing the "good" quality asphalt cement and "poor" quality aggregate blend. The rutting potential was noted to be unchanged for this particular mixture.
- e) The overall ranking of the modifier's performance in the Wheel Tracking Device was:

M401 > M412 >> M415 >> M416

Stripping

The same Wheel Tracking Device used for permanent deformation evaluations was used with a water bath system to evaluate the modified asphalt concrete mixtures' resistance to stripping damage. This modified testing system is known as the Immersion Wheel Tracking Test Apparatus. Four different modifiers were evaluated for resistance to stripping damage under traffic, and the significant test results are listed below:

- a) M413 improved stripping resistance for all test samples.
- b) M409 and M414 improved performance for some asphalt cements and was detrimental for others, suggesting that the benefits of these modifiers are asphalt dependent.
- c) M417 was detrimental to immersion wheel tracking data in every case (as compared to the unmodified mixtures).
- d) The overall ranking of the modifiers' performance in the Immersion Wheel Tracking Device was:

M413 > M409, M414 > M417

Fatigue and Thermal Cracking

Disappointingly, only one laboratory test (Direct Tensile Test) was found to discriminate the effects of modifiers on fatigue cracking, and no laboratory test methods were found to discriminate the modifiers' effects on thermal cracking. Several test methods were recommended for tests of fatigue and thermal cracking evaluations on unmodified asphalt concrete mixtures, and future work with these tests may make them more useful for modified asphalt concrete mixtures. It was speculated that a major reason for the lack of correlation with the modified mixtures was that the tests were performed on unaged materials. Since both fatigue cracking and thermal cracking in asphalt concrete pavements are known to be heavily influenced by the pavements age

and/or level of oxidation, performance predictions of these types of cracking should have included laboratory aging.

SUPERPAVETM MIX DESIGN SYSTEM

Perhaps the most important product of SHRP's Asphalt Program is the SUPERPAVETM mix design system. This system allows for the design of asphalt paving mixes that will satisfy performance criteria dictated by the particular set of traffic, climatic, and structural factors to which the pavement will be exposed. The test methods and specifications of this mix design system apply equally to modified as well as unmodified asphalt mixtures.

The SUPERPAVETM mix design system is fully detailed in at least three SHRP literature references^{28,29,30}, and it encompasses five main steps:

- a) Materials Selection.
- b) Volumetric Mixture Design.
- c) Performance Based Mixture Testing.
- d) Performance Estimates and Comparison with Specifications.
- e) Field Control.

The practice for modifier evaluation interacts with the mix design system in several of the five main design steps by providing the means to:

- a) Pinpoint the need for modifier use during the mix design process.
- b) Estimate the performance capability of modified asphalt binders and paving mixes under specific climatic and traffic conditions.
- c) Perform simple cost comparisons of modified versus unmodified asphalt binders and paving mixes over extended periods of service.
- d) Objectively evaluate manufacturer's claims and choose an appropriate modifier for a given situation.

Although the SUPERPAVETM system was designed for the highway pavements designer, it should be of use to the airport pavements designer as well. At the very least, the test methods, criteria, and specifications associated with this mix design system could serve as models for similar mix design tools in the airport pavements community. Other references produced under the SHRP Asphalt Modification Study³¹⁻³⁵ should also serve as valuable references for the airport pavements engineer.

CONCLUSIONS

1. Additives for bituminous materials and fuel-resistant sealers have been in use for many years. Their use in airport pavements is limited, however.
2. The most prominent reason for using bituminous additives in U.S. airport pavements is to prevent or deter thermal cracking in the asphalt concrete.
3. Bituminous additives are used much more on runway pavements than on taxiway and apron pavement areas.
4. Most airport bituminous additive users are very pleased with the performance of these materials.
5. Most airport fuel-resistant sealer additive users are either moderately satisfied or dissatisfied with the performance of these materials.
6. There is an insufficient amount of field data currently available on additive materials to predict long-term performance and life-cycle cost analyses.
7. Fourier Transform Infrared Spectroscopy using the Attenuated Total Internal Reflectance Accessory is an ideal method for fingerprinting the additives used in bituminous materials and fuel-resistant sealers.
8. Gel Permeation Chromatography does not give a sufficient amount of information to differentiate between the different additives.
9. The Photo Diode Array Detector shows promise as a novel way to characterize additives.
10. Both Fourier Transform Infrared Spectroscopy and Dynamic Mechanical Analysis proved to be acceptable methods for determining the additive content of modified asphalt cements.

RECOMMENDATIONS

1. Future material evaluations and research studies on bituminous additives for airport pavements should concentrate on preventing thermal cracking, stripping, and raveling.
2. New fuel-resistant sealer materials are needed to meet the current airport pavement needs. Very few of these materials currently exist, with the exception of the coal tar based products.
3. Further work is required to evaluate the mechanical properties of the various modified asphalt cements.
4. The test methods, criteria, and specifications produced from the SHRP Asphalt Modification Study should be evaluated for use in future airport pavement design and testing projects.
5. The additive database produced by this study should be updated on a regular basis to conform to manufacturer's current products.
6. FAA specifications should be developed on the use of additives in bituminous materials and fuel-resistant sealers. This will stimulate the use of these materials on at least small-scale projects, and in turn provide more insight as to which products are the most cost-effective.
7. It is recommended that an FTIR spectrum be obtained for all additives submitted for use on airport flexible pavements. This will provide the FAA with a material reference database to verify the additive's composition.

REFERENCES

1. G. L. Anderton, "Evaluation of Asphalt Binder Modifiers," Miscellaneous Paper GL-90-1, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi (1990).
2. J. G. Moore, "A New Method for Molecular Weight Distribution of High Polymers," Gel Permeation Chromatography I, (1963)
3. K. H. Altgelt, "Fractionation of Asphaltenes by Gel Permeation Chromatography," Journal of Applied Polymer Science, Volume 8, 106-113 (1965)
4. W. B. Richman, "Molecular Weight Distribution of Asphalts," Association of Asphalt Paving Technologists, 36, 106 (1967)
5. D. Bynum and R. N. Traxler, "Gel Permeation Chromatography Data on Asphalts Before and After Service in Pavements," Association of Asphalt Paving Technologists, 39, 683-702 (1970)
6. P. W. Jennings, "High Pressure Liquid Chromatography as a Method of Measuring Asphalt Composition," Federal Highway Administration Project Number FHWA-MTDOH-7930 (1980)
7. N. W. Garrick and N. E. Wood, "Quantitative Procedure for Analyzing HP-GPC Profiles of Asphalts," Association of Asphalt Paving Technologist, 57, (1988)
8. R. P. Price and J. L. Burati, "A Quantitative Method Using HP-GPC to Predict Laboratory Results of Asphalt Cement Tests," Association of Asphalt Paving Technologist, 59, 182-219 (1990)
9. B. Brule, G. Ramond, and C. Such, "Relationships Between Composition, Structure, and Properties of Road Asphalts: State of Research at the French Public Works Central Laboratory," Transportation Research Record 1096, 22-34 (1986)
10. J. A. Pribanic, M. Emmelin, and G. N. King, "Use of Multiwavelength UV-VIS Detector With HP-GPC to Give A Three-Dimensional View of Bituminous Materials," Transportation Research Record 1228, (1990)
11. J. F. Branthaver, J. J. Duvall, and J. G. Petersen, "Separation of SHRP Asphalts by Preparative Size Exclusion Chromatography", Symposium on the Chemistry and Characterization of Asphalts, American Chemical Society, (1990)
12. H. G. Barth and J. W. Mays, Modern Methods of Polymer Characterization, Chemical Analysis, Volume 13, Wiley Interscience, New York, (1991)
13. L. H. Tung and J. C. Moore, Fractionation of Synthetic Polymers: Principles and Practices, Marcell Decker, New York, (1977)

14. K. H. Altgelt and L. Segal, Gel Permeation Chromatography, Marcell Decker, New York, (1971)
15. J. V. Dawkins and G. Yeadon, "High Performance Gel Permeation Chromatography," Developments in Polymer Characterization-1, Applied Science, London, (1978)
16. B. D. Beitchman, "Infrared Spectra of Asphalts," Journal of Research of the National Bureau of Standards-A. Physics and Chemistry, 63A, No. 2, (1959)
17. J. C. Petersen, S. M. Dorrence, and F. A. Barbour, "Direct Evidence of Ketones in Oxidized Asphalts," Analytical Chemistry, 46, No. 14, (1974)
18. J. C. Petersen, "Quantitative Method Using Differential Infrared Spectroscopy for the Determination of Compound Types Absorbing in the Carbonyl Region in Asphalts," Analytical Chemistry, 47, No. 1, 112-117 (1975)
19. J. C. Petersen, F. A. Barbour, and S. M. Dorrence, "Identification of Dicarboxylic Anhydrides in Oxidized Asphalts," Analytical Chemistry, 46, No. 14, (1974)
20. T. F. Yen, W. H. Wu, and G. V. Chilinger, "A Study of the Structure of Petroleum Asphaltenes and related Substances by Infrared Spectroscopy," Energy Sources, 7, No. 3, 203-235, (1984)
21. C. J. Glover, R. R. Davison, S. M. Ghoreishi, H. B. Jemison, and J. A. Bullin, "Evaluation of Oven Simulation of Hot-Mix Aging by FTIR Pellet Procedure and Other Methods," Transportation Research Record 1228, (1990)
22. J. Button, "Methods to Determine Polymer Content of Modified Asphalt," Transportation Research Board Preprint, 70th Annual Meeting, Washington, DC (1991)
23. R. A. Romine, "The Determination of SBR-Latex Concentration in Asphalt Cements," 3-C-7-138, State Department of Highways and Public Transportation, Materials and Test Division, Texas, (1987)
24. "Determination of Kraton Rubber Content in Asphalt Blends by Infrared Spectroscopy," Shell Note
25. K. N. Rao and C. W. Mathews, "Molecular Spectroscopy: Modern Research", Academic Press, New York, (1972)
26. P. R. Griffiths and J. A. deHaseth, "Fourier Transform Infrared Spectrometry," Wiley-Interscience, New York, (1986)
27. R. M. Silverstein and G. C. Bassier, "Spectrometric Identification of Organic Compounds," Wiley & Sons, New York, (1967)
28. "The SUPERPAVETM System: The Manual of Test Methods and Practices," SHRP Asphalt Research Program Final Report, Volume 3, Strategic Highway Research Program, Washington, D.C., (1993)

29. "SUPERPAVETM Mix Design Manual for New Construction and Overlays," SHRP Asphalt Research Program Final Report, Volume 4, Strategic Highway Research Program, Washington, D.C., (1993)
30. "The Theoretical Basis and Validation of the SUPERPAVETM System," SHRP Asphalt Research Program Final Report, Volume 2, Strategic Highway Research Program, Washington, D.C., (1993)
31. J. S. Coplantz, et al., "Review of Relationships Between Modified Asphalt Properties and Pavement Performance," Strategic Highway Research Program, Washington, D.C., (1992)
32. M. Tahmoressi, et al., "Performance of Asphalt Modifiers: Review of Reports from State Highway Authorities," Southwestern Laboratories, Inc., Houston, TX, (1989)
33. C. W. Curtis, "A Literature Review of Liquid Antistripping and Tests for Measuring Stripping," SHRP-A/UIR-90-016, Strategic Highway Research Program, Washington, D.C., (1990)
34. G. M. Rowe and J. M. Gibb, "Permanent Deformation Wheel Tracking: Simulative Testing of Modified Asphalts," P358/TM2, SWK Pavement Engineering Ltd., Nottingham, ENGLAND, (1992)
35. G. M. Rowe and R. J. Armitage, "Immersion Wheel Tracking: Simulative Testing of Modified Asphalts," P358/TM1, SWK Pavement Engineering Ltd., Nottingham, ENGLAND, (1992)

APPENDIX A: INFRARED SPECTRA

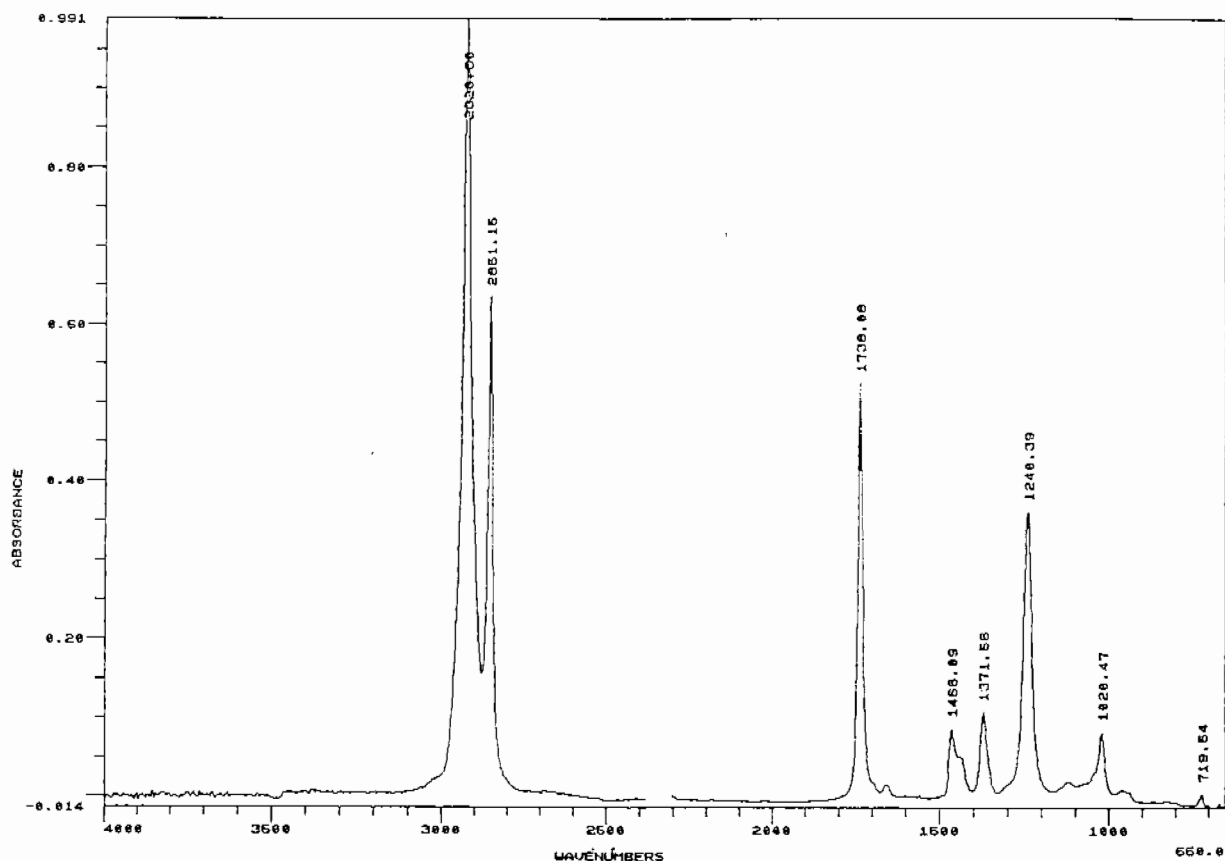


FIGURE A1. FTIR SPECTRUM OF POLYBILT 103S

TABLE A1. SPECTRAL CORRELATION TABLE FOR POLYBILT 103S

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2920.60	0.99060	Asymmetric C-H stretching from -CH ₂ -
2851.15	0.63511	Symmetric C-H stretching from -CH ₂ -
1738.08	0.52408	C=O stretch from ester group*
1466.09	0.08702	Asymmetric C-H bending from CH ₃
1371.56	0.10795	Symmetric C-H bending from CH ₃
1240.39	0.36055	C-O stretch*
1020.47	0.08279	C-O stretch*
719.54	0.00464	Rocking motion of -(CH ₂) ₃ - groups

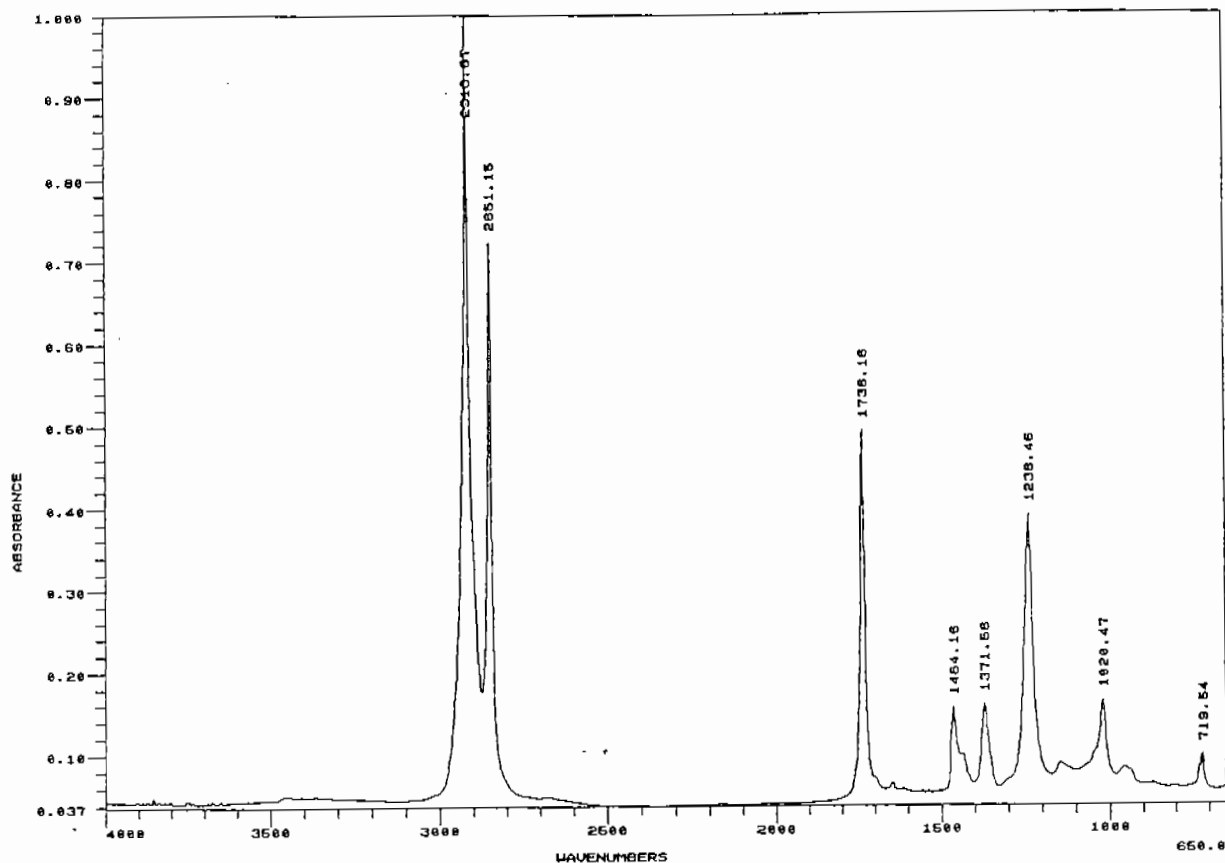


FIGURE A2. FTIR SPECTRUM OF POLYBILT 151

TABLE A2. SPECTRAL CORRELATION TABLE FOR POLYBILT 151

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2918.67	1.00000	Asymmetric C-H stretching from -CH ₂ -
2851.15	0.72250	Symmetric C-H stretching from -CH ₂ -
1736.16	0.49263	C=O stretch from ester group*
1464.16	0.15506	Asymmetric C-H bending from CH ₃
1371.56	0.15965	Symmetric C-H bending from CH ₃
1238.46	0.38899	C-O stretch*
1020.47	0.16378	C-O stretch*
719.54	0.09766	Rocking motion of -(CH ₂) ₃ - groups

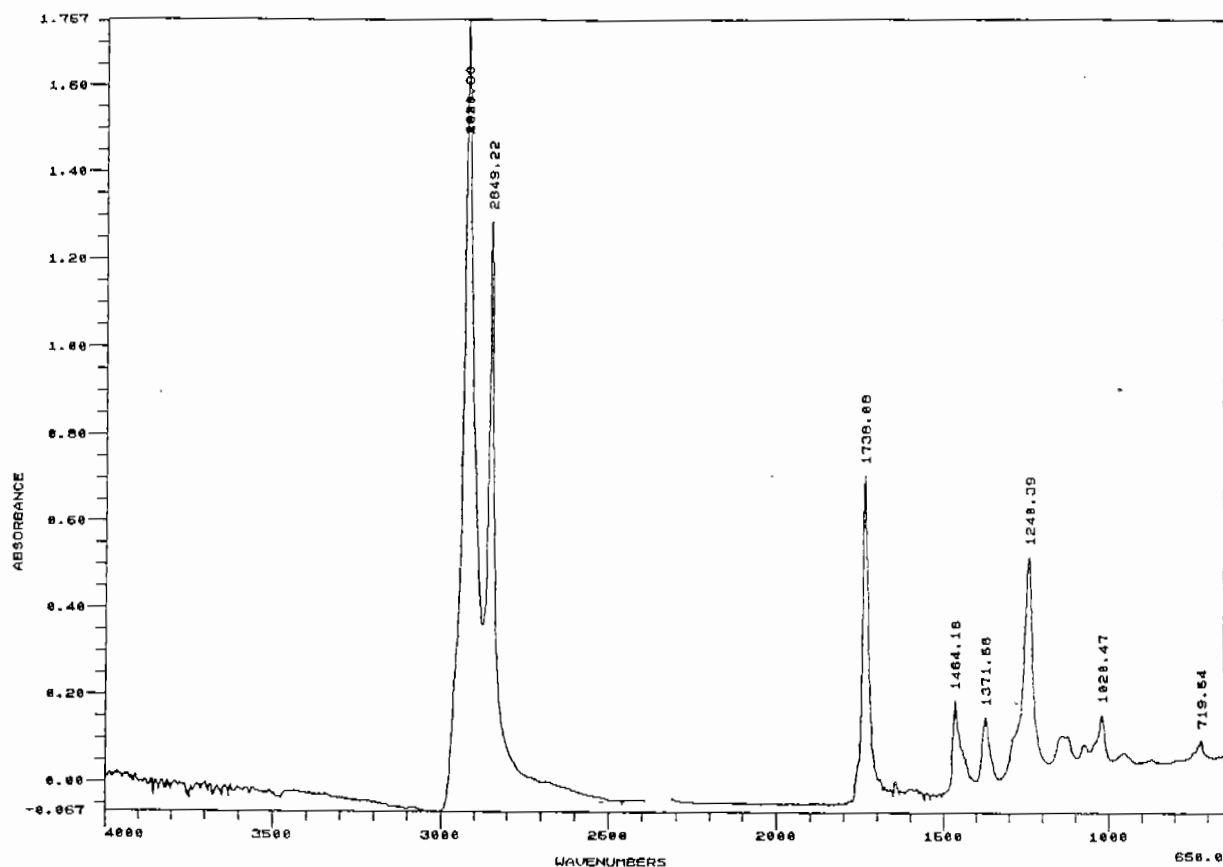


FIGURE A3. FTIR SPECTRUM OF POLYBILT 152

TABLE A3. SPECTRAL CORRELATION TABLE FOR POLYBILT 152

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2920.60	1.72625	Asymmetric C-H stretching from -CH ₂ -
2849.22	1.28696	Symmetric C-H stretching from -CH ₂ -
1738.08	0.70831	C=O stretch from ester group*
1464.16	0.19029	Asymmetric C-H bending from CH ₃
1371.56	0.15359	Symmetric C-H bending from CH ₃
1240.39	0.52172	C-O stretch*
1020.47	0.15802	C-O stretch*
719.54	0.10196	Rocking motion of -(CH ₂) ₃ - groups

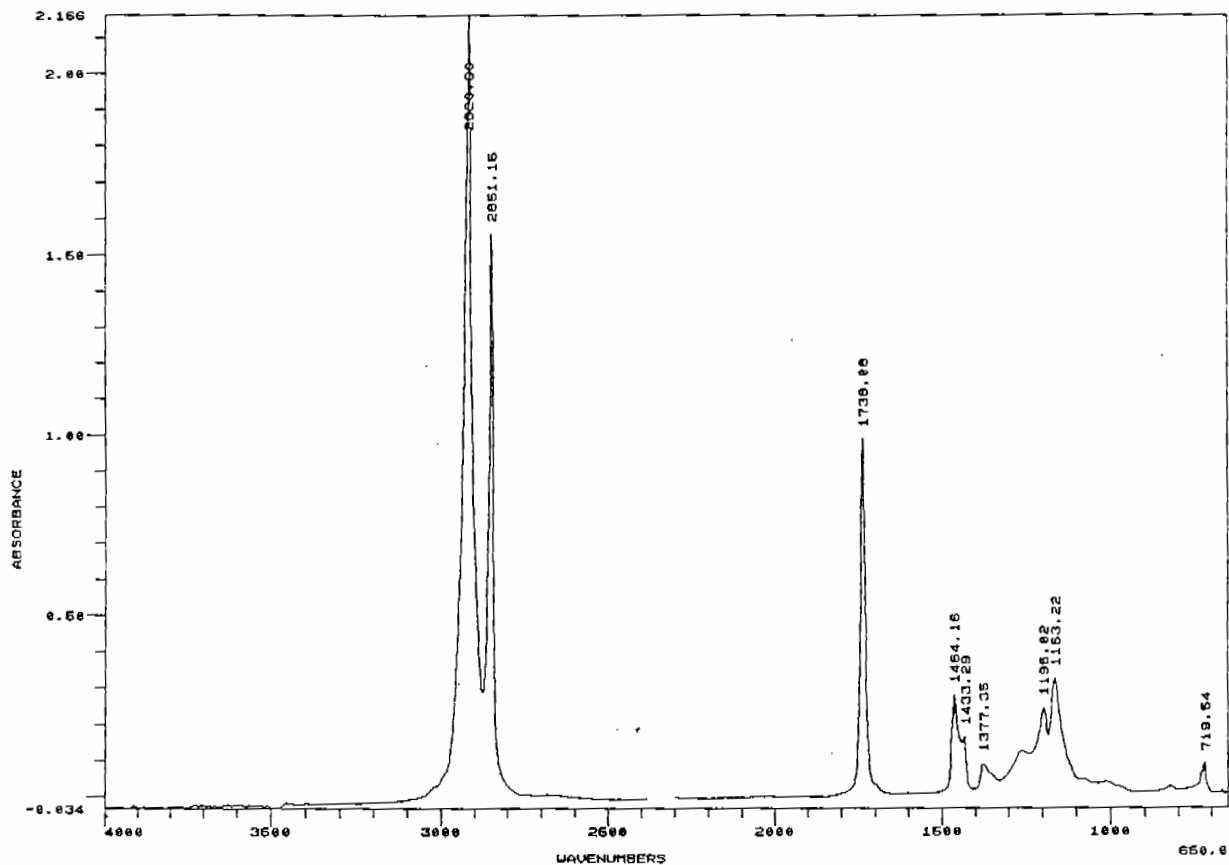


FIGURE A4. FTIR SPECTRUM OF POLYBILT 503

TABLE A4. SPECTRAL CORRELATION TABLE FOR POLYBILT 503

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2920.60	2.12840	Asymmetric C-H stretching from -CH ₂ -
2851.15	1.55747	Symmetric C-H stretching from -CH ₂ -
1738.08	0.98837	C=O stretch from ester group*
1464.16	0.28105	Asymmetric C-H bending from CH ₃
1377.35	0.09011	Symmetric C-H bending from CH ₃
1196.02	0.24611	C-O-C bending from ester group*
1163.22	0.32642	C-O-C bending from ester group*
719.54	0.09135	Rocking motion from -(CH ₂) ₃ - groups

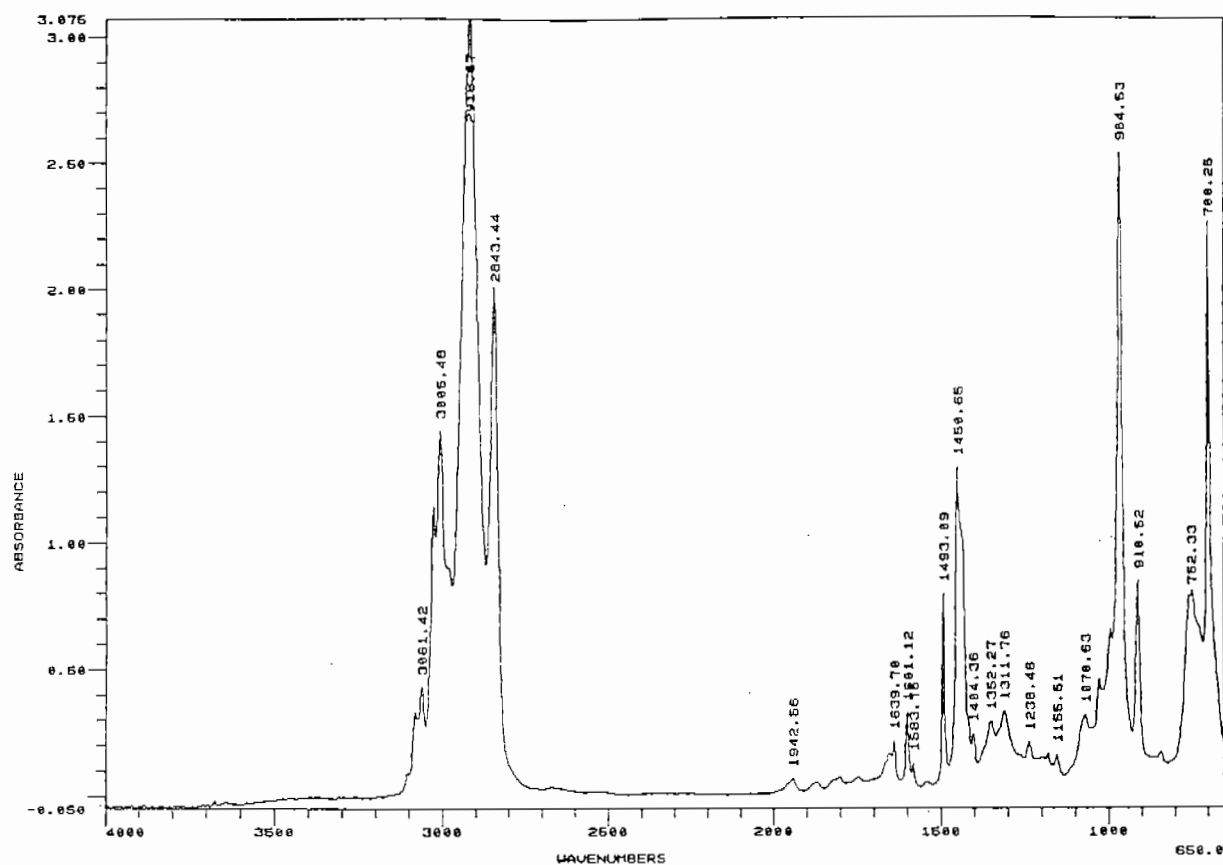


FIGURE A5. FTIR SPECTRUM OF KRATON D1101

TABLE A5. SPECTRAL CORRELATION TABLE FOR KRATON D1101

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
3061.42	0.43143	Aromatic Asymmetric C-H stretch*
3005.48	1.44467	Aromatic Symmetric C-H stretch*
2918.67	3.06816	Asymmetric C-H stretching from -CH ₂ -
2843.44	1.98525	Symmetric C-H stretching from -CH ₂ -
1942.56	0.06892	Combination peak from monosubstituted benzene ring*
1639.70	0.21619	C=C stretching mode*
1601.12	0.32604	C=C conjugated stretching mode
1493.09	0.79501	
1450.65	1.29280	
1404.36	0.24426	
1352.27	0.29153	
1311.76	0.33178	
964.53	2.53650	C-H bending from trans-substituted C=C*
910.52	0.84561	C-H bending from monosubstituted C=C*
752.33	0.78259	C-H bending from monosubstituted benzene*
700.25	2.23378	Ring bending from monosubstituted benzene*

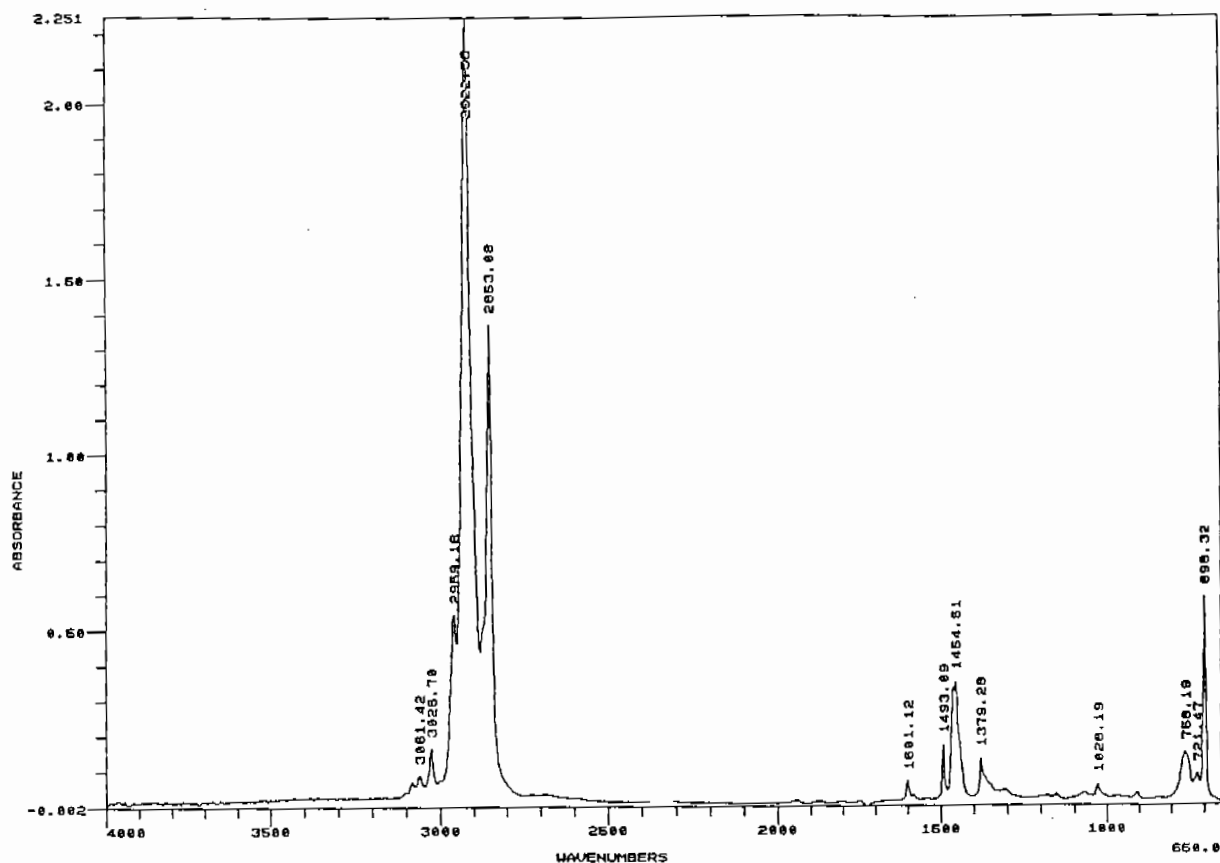


FIGURE A6. FTIR SPECTRUM OF KRATON G1650

TABLE A6. SPECTRAL CORRELATION TABLE FOR KRATON G1650

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
3061.42	0.09018	Aromatic Asymmetric C-H stretch*
3026.70	0.16479	Aromatic Symmetric C-H stretch*
2959.18	0.54276	Asymmetric C-H stretch from CH ₃
2922.53	2.25092	Asymmetric C-H stretch from -CH ₂ -
2853.08	1.37183	Symmetric C-H stretch from -CH ₂ -
1601.12	0.06909	C=C conjugated stretching mode
1493.09	0.17067	
1454.51	0.34988	Asymmetric C-H bending from CH ₃
1379.28	0.13299	Symmetric C-H bending from CH ₃
1028.19	0.05785	
756.19	0.14821	C-H bending from monosubstituted benzene ring*
721.47	0.08795	Rocking motion from -(CH ₂)- groups
698.32	0.58823	Ring bend of monosubstituted benzene ring

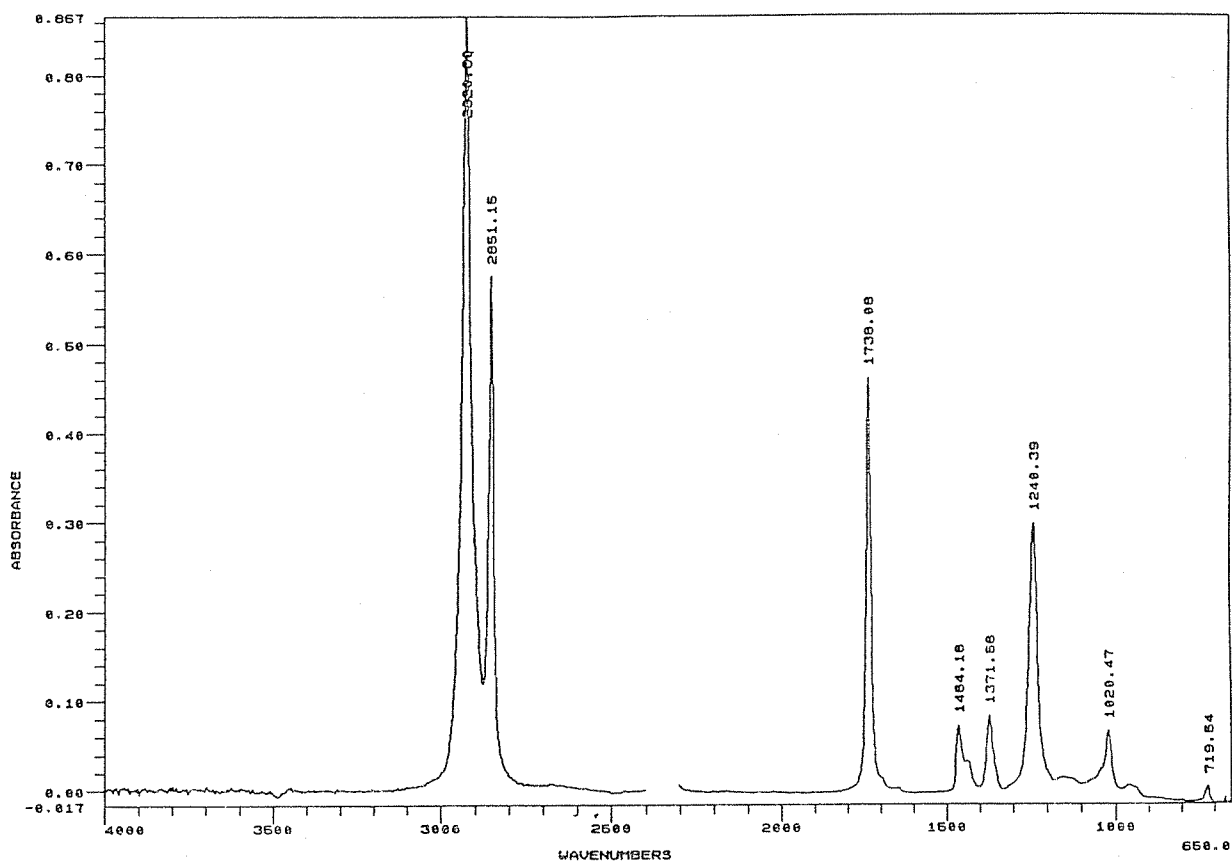


FIGURE A7. FTIR SPECTRUM OF ELVAX 150W

TABLE A7. SPECTRAL CORRELATION TABLE FOR ELVAX 150W

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2920.60	0.86721	Asymmetric C-H stretching from $-(CH_2)-$
2851.15	0.57509	Symmetric C-H stretching from $-(CH_2)-$
1738.08	0.46102	C=O from ester group *
1464.16	0.07112	Asymmetric C-H bending from CH_3
1371.56	0.08214	Symmetric C-H bending from CH_3
1240.39	0.29744	C-O stretch *
1020.47	0.06523	C-O stretch *
719.54	0.00340	Rocking motion from $-(CH_2)_3-$ groups

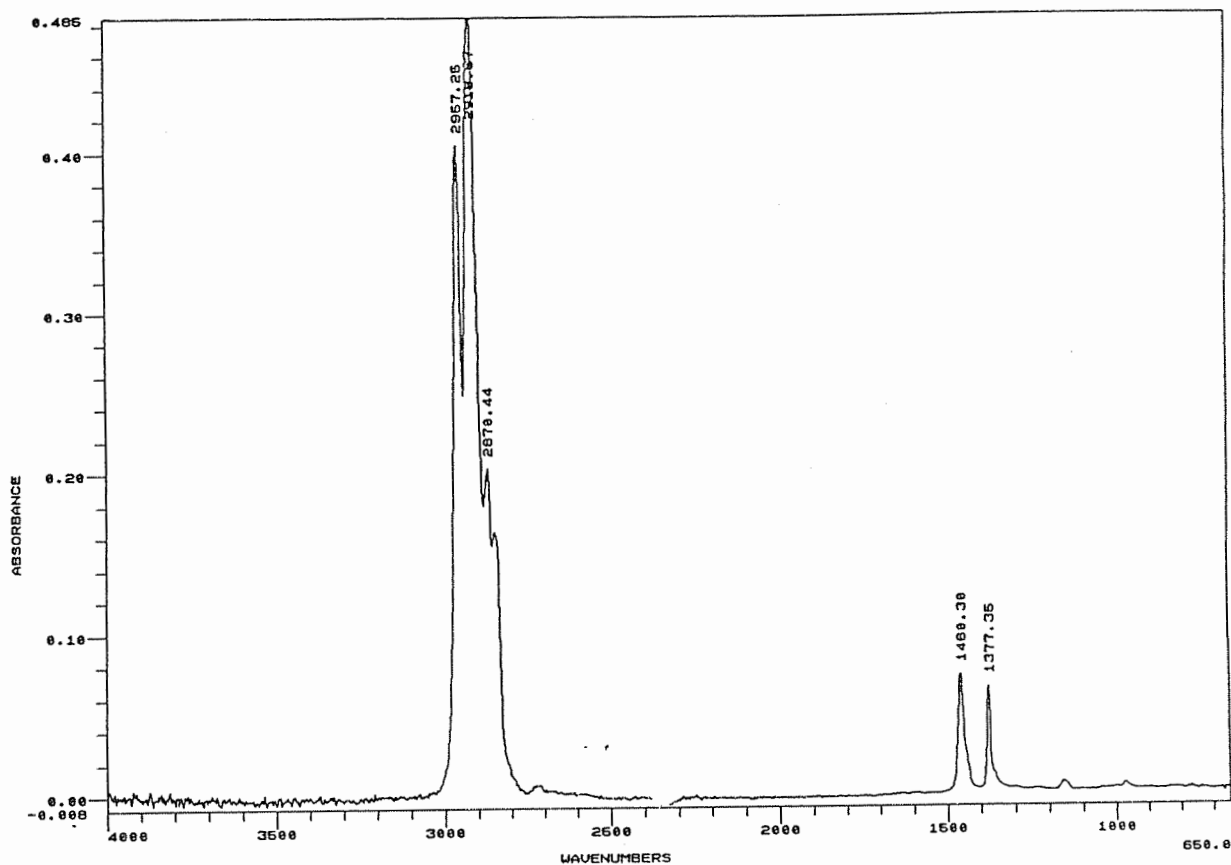


FIGURE A8. FTIR SPECTRUM OF VESTOPLAST-S

TABLE A8. SPECTRAL CORRELATION TABLE FOR VESTOPLAST-S

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2957.25	0.40513	Asymmetric C-H stretching from CH ₃ *
2918.67	0.48480	Asymmetric C-H stretching from -CH ₂ -
2870.44	0.20275	Symmetric C-H stretching from CH ₃
1460.30	0.07295	Asymmetric C-H bending from CH ₃
1377.35	0.65490	Symmetric C-H bending from CH ₃

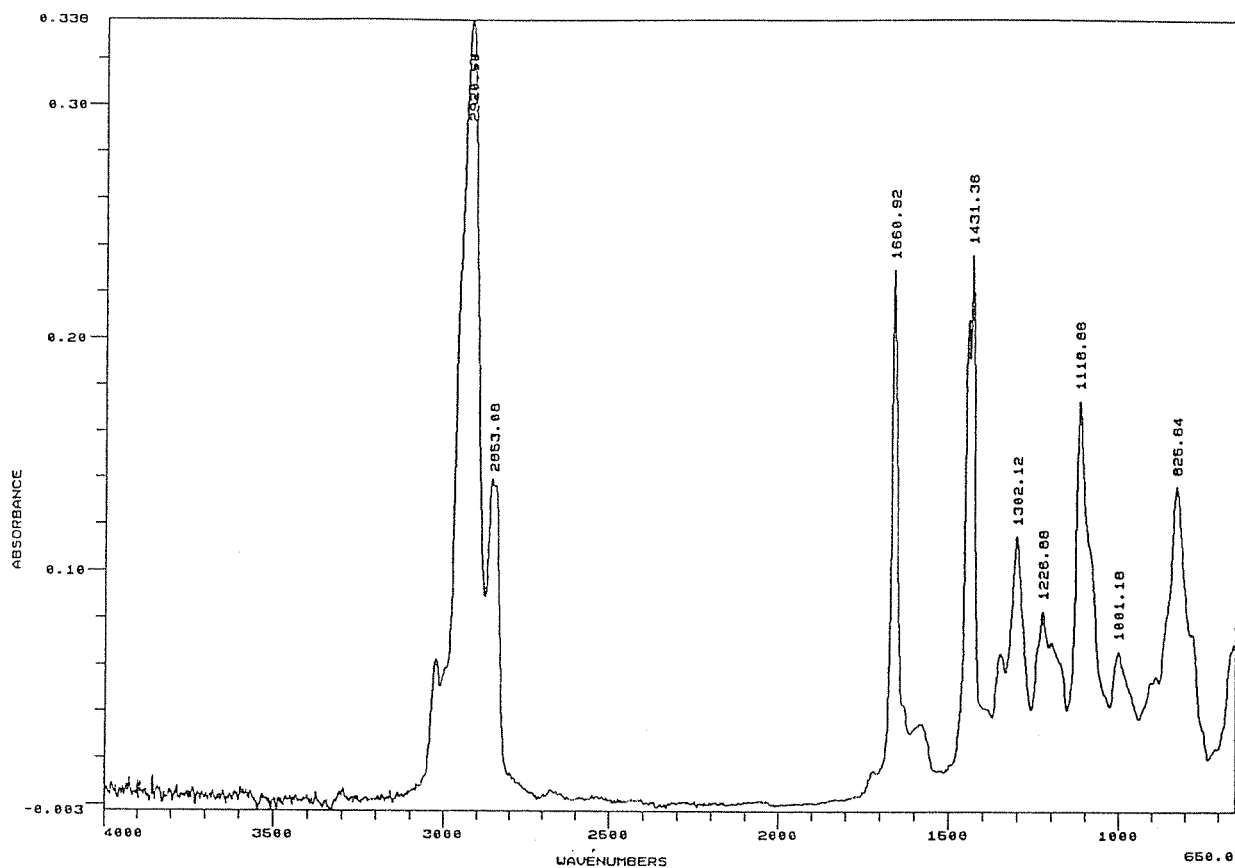


FIGURE A9. FTIR SPECTRUM OF NEOPRENE 735A

TABLE A9. SPECTRAL CORRELATION TABLE FOR NEOPRENE 735A

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2920.60	0.33754	Asymmetric C-H stretching from -CH ₂ - Symmetric C-H stretching from -CH ₂ -
2853.08	0.13736	
1660.92	0.22973	
1431.36	0.23608	
1302.12	0.11492	
1226.88	0.08312	
1118.86	0.17319	
1001.18	0.06604	
825.64	0.13648	

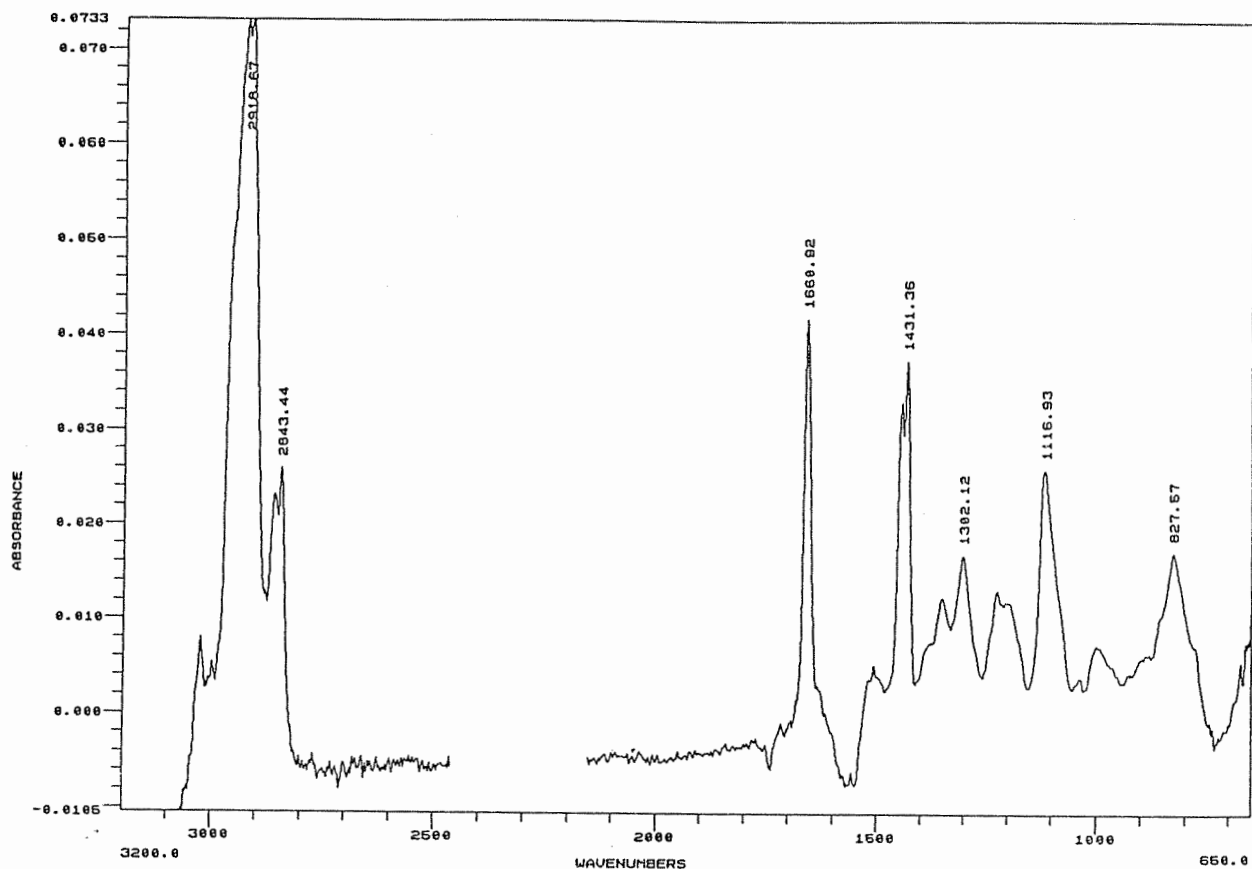


FIGURE A10. FTIR SPECTRUM OF NEOPRENE 654

TABLE A10. SPECTRAL CORRELATION TABLE FOR NEOPRENE 654

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2918.67	0.07219	Asymmetric C-H stretching from -CH ₂ - Symmetric C-H stretching from -CH ₂ -
2843.44	0.02587	
1660.92	0.04182	
1431.36	0.03739	
1302.12	0.01692	
1116.93	0.02589	
827.57	0.01727	

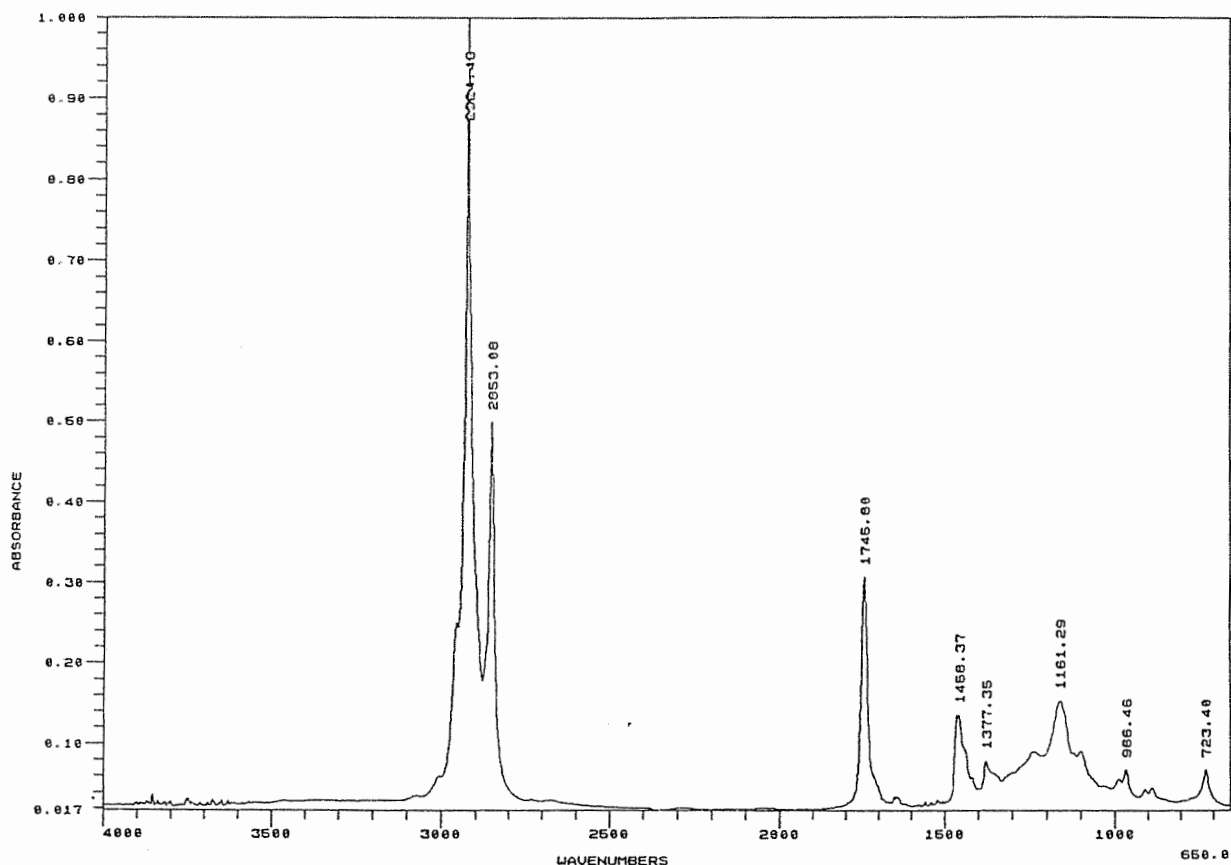


FIGURE A11. FTIR SPECTRUM OF DUCTILAD D1000

TABLE A11. SPECTRAL CORRELATION TABLE FOR DUCTILAD D1000

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2924.46	1.00000	Asymmetric C-H stretching from -CH ₂ -
2853.08	0.49971	Symmetric C-H stretching from -CH ₂ -
1745.80	0.30680	C=O stretch from ester group*
1458.37	0.13627	Asymmetric C-H bending from CH ₃
1377.35	0.07950	Symmetric C-H bending from CH ₃
1161.29	0.15402	
966.46	0.06863	
723.40	0.06869	Rocking motion from -(CH ₂) ₃ -

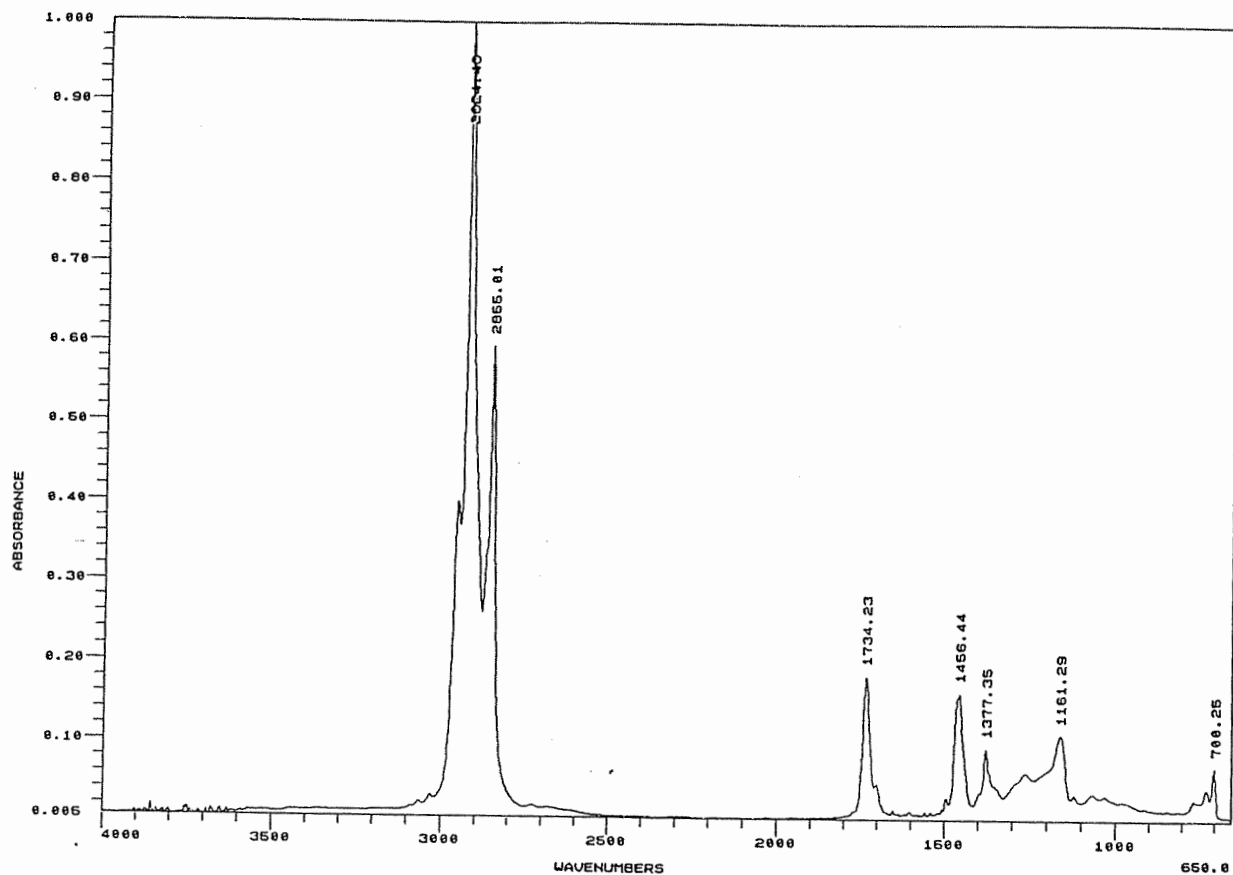


FIGURE A12. FTIR SPECTRUM OF DUCTILAD D1002

TABLE A12. SPECTRAL CORRELATION TABLE FOR DUCTILAD D1002

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2924.46	1.00000	Asymmetric C-H stretching from -CH ₂ -
2855.01	0.59529	Symmetric C-H stretching from -CH ₂ -
1734.23	0.18396	C=O stretch from ester group*
1456.44	0.16433	Asymmetric C-H bending from CH ₃
1377.35	0.09449	Symmetric C-H bending from CH ₃
1161.29	0.11214	
700.25	0.07284	

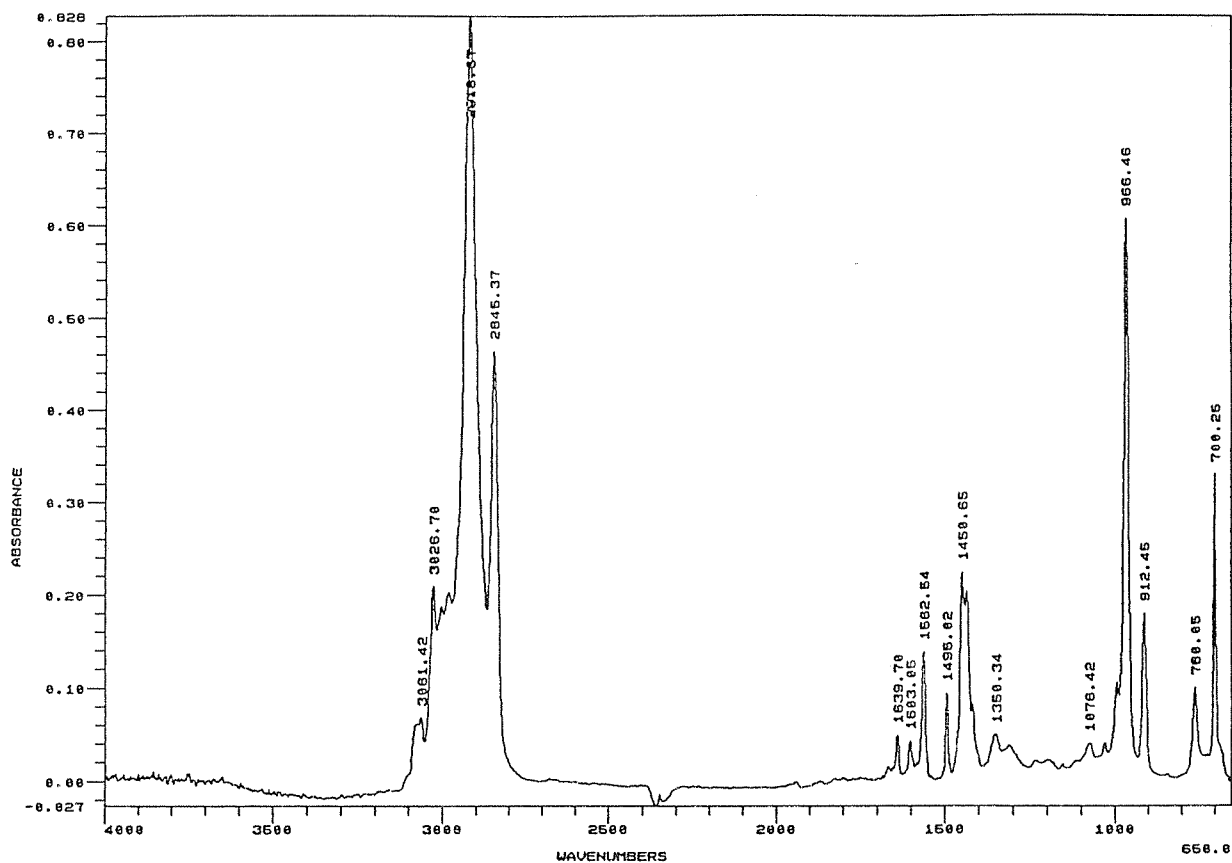


FIGURE A13. FTIR SPECTRUM OF RUB-R-ROAD

TABLE A13. SPECTRAL CORRELATION TABLE FOR RUB-R-ROAD

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
3061.42	0.06840	Aromatic Asymmetric C-H stretching*
3026.70	0.21003	Aromatic Symmetric C-H stretching*
2918.67	0.82808	Asymmetric C-H stretching from -CH ₂ -
2845.37	0.46446	Symmetric C-H stretching from -CH ₂ -
1639.70	0.04945	C=C stretching mode*
1603.05	0.04299	C=C conjugated stretching mode
1562.54	0.13826	
1495.02	0.09471	
1450.65	0.22440	
1350.34	0.04984	
1076.42	0.04049	
966.46	0.60735	C-H bending from trans-substituted C=C*
912.45	0.18010	C-H bending from monosubstituted C=C*
760.05	0.10056	C-H bending from monosubstituted benzene*
700.25	0.33013	C-H bending from monosubstituted benzene*

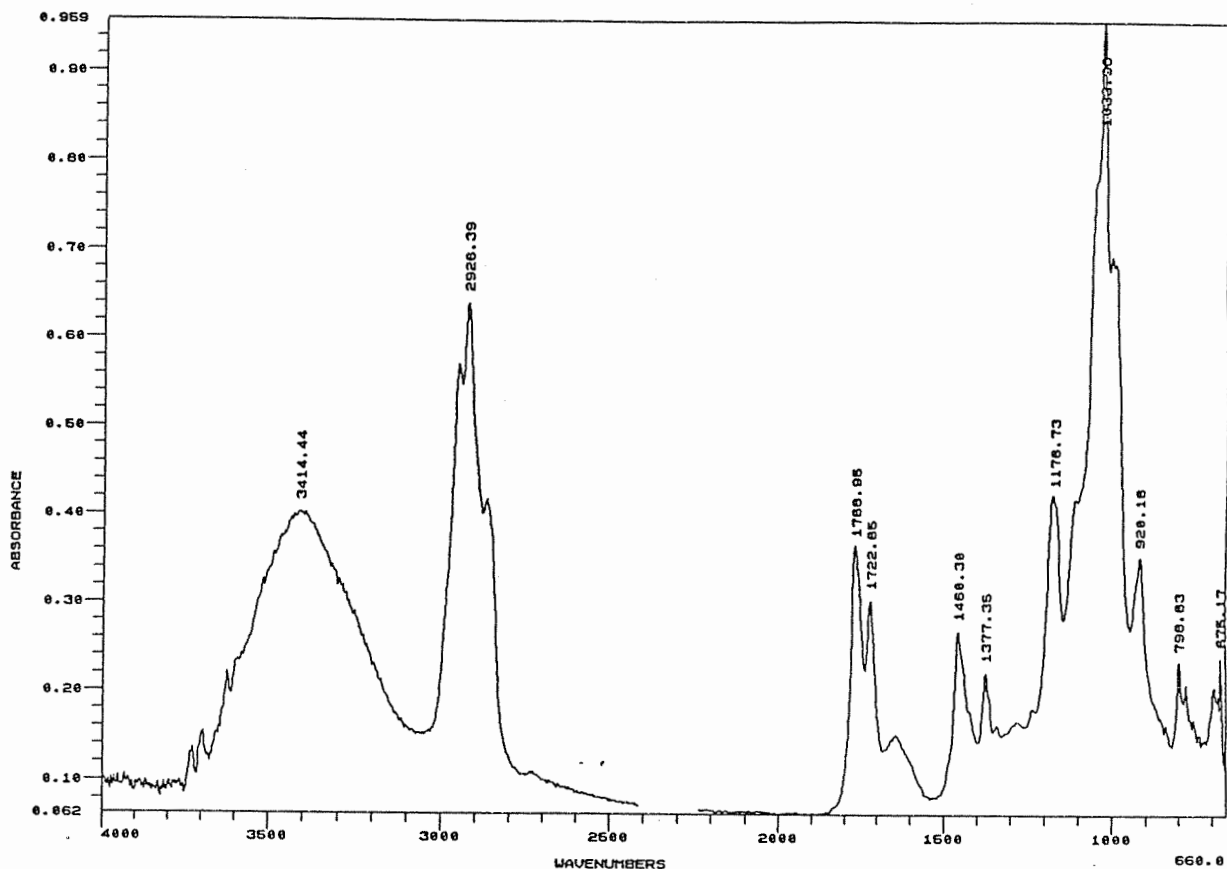


FIGURE A14. FTIR SPECTRUM OF TRINIDAD NATURAL ASPHALT

TABLE A14. SPECTRAL CORRELATION TABLE FOR TRINIDAD NATURAL ASPHALT

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
3414.44	0.40203	O-H stretching*
2926.39	0.63948	Asymmetric C-H stretching from -CH ₂ -
1768.95	0.36369	Anhydride linkages from R'-CO-O-CO-R''*
1722.65	0.30361	Anhydride linkages from R'-CO-O-CO-R''*
1466.38	0.26877	Asymmetric C-H bending from CH ₃
1377.35	0.22146	Symmetric C-H bending from CH ₃
1176.73	0.42049	C-O stretch from the anhydride*
1033.98	0.95903	
920.16	0.35233	
798.63	0.23437	
675.17	0.23938	

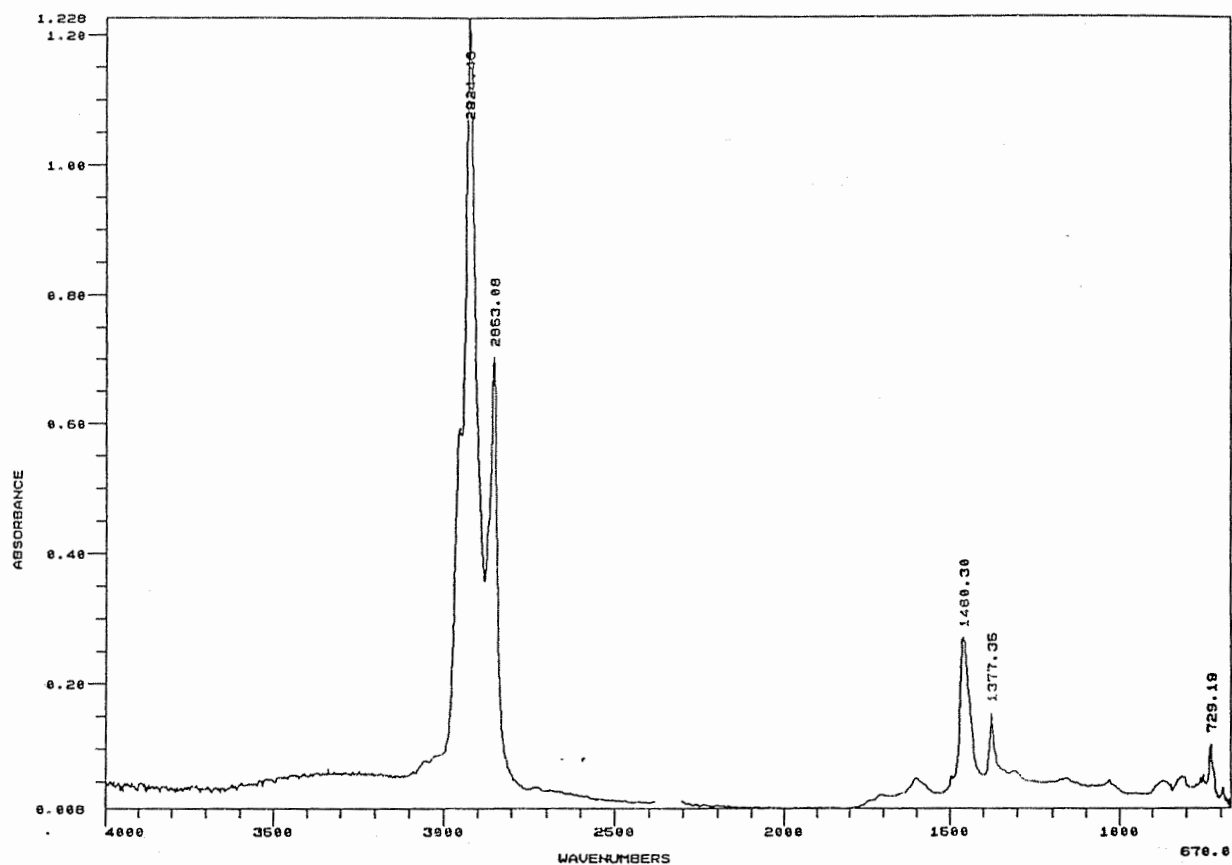


FIGURE A15. FTIR SPECTRUM OF NOVAPHALT

TABLE A15. SPECTRAL CORRELATION TABLE FOR NOVAPHALT

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2924.46	1.22810	Asymmetric C-H stretching from -CH ₂ -
2853.08	0.70125	Symmetric C-H stretching from -CH ₂ -
1480.30	0.26674	Asymmetric C-H stretching from CH ₃
1377.35	0.15368	Symmetric C-H stretching from CH ₃

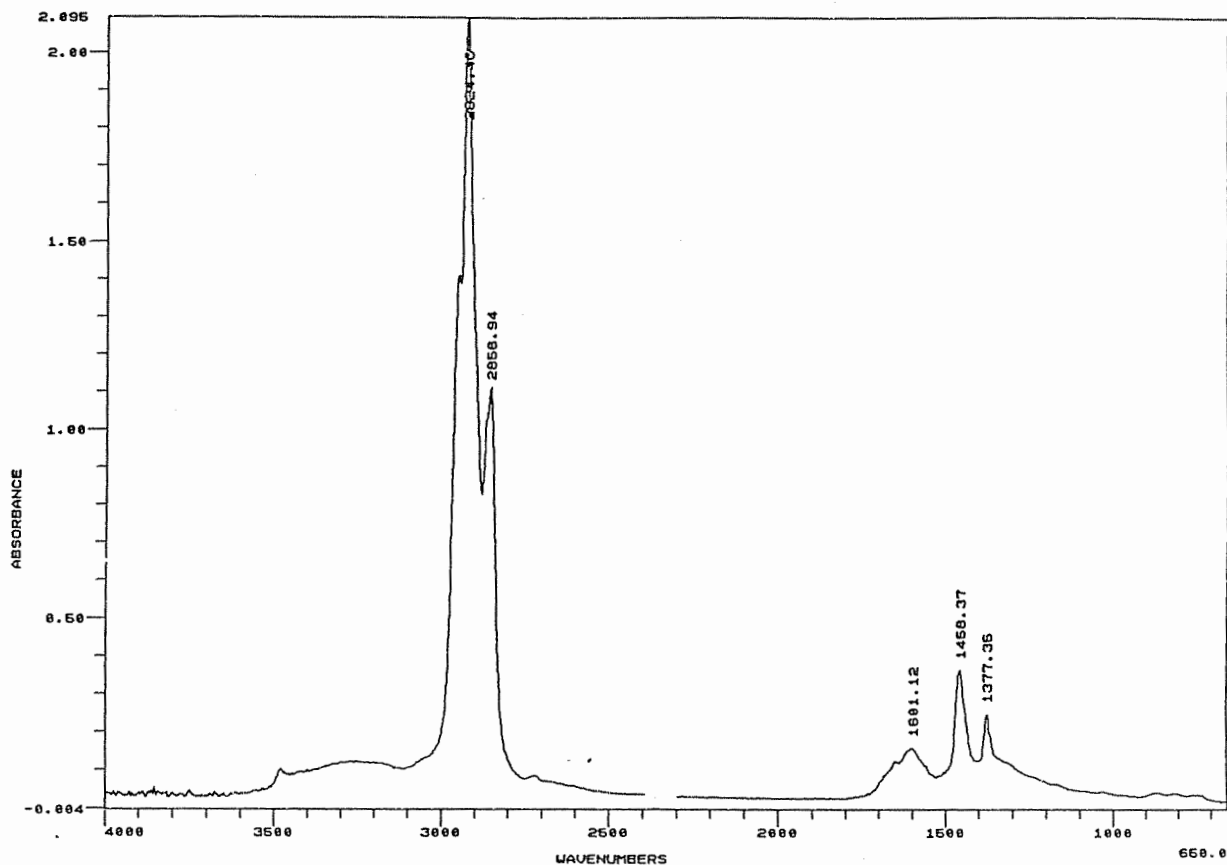


FIGURE A16. FTIR SPECTRUM OF GILSONITE

TABLE A16. SPECTRAL CORRELATION TABLE FOR GILSONITE

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2924.46	2.09507	Asymmetric C-H stretching from -CH ₂ -
2856.94	1.10173	Symmetric C-H stretching from -CH ₂ -
1601.12	0.15944	C=C conjugated stretching mode
1458.37	0.36345	Asymmetric C-H bending from CH ₃
1377.35	0.24743	Symmetric C-H bending from CH ₃

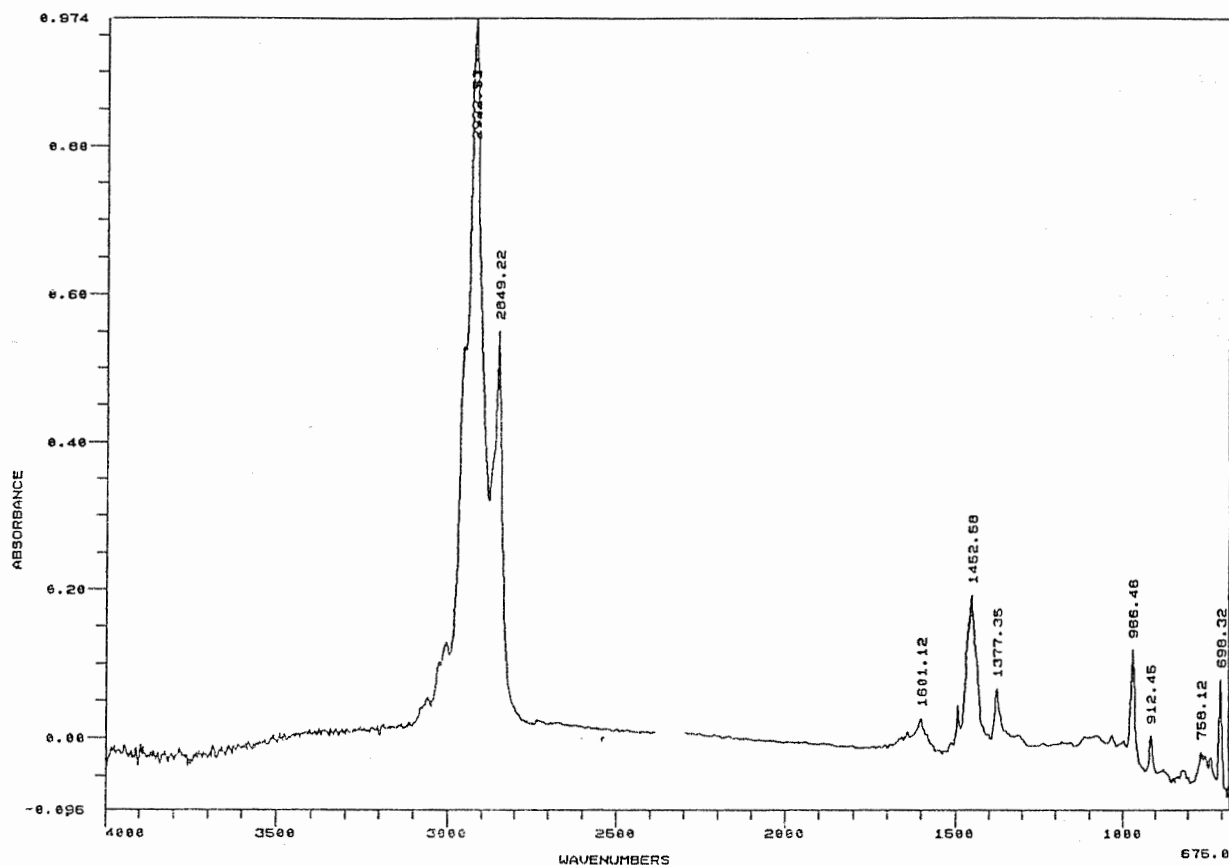


FIGURE A17. FTIR SPECTRUM OF ROSPHALT 50

TABLE A17. SPECTRAL CORRELATION TABLE FOR ROSPHALT 50

Location (cm ⁻¹)	Value (ABS)	Chemical Structure Correlation
2922.53	0.94880	Asymmetric C-H stretching from -CH ₂ -
2849.22	0.55066	Symmetric C-H stretching from -CH ₂ -
1601.12	0.02674	C=C conjugated stretching mode
1452.58	0.19243	Asymmetric C-H bending from CH ₃
1377.35	0.06661	Symmetric C-H bending from CH ₃
966.46	0.11936	C-H bending from trans-substituted C=C*
912.45	0.00404	
698.32	0.07971	Ring bend from monosubstituted benzene ring*

TABLE A18. WAVENUMBER ASSIGNMENTS FOR THE VARIOUS CHEMICAL FUNCTIONAL GROUPS

	4000	3800	3600	3400	3200	3000	2800	2600	2400	2200	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800	700	600	500	400
Alkanes																											
Branched																											
Alkenes																											
vinyl																											
vinylidene																											
cis-disub.																											
trans-disub.																											
trisub.																											
Alkynes																											
monosub.																											
disub.																											
Multi-bonds																											
Nitriles -CN																											
Isonitrile -NC																											
Thiocyanate -SCN																											
Allenes -C=C=C-																											
Isocyanates -NCO																											
Isothiocyanates -NCS																											
Aromatics																											
monosub.																											
ortho disub.																											
meta disub.																											
vicinal trisub.																											
para disub.																											
unsym. trisub.																											
sym. trisub.																											
Carbonyls																											
Ketones - aliphatic																											
Ketones - aromatic																											
Esters - aliphatic																											
Esters - aromatic																											
Anhydrides																											
Carboxylic Acids																											
Aldehydes																											

TABLE A18. CONTINUED

	4000	3800	3600	3400	3200	3000	2800	2600	2400	2200	2000	1900	1800	1700	1600	1500	1400	1300	1200	1100	1000	900	800	700	600	500	400
Other C-O & O-H																											
Carboxylate -COO-																											
Sat. Ether																											
Unsat. Ether																											
Mixed Ether																											
Epoxides																											
Alcohol - 1°																											
Alcohol - 2°																											
Alcohol - 3°																											
Halogens																											
Fluorine																											
Chlorine																											
Bromine																											
Iodine																											
Amides																											
Primary																											
Secondary																											
Tertiary																											
Amines																											
Primary																											
Secondary																											
Inorganics																											
Sulfur																											
Phosphorous																											
Silicon																											
Sulfates																											
Phosphates																											
Carbonates																											
Nitrates																											
Ammonium																											

APPENDIX B: GEL PERMEATION CHROMATOGRAPHS

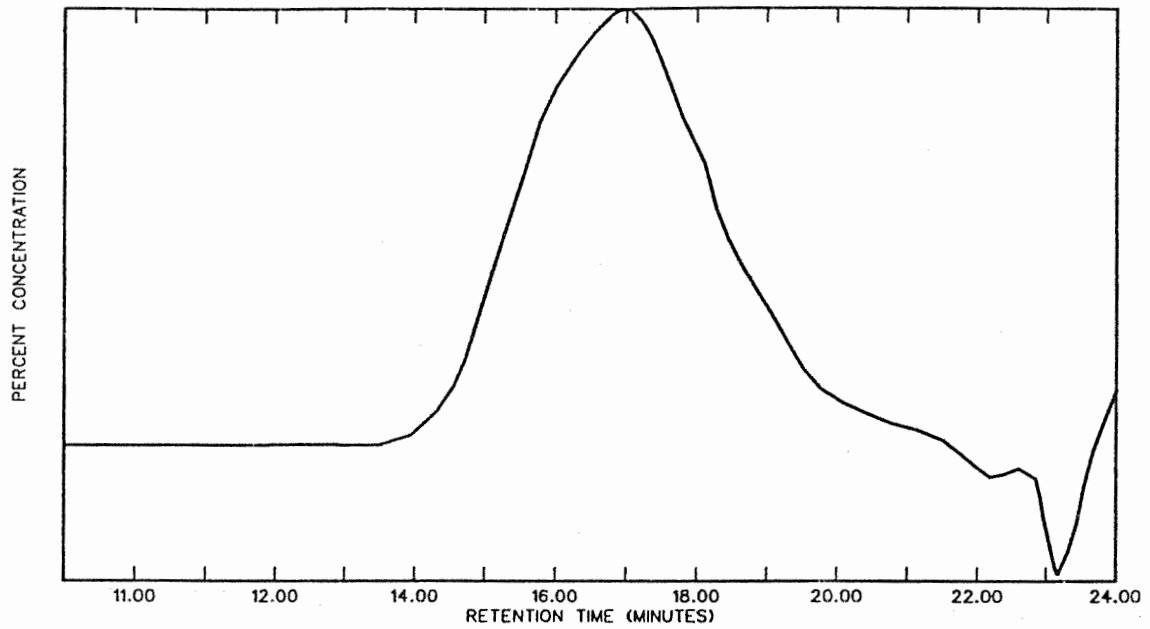


FIGURE B1. GPC CHROMATOGRAPH OF POLYBILT 103S

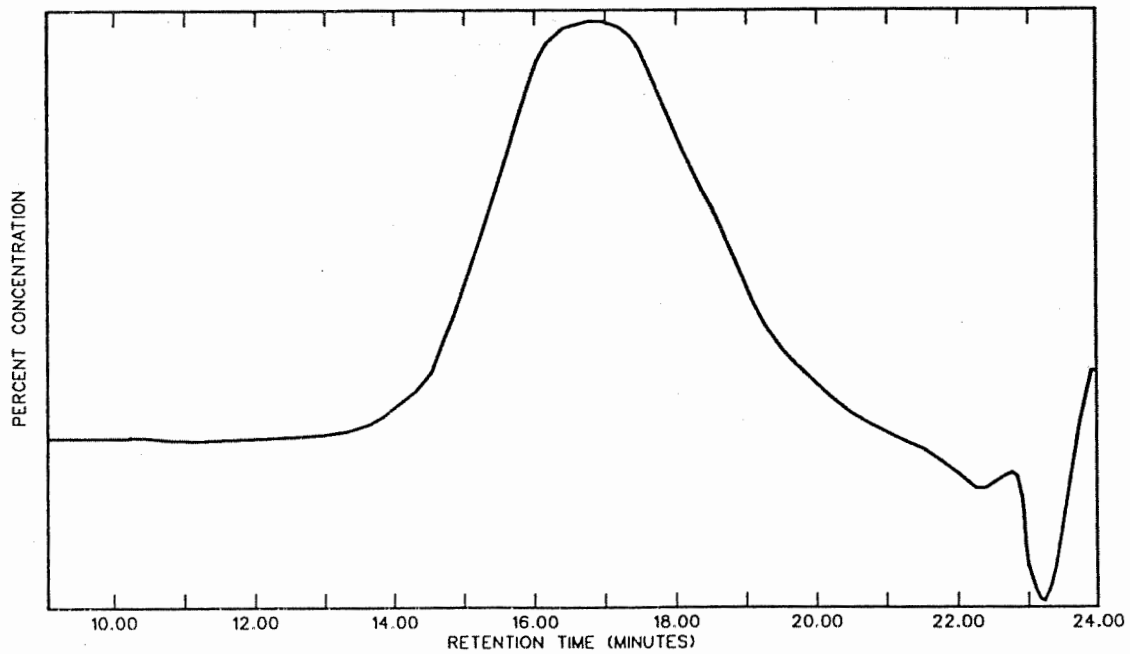


FIGURE B2. GPC CHROMATOGRAPH OF POLYBILT 151

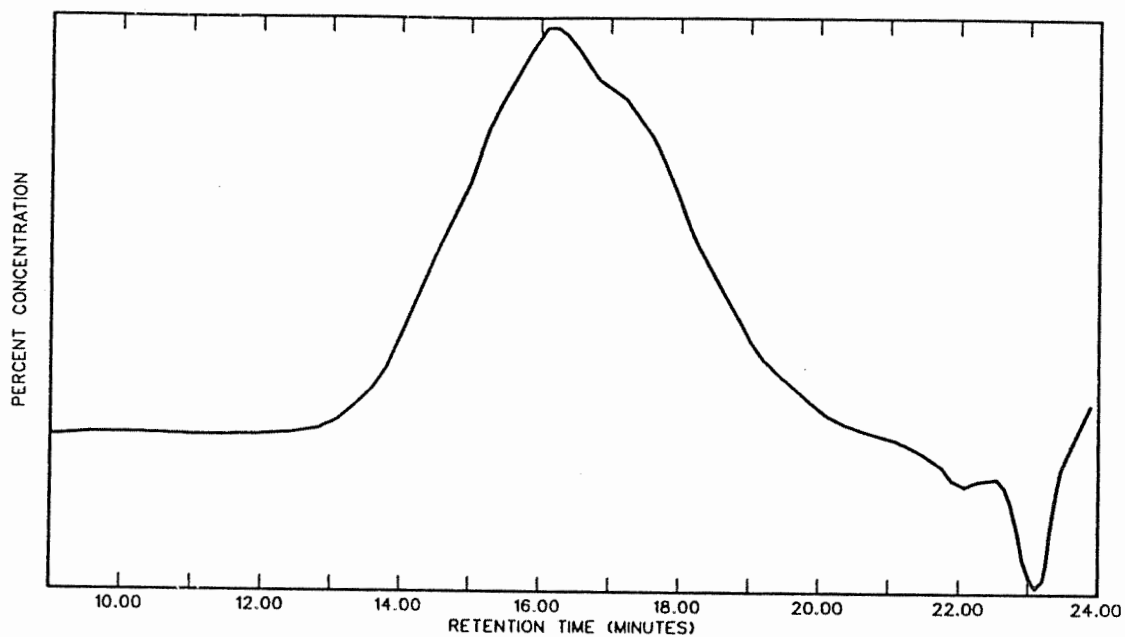


FIGURE B3. GPC CHROMATOGRAPH OF POLYBILT 152

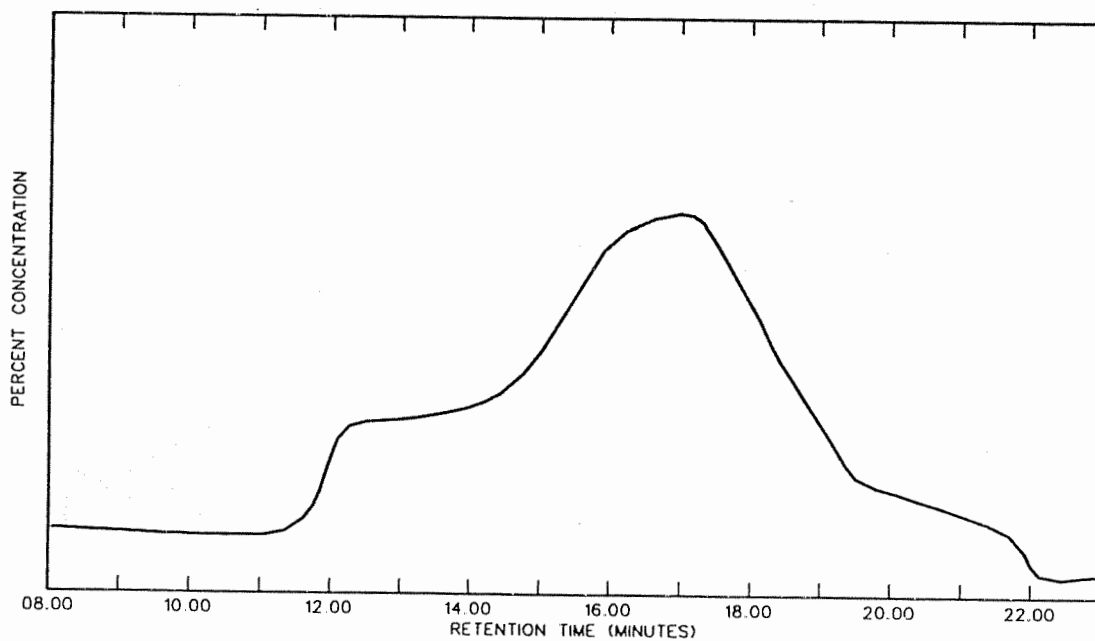


FIGURE B4. GPC CHROMATOGRAPH OF POLYBILT 503

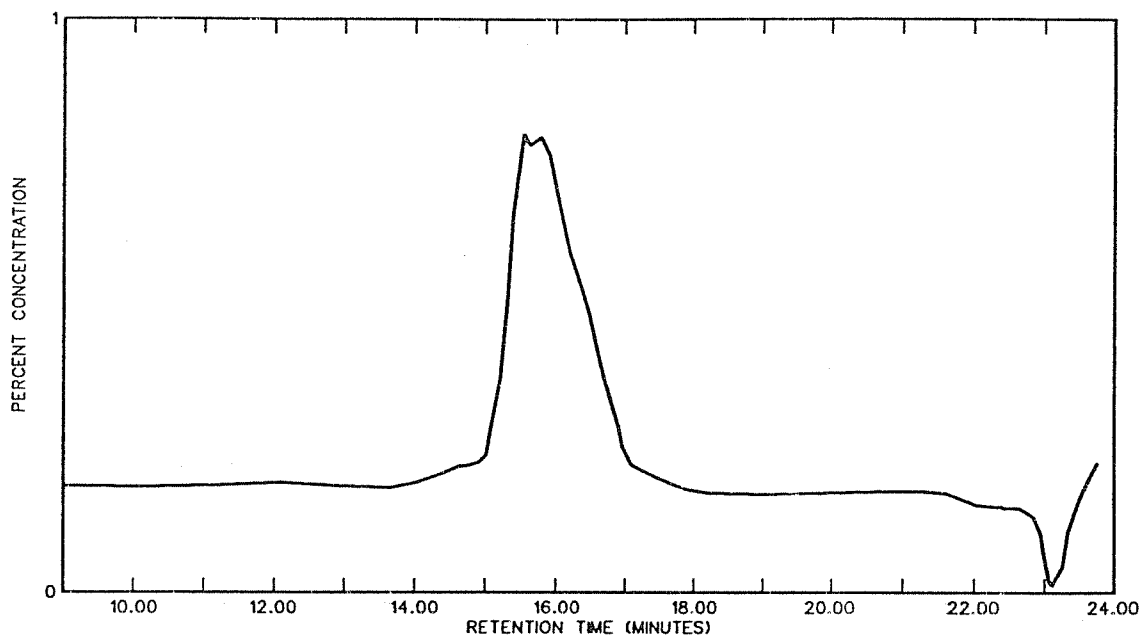


FIGURE B5. GPC CHROMATOGRAPH OF KRATON D1101

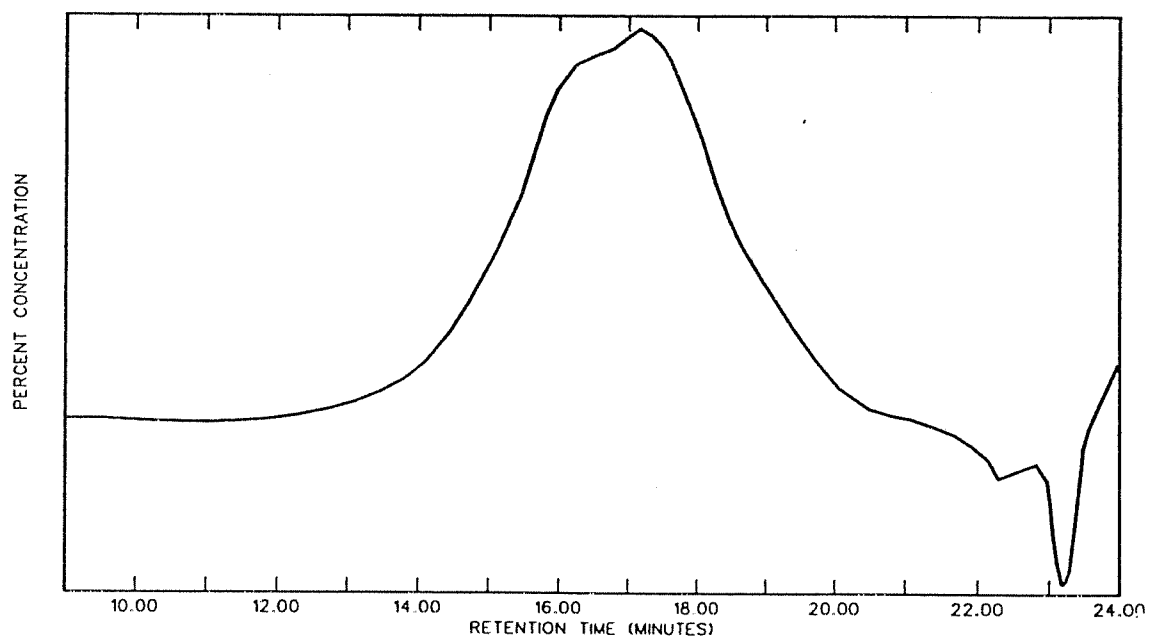


FIGURE B6. GPC CHROMATOGRAPH OF ELVAX 150W

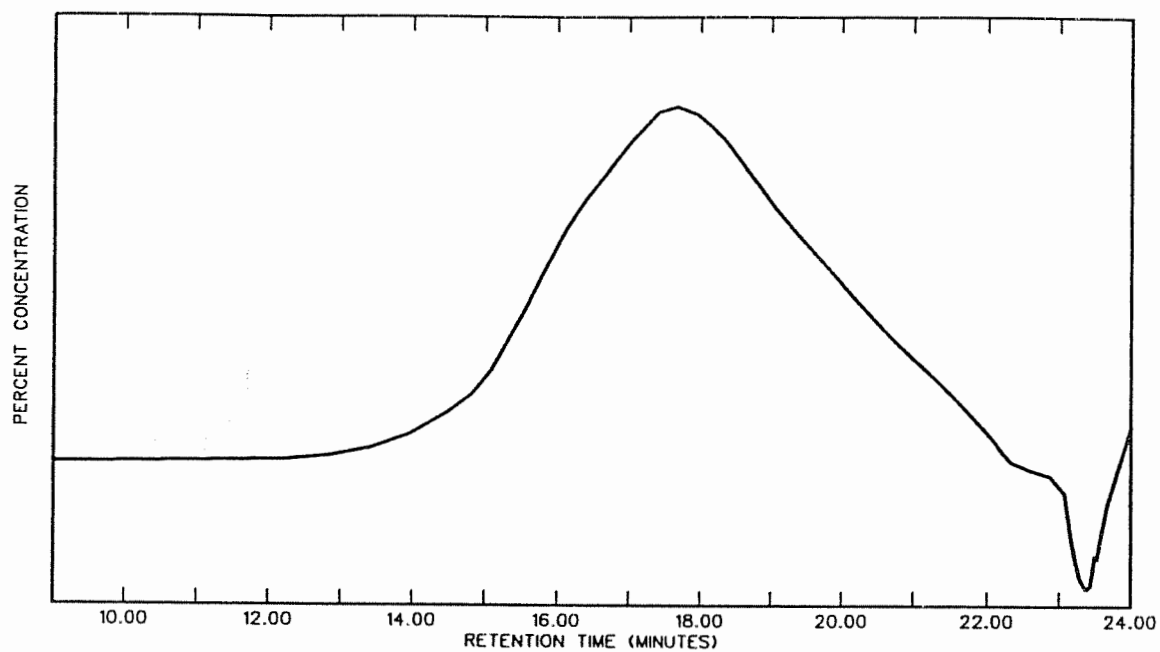


FIGURE B7. GPC CHROMATOGRAPH OF VESTOPLAST-S

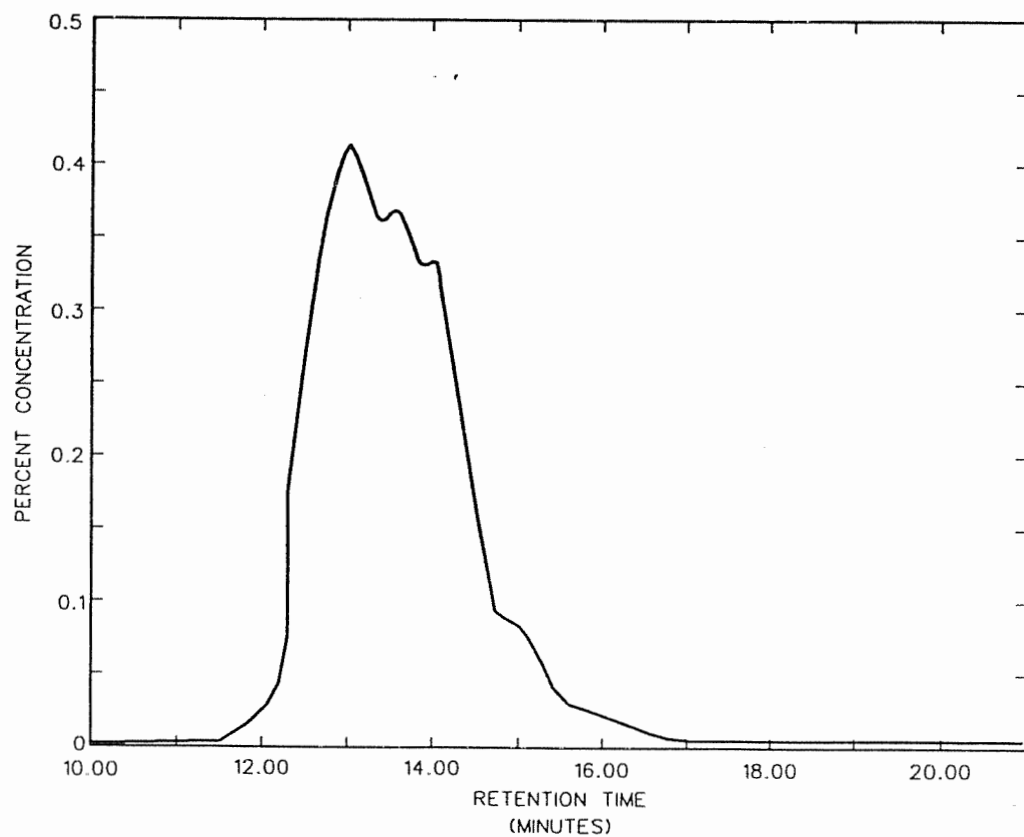


FIGURE B8. GPC CHROMATOGRAPH OF DUCTILAD D1000

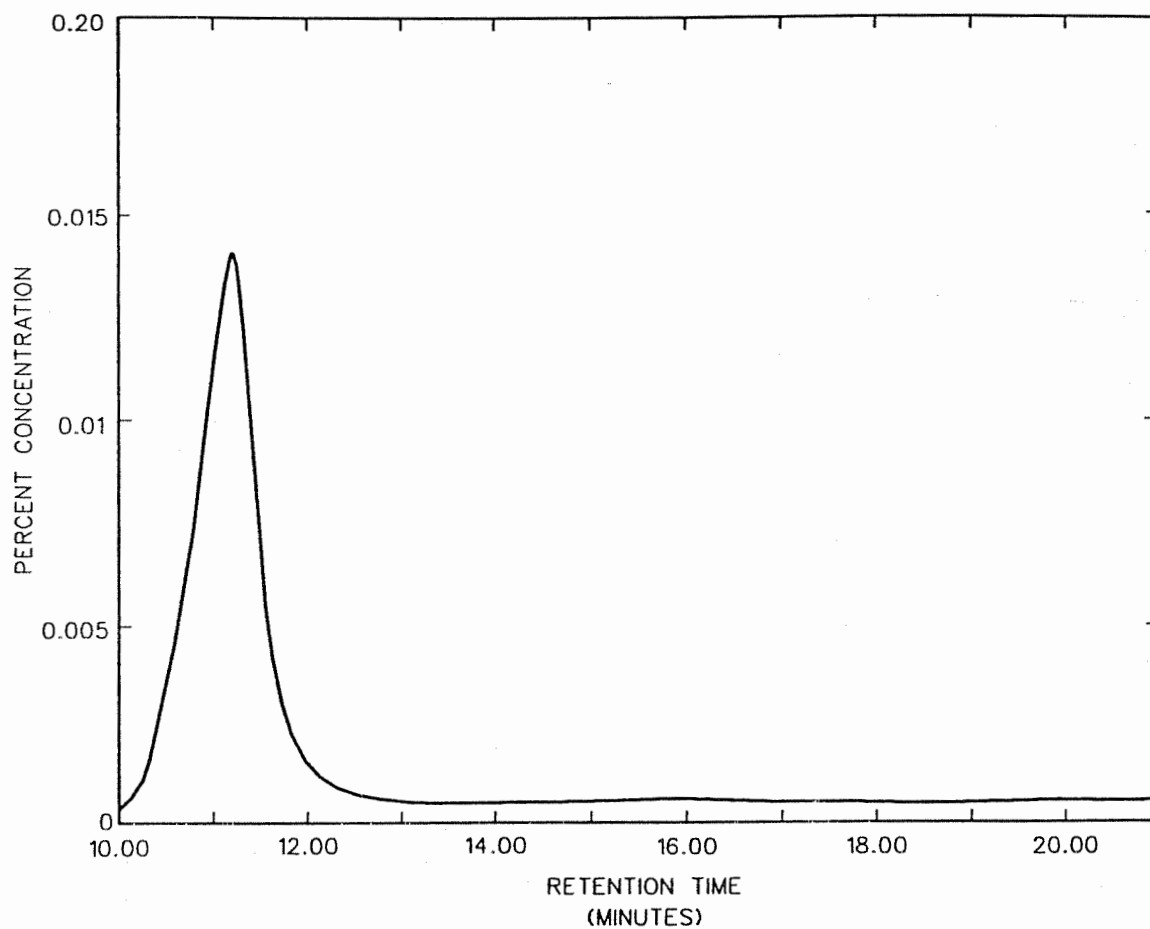


FIGURE B9. GPC CHROMATOGRAPH OF RUB-R-ROAD

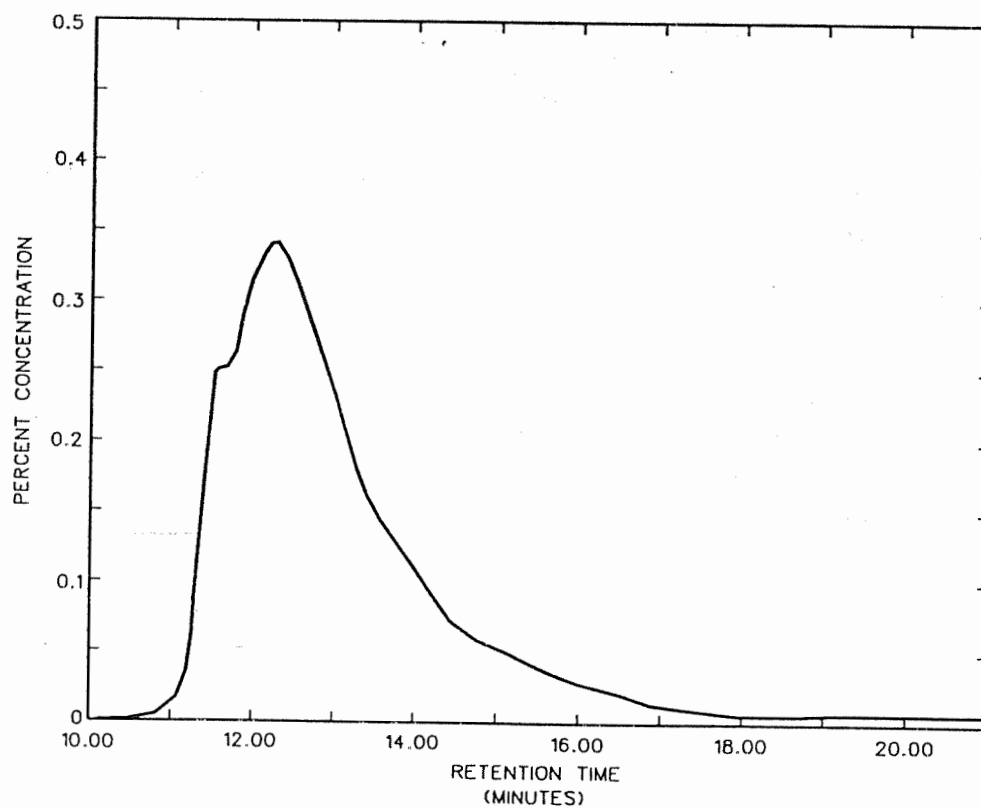


FIGURE B10. GPC CHROMATOGRAPH OF GILSONITE

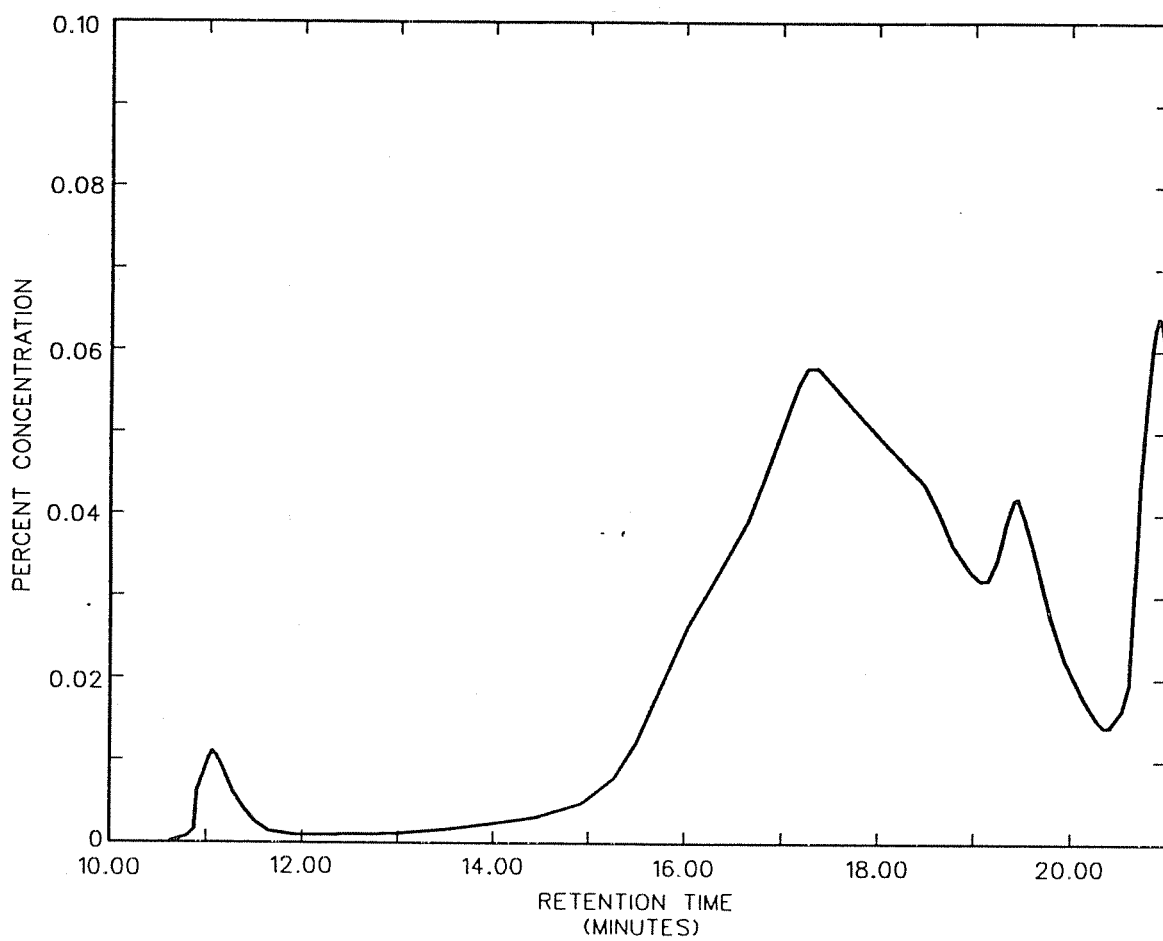


FIGURE B11. GPC CHROMATOGRAPH OF ROSPHALT 50

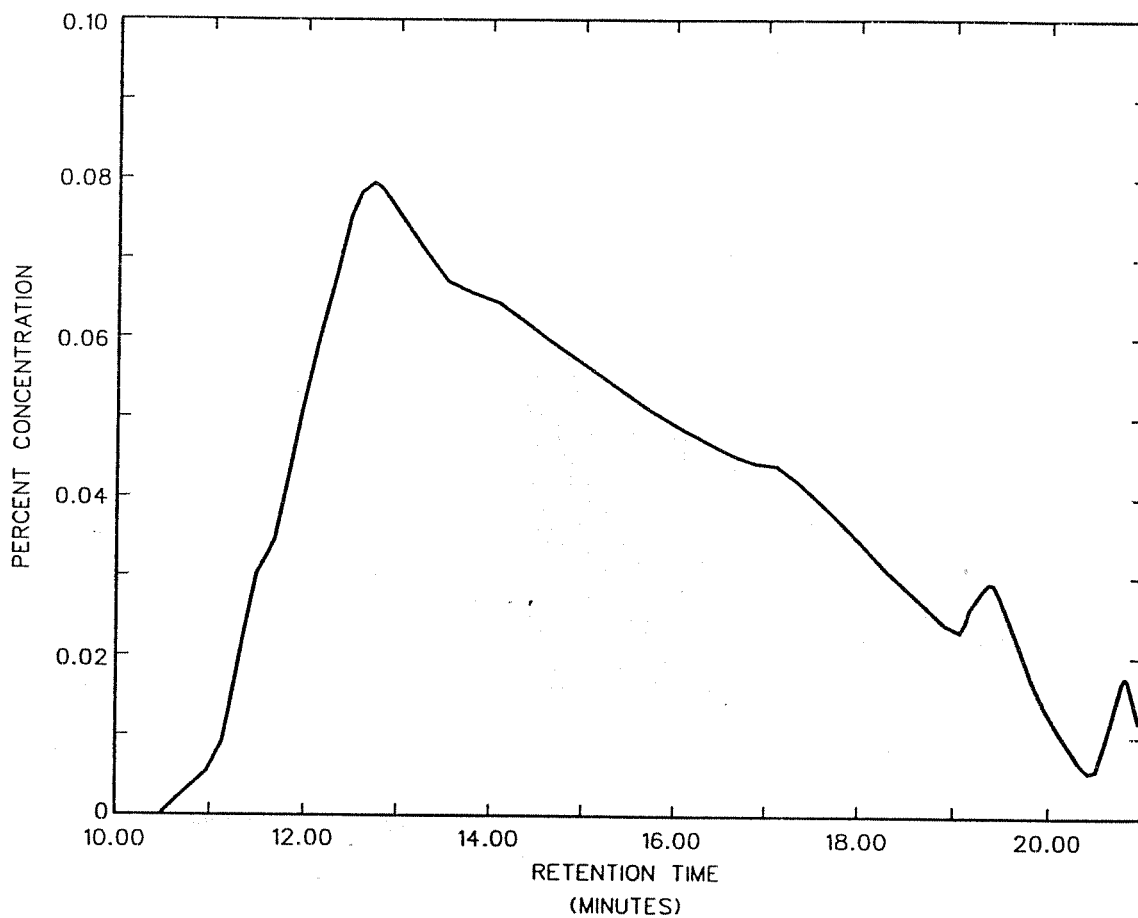


FIGURE B12. GPC CHROMATOGRAPH OF TRINIDAD NATURAL ASPHALT

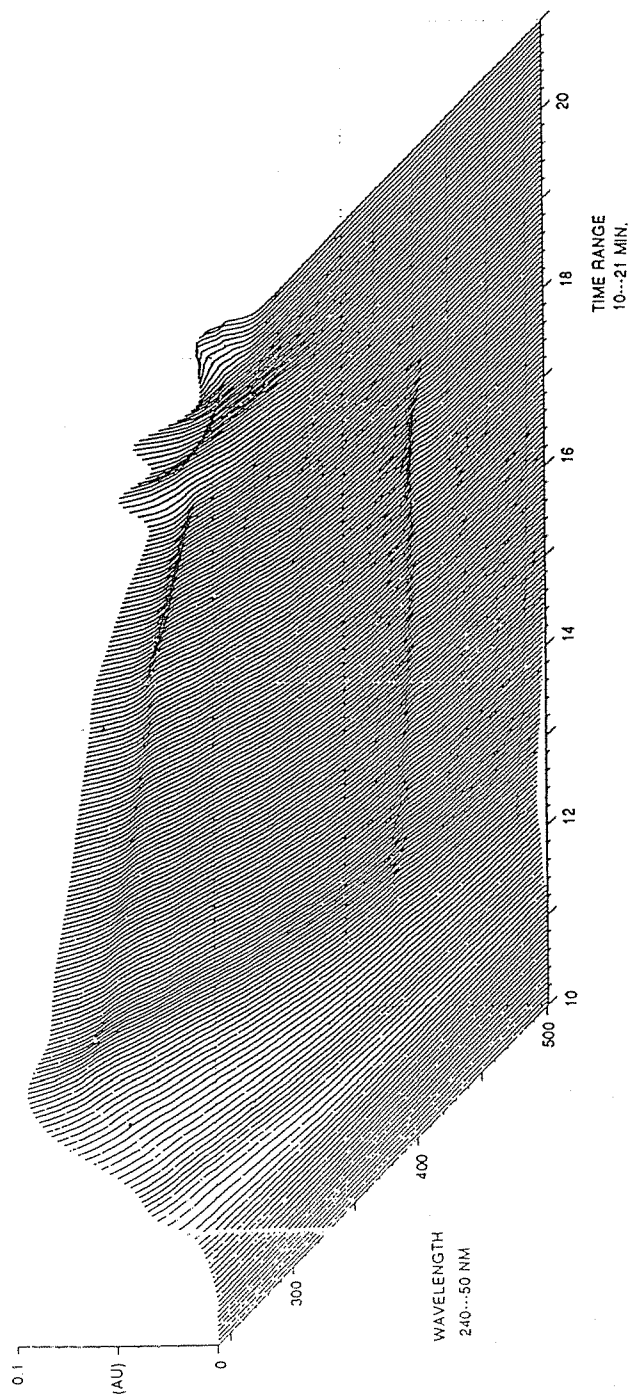


FIGURE B13. PHOTODIODE ARRAY 3-DIMENSIONAL PLOT OF TRINIDAD
NATURAL ASPHALT

APPENDIX C: ADDITIVES DATABASE

NAME: Aqua-Shield

TYPE: Miscellaneous

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

CHEMICAL NAME: Amine Based Anti-Stripping Agent

RECOMMENDED USES:

*Used as an anti-stripping agent for dense and open-graded
asphalt concrete mixtures

FIELD APPLICATIONS:

Childress, Corpus Christi, DeBerry, and Pharr, TX; used as hot-mix
asphalt additive on highway test sections (1987).

NAME: Basf Butonal NS 175

TYPE: Polymer Latexes

SUPPLIER: BASF Corporation
Dispersions & Textile Chemicals
13504-A South Point Blvd
Charlotte, NC 28273
(704) 588-7950

CHEMICAL NAME: Styrene/Butadiene Liquid Latex

RECOMMENDED USES:

*Increases viscosity at high temperatures

*Increases ductility and penetration at low temperatures

FIELD APPLICATIONS:

Salt Lake International Airport, Salt Lake City, UT; hot-mix asphalt additive used in overlays and friction courses (1984-1991).

McCarran Airport, Las Vegas, NV; hot-mix asphalt additive (1989).

Colorado Springs Airport, Colorado Springs, CO; hot-mix asphalt additive (1988-1990).

Palm Springs Airport, Palm Springs, CA; hot-mix asphalt additive (1988).

NAME: Bonifibers

TYPE: Miscellaneous

SUPPLIER: Kapejo, Inc.
P. O. Box 649
New Castle, Delaware 19720-0649
(800) 342-3717

CHEMICAL NAME: Polyester Fibers

RECOMMENDED USES:

- *Achieves greater cohesion between asphalt and aggregate

- *Greater resistance to thermal-cracking, rutting, and ravelling

NAME: Ductilad D1002

TYPE: Polymer Latexes

SUPPLIER: The Lubrizol Corporation
29400 Lakeland Blvd
Wickliffe, Ohio 44092
(216) 943-4200

CHEMICAL NAME: Liquid Styrene Based Polymer

RECOMMENDED USES:

- *Improves oxidative aging of asphalt and polymer-modified asphalt binders

- *Primarily used in bituminous surface treatments; limited use as a hot-mix asphalt additive

FIELD APPLICATIONS:

Childress Airport, Childress, TX; additive in bituminous pavement surface treatment (1987); POC: State of Texas Aeronautics Division.

Deer Park, Houston, and Bayport, TX; hot-mix asphalt additive in various city street applications (1989 and 1990).

Documented applications in at least 19 states as a bituminous surface treatment additive (1986-Present).

NAME: Elvax Resin

TYPE: Block Copolymers

SUPPLIER: E. I. DuPont de Nemours & Company
Polymer Products Department
Barley Mill Plaza
Kirk Mill Building
Wilmington, Delaware 19898
(800) 441-7111

CHEMICAL NAME: Ethylene-Vinyl Acetate Copolymer

RECOMMENDED USES:

- *Improves temperature susceptibility of asphalt binder
- *Improves resistance to deformation at high temperatures
- *Improves abrasion resistance at low temperatures
- *Increases high temperature viscosity

NAME: Fiberpave

TYPE: Miscellaneous

SUPPLIER: Hercules Incorporated
Hercules Plaza
Wilmington, Delaware 19894
(302) 594-5000

CHEMICAL NAME: Short-Length Polypropylene Fiber

RECOMMENDED USES:

*Used for joint and crack sealing

*Used to prevent reflective cracking

FIELD APPLICATIONS:

Minneapolis-St. Paul International, MN; hot-mix asphalt additive (1983).

Eppley Airfield, Omaha, NE; hot-mix asphalt additive on runway (1984).

Stapleton International, Denver, CO; hot-mix asphalt additive (1987, 1988, 1989).

Rhineland Airport, WI and at least eight airports in Ohio; additive in joint and crack sealing materials (1984-Present).

NAME: Gilsonite

TYPE: Miscellaneous

SUPPLIER: American Gilsonite Company
136 East South Temple Street
Suite 1460
Salt Lake City, Utah 84111-1104
(801) 524-7929

CHEMICAL NAME: Natural Hydrocarbon Resin Modifier for Hot-Mix
Asphalt

RECOMMENDED USES:

- *Alleviates rutting, shoving and other load-related deformation problems
- *Improves resistance of pavement to water stripping
- *Improves high temperature viscosity

FIELD APPLICATIONS:

New Jersey Turnpike, NJ; hot-mix asphalt additive used to relieve rutting distresses at more than 19 different locations (1980's).

Port of Seattle, WA; hot-mix asphalt additive used to reduce rutting from heavy forklift traffic (1988).

I-70 near Cambridge, OH; hot-mix asphalt additive used to control shoving and rutting on entrance and exit ramps (1989).

City of Greensboro, NC; hot-mix asphalt additive used to reduce rutting on severely damaged city streets (1989).

I-410 and Highway 37 at San Antonio, TX; hot-mix asphalt additive used to reduce rutting (1989-1990).

NAME: Grip-Flex

TYPE: Miscellaneous

SUPPLIER: Elastic Materials, Inc.
P. O. Box 257
200 Wellar Drive
Smithville, Ohio 44677
(800) 274-8987

CHEMICAL NAME: Thermoplastic Coal-Tar Emulsion Slurry Seal blended
with Polypropylene Fibers

RECOMMENDED USES:

- *Provides resistance to oxidation and fuel penetration
- *Resist reflective cracking
- *Provides watertight seal for joints and cracks in pavement

FIELD APPLICATIONS:

Dulles International Airport, Washington, DC; hot-mix asphalt additive used in 140,000 sq/yds of car parking areas (1985).

Dallas Ft. Worth International Airport, Ft. Worth, TX; hot-mix asphalt additive used in 300,000 sq/yds of car parking lots (1987-1988).

Vero Beach Airport, Vero Beach, FL; hot-mix asphalt additive used in 20,000 sq/yds of airport parking aprons (1985).

Findlay Airport, Findlay, OH; hot-mix asphalt additive used in 25,000 sq/yds of airport parking aprons.

NAME: Ground-Reclaimed Rubber

TYPE: Miscellaneous

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

CHEMICAL NAME: Reclaimed Automobile Tires consisting mostly of
Vulcanized Styrene/Butadiene or Polyisoprene
containing Carbon Black

RECOMMENDED USES:

- *Increase resistance to rutting and shoving

- *Promotes flexibility in the asphalt rubber mixture

- *Slower aging

- *Reduces reflective cracking in the overlay

FIELD APPLICATIONS:

Douglas Municipal Airport, Phoenix, AZ; additive in hot-mix asphalt for runway (1980); POC: Arizona Department of Transportation, Aeronautics Division.

Oakland International Airport, Oakland, CA; additive in open-graded asphalt overlay on runway (1989); POC: Port of Oakland.

NAME: Kraton D1101

TYPE: Block Copolymers

SUPPLIER: Shell Chemical Company
Sales Office
1415 West 22nd Street
Oak Brook, Illinois 60522-9008
(800) 323-3405
(312) 572-5500

CHEMICAL NAME: Styrene-Butadiene-Styrene Copolymer (31/69
Styrene to Butadiene)

RECOMMENDED USES:

- *High and recoverable elongation
- *Increased flexibility at low temperatures
- *Lower penetration at 25C with high ductility at low temperatures
- *Improved tensile strength
- *Dramatically reduced temperature susceptibility
- *Better resistance to flow and deformation at high temperatures
- *Increased stiffness at high temperatures

NAME: Kraton G1650M

TYPE: Block Copolymers

SUPPLIER: Shell Chemical Company
Sales Office
1415 West 22nd Street
Oak Brook, Illinois 60522-9008
(800) 323-3405

CHEMICAL NAME: Styrene-Ethylene-Butylene-Styrene Block Copolymer

RECOMMENDED USES:

- *High and recoverable elongation
- *Increased flexibility at low temperatures
- *Lower penetration at 25C with high ductility at low temperatures
- *Improved tensile strength
- *Reduced temperature susceptibility
- *Better resistance to flow and deformation at high temperatures
- *Increased stiffness at high temperatures

NAME: Kraton RP6904

TYPE: Block Copolymers

SUPPLIER: Shell Chemical Company
Sales Office
1415 West 22nd Street
Oak Brook, Illinois 60522-9008
(800) 323-3405
(312) 572-5500

CHEMICAL NAME: Styrene-Ethylene-Butylene-Styrene Block Copolymer

RECOMMENDED USES:

- *Better resistance to flow and deformation at high temperatures
- *Increased flexibility at low temperatures
- *Improved tensile strength
- *Increased stiffness modulus at high temperatures
- *Improved fatigue life
- *Greater resistance to abrasion

NAME: Microfil 8

TYPE: Miscellaneous

SUPPLIER: Cabot Corporation
Billerica Technical Center
Concord Road
Billerica, Massachusetts 01821
(617) 663-3455

CHEMICAL NAME: Mixture of HAF Carbon Black and high boiling
point Maltenes

RECOMMENDED USES:

- *Increased viscosity and stiffness at higher service temperatures
- *Improved wear and abrasion resistance
- *Longer predicted service life of pavement

NAME: Mineral Filler

TYPE: Miscellaneous

SUPPLIER: Cabot Corporation
Concord Road
Billerica Technical Center
Billerica, Massachusetts 01821
(617) 663-3455

CHEMICAL NAME: Mineral Filler passing Number 200 Sieve

RECOMMENDED USES:

- *Improves mixtures resistance to moisture damage
- *Lowers optimum asphalt content, thus reducing cost
- *Produces stiffer mixture at higher temperature

NAME: Neoprene Latex 654

TYPE: Polymer Latexes

SUPPLIER: E. I. DuPont de Nemours & Company, Inc.
Polymer Products Department
Barley Mill Plaza
Kirk Mill Building
Wilmington, Delaware 19898
(800) 441-7111

CHEMICAL NAME: Polychloroprene

RECOMMENDED USES:

- *Improves temperature susceptibility
- *Improves high temperature viscosity
- *Improves toughness

FIELD APPLICATIONS:

Stapleton International Airport, Denver, CO; hot-mix asphalt additive.

Greensboro/High Point/Winston-Salem Airport, Winston-Salem, NC; additive in asphalt open-graded friction course (1974).

Washington National, Washington, D. C.; hot-mix asphalt additive.

NAME: Neoprene Latex 735A

TYPE: Polymer Latexes

SUPPLIER: E. I. DuPont de Nemours & Company, Inc.
Polymer Products Department
Barley Mill Plaza
Kirk Mill Building
Wilmington, Delaware 19898
(800) 441-7111

CHEMICAL NAME: Polychloroprene (2-Chloro-1, 3-Butadiene)

RECOMMENDED USES:

- *Improves temperature susceptibility
- *Improves high temperature viscosity
- *Improves toughness

NAME: Novophalt

TYPE: Miscellaneous

SUPPLIER: Novophalt America, Inc.
107 Carpenter Drive
Suite 200
Sterling, Virginia 22170

CHEMICAL NAME: Low Density Polyethylene (LDPE)

RECOMMENDED USES:

- *Reduction of brittleness and cracking at low temperatures
can be controlled by selecting low viscosity base
asphalts for modification
- *Improved elasticity over a wide temperature range
- *Outstanding reduction of rutting and permanent deformation,
especially at high temperatures
- *Adhesion of asphalt to aggregate is substantially improved.
Stripping is reduced.

FIELD APPLICATIONS:

Pittsburgh International Airport, Pittsburgh, PA; hot-mix asphalt additive
on taxiway test section (1988); POC: Allegheny County Department of Aviation.

Houston Hobby Airport, Houston, TX; hot-mix asphalt additive on taxiway
test section (1986) and on runway (1989); POC: City of Houston, Department of
Aviation.

NAME: Petroflex

TYPE: Miscellaneous

SUPPLIER: GFC Materials Company
A Division of the Mariden Corp.
2183 Pennsylvania Ave.
Apalachin, New York 13732
(607) 625-3000

CHEMICAL NAME: Polyethylene Terephthalate Fibers

RECOMMENDED USES:

*Increased resistance to rutting and flushing at higher temperatures

*Increased cohesion, tensile strength, and flexibility

FIELD APPLICATIONS:

Logan International Airport, Boston, MA; hot-mix asphalt additive on taxiway pavements (1988-1989) and runway pavements (1992).

NAME: Pliopave

TYPE: Polymer Latexes

SUPPLIER: Goodyear Tire and Rubber Company
Akron, Ohio

CHEMICAL NAME: Latex Rubber

RECOMMENDED USES:

*Improves performance of asphalt pavement systems

NAME: Plusride Asphalt

TYPE: Miscellaneous

SUPPLIER: Pavetech Corporation
Angle Lake Plaza Building, Suite 200
19518 Pacific Highway South
Seattle, Washington 98188
(206) 824-6170

CHEMICAL NAME: Scrap Tire Rubber/Asphalt Mix

RECOMMENDED USES:

- *Increases low temperature performance
- *Increased resistance to moisture damage
- *Increased stability at higher temperatures
- *Gives improved skid resistance

NAME: Polybilt 103S (C1)

TYPE: Block Copolymers

SUPPLIER: Exxon Chemical Company
13051 Katy Freeway
Houston, Texas 77079-1398
(800) 231-6633

CHEMICAL NAME: Ethyl Vinyl Acetate Copolymer

RECOMMENDED USES:

*Higher stiffness modulus at elevated temperatures

*Reduced brittleness at low service temperatures

*Improved adhesion between asphalt binder and aggregate

NAME: Polybilt 151 (C2)

TYPE: Block Copolymers

SUPPLIER: Exxon Chemical Company
13501 Katy Freeway
Houston, Texas 77079-1398
(800) 231-6633

CHEMICAL NAME: Ethyl Vinyl Acetate Copolymer

RECOMMENDED USES:

- *Higher stiffness modulus at elevated temperatures
- *Reduced brittleness at low service temperatures
- *Improved adhesion between asphalt binder and aggregate

NAME: Polybilt 152 (C3)

TYPE: Block Copolymers

SUPPLIER: Exxon Chemical Company
13501 Katy Freeway
Houston, Texas 77079-1398
(800) 231-6633

CHEMICAL NAME: Ethyl Vinyl Acetate Copolymer

RECOMMENDED USES:

- *Higher stiffness at elevated temperatures
- *Reduced brittleness at low service temperatures
- *Improved adhesion between asphalt binder and aggregate

NAME: Polybilt 503 (C4)

TYPE: Block Copolymers

SUPPLIER: Exxon Chemical Company
13501 Katy Freeway
Houston, Texas 77079-1398
(800) 231-6633

CHEMICAL NAME: Ethyl Vinyl Acetate Copolymer

RECOMMENDED USES:

- *Higher stiffness modulus at elevated temperatures
- *Reduced brittleness at low service temperatures
- *Improved adhesion between asphalt binder and aggregate

NAME: Rosphalt 50

TYPE: Miscellaneous

SUPPLIER: Royston Laboratories, Inc.
128 First Street
Pittsburgh, Pennsylvania 15238
(412) 828-1500

CHEMICAL NAME: Aromatic Styrenic Polymeric additive

RECOMMENDED USES:

*Inhibits reflective cracking in overlays

*Used as a waterproofing or wearing course

*Most applications since 1977 have been on bridge decks

FIELD APPLICATIONS:

Over 45 locations (concentrated in New York, Pennsylvania, and Ohio) as an additive in bridge deck wearing courses and waterproofing layers.

NAME: RUBR-ROAD

TYPE: Polymer Latexes

SUPPLIER: RUBR-ROAD, Inc.
P. O. Box 456
Kent, Ohio 44240
(216) 678-7050

CHEMICAL NAME: Styrene-Butadiene Rubber Latex

RECOMMENDED USES:

- *Resistance to flexure fatigue
- *Retarding oxidative aging
- *Increased low temperature ductility
- *Increased toughness

FIELD APPLICATIONS:

Airport at Beaver Island, MI; used as additive in bituminous chip seal (1982 and 1987); POC: Michigan Department of Transportation.

Airport at Muskegon County, MI; hot-mix asphalt additive (1983 and 1987); POC: Michigan Department of Transportation.

Detroit City Airport, Detroit, MI; hot-mix asphalt additive (1987 and 1992); POC: City of Detroit, MI.

Newark International Airport, Newark, NJ; used as an additive in various bituminous pavement applications (1985-1992); POC: Port Authority of New York and New Jersey.

J. F. Kennedy International Airport, New York, NY; additive in hot-mix asphalt (1985-1992); POC: Port Authority of New York and New Jersey.

NAME: Sealgum

TYPE: Polymer Latexes

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

CHEMICAL NAME: Latex modifier

RECOMMENDED USES:

- *Maximizes waterproofing characteristics of asphalt
- *Minimizes the risk of bleeding
- *Provides greater skid resistance
- *Provides overlays with better leveling and finishing characteristics

NAME: Styrelf

TYPE: Block Copolymers

SUPPLIER: Elf Asphalt, Inc.
1000 Executive Parkway
St. Louis, Missouri 63141
(314) 878-0793

CHEMICAL NAME: Styrene/Butadiene Block Copolymer

RECOMMENDED USES:

- *Reduces age hardening and increases durability
- *Improves low temperature flexibility
- *Provides excellent cohesive and adhesive properties

FIELD APPLICATIONS:

Various locations in New Mexico; used as rejuvenating spray application (annual maintenance) and as additive in hot-mix asphalt; POC: New Mexico State Highway and Transportation Division, Aviation Division.

Pueblo Memorial Airport, Pueblo, CO; hot-mix asphalt additive for runway projects in 1987, 1989, and 1990.

NAME: Trinidad Natural Asphalt

TYPE: Miscellaneous

SUPPLIER: Trinidad Asphalt Corporation of America
P. O. Box 310
Bronxville, New York 10708
(914) 793-5100

CHEMICAL NAME: Natural Asphalt

RECOMMENDED USES:

- *Improved performance at extreme temperatures
- *Reduced maintenance and extended service life
- *Increased fatigue life
- *Increased stability

FIELD APPLICATIONS:

LaGuardia Airport, New York, NY; additive in hot-mix asphalt for aircraft apron (1981); POC: Port Authority of New York and New Jersey.

Newark International Airport, Newark, NJ; additive in hot-mix asphalt for taxiway (1981); POC: Port Authority of New York and New Jersey.

J. F. Kennedy International Airport, New York, NY; additive in hot-mix asphalt for runway (1984); POC: Port Authority of New York and New Jersey.

NAME: Ultrapave

TYPE: Polymer Latexes

SUPPLIER: Textile Rubber and Chemical Co.
1300 Tiarco Drive, SW
Dalton, Georgia 30720
(706) 277-1300

CHEMICAL NAME: Styrene/Butadiene Latex

RECOMMENDED USES:

*Improved resistance to rutting and shoving

*Improved low temperature ductility

*Improved cohesive and adhesive properties

FIELD APPLICATIONS:

Airport locations in Michigan: Alma, Bay City, Benton Harbor, Jackson, Traverse City, Adrian, Cadillac, Detroit City, Flint, Houghton County, Kalamazoo, Lansing, Muskegon, Charlevoix, Grand Rapids, Houghton Lake, Iron Mountain, Manistee, Ontonagon, Three Rivers; POC: Bureau of Aeronautics, State of Michigan.

NAME: Vestoplast-S

TYPE: Block Copolymers

SUPPLIER: VP-S Company
4951 Edgewood Drive
Richmond, Indiana 47374
(317) 935-1750

CHEMICAL NAME: Ethylene, Propylene, Butylene Terpolymer

RECOMMENDED USES:

- *Increased stiffness of the asphalt concrete mixture at elevated pavement service temperature, thereby reducing rutting

- *Increases the adhesion of the asphalt cement binder to the surface of the aggregate, thus decreasing the amount of stripping when moisture sensitive aggregate is used in asphalt concrete mixtures

FIELD APPLICATIONS:

Kentucky: US 80 west of KY 461, Pulaski County (1990) and US 460, Magoffin County Line to US 23 (1991); hot-mix asphalt additive for Special K Surface; POC: Kentucky Department of Transportation.

Wisconsin: US 45, north of Wittenberg, hot-mix asphalt additive (1990) and I-94 west of SR 67 near Oconomowoc, stone mastic asphalt additive (1991).

Minnesota: I-94 east of Exit 140 to Freeport, hot-mix asphalt additive (1990).

Michigan: M52, south of I-96, east of Lansing, between Howell and Columbia Road, stone mastic asphalt additive (1991).

Maryland: US 15, south of Frederick, stone mastic asphalt additive (1992).

