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Criteria for Use of Seal Coats on Airport Pavements

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16. Abstract

Seal coats are generally used to protect the pavement surfaces from oxidation and ingress of water to layers below. Additionally, seal coats on airport pavements are expected to protect the pavement from the potential damage of fuel spillage.

This report describes the results of literature search conducted for this study. It also describes the information gathered from visits to eight airport sites located throughout the U.S. Samples of seal coat materials obtained from five airport sites were tested in the laboratory to determine their performance characteristics. Also, the characteristics of asphalt and coal tar seal coat mixes were tested under dry and wet freeze-thaw cycling to determine the effect of wet freeze-thaw cycling on cracking of sixteen different mixes. The results of all these tests are included in this report along with a summary and conclusions, and a list of recommendations.

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PREFACE

This report is a result of a two year study of seal coat materials sponsored by the Federal Aviation Administration titled "Criteria and Guidance Regarding the Type and Characteristics of Seal Coating Materials," Contract No. DTFA01-90-C-00029. The assistance and guidance provided by Dr. Aston McLaughlin, Project Manager for FAA, are gratefully acknowledged.

Several airport engineers participated in the study and provided assistance during the visits to the airport sites. Also, contractors and suppliers of seal coat materials provided samples for this study. Special thanks are due to Mr. Bernie Schlake of Neyra Industries, Inc., who provided some samples of emulsions and shared his experience related to seal coating materials.

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EXECUTIVE SUMMARY

Asphalt pavement surfaces generally weather due to oxidation and sunlight. Also, the ingress of water through cracks in the pavement causes considerable damage to the pavement structure. Therefore, seal coats are generally used to protect the pavement surface from the effects of oxidation, sunlight and ingress of water to the layers below. Additionally, seal coats on airport pavements protect them from the potential damage of fuel spillage. Therefore, seal coats can prolong the useful life of pavements when properly designed and placed.

The objective of this study was to provide criteria and guidance regarding the types and characteristics of seal coating materials, optimal timing of seal coating applications, conditions under which airport pavement seal coating is most effective, and to determine the degree to which pavement life can be prolonged by this procedure.

The scope of the study included interviews with several engineers familiar with seal coats, visits to airport sites to collect data on seal coat materials and their performance in the field, testing of seal coat materials and mixes in the laboratory, analysis of data, a summary of results and recommendations for consideration by FAA.

A literature search related to seal coat materials and mixes was conducted. The results of this study indicated that seal coats have been used in the past to improve the skid resistance characteristics of pavement surfaces and provide a protective surface against environmental damage to runways, taxiways, and apron areas. Coal-tar emulsion seal coats are generally used by airport engineers to provide a protective layer to their pavement against the environment and fuel damage.

The information gathered from visits to several airport sites indicated that asphalt emulsion seal coats were not used as extensively as coal-tar emulsion seal coats. The performance of coal-tar emulsion seal coats with latex was generally considered to be satisfactory by the airport engineers. The average life of seal coated surface varied from 3-5 years. But most of the seal coats were considered to be satisfactory if they lasted 2-3 years. Many airport engineers considered the use of seal coats as a temporary measure to keep the pavement in usable condition until enough funds became available to rehabilitate the pavement with overlays.

The effect of high rainfall at the Florida site was not noticeable on the performance of seal coats. Also, the seal coats in Colorado were performing satisfactorily although the temperatures were relatively low.

Seal coat materials from five airport sites were obtained and tested in the laboratory. The results of these tests indicated that the performance of seal coat mixes is affected by the sources of sands and emulsions. Sands which are slightly coarser than the FAA specified gradation tend to show problems with adhesion. The sands which contain fine fractions (passing sieve #40) in relatively larger quantities (about 12%) may require higher percentage of additives to pass freeze-thaw tests. These tests also indicated that the current FAA design criteria contained in Engineering Brief No. 46 can be used to assess the performance of seal coat mixes.

Effect of dry and wet freeze-thaw cycling was also tested on four mixes. two of these mixes contained asphalt emulsions and the other two contained coal-tar emulsions. In general, it was observed that wet freeze-thaw cycling reduced the number of cycles to develop first crack in the samples when compared with dry freeze-thaw cycle samples. Also, the level of cracking at the end of 10 cycles of freeze-thaw was higher in samples tested under wet conditions than samples tested under dry conditions.

The results of laboratory tests on seal coat mixes also indicated that viscosity of mixes did not affect the freeze-thaw cycling or cracking of samples. Also, the type of emulsion (asphalt and coal-tar) did not show any significant effect on the performance of mixes when assessed by freeze-thaw cycling. Only, the fuel resistance properties of mixes were affected by the type of emulsion used in the mix.

The effect of latex additive used in coal-tar mix was noticeable in wet freeze-thaw samples. The number of cycles to develop first crack in mixes containing latex were more than the mixes without latex when tested under the same condition (wet freeze-thaw). However, the use of latex did not completely negate the effect of wet freeze-thaw cycling.

CRITERIA FOR USE OF SEAL COATS ON AIRPORT PAVEMENTS

CHAPTER I

INTRODUCTION

INTRODUCTION

Proper functioning and good performance of seal coats depend on several factors. A good design of seal coat mix to accommodate traffic and weather conditions of the site, proper construction methods and equipment, appropriate time to construct the seal coat, etc., are some of the important factors which govern the performance of seal coats. Materials used in seal coat mixes are other variables which affect the proper functioning and performance of these surfaces.

Asphalt as well as coal-tar binders have been used in the seal coat mixes of airport pavements. However, when fuel resistance characteristics are important, coal-tar binders have been preferred over the asphalt binders. Also, due to practical reasons, slurry seal coats have been used in almost all airport pavements. Other types of seal coats have not been used by airport engineers as was learned from the telephone interviews with several airport engineers in connection with this study (see Chapter III).

It is generally expected that seal coats will increase the useful life of pavement, but this benefit is not derived from the strengthening of the pavement as is the case with overlays. The seal coats derive their benefits from the fact that the protective coating on the surface of pavement slows the aging of surface layer and prevents damage caused by the ingress of water to the pavement below. Therefore, characteristics desired in a seal coated surface are as follows:

1. It should be relatively impermeable to water,
2. It should be free from cracks,
3. It should be properly bonded to pavement surface,

4. It should be fuel resistant, and
5. It should provide adequate skid resistance.

Past efforts in designing the seal-coating mixes have been directed towards achieving these characteristics.

OBJECTIVE AND SCOPE OF STUDY

The objectives of the study are as follows:

1. Provide criteria and guidance regarding the types and characteristics of seal coating materials,
2. Optimal timing of seal coating applications,
3. Conditions under which airport pavement seal coating is most effective, and
4. Degree to which pavement life may be prolonged by seal coating procedure.

In order to achieve the objectives of this study, the following items were included in its scope:

1. Conduct interviews with cognizant individuals as necessary,
2. Make site investigations (at least 5 sites) for relevant data,
3. Perform a literature search,
4. Fabricate specimens and perform all necessary laboratory tests in a factorial design, and
5. Collect and analyze all necessary data in order to achieve the objectives of this study.

The study was divided into several tasks. These tasks included the items mentioned above (under the scope of this study). The work performed under each task and the results are summarized in subsequent chapters of this report.

Chapter II is a summary of the literature search conducted for this study. Chapter III summarizes the efforts of interviewing the airport engineers, site investigations and relevant data collections. Chapter IV summarizes the data collected during laboratory tests of various seal coat materials.

Analysis of the data is described in Chapter V. A summary of the results of data analysis is also included in this chapter. Summary and conclusions are described in Chapter VI. Chapter VII includes a list of recommendations which were developed from the results of this study.

CHAPTER II
LITERATURE REVIEW

INTRODUCTION

Pavement research engineers are continually looking for ways to improve the long term durability of asphalt mixtures to be used in airfield pavements. Seal coats are not expected to enhance the structural capacity of a pavement; rather the primary functions of the materials are the improvement of the surface characteristics, and providing a protective surface against environmental damage to the runway and/or taxiways. There are several purposes for seal coating of pavements [1, 2]:

1. To enrich the dry, weathered or oxidized surface, preventing to some extent the loss of material from the old surface by traffic abrasion.

2. To prevent the intrusion of moisture into the pavement, through cracks in the existing pavement surface. Ingress of moisture through the cracks is likely to reduce the load carrying capacity of the pavement structure.

3. To develop a skid resistant surface, as by using sharp and angular aggregate in seal coat, a highly skid resistant surface can be provided.

It should be however emphasized that seal coats do not strengthen the existing pavement, increase load bearing capacity, bridge major cracks greater than 3 mm wide or eliminate maintenance and/or rehabilitation of pavements. The average service life of seal coats is generally 3 to 5 years depending upon weather, traffic volume, construction techniques, material type, etc. Construction and subsequent satisfactory performance of seal coats are affected by several factors, namely, quality of materials (binder and aggregate), design of individual material quantities, strict control of application quantities and operational (construction) methods, pavement surface conditions on which seal coat was applied, favorable weather conditions and sufficient traffic control to ensure adequate hardening time for seal coat along with minimum loss of aggregate [3].

BINDERS FOR SEAL COATS

Four common binders used for seal coats are: asphalt cements, asphalt cut-backs, asphalt emulsions and coal-tar emulsions. These binders have been used both in its original form as well as by modifying the binders with additives.

Asphalt cement AC-5 grade is commonly used in seal coat work in areas of average temperature and AC-10 in warmer areas. As asphalt cement requires a high application temperature, which in turn is determined by the viscosity of the asphalt cement, the high temperature requirement (250 to 300°F) is a constraint in rapid applications of cover aggregates [3].

The solvents in cutback asphalt make it more workable and easier to spray. The application temperature is not a major constraint, as the binder will remain fluid for a longer period after it has been applied, thus giving enough time for application of cover aggregate. Emulsified asphalt, which is a combination of asphalt, water and an emulsifying agent, can also be handled at lower temperatures. Emulsified asphalt can be mixed with even damp and cool aggregates.

Coal-tar pitch emulsion prepared from high temperature coal-tar pitch conforming to the requirements of ASTM D 490, grade 11/12, has been extensively used by airports as a seal coat binder for pavements. The current FAA specifications stipulate the use of latex rubber as an additive and the seal coat is a combination of aggregate, coal-tar, water and latex rubber [4].

AGGREGATES FOR SEAL COATS

Aggregate selection depends on what characteristics are being considered in the seal coat performance, namely skid resistance, cost or other factors of most importance and/or concern. Optimum gradation of aggregate is dependent upon the type of aggregate, volume of traffic, climatic region, etc. According to Texas State Department of Highways and Public Transportation (SDHPT), aggregates which are coated and uncoated are recommended for seal coats [3]. They also recommend the use of lightweight aggregates. According to Texas SDHPT the purpose of precoated aggregates is to reduce aggregate dust and to promote bond with the binder.

FAA Engineering Brief #46 [4] stipulates the use of natural or manufactured angular aggregates composed of clean, hard, durable, uncoated particles, free from lumps of clay and all organic matter.

Use of relatively one-sized aggregate particles (chips) was experimented by Saskatchewan Highways and Transportation, for conventional seal coating [5], but test results were not satisfactory. However, use of graded aggregates in high-float emulsion seal coats, resulted in improved performance especially with rubber asphalt as a binder. Gradation with 16 mm and 12.5 mm maximum size with 65 percent passing the 5 mm and 6 percent passing the 71 mm sieves gave them the best results.

Studies of slurry seal coat mixes in the laboratory indicated that the type of aggregate used in the mix affects its performance [6]. Hard aggregates with low absorption performed better than low quality aggregates with high absorption. The effect of fine aggregates (fraction passing sieve #200) on the performance of seal coat mixes was not statistically significant when the percentages of these fractions were reduced from 8% to 5% by weight of aggregate in the mix [6].

The texture of seal coated surface is affected by the aggregates used in the seal coat mix. Two types of surface textures are generally considered important for determining the skid resistance characteristics of pavement surfaces. Macrotexture or large-scale pavement texture is caused by the size and shape of the surface aggregate. Microtexture or fine-scaled pavement texture is contributed by individual small asperities on each aggregate particle [7]. In a field study, the measurements of macrotexture of a bituminous seal coat ranged between 0.00 and 0.01", whereas, the macrotexture of hot-mix asphalt concrete ranged between 0.01 and 0.04". The skid number at 40 mph for these surfaces ranged from 18-27 and 29-59 respectively [7]. These measurements indicated that the macrotexture of surface may affect the skid resistance characteristics of pavement surfaces. The researchers [7] believe that a combination of macrotexture, microtexture and internal damage largely determine the friction characteristics of pavement surfaces.

DESIGN PRACTICES

Literature review of work carried out by various Department of Transportation (DOT's) pertaining to the design approach of seal coat focuses on the selection of (i) the type and amount of asphalt emulsions and (ii) the type, amount and gradation of aggregate. Design formula is limited to determining the amount of area covered per volume of aggregate, and the volume of asphalt emulsion needed per unit area of seal coat. Specified tests were limited to finding physical properties of aggregate such as dry loose unit weight, bulk specific gravity, as well as the amount of coverage of the aggregate [8].

Prevailing climatic conditions of the area where seal coat is to be applied and the season of the year have considerable bearing of the selection of the type of asphalt binder. Literature review has indicated that best results have been obtained when seal coat work is performed during the early part of the warm season, such that the newly sealed surface is subjected to a considerable amount of traffic during the warmer months [9]. Prevalent environmental conditions after construction greatly influence the performance of emulsion seal coats more than that of coal-tar seal coats. High viscosity, rapid - setting emulsified asphalt is satisfactory for all seasons of the year except when the temperature is near freezing point [10].

Other important considerations in the design of seal coats are the characteristics of the existing pavement surface and the character (surface texture) and size of aggregate used in seal coating. If the surface to be sealed is of open texture and has oxidized, a portion of the binder will penetrate it and partially act as a primer. Thus, a slightly heavier application is required than when the existing surface is smooth. The character of the aggregate (surface texture), whether it is absorptive or non-absorptive, and its maximum effective size are of importance in governing the rate of application of both binder and aggregate. In addition to making some allowances for absorption of the binder into the old surface, other allowances are made for absorption by the aggregate when a highly absorptive stone is used [10]. Lightweight aggregates having a very high rate of absorption has been used by Texas SDHPT, and these have yielded fairly satisfactory performance of the seal coats [3].

CALTRANS (California Department of Transportation) in its research study has stated that certain closely controlled procedures are to be followed to take advantages of the benefits of coal-tar seal coats [11]. These procedures pertain to aggregate gradation. It has concluded that for satisfactory performance of seal coats, the cover aggregate should be composed of 50 percent well graded sand and 50 percent limestone screenings. It has also stated that laboratory tests should be conducted to determine the necessary amounts of binder, but in any case before field application, necessary adjustments should be made to the mix to account for binder absorption by the existing pavement surface to be seal coated. A low amount of coal-tar in the mix will result in excessive surface wear, whereas a mixture having an excess of coal-tar will produce a slippery surface when wet. Figure 1 shows, in a qualitative manner, the basis for selection of both optimum water content and minimum emulsion content.

Researchers have indicated that the design method for seal coat construction with asphalt cement as a binder is beset with problems due to high spraying temperature and sensitivity to aggregate surface moisture which in turn may necessitate the heating of aggregates before application [12,13,14]. Laboratory tests and calculations required in the formulation of mix design are:

1. Dry loose aggregate unit weight determined on aggregates in a dry condition.

2. Bulk specific gravity of aggregate.

3. Board tests to determine weight of aggregate applied on a given area.

4. Calculation of asphalt cement content and aggregate quantities, which is dependent on project location, traffic intensity, condition of pavement and environmental conditions.

Research carried out in the Republic of South Africa for the design of single and double surfacing seals is based on the modified tray test [15]. Two factors are important for the proper construction and performance of single and double seal coats: (1) the correct binder application, (2) the correct aggregate spread rate. The reason for this approach is to retain a certain portion of the voids in the aggregate unfilled by the binder to ensure good skid resistance. A portion of the void is lost during the life of the slurry seal because of embedment and wear of aggregate. It is therefore considered necessary to take this factor of loss of voids over a period of time into account, while designing slurry seal coats. Most design methods used for determining

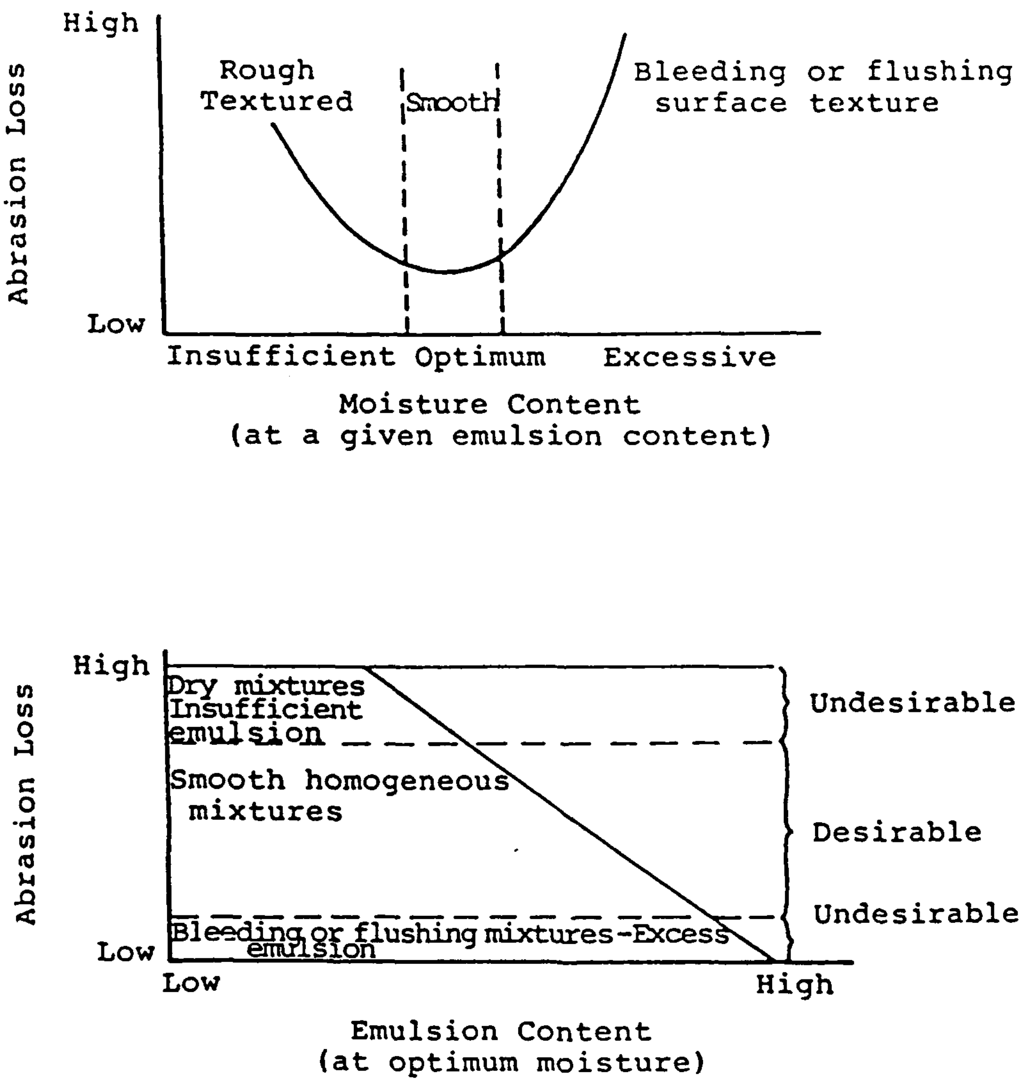

Figure 1. Typical consistency curves for slurry seal coats

the void content in a seal coat layer are empirical. Designers assume an equation for the void content based on the average least dimension (ALD) of the aggregate. However, tests have shown that the empirical method is not the right procedure to use for void determination. A simple test, called the modified tray test, was devised by the researchers to measure the actual void content. This test could be used both for laboratory design of the mix and for field quality control.

Slurry seal coats are the most common types of seal coats generally used at the airport sites. Current FAA specifications define the aggregate gradation, amount of emulsions, additives, and aggregates in the mix. The specific Items which cover these specifications are: (1) Item P-625, Tar Emulsion protective seal coat, and (2) Item P-626, Asphaltic Emulsion Slurry Seal or Surface Treatment. A recent revision to Item P-625 is contained in the FAA Engineering Brief No. 46 [4]. Due to its fuel resistance characteristic, coal-tar emulsion slurry seal coats have been used in most of the airport sites as was revealed by a recent telephone survey conducted in connection with this study (see Chapter III). However, some airport sites have used asphalt emulsion slurry seal coats also.

Shooi and Shannon in their report regarding state of the art for coal-tar seal coats [16] have indicated the coal-tar emulsion seal coat formulations. Coal-tar emulsions are generally classified as clay emulsion with 30 to 35 percent of coal-tar pitch, 20 percent of clay including bentonite and 45 to 50 percent of water. Mix design formulation for coal-tar emulsion seal coats according to FAA Item P-625 are described in Appendix A of Engineering Brief No. 46. [4] This document in its entirety is reproduced in Attachment 1 of this report.

A number of additives to the basic coal-tar emulsion have been proposed and used. Some of these are latex additive containing 51-70 percent butadiene and 30-49 percent acrylonitrile with the possible addition of 3 percent silicone by weight of rubber [17]. Also some polymers have been proposed by manufactures to provide additional improvements, and the use of chemical emulsifying agents to reduce or eliminate the use of clay [16]. Sand in coal-tar seal coats is generally required to improve skid resistance of the pavement surface. According to the authors there is still a difference of opinion over the quantity of sand, gradation range and type of sand to be used [16].

According to FAA Item P-625 sand loadings up to 14 pounds per gallon of emulsion is permissible, however some suppliers feel that this quantity should be limited to about 8 pounds, as a higher rate would decrease the fuel resistance properties of the coating [16].

The design of slurry seal coats using asphaltic emulsions is controlled by the requirements included in the FAA Item P-626. These requirements are reproduced in Table 1 for ready reference here [17]. Asphalt emulsions of types SS-1, SS-1h, SS-K, or SS-Kh are recommended.

Although specifications for seal coats other than slurry seals are available in the FAA Advisory Circular on standards for specifying construction of airports, [17] other types of seal coats are not constructed. There are several reasons to use slurry seal coats at airports. The following reasons are more prominent:

1. Emulsion seal coats are mixed and applied to the surface at normal temperatures, whereas, seal coats with cutbacks or asphalt cements will require special arrangements for heating the ingredients and mix,
2. Aggregates for mix need not be completely dried before mixing, and
3. After the seal coat sets properly, there is no loose material on surface which can cause damage to the aircraft.

Table 1. Requirements for Gradation of Aggregate (from FAA Item P-626)

Sieve Designation (square openings)	Percentage by Weight Passing Sieves			
	A	B	C	D
	1/2" Maximum	3/8" Maximum	3/8" Maximum	#4 Maximum
1/2	100	100	100	100
3/8	85-100	100	100	100
No. 4	60-87	70-90	98-100	100
No. 8	40-60	45-70	65-90	98-100
No. 16	28-45	28-50	45-70	65-90
No. 30	19-34	19-34	30-50	40-60
No. 50	12-25	12-25	18-30	25-42
No. 100	8-17	7-18	10-21	15-30
No. 200	4- 8	5-15	5-15	10-20
Asphalt content percent dry aggregate	5.5-7.5	6.5-12	7.5-13.5	10-16
Pounds of aggregate per square yard	20-50	15-20	10-15	6-10

CONSTRUCTION

There are several types of seal coats which are used in highways and airport pavements. Aggregate seal, slurry seal, sand seal, etc. are some of the seal coats which are used for pavement surface treatments. The specifications developed by highway and airport agencies contain guidelines for the construction of each seal coat type. These guidelines contain several items. For example, the construction of asphalt emulsion slurry seal includes details on the following items:

1. Weather limitations,
2. Equipment and tool,
3. Cleaning existing surface,
4. Application of tack coat,
5. Composition of slurry mix, and
6. Application of slurry seal coat.

A review of literature on this aspect indicates that adequate information is available for the construction of various types of seal coats.

DISTRESSES IN SEAL COATS

Cracking, poor adhesion of seal coat to pavement, and low friction values are some of the common distresses observed in seal coated surfaces [16]. Although the causes of these failures are as specific as the site itself, the literature contains information regarding the factors involved in each one of these distresses. For example, cracking could be due to the shrinkage and brittleness of the seal coat itself or it may develop due to the reflection of cracks from the underlying pavement. Similarly, poor adhesion of seal coat to the pavement may be due to improper mix, poorly cleaned pavement surface, or poor construction method. Type of sand used in the mix or the amount of sand added to the emulsion may be responsible for a low friction mix. Again, the current revisions to FAA Item P-625 [4] contain provisions for testing the materials and mixes so that cracking and adhesion characteristics of seal coating mixes can be assessed in the laboratory.

SUMMARY

The results of literature review related to seal coat materials and mixes have been described in this chapter. Seal coats are generally used to improve the skid resistance characteristics of pavement surface and provide a protective surface against environmental damage (aging and water) to the runways, taxiways, and/or apron areas. Additionally, coal-tar slurry seal coats provides protection to pavement surfaces from fuel damages. It is however important to note that seal coats do not strengthen the existing pavement, increase its load carrying capacity, bridge major cracks greater than 3 mm wide or eliminate need for rehabilitation of pavements.

Both, asphalt and coal-tar binders are used for seal coating purposes. However, majority of airports use coal-tar and asphaltic emulsions for seal coating the pavements. Asphalt cutbacks and cements are also included in the specifications, but are not used for practical reasons. Current FAA specifications for coal-tar slurry seals also include provisions for the use of rubberized additive materials in the seal coat mixes.

The guidelines for the gradations of seal coat aggregates are also available in the literature as well as specifications of the state highway agencies and airport authorities. The various sizes of aggregate particles present in the mix affect the characteristics of mix. Therefore, it is important to select a gradation which will satisfy the needs of a specific site as well as the ranges of the specifications.

The design practices generally include the consideration for the selection of type and amount of binder (emulsion), the type, amount and gradation of aggregates, and the type and amount of additive (if used). The application rate and number of applications of mixes generally control the thickness of seal coat layer. This is generally determined from experience based on the usage of pavement surface by aircraft traffic and the expected life of the seal coat.

Weather conditions, equipment and tools available to construct a seal coat, cleanliness of the surface are some of the considerations included in the specifications for the construction of seal coats.

Most commonly observed distresses in seal coated surfaces are: cracking, poor bond, and low skid resistance. Proper design of seal coat mixes and adequate care during their construction can reduce the chances of premature failure of seal coated surfaces.

CHAPTER III
VISITS TO AIRPORT SITES

INTRODUCTION

Visits to airport sites were included in this study to collect data from these sites which may be relevant to the study of seal coats. This task was performed under the following two subtasks:

1. Selection of appropriate sites, and
2. Visits to sites for data collection

The data collected from these sites were used to determine the material types used in the seal coats and their performance under prevailing conditions. A description of the activities related to these two subtasks is included in the subsequent sections of this chapter.

SELECTION OF SITES

Several airport sites located throughout the country were contacted by phone to gather preliminary information regarding the use of seal coats. Specifically, the questions were related to the following items:

1. The type of seal coat used in the last 10 years and their performance.
2. Type of original surface on which seal coat was applied.
3. Purpose of seal coating the existing surface.

A total of 56 airport sites were contacted in this connection but only 47 sites indicated that they have used seal coats in their airports. A list of these airports is included in Table 2.

Table 2. List of airports contacted for preliminary selection of sites

Airports	State	SC Type * 1	SC Type * 2	Candidate Sites	Sites Selected By FAA
1. Anchorage	AK	X			
2. Juneau	AK	X			
3. Winnzchee	AK	X			
4. Yakutat	AK	X			
5. Montgomery	AL	X			
6. Scottsdale	AZ	X		X	X
7. Merced	CA	X			
8. Oakland	CA	X			
9. Santa Barbara	CA	X			
10. Willows	CA	X			
11. Denver	CO	X		X	X
12. Bridgeport	CT	X			
13. Fort Lauderdale	FL	X	X	X	X
14. Okeechobee	FL	X	X		
15. Palatka	FL	X			
16. Sarasota	FL	X			
17. Venice	FL	X			
18. Boise	ID	X			
19. Chicago, O'Hare	IL	X			
20. Campbellsville	KY	X			
21. Covington	KY	X			
22. Bedford	MA	X	X	X	X
23. Nantucket	MA	X	X		
24. Detroit	MI	X			
25. Flying Cloud	MN	X	X	X	X

Airports	State	SC Type * 1	SC Type * 2	Candidate Sites	Sites Selected By FAA
26. St. Paul	MN	X			
27. Kansas City	MO	X			
28. Gulf Port	MS	X			
29. Charlotte	NC	X			
30. Lincoln	NE	X	X		
31. Albuquerque	NM	X	X		
32. Tonopah	NV	X			
33. La Guardia	NY	X			
34. Onell	NY	X			
35. Rochester	NY	X			
36. Cincinnati	OH	X	X	X	X
37. Portland	OR	X		X	
38. Philadelphia	PA	X			
39. Quaker Town	PA	X		X	
40. Gallatin	TN	X			
41. Jackson	TN	X	X	X	
42. Memphis	TN	X			
43. Paris	TN	X	X		
44. Union City	TN	X			
45. Austin	TX	X		X	
46. San Antonio	TX	X			
47. Beckley	WV	X			

*SC TYPE = Seal Coat Type (1 = Coal-tar; 2 = Asphalt)

Based on the information gathered from these sites it appeared that these airports have used mainly coal-tar seal coats, and only few airports have used asphaltic seal coats in addition to coal-tar seal coats as indicated in Table 2. There was no particular reason given by the airport engineers for using coal-tar seal coats instead of asphalt seal coats. Answers related to the performance of seal coats varied from satisfactory to poor at the same site. Therefore, details of this information were gathered from each site when visited later.

In all cases the seal coats were applied to asphaltic surfaces. The purpose, as reported, of seal coating the surface was to seal the cracks and pavement surfaces from the ingress of water and reduce the possibility of water related damages.

In some cases, the seal coats were used to protect the cracked and damaged surfaces temporarily from water damages until adequate funds were available to rehabilitate the surface with overlays.

Summarizing the information gathered from telephone interviews, it was evident that coal-tar seal coats were used in all airports. However, there were some airports where asphalt seal coats were also used but asphalt seal coats alone were not used in any airport contacted by Resource International (RI) and listed in Table 2.

Considering several factors, such as: type of seal coats used, climatic conditions of airport sites (temperature, rainfall, etc.), and their geographic locations, a total of 10 potential sites were selected for visits and data collection. These sites are marked with an "X" in the column "candidate sites" in Table 2. Figure 2 shows the approximate locations of all 10 sites.

This list was submitted to the FAA for its review. After the review, the FAA finally approved the following six areas for visits and data collection:

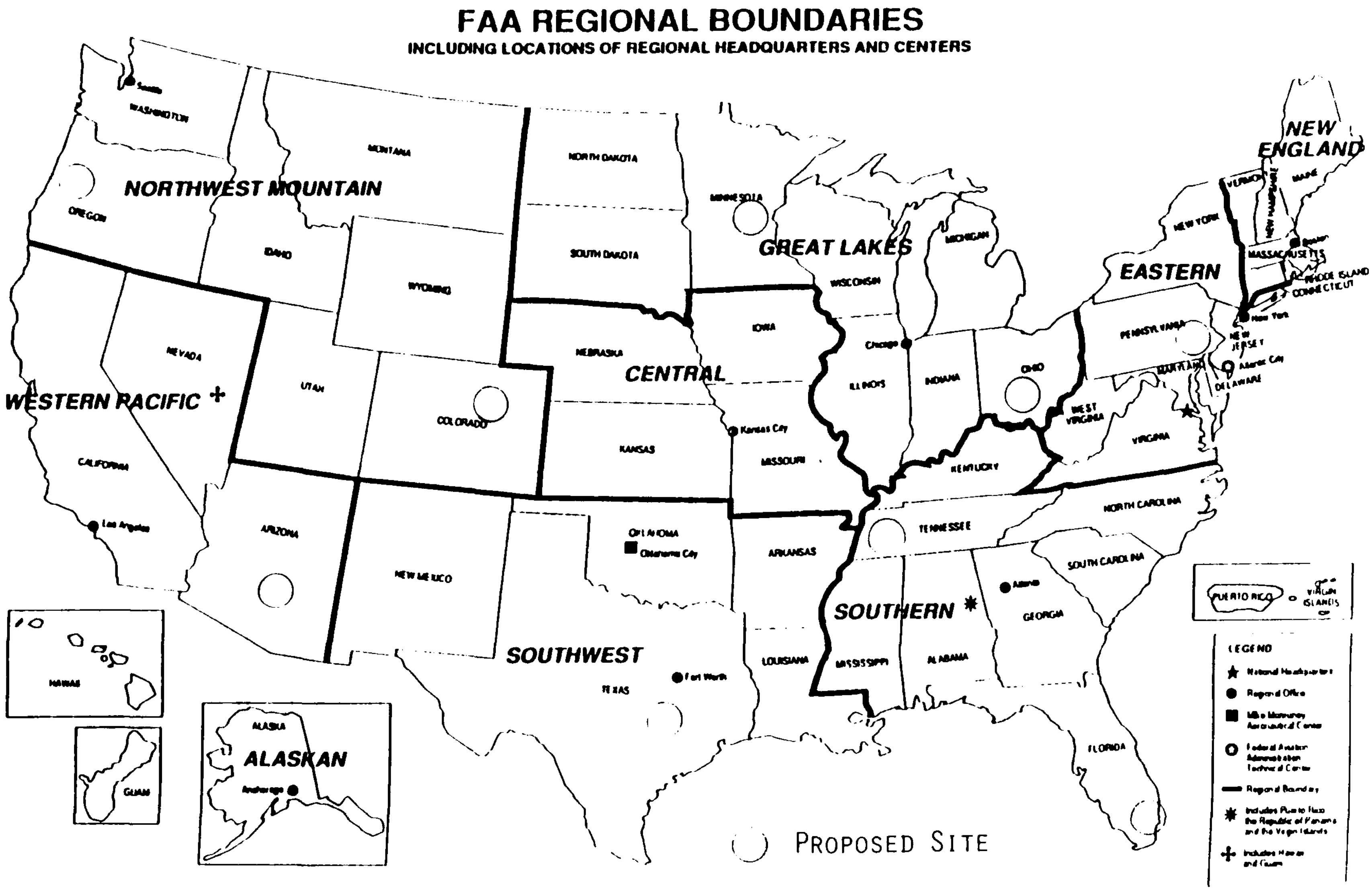

FIGURE 2. APPROXIMATE LOCATIONS OF PROPOSED SITES

1. Scottsdale, AZ
2. Denver, CO
3. Fort Lauderdale, FL
4. Bedford, MA
5. Flying Cloud, MN
6. Cincinnati, OH

All these sites were subsequently visited to collect data related to seal coats.

Prior to the site visit, each site engineer was contacted by phone and the purpose of visit was explained. Also, a list of "Items of Interest" was prepared and mailed to the airport engineer so that relevant information could be gathered in advance in case it required time to gather it. Table 3 lists these items of interest.

VISITS TO AIRPORT SITES

As mentioned earlier, the purpose of these visits was to gather data from various sites where seal coats have been used in the past. Therefore, during each visit, the following items were included in the agenda for meeting with the airport engineers and also contractors, if possible:

1. Review drawings and construction documents of areas where seal coats were used,
2. Perform visual inspection of seal coated surfaces and also record their current PCI (Pavement Condition Index) using the procedure described in FAA Advisory Circular AC:150/5380-6(3-1),
3. Discuss with airport engineers their experiences in using the seal coats, and
4. Contact the contractors who seal coated the airport pavements and obtain samples of materials used at the site, if available.

Table 3. List of "Items of Interest"

Item #	Description of the Item of Interest
1.	Location of Airport
2.	Types of pavements used in Runways, Taxiways, and Aprons.
3.	Lengths of pavements used in Runways, Taxiways, and Aprons.
4.	Design (or expected) lives of various types of pavements (Rigid, Flexible and Composite) used at the airport.
5.	Ages of existing pavements of Runways, Taxiways, and Aprons.
6.	Pavement maintenance history (including seal coating) of pavements in Runways, Taxiways, and Aprons.
7.	Types of Seal coating materials used (e.g., coal-tar emulsions, asphalt emulsions and asphalt cements, etc.).
8.	Seal Coat Specifications used by the airport authorities.
9.	Source(s) of Seal Coat Materials.
10.	Laboratory and/or Field Test data on Seal coats and seal coating materials.
11.	Years in which seal coats were applied (it will be helpful if specific dates are known).
12.	Pavement condition just before seal coating the surface (PCI, Crack count, or any other data available).
13.	Pavement Condition evaluation since seal coating the surface, if available.
14.	Photographs of pavement surface before and after seal coating the surface, if available.
15.	Effect of oil spillage on the seal coated surface.
16.	Skid resistance test data of seal coated surface (before and after), if available.
17.	Any other relevant information pertaining to seal coat, if available.
18.	Climatic and other environmental conditions of the airport site.

A detailed report of each site visited for this study was prepared and a copy was submitted to the FAA. A summary of these visits is included in the following section.

1. Greater Cincinnati International Airport, Cincinnati, Ohio

This airport site was visited in April, 1991. Discussions with airport engineers indicated that the Taxiway D, from Station 75+01 to Station 111+08 was seal coated according to FAA specifications P-631, using cationic emulsified asphalt binder. Both in the drawings and specifications, the seal coating work was referred to as Item P-631. but it should be Item P-626 [4]. The seal coat work was performed in 1987, over an existing 16 inches thick bituminous concrete (P-401, see reference 4). No data were available regarding the condition of the pavement before seal coat work was carried out.

Also discussions with engineers revealed that the Taxiway D was constructed in 1971 The pavement was built with 10 inches of bituminous concrete (P-401) over 11 inches of base course. It was overlaid with 3 inches of P-401, once in 1981 and again in 1985.

The seal coated section of Taxiway "D" was inspected to evaluate its condition. Inspection revealed extensive ravelling and reflection of cracks from pavement underneath. The average condition of the pavement surface was fair.

Most of the cracks appeared to be reflection cracks. Some cracks were wide and deep. The crack sealing material was unbonded in several locations, indicating that crack sealing was not very effective.

Samples of the seal coating material were requested from the contractor for their testing and evaluation in the laboratory.

2. Fort Lauderdale Hollywood International Airport, Fort Lauderdale, Florida

This airport site was visited in June, 1991. Data pertaining to seal coated pavements, which were mainly over the flexible pavement to a width of 85 feet and just adjacent to the rigid pavement, were collected by reviewing airport records, including as-built plans, previous consultants reports, and master plan reports. The information collected from this site included data on existing pavement cross sections and weather patterns. Airport engineers provided all available information on the pavements including consultants reports for our use.

Seal coat work was carried out only in the apron area as routine maintenance activity in 1985, 1986, and 1987. Work was carried out according to FAA Specifications P-625 [4]. Work was done consecutively for three years, because the seal coat was not holding up very well due to continuous fuel spillage. In 1989 seal coating was carried out using rubberized coal-tar emulsion in the apron areas opposite terminals 3 and 4, as an experimental measure. A portion of apron opposite terminal #1 was also seal coated according to P-625 specifications but without latex. The performances of the two types of seal coats were monitored by the airport engineers for a period of one year. Based on this study it was concluded that the seal coat with latex outperformed the seal coat without latex.

The apron opposite terminals 1 and 2 was seal coated in 1990, using rubberized coal-tar emulsion. All the rubberized seal coated aprons were inspected during this visit and were found to be performing well, as noted in the visual condition survey results.

Laboratory Test Data: Tests performed as a part of quality control during construction of seal coats were not available from airport engineers. However, discussions with engineers indicated that only individual components of the coal-tar emulsion seal coat were tested, but not the mix as a whole. Gradation of aggregate used and manufacturer's certification for the emulsion and copolymer latex, were furnished by the contractor before the start of work. Mix design for the work was not available for review. Copies of the specifications and requirements for seal coating with coal-tar pitch emulsion were obtained for this study. These specifications are applicable to work performed in 1989 and 1990.

Visual Condition Survey: A visual condition survey of the seal coated section of the pavement and the adjacent flexible pavement without seal coat, was conducted in general accordance with FAA Advisory Circular, AC:150/5380-6 "Guidelines and Procedures for Maintenance of Airport Pavements." [18] Prior to beginning the surveys, pavement were subdivided into sample units generally of a 5000 square foot area.

During the visual condition survey, it was observed that very few distresses were present in the seal coated pavements, and these were mainly in the form of a few reflection cracks from the pavement underneath, and ravelling. No distress due to fuel spillage was noticed, even though spillage has occurred at a few locations with no apparent damage to the seal coat. This indicated that the seal coating was performing satisfactorily.

Conclusions: Based on the above it was concluded that the rubberized coal-tar pitch emulsion seal coat was performing well, but it should be noted that the climatic and other environmental conditions at the airport site were either hot and/or humid, but never below freezing. Therefore, the effect of freeze and thaw action on seal coat performance needs to be investigated.

Samples of the material used in seal coating the pavement surfaces at this airport were obtained for their evaluation in the laboratory. The results of these evaluations will be discussed in the next chapter of this report.

3. North Perry General Aviation Airport, Fort Lauderdale, Florida

This airport site was visited in June, 1991. During this visit discussions were held with the Broward County Aviation Department engineers regarding seal coat work carried out for the apron area of Savco Flying at North Perry airport. The apron area was built in 1976 and the composition of the pavement was 6 inches of bituminous concrete (P-401) over 12 inches of base (P-209), on a compacted subgrade. This area was overlaid in 1985 with 4 inches of P-401 and again in 1990 with 3 inches of P-401 bituminous concrete. The pavement was seal coated with P-625 rubberized coal-tar pitch emulsion in April 1990.

Discussions with airport engineers revealed that the newly resurfaced pavement was damaged at isolated locations due to fuel spillage. This prompted the engineers to take effective action to prevent further damage to the pavement and decided to seal coat the surface. Before seal coat work was carried out, the localized damaged areas were repaired by patchwork repair.

Visual inspection of the seal coated pavement was performed, and no distresses were observed. Locations where fuel spillage had taken place were closely examined, and no apparent damage to the seal coat was noticed.

Samples of materials used in the seal coat were obtained for their evaluation in the laboratory. The results of these tests will be discussed in the next chapter.

4. Jefferson County Reliever Airport, Broomfield, Colorado

This airport was visited in June, 1991. Discussions were held with Denver's Corporate Reliever Airport engineers and the airport consultants, Isbill Associates, Inc., at the same time regarding seal coat work carried out at Jefferson County Airport. The following information was obtained from discussions and review of available documents.

Data pertaining to seal coated pavement which were mainly over the flexible pavement in the apron area, were collected by reviewing airport records, including as-built plans and consultants reports. Review of drawings and relevant documents indicated that the rubberized coal-tar emulsion seal coating was carried out for the ramps in two stages as noted below:

Stage 1: Reconstruction of isolated portions of the apron, and the leveling and overlay of the apron between the Terminal building and the firehouse were performed in 1987 and 1988. Reconstruction included removal of the existing bituminous layers and base material at isolated preselected locations down to subgrade, and replacement with new materials of matching layer thicknesses. The areas were paved with two layers of bituminous leveling courses (P-401) and a stress absorbing membrane was placed over the leveling course to the full width of the apron. The final surface course of thickness varying from 3 to 5 inches was placed over the membrane and work was completed in November, 1987. The pavement was allowed to cure till June, 1988, before seal coat work was performed. The coal-tar seal coat was placed in four applications as noted below:

Application #1:	Prime coat
Application #2:	Seal coat with sand
Application #3:	Seal coat with sand
Application #4:	Sealing of the surface.

Stage 2: This stage of work was performed between September, 1989 and October, 1990. Work consisted of the rehabilitation of the north apron, which included reconstruction of many isolated areas of the apron and then the overlay of the entire apron. The reconstruction work had to be carried out due to subgrade failure around the Denver Air Center hanger. Those areas where clay subgrades were above optimum moisture content, required removal of the existing pavement to the existing subgrade and if necessary the subgrade was scarified and recompacted. Areas where reconstruction

work was not carried out, the cracks in the pavement were sealed with a rubberized crack sealant material. The pavement design called for the areas that were reconstructed to be paved with a total of 9 inches of full depth asphalt. The remaining portions of the pavement (apron) that did not require reconstruction called for a nominal 4 inch overlay. This meant that the reconstruction areas were paved back to match existing pavement grades with approximately 5 inches of asphalt before the leveling course and overlay were placed. The apron also received a stress absorbing fabric membrane over the existing pavement before overlay was placed, with the intent of reducing reoccurrence of reflection cracks from the old surface.

Seal coat work was carried our in October, 1990, after a curing time of more than 120 days for the new asphalt overlay. Specifications for seal coat were same as for Stage 1 construction as desribed above.

Quality Control Test Data: Data regarding laboratory tests performed during construction of either Stage 1 or Stage 2 were not available in the files. However test data were available for soils, base and asphalt concrete works. Discussions with consultant and airport engineers indicated that specific tests on seal coat work might not have been performed except for obtaining certification from the contractor regarding physical and chemical properties of the individual materials.

Visual Condition Survey: Visual inspection indicated that the seal coat work carried out for the aprons in 1988 and 1990, is performing satisfactorily. No deterioration of the surface due to fuel spillage was noticed. However a small area of about 6,000 square yards has shown evidence of debonding of the seal coat. This appears to be due to the fact that the bituminous concrete pavement might not have been cleaned properly before application of the prime and seal coat. A total of 87,000 square yards of pavement was seal coated and the area of scaling was roughly about 7 percent of the total area. This is located entirely in one location of Stage 1 work.

The overall performance of seal coat at this project site is considered to be satisfactory, especially in view of the adverse climatic and environmental conditions to which the seal coat is exposed (freeze and thaw).

Samples of materials used in seal coat construction work were obtained for their evaluation in the laboratory.

5. Flying Cloud Airport: Eton Perry, Minneapolis, Minnesota

This airport site was visited in June, 1991. Taxiways of this airport were last overlaid in 1986 with bituminous mixes 5 to 6 inches thick. Asphalt slurry seal coat was applied to these taxiways in 1988. The condition of pavement before seal coating the surface was recorded by the airport engineers as follows:

- North side of the taxiway was observed to have uniform textured surface but uneven settlement at longitudinal and transverse cracks. No spalling of these cracks was observed at that time and these cracks were less than 1/2" wide. Also, no raveling of surface was observed before seal coating.

- Some pavement sections of the west perimeter taxiway were observed to have alligator cracks. Also, the transverse cracks were less than 1/2 inch wide. The pavement surface (before seal coating) did not show signs of aging or weathering.

The above mentioned taxiways were seal coated in 1988, after localized repair to the pavement as directed by the engineer.

Quality Control Test Data: Data regarding either mix design or laboratory test results of emulsified asphalt slurry seal coat were not available. Discussions with consultant's engineer indicated that specific tests on seal coat work were not performed, except for obtaining certification from the contractor regarding physical and chemical properties of the individual material components of seal coat.

Visual Condition Survey: Based on the visual inspection of the seal coated pavement, which is more than two years old, it was observed that the seal coat was performing satisfactorily. No deterioration of the seal coated surface due to fuel spillage was noticed. The adverse climate to which the seal coat was exposed (freeze & thaw) did not seem to have a significant impact on its performance.

Samples of materials used in seal coat construction were obtained for further laboratory tests and analysis.

6. Fregus Falls Municipal Airport, City of Fregus Falls, Minnesota

This airport site was visited in June, 1991. The existing runway and taxiway pavements were last overlaid in 1986 with asphaltic mixes. After localized repairs to the existing pavements, which included milling and replacement up to a depth of 2 inches and width of 24" at all longitudinal and transverse cracks, the surface was seal coated with asphalt emulsion slurry seal in April - May, 1991. Therefore, the seal coated surface was almost new and showed no distress at the time of visit to the site.

7. L.G. Hanscom Field Airport, Bedford, Massachusetts

This airport site was visited in June, 1991. Discussions were held with Massachusetts Port Authority engineers associated with the design and construction of asphaltic emulsion slurry seal coat at Hanscom Field Airport. The following information was obtained from discussions with engineers and by review of documents.

The airport was built in 1979, for use as a civil terminal. Details regarding pavement cross sections were not readily available. Information on overlay and/or reconstruction work carried out at the airport was also not readily available. However, information regarding sections of pavements treated with asphaltic emulsion slurry seal coat according to FAA specifications P-626 was available. Seal coat work has been carried out at the following locations:

- Shoulders, to Runway 11-29
- Runway 11-29 Overrun
- Shoulders, to Runway 5-23, to the south of main runway 11-29
- Aprons

Seal coat work was carried out in 1989.

Visual Condition Survey: A visual condition survey of the seal coated pavements was performed in general accordance with FAA Advisory Circular AC 150/5380-6. The conditions of these pavements were observed to be as follows:

Pavement	Condition
Shoulders, to Runway 11-29	Poor
Runway 11-29 Overrun	Good
Shoulders, to Runway 5-23	Poor
Apron	Poor

In general seal coats have not performed satisfactorily at this site.

Quality Control Test Data: Data regarding either mix design or laboratory test results of emulsified seal coat were not available.

Samples of materials used in seal coat construction were requested for further laboratory tests and analysis.

8. <u>Port Columbus International Airport, Columbus, Ohio:</u>

This airport site was visited in October, 1991 to observe the seal coating of ramps at the airport. A thermoplastic coal-tar emulsion seal coat was used for this purpose. This type of seal coat was originally developed in Germany as a jet fuel resistant and anti-skid wearing surface for airport pavements. This work was carried out according to the FAA Interim Specifications for thermoplastic coal-tar emulsion slurry seal.

A recent evaluation of seal coated surface indicated that fine cracks were developing on the surface. But no major damage was noticed at the time of site visit. The surface was only about 6 months old at the time of this observation.

OTHER CONTACTS

1. <u>LaCrosse Municipal Airport, LaCrosse, Wisconsin</u>

This airport site was not visited personally. However, telephonic discussions were conducted with airport engineers during August, 1991 regarding coal-tar emulsion seal coat work carried out for the pavements at LaCrosse Municipal Airport. Based on the discussions with the engineers, the following information was obtained:

Seal Coat Construction History

1. In 1983, Runways 18/36 and 13/31 were seal coated with rubberized coal-tar pitch emulsion seal coats.

Part of Runway 18/36 was constructed in 1944 and part of it was constructed in

1968. The entire runway was overlaid in 1973 with 1-1/2 inches of bituminous surface course. The entire runway was overlaid again in 1978 with 6-1/2 inches of bituminous surface course.

Runway 13/31 was constructed in 1944. The entire runway was overlaid with 1-1/2 inches of bituminous surface course in 1973. Part of the runways was overlaid with 6-1/2 inches of bituminous surface course in 1978. The rest was overlaid with about 4 inches of bituminous surface course in 1980.

According to the surveys conducted in 1984. Runways 18/36 and 13/31 were in very good condition. However the seal coat started disintegrating fast in 1985. The seal coat started debonding and could be easily scraped with a spade. The frictional properties of the seal coat were almost non-existent. The seal coat did not seem to have the tensile strength needed to hold the sand together and to adhere to the pavement.

2. In 1985, parts of Runway 3/21, apron and several parts of Taxiway were seal coated with emulsified asphalt slurry seal coats.

   According to a 1986 pavement evaluation, these pavements were in good to very good condition.

3. In 1985, several apron areas were seal coated. They were sealed with coal-tar emulsion slurry seal coat. These areas were constructed with different materials and at different dates.

   The overall condition of apron pavements (as taken from the 1986 Wisconsin Airport System Pavement Evaluation) ranged from failed to good. The major portion of the pavement was found to be in very poor condition.

In ... mary, the seal coat (rubberized coal-tar emulsion or P-625) constructed in 1983 on Runways 18/36 and 13/31 performed poorly from the beginning. Poor braking action was reported by both air carrier and G.A. aircraft when the runways were wet. The following year a topcoat of P-625 with slag was constructed on both runways and then grooved to dissipate the water. P-625 alone has not been used on any runways since good results were obtained with a P-625 with wet bottom boiler slag. The failure of P-625 in 1985 was due to a number of factors as follows:

- Application was squeegeed and this tended to give a "table-top" flat texture thus increasing hydroplaning.
- The sand was a wind blown product which tended to act like tiny ball bearings (round aggregates).
- The sand loadings were too heavy for the emulsion to hold in place.
- Aggregate was also too fine.
- The ingredients may not have been compatible.

After the first year the grooving was completed, the seal coat (P-625) began to lose adhesion. Today approximately 20% of the seal coat is remaining.

In 1985, P-625 was constructed on taxiways and portions of the cross-wind runway. Approximately 50% of the aggregate was wet bottom boiler slag. They had excellent results with this product in non-fuel spill areas. Friction was excellent. The only negative aspect of this product is that it is slightly tender until the summer cycle is complete. Power steering turns from maintenance vehicles or back taxi turns from large aircraft has scuffed the seal coat. The current condition of this seal coat at LaCrosse is excellent.

Also, in 1985, rubberized coal-tar emulsion seal coat (revised FAA Item P-625) was placed on the aprons due to its fuel resistance qualities. The specifications called for angular sand, lighter sand loading, a milled coal-tar emulsion, spray applications, slightly coarser sand gradation, and a tack coat. Minimum skid resistance readings were also required. The mix design meets both FAA criteria and those of the manufacturures, and Engineering Industries.

Currently the seal coats are performing satisfactorily. Loss of adhesion is minimal and fuel resistance appears to be acceptable after 6 years in service.

SUMMARY AND CONCLUSIONS

The activities under Task B were subdivided into two subtasks: (1) site selection and (2) visits to selected sites. The purpose of these visits was to collect seal coat performance data from airport sites located in different regions of the country. Preliminary selection of these sites was based on the information gathered from 56 airport sites located in various parts of the country. Considering factors such as: type of seal coat materials used, climatic conditions (temperature, rainfall, etc.) and geographical locations, ten candidate sites were recommended to FAA for their review and final selection. Approximate locations of these sites are shown in Figure 2. A total of six airport sites were finally selected by FAA.

All these six sites as well as some adjacent airports were visited during April to June 1991 for gathering information and samples of seal coating material. A summary of these visits and the data gathered from the airport engineers is described in this chapter. Table 4 summarizes the infomation regarding the types of seal coats used at each site visited, their conditions as observed during these visits, and the temperature and rainfall data. It was observed that seal coats were applied to asphaltic surfaces in all sites visited. The main purpose of seal coating was to seal the cracks and pavement surfaces from the ingress of water and reduce the possibility of water related damages. All airports generally used coal-tar seal coats but sometimes they also used asphalt seal coats.

Rubberized coal-tar emulsion seal coats used in Florida and Colorado were observed to be performing satisfactorily. The ages of these surfaces varied from 1 to 3 years.

Asphalt emulsion slurry seal coat used in Minnesota varied in age from 2 months to about 3 years. Their performance was observed to be satisfactory. Also, asphaltic emulsion slurry seal coat used in Massachusetts was about 2 years old and was observed to be in good to poor condition. However, a 4-year old seal coated surface in Cincinnati, Ohio was observed to have developed extensive cracking. Emulsified asphalt was used in this seal coat.

Thermoplastic coal-tar emulsion slurry seal coat was used at Columbus airport. A recent observation (about 6 months after its construction) indicated that it may not last very long because it was already showing signs of cracking.

Comparing the field performances of coal-tar and asphalt seal coats (based on the visits to airport sites) it was observed that both types of seal coated surfaces provided reasonable service for 2-3 years. Whenever there was less concern for fuel damage and more for frictional characteristics of the surface, asphalt seal coat was used. One of the airport engineers mentioned that the fuel resistance characteristics of coal-tar seal coats may cause the fuel to stay on the surface and subsequently cause it to become slippery, a hazard to workers. On the other hand a fuel absorbing surface will stay non-slippery and a minor repair can take care of the damage. Therefore, he preferred an asphalt seal coat for his airport. Of course, the issue will become more critical if the fuel spillage is significant.

The temperature and rainfall records summarized in Table 4 indicate that although the seal coats were subjected to relatively colder temperatures in Colorado and Minnesota, low levels of rainfall (15 - 30 in/yr) apparently negated the effect of these temperatures. The seal coats at these airports were performing as well as seal coats in warm locations like Florida. Warmer temperatures of about 50 deg. F and relatively higher levels of

Table 4. Types of Seal Coats Used at Various Airport Sites and the Condition of Seal Coated Surface Observed During the Visit

Site #	Location	Date of Visit	Type of Seal Coat	Year of Seal Coat	Condition of Seal Coat	Average Temp. °F	Total Rainfall, in/yr
1	Cincinnati, Ohio	4/91	Asphalt emulsion slurry seal (AESS)	1987	Extensive Cracks	53	40
2,3	Fort Lauderdale, Florida	6/91	Rubberized Coal-tar emulsion slurry seal (RCESS)	1989 1990	Good, no visible damage	75	61
4	Broomfield, Colorado	6/91	RCESSS	1988 1989 1990	Good to very good very good	50	15
5	Minneapolis, Minnesota	6/91	AESS	1988	Good, uniform surface texture	45	28
6	Fregus Falls, Minnesota	6/91	AESS	1991	New, no damage	45	28
7	Bedford, Massachesetts	6/91	AESS	1989	Poor to good	52	44
8	Columbus, Ohio	10/91	Thermoplastic Coal Tar Emulsion Slurry Seal	1991	New, but cracks after 6 months	52	37

Site #	Location	Date of Visit	Type of Seal Coat	Year of Seal Coat	Condition of Seal Coat	Average Temp. °F	Total Rainfall, in/yr
Other, 1	LaCrosse, Wisconsin	Tele. 6/91	RCESS	1985	Good	46	31

rainfall (about 40 in/yr) at Cincinnati, Columbus and Massachusetts airports seem to have some effect on the performance of seal coat surface. The seal coats at these locations were performing less satisfactorily as was observed during the visits to these sites. High temperature of 75 deg. F and high level of rainfall (61 in/yr) in Florida did not cause any problem to seal coats when the mix contained additive (latex) in it.

CHAPTER IV
MATERIALS TESTING

INTRODUCTION

It was indicated in Chapter III that samples of materials were requested from all airport sites visited for this study. Although efforts were made to contact the contractors as well as the manufacturers of the materials for this purpose, it was not possible to obtain the samples of materials for all the airport sites visited. However, we were able to obtain samples of coal-tar emulsions, additives (latex) and sands used at the following locations:

1. Columbus, Ohio,
2. Fort Lauderdale, Florida,
3. Denver, Colorado,
4. Saint Paul, Minnesota, and
5. Bedford, Massachusetts.

Samples of these materials were tested in the laboratory to determine the characteristics of aggregates (sand), coal-tar emulsions and the seal coat mixes. The purpose of these tests was to assess the performance of seal coat mixes using the current quality control tests as described in the FAA Engineering Brief No. 46 [4].

Since the scope of this study included testing of asphaltic materials also (emulsions, cutbacks and asphalt cements), attempts were made to obtain samples of these materials from other sources (other than the contractors for the airport sites visited). As a result of these efforts, samples for the following materials were also obtained:

1. Asphalt emulsions: CSS-1 and an asphalt emulsion from a commerical source,
2. Asphalt cut backs: MC-250 and MC-800, and
3. Asphalt cements: AC-10, AC-20 and Polymer modified AC-20R.

MATERIALS TESTING PLAN

A laboratory testing plan was prepared earlier and submitted to the FAA for their approval. This plan was used to develop the details of material testing in the laboratory.

Keeping in mind the objectives of this study (as described in Chapter I) it was decided to perform the laboratory testing under two series of tests. The first series of tests included the testing of samples of coal-tar emulsions, sands, and seal coat mixes obtained from all five airport sites. The second series of tests included testing of typical seal coat mixes containing coal-tar and asphalt emulsions under dry and wet conditions. The purpose of the first series of tests was to evaluate the seal-coat mixes in the laboratory and compare their performance as recorded during the visits to the airport sites. The purpose of the second series of tests was to assess the effect of various parameters (type of sand, dry and wet conditioning of samples in the laboratory, type of binder in the emulsion, etc.) on the laboratory measured performance of the seal coat mixes.

TESTS PERFORMED AND DATA COLLECTED DURING SERIES NO. 1

This series of tests included tests on all five sands, coal-tar emulsions and seal coat mixes. Typical tests on sands were performed using ASTM standards. Specific ASTM test numbers for the measurement of these properties are listed below:

	Test	ASTM Test Number
1.	Aggregate gradation	C 136
2.	Specific gravity	C 128
3.	Absorption	C 128
4.	Soundness	C 88
5.	Deleterious content	C 142

The results of these tests are summarized in Table 5. The FAA Specifications for gradation contained in Item P-625 [17] are also listed in this table for a side-by-side comparison with the gradation of sands used at various job sites.

Viscosity tests on emulsions were performed using a Brookfield Viscometer (Model DV-II) as specified in the FAA Engineering Brief No. 46 [4]. Total liquids (emulsion and latex additive) were tested for the following four combinations:

Amounts of additive are: 6, 9, 12 and 16 gal/100 gal of emulsion

The results of these tests are summarized in Table 6.

Seal coat mixes were similarly tested by combining the emulsions with additive and sands. Four different amounts of additives and four different amounts of sands were combined with emulsions to obtain 16 mixes of each sand. The amounts of additives were the same as described above for total liquids. The four amounts of sands were: 4, 6, 8 and 10 lb/gal of emulsion. The results of tests performed on seal coat mixes for all five sands are summarized in Table 7.

According to the FAA Engineering Brief No. 46, tests on rubberized seal coat mixes are performed in sequence to gradually eliminate those mixes which do not satisfy the specified criterion of each test. For the purpose of ready reference these criteria are

Table 5. Summary of Tests on Sands used at Various Airport Sites for Seal Coat Mixes

Test	Sieve Size	% Passing the Sieve, by Weight					
		OH	FL	CO	MN	MA	P-625 (FAA)
Gradation	#8 #16 #20 #30 #40 #50 #100	100 85* 67* 55 3 1 0.6	100 98 87 62 12 2 0.6	100 100 97 32 3 2 0.2	100 98 92 46 4 1 0.2	100 98 90 26 3 0 0	100 97-100 85-100 15-85 2-15 - 0-2
sp. gr., gm/cc		2.07	2.16	2.22	2.13	2.16	
Absorption, %		1.8	1.6	2.3	2.1	2.2	
Soundness, (at 5 cycles)		<5%	<5%	<5%	<5%	<5%	
Deleterious Content, %		0.1	0.3	none	none	none	

* Material is coarser than FAA Specifications.

Table 6. Brookfield Viscosity of Total Liquids (emulsion + additive), Poises at 77°F

Site Location	Latex Additive, gal/100 gal of emulsion			
	6	9	12	16
Ohio	48 42	28 48	52 58	58 54
Florida	36 32	48 38	52 46	50 44
Colorado	28 36	42 38	49 56	63 60
Minnesota	49 59	38 56	46 40	49 56
Massachusetts	36 53	43 49	41 42	48 46

Table 7. Brookfield Viscosity of Seal Coat Mixes, Poises at 77°F

	Latex Additive, gal/100 gal of Emulsion															
	6				9				12				16			
	Sand, lb/gal of Emulsion															
Site Location	4	6	8	10	4	6	8	10	4	6	8	10	4	6	8	10
Ohio	40 32	*	*	*	*	*	32 36	*	48 48	40 48	36 32	40 41	52 50	48 49	46 47	41 44
Florida	18 12	*	*	*	23 22	28 29	*	*	44 46	40 30	40 32	26 36	38 34	32 30	26 28	28 28
Colorado	*	*	*	*	40 36	40 39	38 37	34 37	48 50	44 49	41 46	40 30	56 59	52 57	50 49	44 43
Minnesota	*	*	*	*	*	*	*	*	42 41	38 39	34 35	31 31	46 48	43 36	39 38	33 36
Massachusetts	51 49	*	*	*	46 43	*	*	*	38 39	35 36	33 33	22 20	47 44	43 40	38 39	33 36

* Mix too stiff to ‘est.

listed below. The complete document is available in Attachment 1 of this report.

DESIGN CRITERIA

Test Property	Purpose	Criteria
Brookfield Viscosity, poises at 77°F	Incompatibility between latex and coal-tar	10-90
Brookfield Viscosity, poises at 77°F	Workability of mix	10-90
Freeze-Thaw	Cracking	
at 5 cycles		< 1
at 10 cycles		< 3
Adhesion	Loss of adhesion	Rating = 5A
Fuel Resistance	Fuel penetration Loss of adhesion	No penetration or loss of adhesion

Using the viscosity requirements criteria, certain mixes were found to be unsuitable for further testing. Therefore, the third set of tests to determine freeze-thaw cracking properties of mixes includes only those mixes which indicated the potential for passing the successive tests. The results of these tables are summarized in Tables 8-12 for sands obtained from each of the five sources. Although some of the mixes did not meet the criteria for cracking under freeze-thaw cycling (5 and 10 cycles), the next test for loss of adhesion was conducted on all mixes included in Tables 8-12. The results of these tests are summarized in Table 13.

A final test on all these mixes was performed to determine their fuel resistance characteristics. It was observed that all these mixes passed this test. This concluded the testing of materials for series number one. The analysis of data and the results are discussed in the next chapter of this report. The next section of this chapter

Table 8. Summary of Freeze-thaw Cycling Data, Ohio Seal Coat Mix

Site Location	Latex, gal/100 gal of emul.	Sand, lb/gal of emul.	Freeze-Thaw Cycle 1	2	3	4	5	6	7	8	9	10
Ohio	6	4	0	1	1	1	1	3	3	4	4	4
			0	2	2	2	2	2	2	3	3	4
		6										
		8										
		10										
	9	4										
		6										
		8	0	0	1	1	1	1	2	2	2	3
			0	0	2	3	3	3	3	3	4	4
		10										
	12	4	0	0	1	2	2	2	3	3	3	3
			0	1	1	1	2	3	3	4	4	4
		6	0	1	1	1	1	2	2	2	2	2
			0	1	1	1	1	1	1	2	2	4
		8	0	0	0	1	1	1	1	1	2	2
			0	0	0	0	0	1	1	1	1	1
		10	0	0	0	0	0	0	0	0	1	1
			0	.0	0	0	0	0	0	0	0	1
	16	4	0	0	1	1	3	3	3	3	4	4
			0	1	1	1	1	1	2	2	3	3
		6										
		8										
		10										

Cracking Scale

0 - No cracking
1 - Hairline cracking
2 - Slight cracking
3 - Moderate cracking
4 - Severe cracking

Table 9. Summary of Freeze-thaw Cycling Data, Florida Seal Coat Mix

Site Location	Latex, gal/100 gal of emul.	Sand, lb/gal of emul.	Freeze-Thaw Cycle									
			1	2	3	4	5	6	7	8	9	10
Florida	6	4	0	0	2	2	4	4	4	4	4	4
			0	0	0	2	4	4	4	4	4	4
		6										
		8										
		10										
	9	4	0	0	0	2	2	3	3	3	3	3
			0	0	0	2	2	3	4	4	4	4
		6	0	0	0	0	0	0	0	1	1	1
			0	0	0	0	0	0	1	1	1	1
		8										
		10										
	12	4	0	0	1	1	1	2	3	3	4	4
			0	0	1	1	1	2	2	2	2	3
		6	0	0	2	2	2	2	2	2	2	2
			0	0	0	0	1	1	2	3	4	4
		8	0	0	0	0	0	0	0	0	0	1
			0	0	0	0	1	1	1	1	1	1
		10	0	0	0	0	0	1	1	2	2	2
			0	0	0	0	0	0	0	1	1	1
	16	4	0	0	0	0	1	2	3	3	4	4
			0	0	0	0	1	2	2	2	2	3
		6	0	0	0	0	0	1	1	1	1	1
			0	0	0	1	1	1	1	1	1	1
		8	0	0	0	0	0	1	1	1	1	1
			0	0	0	1	1	1	1	1	2	2
		10	0	0	0	0	0	1	2	2	2	2
			0	0	0	0	0	1	2	2	2	2

Cracking Scale

0 - No cracking
1 - Hairline cracking
2 - Moderate cracking
3 - Moderate cracking
4 - Severe cracking

Table 10. Summary of Freeze-thaw Cycling Data, Colodaro Seal Coat Mix

Site Location	Latex, gal/100 gal of emul.	Sand, lb/gal of emul.	Freeze-Thaw Cycle									
			1	2	3	4	5	6	7	8	9	10
Colorado	6	4 6 8 10										
	9	4	0	0	0	0	0	1	1	1	2	2
			0	0	0	0	0	0	1	1	1	1
		6	0	0	0	0	0	0	1	2	2	2
			0	0	0	0	0	0	1	1	1	1
		8	0	0	0	0	0	1	1	1	1	1
			0	0	0	0	0	1	1	1	1	2
		10	0	0	0	0	0	0	2	2	2	2
			0	0	0	0	0	0	1	1	1	1
	12	4	0	0	1	1	1	1	1	2	2	2
			0	0	0	0	1	1	1	1	2	2
		6	0	0	1	1	1	1	1	1	1	1
			0	0	1	1	1	1	1	1	2	2
		8	0	0	0	0	0	0	0	1	1	1
			0	0	0	0	0	0	1	1	1	2
		10	0	0	0	0	1	1	1	1	1	1
			0	0	0	0	0	0	0	0	0	1
	16	4	0	1	1	1	1	2	2	2	2	2
			0	1	1	1	1	2	2	2	2	2
		6	0	1	1	1	1	1	1	1	1	1
			0	1	1	1	1	2	2	2	2	2
		8	0	0	0	0	1	1	1	1	1	1
			0	1	1	1	1	1	1	1	2	2
		10	0	0	0	1	1	2	2	3	3	3
			0	0	0	1	1	2	2	2	3	2

Cracking Scale
0 - No cracking
1 - Hairline cracking
2 - Moderate cracking
3 - Moderate cracking
4 - Severe cracking

Table 11. Summary of Freeze-thaw Cycling Data, Minnesota Seal Coat Mix

Site Location	Latex, gal/100 gal of emul.	Sand, lb/gal of emul.	Freeze-Thaw Cycle									
			1	2	3	4	5	6	7	8	9	10
Minnesota	6	4										
		6										
		8										
		10										
	9	4										
		6										
		8										
		10										
	12	4	0	0	1	2	2	3	3	4	4	4
			0	1	1	2	2	2	2	2	3	3
		6	0	0	2	2	2	2	2	3	3	3
			0	0	1	1	2	2	3	3	3	4
		8	0	0	0	1	1	3	3	2	3	3
			0	0	1	1	1	1	1	1	1	2
		10	0	0	0	0	0	0	1	1	1	1
			0	0	1	1	1	1	1	1	1	2
	16	4	1	1	1	1	1	2	2	3	3	3
			1	1	2	2	3	3	3	3	4	4
		6	1	2	2	2	1	2	2	2	2	2
			1	1	1	1	1	2	2	2	2	3
		8	0	1	1	1	1	1	1	1	1	2
			1	1	1	1	1	1	1	1	1	1
		10	0	1	1	1	1	2	2	2	2	2
			0	1	1	1	1	2	2	2	2	2

<u>Cracking Scale</u>

0 - No cracking
1 - Hairline cracking
2 - Moderate cracking
3 - Moderate cracking
4 - Severe cracking

Table 12. Summary of Freeze-thaw Cycling Data, Massachusetts Seal Coat Mix

Site Location	Latex, gal/100 gal of emul.	Sand, lb/gal of emul.	Freeze-Thaw Cycle									
			1	2	3	4	5	6	7	8	9	10
Mass.	6	4	0	0	0	2	3	3	3	4	4	4
			0	0	0	1	1	3	3	4	4	4
		6										
		8										
		10										
	9	4	0	0	1	1	1	1	2	3	3	3
			0	2	2	2	2	2	2	2	2	2
		6										
		8										
		10										
	12	4	1	1	1	1	2	2	2	3	3	3
			0	0	1	2	2	4	4	4	4	4
		6	0	1	1	2	2	3	3	3	3	3
			0	1	1	1	2	2	3	4	4	4
		8	0	0	0	1	1	1	1	1	2	2
			0	0	0	0	0	1	1	1	1	1
		10	0	0	0	0	0	0	0	1	1	1
			0	0	0	0	1	1	1	1	1	2
	16	4	0	1	1	2	3	3	3	3	3	3
			0	0	1	2	2	2	2	3	3	3
		6	0	1	1	1	1	2	3	3	3	3
			0	1	1	1	1	1	1	1	1	2
		8	0	0	0	0	1	1	1	1	1	1
			0	1	1	1	1	1	1	1	1	1
		10	0	0	1	1	1	1	1	1	1	1
			0	0	0	1	1	1	1	1	1	1

<u>Cracking Scale</u>

0 - No cracking
1 - Hairline cracking
2 - Moderate cracking
3 - Moderate cracking
4 - Severe cracking

Table 13. Results of Adhesion Tests on Seal Coat Mixes

Site Location	Latex Additive, gal/100 gal of Emulsion															
	6				9				12				16			
	Sand, lb/gal of Emulsion															
	4	6	8	10	4	6	8	10	4	6	8	10	4	6	8	10
Columbus, Ohio	2A-0A	*	*	*	*	*	2A-0A	*	2A-0A	2A 2A 2A	4A 4A 4A	5A 5A 5A	2A 2A 2A	3A 3A 3A	4A 4A 4A	5A 5A 5A
Florida	2A-0A	*	*	*	2A-0A	5A 5A 5A	*	*	2A-0A	2A 2A 2A	5A 5A 5A	5A 5A 5A	2A 2A 2A	5A 5A 5A	5A 5A 5A	4A 4A 5A
Colorado	*	*	*	*	5A 5A 5A	5A 5A 5A	5A 5A 5A	4A 4A 5A	5A 5A 5A	5A 5A 5A	5A 5A 5A	5A 5A 5A	5A 5A 5A	5A 5A 5A	5A 5A 5A	5A 5A 5A
Minnesota	*	*	*	*	*	*	*	*	2A-0A	2A 2A 2A	5A 5A 5A	5A 5A 5A	2A 2A 2A	3A 3A 3A	4A 4A 4A	3A 3A 3A
Massachusetts	2A-0A	*	*	*	2A-0A	*	*	*	2A-0A	2A 2A 2A	5A 5A 5A	5A 5A 5A	2A 2A 2A	3A 3A 3A	5A 5A 5A	5A 5A 5A

<u>Adhesion Rating Scale:</u>
5A - No peeling or removal
4A - Trace peeling or removal along incisions
3A - Jagged removal along incisions upto 1/16 in on either side
2A - Jagged removal along incisions upto 1/8 in on either side
1A - Removal from most of the area of "X" under the tape
0A - Removal beyond the area of the "X"

* These mixes were not tested

summarizes the tests performed and data collected during series no. 2.

TESTS PERFORMED AND DATA COLLECTED DURING SERIES NO. 2

Asphalt and coal-tar emulsions as well as asphalt cutbacks and cements were considered for inclusion in this series of tests. Available information on the use of asphaltic binders for seal coating mixes indicated that slurry seals generally use emulsified asphalts [19]. Asphalt cutbacks and asphalt cements are not suitable for slurry seals because of their consistency at normal temperatures and the requirements of heating during mixing and laying on the pavement surface. Therefore, it was decided to use the following binder materials and sands in this series of tests:

1. Asphalt emulsion - CSS-1,
2. Asphalt emulsion obtained from a commerical source,
3. Coal-tar emulsion with and without latex (used at Colorado site), and
4. Sand samples obtained from Ohio, Florida, Colorado, Minnesota, and Massachusetts (see Table 5 for gradation).

Tests were performed on the seal coat mixes using different types of emulsions and sand sources. The proportions of materials used in each mix are listed below:

Mix #1:	Proportions in Mix
Asphalt Emulsion CSS-1	12.5 gm
Water	25.0 gm
Sand (See Table 5 for gradation)	100.0 gm

The guidelines of the FAA Item P-626 (Asphaltic Emulsion Slurry Seal) were used to design this mix. The mix contained approximately 8% asphalt content by weight of dry aggregate. However, the gradation requirements specified under this item were not used. The sand samples listed in Table 5 were used so that this mix could be compared directly with other mixes.

Mix #2:	Proportions in Mix
Asphalt emulsion (commerical source)	1.0 gal
Water	0.3 gal
Sand (see Table 5 for gradation)	8.0 lb

Mix #3:	
Coal-tar emulsion used in Colorado	1.0 gal
Water	0.7 gal
Additive (latex)	0.07 gal
Sand (see Table 5 for gradation)	8.0 lb

Mix #4:	
Coal-tar emulsion used in Colorado	1.0 gal
Water	0.3 gal
Sand (see Table 5 for gradation)	1.0 lb

Mixes #2, 3, and 4 were prepared according to the FAA Item P-625 (Coal-tar pitch emulsion seal coat). The gradation of sanas used in these mixes are summarized in Table 5.

The following tests were conducted on each mix using the procedures described in the FAA Engineering Brief No. 46 [4]:

1. Brookfield Viscosity of emulsions, total liquids and mix,
2. Freeze-thaw cycles,
3. Adhesion, and
4. Fuel resistance.

Freeze-thaw cycle tests were conducted under two different thawing conditions:

1. Thawing by placing the sample in the 140°F oven for 24 hours (dry condition), and
2. Thawing by placing the sample in the Chamber at 85°F and 100% relative humidity (wet condition).

Four samples of each mix containing a given sand were prepared. Two of these samples were tested for wet and two for dry condition. Thus, a total of 16 samples were tested for each mix. This resulted in a total of about 64 samples for four different sands and four emulsions.

The results of viscosity tests are summarized in Table 14. Tables 15-18 summarize the wet and dry freeze-thaw condition testing.

Adhesion and fuel resistance tests on samples of all mixes were performed according to the procedure described in the FAA Engineering Brief No. 46. Samples of all mixes indicated no peeling or removal (according to the scale all samples were 5A). Two samples of each mix were prepared for this purpose and two tests were performed on each mix.

The results of fuel resistance tests were as follows:

	Results of Tests
Mix #1	Fail
Mix #2	Fail
Mix #3	Pass
Mix #4	Pass

Samples for both of these tests were cured at room temperature only. No attempt was made to cure them in the humid chamber for wet conditions.

Table 14. Results of Viscosity Tests on Seal Coat Mixes, Poises

Item	Mix #1	Mix #2	Mix #3	Mix #4
Emulsion	0.8	42.5	76.0	76.0
Total Liquids (Emulsion, Water and Additives if any)	0.112	2.7	31.0	4.6
Mix (Ohio Sand)	35.0	7.0	31.4	16.6
Mix (Florida Sand)	150.0	7.0	73.8	20.4
Mix (Colorado Sand)	80.0	7.0	40.0	17.3
Mix (Minnesota Sand)	6.4	7.4	48.4	16.5

Table 15. Summary of Freeze-thaw Cycling Data, Mix #1

Sand Source	Curing Condition	Freeze-Thaw Cycle 1	2	3	4	5	6	7	8	9	10
Ohio	Dry	0	0	0	0	0	0	1	1	1	1
	Dry	0	0	0	0	0	0	1	1	1	1
	Wet	0	0	0	1	1	1	1	1	1	1
	Wet	0	0	0	0	1	1	1	1	1	1
Florida	Dry	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0
	Wet	0	0	0	1	1	1	1	1	1	1
	Wet	0	0	0	0	1	1	1	1	1	2
Colorado	Dry	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0
	Wet	0	0	0	0	0	0	0	0	0	0
	Wet	0	0	0	0	0	0	0	0	0	0
Minnesota	Dry	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0
	Wet	0	1	1	1	1	1	1	1	1	1
	Wet	0	1	1	1	1	1	1	1	1	1

<u>Cracking Scale</u>

0 - No Cracking
1 - Hairline Cracking
2 - Slight Cracking
3 - Moderate Cracking
4 - Severe Cracking

Table 16. Summary of Freeze-thaw Cycling Data, Mix #2

Sand Source	Curing Condition	Freeze-Thaw Cycle									
		1	2	3	4	5	6	7	8	9	10
Ohio	Dry										
	Dry	0	0	0	0	0	0	0	1	1	1
	Wet										
	Wet	0	0	1	1	2	2	2	2	3	3
Florida	Dry	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0
	Wet	0	0	0	0	0	0	0	0	0	0
	Wet	0	0	0	0	0	0	0	0	0	0
Colorado	Dry	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0
	Wet	0	0	0	0	0	0	0	0	0	0
	Wet	0	0	0	0	0	0	0	0	0	0
Minnesota	Dry	0	0	0	0	0	0	0	0	0	0
	Dry	0	0	0	0	0	0	0	0	0	0
	Wet	0	0	0	0	0	0	1	1	1	1
	Wet	0	0	0	0	0	0	0	0	0	1

<u>Cracking Scale</u>

0 - No Cracking
1 - Hairline Cracking
2 - Slight Cracking
3 - Moderate Cracking
4 - Severe Cracking

Table 17. Summary of Freeze-thaw Cycling Data, Mix #3

Sand Source	Curing Condition	Freeze-Thaw Cycle									
		1	2	3	4	5	6	7	8	9	10
Ohio	Dry	0	0	0	0	1	1	1	1	1	1
	Dry	0	0	1	1	1	1	1	1	1	1
	Wet	0	1	1	1	1	2	2	2	2	2
	Wet	0	1	2	2	2	2	2	2	2	2
Florida	Dry	0	0	1	1	1	2	2	2	2	2
	Dry	0	0	0	1	1	2	2	2	2	2
	Wet	0	0	1	1	1	1	1	1	1	1
	Wet	0	0	1	1	2	2	2	2	3	3
Colorado	Dry	0	0	1	1	1	1	1	1	1	1
	Dry	0	0	1	1	1	1	1	1	1	1
	Wet	0	2	1	1	1	1	1	1	2	2
	Wet	0	2	0	0	2	2	2	2	2	2
Minnesota	Dry	0	0	0	1	1	1	1	1	1	1
	Dry	0	0	0	1	1	1	1	1	1	1
	Wet	0	1	1	1	1	1	1	1	2	2
	Wet	0	0	0	0	2	2	2	2	2	2
Mass.	Dry	0	0	0	0	1	1	1	2	2	2
	Dry	0	0	0	0	1	1	1	2	2	2
	Wet	0	0	1	2	2	3	3	3	3	3
	Wet	0	0	0	1	1	2	2	3	3	3

Cracking Scale

0 - No Cracking
1 - Hairline Cracking
2 - Slight Cracking
3 - Moderate Cracking
4 - Severe Cracking

Table 18. Summary of Freeze-thaw Cycling Data, Mix #4

Sand Source	Curing Condition	Freeze-Thaw Cycle									
		1	2	3	4	5	6	7	8	9	10
Ohio	Dry	0	0	0	1	2	3	3	3	3	3
	Dry	0	0	1	1	2	3	3	4	4	4
	Wet	0	1	2	2	3	3	3	4	4	4
	Wet	0	0	1	2	3	4	4	4	4	4
Florida	Dry	0	0	0	1	1	1	1	1	1	1
	Dry	0	0	0	1	1	1	1	1	1	1
	Wet	0	0	1	1	1	1	1	1	2	2
	Wet	0	0	1	1	1	1	2	2	2	2
Minnesota	Dry	0	0	1	1	1	2	2	2	2	2
	Dry	0	0	0	0	1	1	1	1	1	1
	Wet	1	1	1	2	3	3	4	4	4	4
	Wet	0	0	1	2	2	2	3	3	3	3
Mass.	Dry	0	0	0	1	1	1	1	2	2	2
	Dry	0	0	0	0	0	2	3	3	3	3
	Wet	0	1	1	1	1	2	3	4	4	4
	Wet	0	1	2	2	3	3	3	3	3	3

<u>Cracking Scale</u>

0 - No Cracking
1 - Hairline Cracking
2 - Slight Cracking
3 - Moderate Cracking
4 - Severe Cracking

SUMMARY

Materials testing performed for this study is described in this chapter. The testing was conducted in two series. The first series of tests were performed on the materials obtained from the following five locations:

1. Columbus, Ohio,
2. Fort Lauderdale, Florida,
3. Denver, Colorado,
4. Saint Paul, Minnesota, and
5. Bedford, Massachusetts.

All the tests described in FAA Engineering Brief No. 46 [4] were performed on the samples of these materials. These tests included viscosity tests, freeze-thaw cycling, adhesion and fuel resistance tests.

The purpose of these tests was to assess the performance of seal coat materials used at these locations using the current quality control tests.

The second series of tests were performed on two samples of asphalt emulsions and two samples of coal-tar emulsions. These materials were tested in a factorial consisting of atleast four sources of sands and two freeze-thaw conditions (dry and wet). A total of 64 samples were tested under this series of tests. These tests were also conducted according to the procedure described in reference [4].

CHAPTER V
ANALYSIS OF DATA AND RESULTS

INTRODUCTION

The data collected during test series numbers 1 and 2 were analyzed to assess the performance of seal coat mixes and determine the effects of variables, such as: additives and sand contents, wet and dry freeze-thawing of samples, etc., on the performance of seal coat mixes containing different types of emulsions and sand sources. A summary of these analyses and their results are described in this chapter.

ANALYSIS OF DATA, TEST SERIES #1

It was indicated earlier that the purpose of test series #1 was to gather test data on seal coat mixes which were used at each airport site so that the performance of these mixes can be compared with their observed performance in the field. However, at the end of visits to various airport sites it was discovered that seal coat performance data were not available at any location. Also, the contractors (who placed the seal coats) were unable to provide the details of the job mix formula. Therefore, it was decided to test materials from all five airport sites according to the Mix Design procedure described in Appendix A of the FAA Engineering Brief No. 46. This is a five step process and at the end of the 5th step, the compositions of all satisfactory mixes become known. It was anticipated that the results of these tests would indicate how sensitive seal coat mixes were to the quantities of individual ingredients (emulsions, additive, and sand) in the mix. This information will be used to evaluate the performance of mixes on a relative scale since no quantitative measurements of their performances were available at this time. The analytical procedures used for this purpose and the results of analysis are described in the following sections of this chapter.

1. Analysis of Sieve Data (see Table 5)

The results of sieve analysis of all five sand samples obtained from airport sites are summarized in Table 5. A comparison of these results with the current specifications (see FAA Item P-625) indicated that all sand samples except Ohio were within the range of FAA specifications. The Ohio sand contained slightly higher percentage of coarser materials (sieve #16 and #20) than specified. Similarly, Florida sand contained a slightly higher percentage of finer material (sieve #50) than other sands. Specific gravity, percent absorption, soundness and deleterious contents of these samples were approximately same for each sand.

2. Analysis of Viscosity Data

Samples of emulsions obtained from each site were combined with four different percentages of additives. The results of viscosity measurements of these samples (total liquids) are listed in Table 6. Although no consistent trend between viscosity and additive content was observed, the general trend indicated a slight increase in the viscosity of total liquids due to increase in additive content (see Table 6). A comparison with the FAA specifications indicated that these measurements were well within the specified range of 10-90 poises. Therefore, all combinations tested in the laboratory were acceptable according to the current FAA specifications.

The "mix" viscosities for different sand contents and additives are summarized in Table 7. A clear trend between the sand content and mix viscosity was observed. The viscosity of seal coat mix decreased with the increase in the amount of sand when the additive content was same. Therefore, an analysis was performed on each source of sand to determine the effect of sand and additive on the viscosity of mix. The following relationships were obtained from this analysis:

Ohio Sand

$$VISC = 32.8 - 1.51(SAND) + 1.57(ADDIT) \quad (R^2 = 0.74) \tag{1}$$

Florida Sand

$$VISC = 67.6 - 1.73(SAND) - 1.56(ADDIT) \quad (R^2 = 0.65) \tag{2}$$

Colorado Sand

$$VISC = 32.0 - 1.69(SAND) + 1.95(ADDIT) \quad (R^2 = 0.83) \tag{3}$$

Minnesota Sand

$$VISC = 38.8 - 1.85(SAND) + 0.88(ADDIT) \quad (R^2 = 0.87) \tag{4}$$

Massachusetts Sand

$$VISC = 23.9 - 2.28(SAND) + 2.00(ADDIT) \quad (R^2 = 0.89) \tag{5}$$

where,

VISC	=	Viscosity of mix, poises at 77°F,
SAND	=	Amount of sand in the mix, lb/gal of emulsion, and
ADDIT	=	Amount of additive in the mix, gal/100 gal of emulsion.

R^2 values listed with each equation are the results of the regression analysis of data which indicate the degree of data fit to regression line represented by the corresponding equation. Generally the values of R^2 range between zero (0) and 1. A zero value of R^2 indicates no fit to data and 1 indicates a perfect fit. Therefore, the fit to data represented by Equations (1) to (5) are reasonable. The significance of parameters, SAND and ADDIT in each equation were also tested statistically. These tests indicated that both parameters contributed significantly to the viscosity of mix.

A consistent trend between the amount of sand in the mix and its viscosity was observed from these analysis. An increase in the amount of sand always decreased the viscosity, when the amount of additive was held constant. This decrease, however, depended on the source of sand. Sand obtained from Massachusetts site showed the largest decrease (2.28 poises) in viscosity per lb of additional sand and Ohio sand showed the smallest decrease (1.51 poises) in viscosity per lb of additional sand. Similarly, the amount of additive generally increased the viscosity except Florida sand. The increase or decrease in the viscosity also depended on the sand source.

In order to examine the effect of additive on the viscosity of mix further, the coefficients of parameter ADDIT (see Equations 1-5) were compared with the percentages of sand fractions passing the sieve #40 (see Table 5). The values obtained for this purpose are listed below:

Source of Sand	% Passing Sieve #40	Coeff. of ADDIT
Ohio	3	1.57
Florida	12	-1.56
Colorado	3	1.95
Minnesota	4	0.88
Massachusetts	3	2.00

Figure 3 shows a plot of these values on a semi-log scale. A consistent trend between the percent of sand passing sieve #40 and the coefficient of ADDIT was observed as shown by a dotted line in this figure. This trend indicated that as the

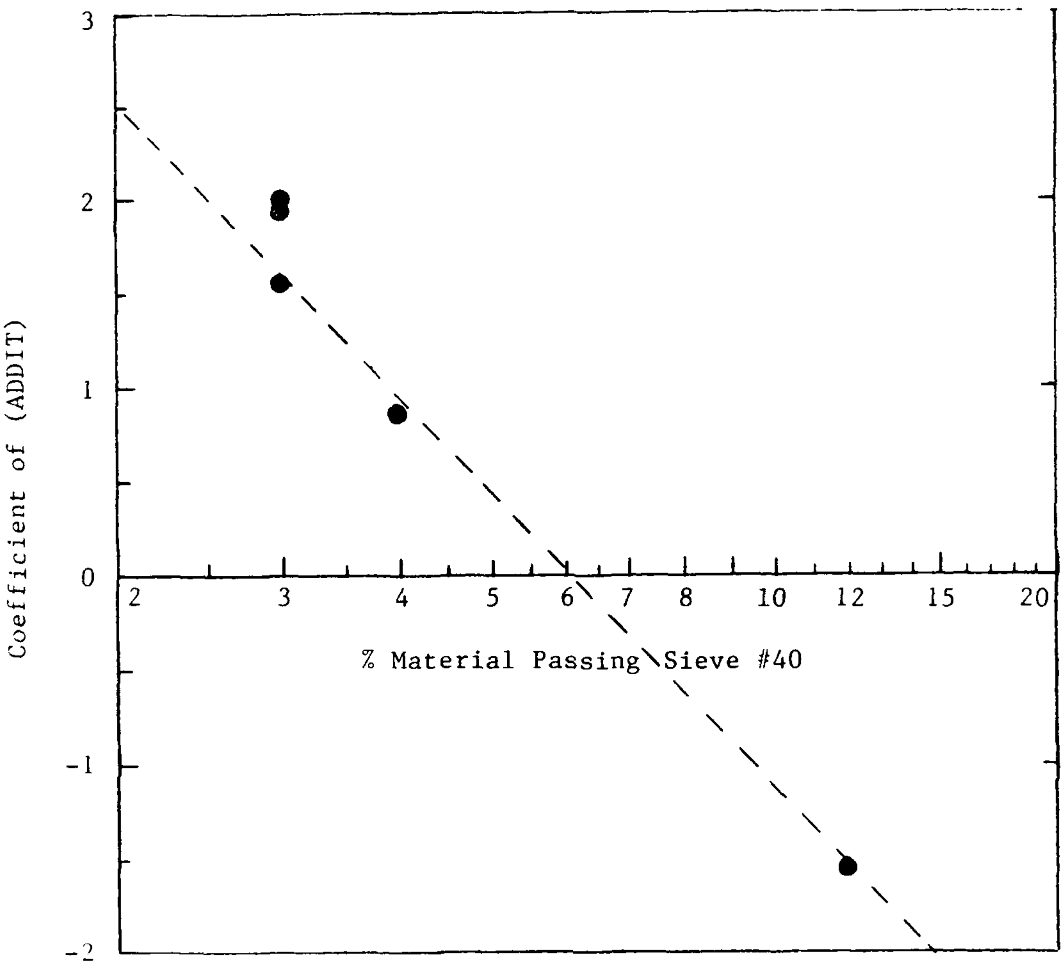

Figure 3. Effect of Material Passing Sieve #40 on the Coefficient of (ADDIT)

sand fraction passing sieve #40 increased, the value of the coefficient to parameter ADDIT decreased. The value of this coefficient waspositive if the percentage of material passing #40 was less than or equal to 6% and negative if the percentage passing #40 was greater than 6%. Since the current specifications allow between 2 to 15% of material passing #40, this coefficient is likely to be either positive or negative, meaning that the additional quantity of additive can either increase or decrease the viscosity of mix depending on the percentage of material passing #40 present in the sand.

3. Analysis of Freeze-Thaw Cycling, Adhesion and Fuel Resistance Test Data

The subsequent tests performed on samples of materials used in test series number 1 included freeze-thaw cycling (Step #3), adhesion (Step #4) and fuel resistance (Step #5) tests. According to the current FAA specifications (see Engineering Brief No. 46) these tests are performed in sequence. The mixes which do not meet the criteria of a given test are eliminated from subsequent tests. Therefore, using these guidelines, freeze-thaw cycling was performed on all those mixes which passed the viscosity tests (Steps #1 and 2). The results of these tests (Step #3) are summarized in Tables 8-12. The current criteria for freeze-thaw cycling (as listed in Chapter IV) is to accept the mix if cracking at 5 cycles is <1 and at 10 cycles it is <3. Using this criteria, the mixes for adhesion and fuel resistance tests were selected. The composition of these mixes is listed in Table 19. The results of adhesion and fuel resistance tests are also summarized in this table. The last column of the table indicates the mixes which passed all the tests (Steps 1 to 5, see FAA Engineering Brief No. 45). This column shows that only one mix of Ohio and Minnesota materials passed all tests. Two mixes of Massachusetts passed all tests and five mixes of Florida and Colorado passed the tests. These results indicate that the materials used at different airport sites do not perform in the same manner when tested in the laboratory. The materials received from Florida and Colorado are likely to perform bettern than the materials received from Ohio or Minnesota or

Table 19. List of Seal Coat Mixes Accepted by Current Freeze-Thaw Criteria (See FAA Engineering Brief No. 46) and the Results of Adhesion and Fuel Resistance Tests.

Sand Source	Mix Meeting Freeze-Thaw Criteria		Results of Adhesion Test	Results of Kerosene Test	Final Acceptance
	Additive, gal per 100 gal emulsion	Sand, lb per gal emulsion			
OH	12	8	4A		
		10	5A	Pass	Yes
FL	9	6	5A	Pass	Yes
	12	8	5A	Pass	Yes
		10	5A	Pass	Yes
	16	6	5A	Pass	Yes
		8	5A	Pass	Yes
		10	4A-5A		
CO	9	4	5A	Pass	Yes
		6	5A	Pass	Yes
		8	5A	Pass	Yes
		10	4A		
	12	8	5A	Pass	Yes
		10	5A	Pass	Yes
MN	12	10	5A	Pass	Yes
MA	12	8	5A	Pass	Yes
		10	5A	Pass	Yes

Massachusetts, considering every thing else being same. The reason to support this statement is that there is greater range of sand and additive quantities in Florida and Colorado materials which will allow the mixes to be satisfactory. But in case of Ohio, Minnesota or Massachusetts materials, only a small range of sand and additive quantities will be satisfactory. Therefore, a strict control of mix ingredients is needed during the construction of seal coats in the field in order to assure a satisfactory seal coating with Ohio or Minnesota or Massachusetts materials. However, even larger variations in the ingredients of mixes prepared out of Florida or Colorado materials will assure a satisfactory mix.

Discussions with the airport engineer in Florida indicated that the rubberized coal-tar emulsion seal coats were performing satisfactorily. A visual inspection of site condition indicated that seal coats were in good condition after about 2 years of service. Similar conditions of seal coated surfaces were observed in Colorado also. These surfaces were seal coated in 1988, 1989 and 1990. All surfaces were in satisfactory condition.

Seal coat surface in Ohio was constructed in October, 1991. Therefore, long-term performance of this mix is not known. However, recent observations of the surface indicated that there are already some cracks on the surface and the seal coat may not be performing satisfactorily.

Performance history of Minnesota and Massachusetts materials are not available. Therefore, no comparison with field performance can be made at this time.

The conclusions of this analysis indicated that the materials received from all five sites produced at least one satisfactory seal coat mix containing 12% additive by volume of emulsion and 10 lbs. of sand per gal. of emulsion. Some materials produced another mix with 12% additive and 8 lbs of sand also. The results of these tests indicated that the amount of additive and sand in the mix controlled the performance of the mix.

Therefore, the seal coat mixes placed on airport pavements need to be checked appropriately to assure adherence to specified job mix formula.

ANALYSIS OF DATA, TEST SERIES #2

The intent of this test series was to determine the effect of two different freeze-thaw conditions (wet and dry) on the cracking characteristics of the seal coat mixes. For this purpose, four mixes each containing a different type of emulsion were tested. The amount of sand and additive (if used) was kept constant, but sands obtained from four different sources were used in each mix. The ingredients of these mixes are listed in Chapter IV. The following tests were performed on each mix:

1. Brookfield viscosity of emulsions, total liquids and mixes,
2. Freeze-thaw cycling under dry and wet conditions,
3. Adhesion, and
4. Fuel resistance tests.

The analysis p... ..ned on the data collected from each test is described in the following sections of this chapter.

1. Analysis of Viscosity Data

Viscosities of all emulsions selected for this series of tests were determined by Brookfield Viscometer (Model DV-II) and spindle number 3 HB. The results of these tests are shown in Table 14. Viscosities of total liquids and mixes were also measured and the results of these measurements are also listed in this table.

Mix #1 contains asphalt emulsion (CSS-1). The current FAA specifications (Item P-626, Asphaltic Emulsion Slurry Seal) require this material to conform to Fed. Spec. SS-A-674. This emulsion was tested according to the ASTM T59. The results of these tests along with the specifications according to AASHTO: M208-87 (in lieu of Fed. Spec.: SS-A-674) are listed in Table 20. The results of these tests indicated that the sample of asphalt emulsion used in this study will meet the specifications. However, in order to compare the viscosity of this emulsion with the viscosity of coal-tar emulsions, an attempt was made to measure its viscosity by Brookfield Viscometer also. The results of these tests are listed in Table 13. It was observed that the viscosity of this emulsion was far less than the emulsions of coal-tar (Mix #3 and #4). However, the viscosity of mixes were comparable to those containing coal-tar emulsions.

Due to the difficulty in keeping the sand in suspension in Mix #1, the results of viscosity measurements by Brookfield Viscometer are not reliable. However, these results are included in Table 14 for comparison purposes. The results of viscosity measurements indicated that the source of sand significantly affected the viscosity of mix #1.

Mix #2 contains asphalt emulsion, which according to the manufacturer was prepared in the same manner as other emulsions containing coal-tar. Therefore, the viscosities of this emulsion were measured by Brookfield Viscometer. The viscosities of total liquids and mixes were also measured by Brookfield Viscometer and the results are listed in Table 14. These measurements indicated that the viscosities of total liquids and mixes were slightly below the minimum of 10.0 poises required by FAA for coal-tar emulsion mixes. Also, the effect of sand source on the viscosity of mix was observed to be negligible. Although, the tests on these mixes were continued to determine the results of freeze-thaw cycling, adhesion and fuel resistance tests, two more samples of this emulsion were tested for their viscosities. These samples contained a different amount of water in the total liquids. The results of these tests were as follows:

Table 20. Results of Laboratory Tests on Cationic Asphalt Emulsior s CSS-1 and Standard Specifications According to AASHTO: M208-87

	Laboratory Data	M 208-87 Specs.
Viscosity, Saybolt Furol at 77°F, S	87.6	20-100
Sieve Test, %	0.06	0.10 (max)
Cement Mixing Test, %	1.3	2.0 (max)
Residue, % (by Distillation)	63.2	57 (min)
Tests on residue from Distillation Test:		
Penetration, 77°F, 100g, 5S	136	100-250
Ductility, 77°F, 5cm/min, cm	52	40 (min)
Solubility in trichlorethylene, %	98.3	97.5 (min)

Water, gal/100 gal of emul.	Viscosity, poises
10	12.6
20	2.4
30 (as recorded in Table 13)	2.7

These data indicated that the viscosity of the emulsion changes considerably from the original value of 42.7 to 12.6 after adding 10% water to the emulsion and then from 12.6 to 2.4 after adding additional 10% water. However, the next 10% additional water did not show any significant change in the viscosity of this emulsion (asphalt). Also, as stated earlier, the source of sand did not show any effect on the viscosity of mix (see Table 14).

Mix #3 and Mix #4 contain coal-tar emulsions. Mix #3 also contains 7% additive (latex) by volume of emulsion. The viscosities of both mixes were within the FAA specified range of 10-90 poises, except total liquids of Mix #4 (see Table 14). The effect of sand source on the viscosity of mix was more prominent in Mix #3 than in Mix #4, specially for Florida. Since the amount of water added to Mix #3 was 70% and Mix #4 was 30% by volume of emulsion, it was decided to further investigate the effect of water on the viscosity of total liquids with and without latex. The viscosities in poises obtained from these tests are listed in the table below.

Water, gal/100 gal of emulsion	Total liquids without Latex visc, poises	Total liquids with 7% Latex visc, poises
0	76.0	-
5	-	114.0
15	-	60.2
30	4.6	-
50	3.5	37.4
70	2.4	31.0

An analysis of this data was performed to obtain the following relationship for this emulsion (coal-tar):

$$\ln(VIS) = 4.345 - 0.30\ln(WATER) + 0.29\ln(LATEX) \quad (R^2 = 0.985) \tag{6}$$

where,

VIS	=	Viscosity of total liquids, poises,
WATER	=	Water added to emulsions, gal/100 gal of emulsion, and
LATEX	=	Latex added to emulsion, gal/100 gal of emulsion.

Since this is an equation with parameters transformed to natural log, the equation is applicable to water and latex contents greater than zero. Also, latex percentage was 7% only. Therefore, care is needed when using this equation for latex contents greater than 7%.

This equation clearly shows that the increase in water content will reduce the viscosity of total liquids, whereas, increase in latex quantity will increase the viscosity. Therefore, suitable combinations of water and latex percentages can be established with the help of this equation to satisfy the requirements of viscosity when designing a mix.

The effect of different sand sources on the viscosities of Mix #3 and Mix #4 is also shown in Table 14. As mentioned earlier, the effect of sand source on mix viscosity was more prominent in Mix #3 than in Mix #4. Since, Mix #3 contains additive, it appears that in the presence of additive, the source of sand has larger impact on mix viscosity than the mix without latex. Also, it was shown in Figure 3 that the factor which characterized the source of sand for this purpose was the percent of sand passing sieve #40. A similar effect is apparent from above data also. The viscosity of mix containing sand from Florida is the highest of all other sand sources. An approximate relationship of the following form represent this characteristics of the mix:

$$VISM = 7.4 + 27.0 \ln(P40)$$

where,

VISM = Viscosity of mix containing 7% latex, poises. and

P40 = Percent of sand passing sieve #40.

This equation can be used to estimate the approximate viscosity of a mix with latex (7%) and sand from different sources which contain different amount of material passing sieve #40 (although the gradation is still within FAA specifications). There was no significant effect of P40 on mix viscosity when no latex was used in the mix (Mix #4).

2. Analysis of Freeze-Thaw Cycling, Adhesion and Fuel Resistance Test Data

Freeze-thaw cycling data for all four mixes are summarized in Table 15-18. The purpose of these tests was to determine the effect of dry and wet thawing of samples in the laboratory when tested for freeze-thaw cycling.

Mix #1 containing asphalt emulsion (CSS-1) shows that samples of all four sands will pass the freeze-thaw cycle tests under dry thawing conditions. However, only Colorado sand mix will pass this test under wet thawing, because mixes of other sands will fail the test at 5 cycles.

Mix #2 containing asphalt emulsion manufactured by Neyra Industries will also pass this test for all sand sources under dry conditions. But it will fail the test for Ohio sand at 5 cycles for wet conditions.

Mix #3 containing coal-tar emulsion and latex will not pass freeze-thaw cycle tests for any source of sand at 5 cycles, although all of them will pass the test at 10 cycles for dry conditions as well as wet conditions except the mix using Massachusetts sand.

This data shows that the performances of all mixes under wet conditions were consistently poorer than under dry conditions, because it required less number of freeze-thaw cycles to show first crack under wet conditions than under dry conditions. For example, mix using Ohio sand required 3-5 cycles (or average 4 cycles) to show first crack under dry conditions. Whereas, it required only 2 cycles to show first crack under wet condition. Similar observations were made for mixes using sands from other sources.

Mix #4 using coal-tar emulsion without any additive shows that mixes containing Florida, Minnesota and Massachusetts sands will pass the test at 10 cycles under dry conditions but Minnesota and Massachusetts sand mixes will fail the test under wet conditions. Again, as with Mix #3, the number of cycles required to show first crack in the sample were more for dry conditions than under wet conditions.

Although freeze-thaw cycle evaluation scale is not strictly a quantitative scale, an attempt was made to use the data as if it was a quantitive measurement so that the relative effect of wet and dry condition could be estimated. Two different parameters were defined for this purpose as follows:

1. Survival Index (SI) - defined as a ratio of number of cycles required to develop first crack under wet (cyw) and dry (cyd) condition, or, SI = (cyw/cyd).

2. Damage Index (DI) - defined as the ratio of crack levels at 10 cycles under wet (ckw) and dry (ckd) condition, or, DI = (ckw/ckd).

A survival index of less than one indicates that the sample under wet conditions will develop first crack earlier than under dry conditions. Also, the damage index of greater than one indicates that a greater level of cracks will develop under wet conditions than under dry conditions. The results of these analyses for all four mixes and sand sources are summarized in Table 21.

The averages of SI for each mix shown in Table 21 indicate that among the two asphalt emulsion mixes, Mix #2 is likely to survive longer than Mix #1 under wet conditions. Similarly among the two coal-tar emulsion mixes, Mix #3 is likely to survive longer than Mix #4. However, the damage indexes (DI) of Mixes 1 and 2 were almost same. Similarly, DI of Mixes 3 and 4 were also same, indicating that the effect of wet condition on cracking at 10 cycles depend on the type of emulsion (asphalt or coal-tar), but not on the mix composition (with or without latex). Therefore, it appears that latex may be helpful to delay the development of cracks in the seal coat, under wet conditions but there may not be any significant effect of latex in the mix as far as final cracking of seal coat mixes is concerned.

The adhesion tests were conducted under normal curing at room temperature for all mixes. Therefore no effect of dry or wet conditions can be deduced from these tests. The fuel resistance tests were also conducted under normal room temperature. The results of adhesion tests indicated no problems with the samples. However, the samples of Mix #1 and #2 did not pass fuel resistance tests.

RESULTS

The analysis of data collected for this study has been described in this chapter. A summary of results of this analysis is as follows:

1. Data from test series #1 indicated that the viscosity of seal coat mix was significantly affected by the sand and additive content as well as source of

Table 21. Summary of Data Analysis (Freeze-Thaw Cycling Under Dry and Wet Conditions)

Sand Source	Mix #1		Mix #2		Mix #3		Mix #4	
	SI	DI	SI	DI	SI	DI	SI	DI
OH	.64	1.0	0.38	3.0	0.5	2.0	0.71	1.14
FL	0.45-	*	1.00	*	0.86	1.00	0.60	2.00
CO	1.00	*	1.00	*	0.67	2.50		
MN	0.20-	*	0.85-	*	0.88	2.00	0.50	2.33
MA					0.70	1.50	0.44	1.40
Average	0.57	*	0.81	*	0.72	1.80	0.56	1.72

\- The ratio is less than this number.

* The ratio is not defined because of division by zero.

Blanks indicate no data were available for the mix.

sand. In general, increase in the amount of sand in the mix, decreased its viscosity. Also, increase in the amount of additive increased the viscosity of mix, if the sand source contained up to a maximum of 6% passing sieve #40. If percent passing #40 was greater than 6%, the increase in the additive content decreased the viscosity of mix (see Equations 1-5).

2. No correlation between either total liquid viscosity or mix viscosity and freeze-thaw cycle cracking was observed from Series #1 tests. However, it was observed that the materials obtained from different sources showed some differences in their performance. Only one mix of Minnesota materials, two each of Ohio and Massachusetts, and six each of Florida and Colorado survived the freeze-thaw tests.

3. Adhesion tests eliminated one mix from Ohio, and one mix from Florida. In case of Ohio, the sand sample contained slightly higher percentages of coarse fractions (sieve #16 and #20, see Table 5). It is speculated that this may be the cause for poor adhesion quality of this mix. In case of Florida sand, some mixes contained a slightly higher amount of sand and additive content than other sands (see Table 19).

4. Most of the mixes which passed freeze-thaw cycling test also passed adhesion test, except a small percentage, which did not pass this test. All the mixes which passed adhesion tests also passed the fuel resistance tests (remember that all these mixes were made with coal-tar emulsions).

5. Seal coat mixes containing sand and emulsions obtained from different sources are likely to perform differently. Their relative performance can be estimated by freeze-thaw cycling. The effect of change in the quantities of sand and additive on the cracking of laboratory samples can be used for this purpose. If, the mixes which pass these tests contain a wider range of sand and additive

amounts, then these mixes are likely to survive longer than the mixes which contain a narrow range of sand and additive amounts. Because, these mixes are more likely to be out of range of desirable properties than those which have a wider range of acceptable proportions. This fact was verified only partially because long-term performance data for these mixes were not available from airport sites.

6. The results of viscosity tests on total liquids and mixes of test series #2 were very much similar to those of test series #1. However, the mixes containing asphalt emulsion CSS-1 did not produce reliable data because the sand could not be kept in suspension for a reasonable amount of time to measure its viscosity.

7. The mixes which did not contain additive were not affected by the type of sand for viscosity purposes. However, presence of additive in the mix affected the mix viscosity of different sands (see Table 14).

8. The mixes subjected to "dry" freeze-thaw cycling in general performed better than samples subjected to "wet" freeze-thaw cycling.

9. The mixes containing asphalt emulsions performed slightly better than mixes containing coal-tar emulsions (under both, dry and wet conditions).

10. The effect of wet freeze-thaw cycling measured by a ratio between the cycles to first crack under wet condition and dry conditions indicated that these ratios were similar for asphalt and coal-tar emulsions. This indicated that type of emulsion may not affect the relative damage in mix caused by wet thawing.

11. The ratios of cracking levels (DI) at 10 cycles under wet and dry conditions were determined for all mixes. These ratios were similar within the emulsion

types (see Table 21). For example, DI for Mix #3 and Mix #4 (coal-tar emulsion mixes) were 1.80 and 1.72, respectively.

12. The results of analysis summarized in Items 10 and 11 indicated that additive in coal-tar emulsion mix delayed the development of first crack but the relative levels of cracking at 10 cycles were same in both mixes (with and without latex).

13. Asphalt emulsions did not contain additives. But their performance under both wet and dry freeze-thaw cycling was comparable to the mixes containing coal-tar emulsion and additive.

14. Limited data obtained from visits to airports indicated that Ohio materials may perform less satisfactorily in the field. Laboratory tests of these materials also indicated "similar" trends.

15. Colorado and Florida materials tested in the laboratory indicated that they are likely to perform better in the field. Field observations and reports from airport engineering also indicate that seal coats at these locations are performing satisfactorily.

CHAPTER VI
SUMMARY AND CONCLUSIONS

SUMMARY

This study was conducted to investigate the characteristics of different types of seal coating materials using asphalt and coal-tar emulsions, additives and sands from different sources. The scope of the study also included visits to different airport sites where seal coats have been used. The data collected from the visits and the laboratory testing were to be used in developing criteria and guidelines for the types and characteristics of seal coating materials, optimal timing of seal coating applications, conditions under which airport pavement seal coating is most effective, and the effect of seal coating on the pavement life.

A review of literature indicated that asphalt as well as coal-tar binders are used in seal coating the asphalt pavement surfaces. The seal coats provide a protective layer to these pavements and prevent damage due to ingress of water to the pavement below the seal coat surface. Several types of seal coats are used in highway pavements, but airport pavements generally use slurry seal coats. Although asphalt emulsions were used in some airport sites, the majority of airport pavements were seal coated with the coal-tar emulsion slurry seals. The main reason for this was the fuel resistant properties of the coal-tar emulsion seal coats. Generally, rubberized coal-tar seal coats have been used in the past years using an additive (latex) to the emulsions. The performance of rubberized coal-tar emulsion seal coats was observed to be better than the seal coats without latex, as was indicated by airport engineers during visits to these sites.

Records of seal coat mix formula, their performance and quality control data were not available in any airport site visited for this study (a total of 7 sites were visited). Also, the contractors, who constructed the seal coats at these sites were unable to provide any details regarding these items. However, samples of materials from five airport sites were obtained for testing them in the laboratory. The information gathered from these visits indicated that most of the airport authorities used seal coats as a temporary measure to keep the surface usable and slow down further deterioration of the existing pavement surface until sufficient funds became available to rehabilitate them with overlays. There was no indication from these visits that the seal coats were considered important for prolonging the life of relatively new pavements. Therefore, information in this regard was not available. However, there was a general feeling among airport engineers that the seal coats generally last for 3 to 5 years. Most of the sites visited did not have seal coats more than 4 years old. Therefore, this information could not be verified. A 4-year old seal coat at Cincinnati airport was not in good condition due to wide and extensive cracks on the surface.

Laboratory testing of seal coat materials (sand, coal-tar emulsion and rubber additive) obtained from 5 airport sites was performed. The testing procedures described in FAA Engineering Brief No. 46 were used for this purpose. A copy of this document is enclosed in Attachment 1 of this report. It was observed that the percentage of sand fraction passing sieve #40 affected the viscosity of seal coat mix when latex was present. The higher percentage of this fraction present in Florida sand resulted in a different characteristic of this mix than others with lower percentage of this fraction (see Equations 1 - 5). This fraction also had some effect on the freeze-thaw characteristic of the mix. This was the only mix which allowed a higher percentage of additive in the mix and yet was acceptable. Other mixes did not allow the use of 16 gal additive/100 gal of emulsion in their mixes.

The effect of coarser fractions present in Ohio sand (Sieve #16 and #20, see Table 5) was noticeable in one of the formulation. This mix failed under adhesion test but passed freeze-thaw test (see Table 19). Other sands which did not contain these fractions outside the limits of FAA specifications, Item P-625 passed adhesion test. The mix contained 12 gal of latex and 8 lb of sand (see Table 13).

Although 16 combinations of sand and latex contents were tested for materials received from each site, different number of combinations passed the tests of acceptance at the end. This indicated that the seal coat mixes containing sand and emulsions from different sources will have different potential for their survival when subjected to similar conditions (in this case all samples were subjected to same laboratory conditions). However, it was observed that at least one common mix (containing the same percentages of sand and additives) survived all tests. This mix contained 10 lb sand/gal of emulsion and 12 gal of latex/100 gal of emulsion.

The number of mixes surviving the tests can be used as an indicator of materials sensitivity to variations in their quantities present in the mix. For example, if the range of sand quantity in a successful mix varied from 8-10 lb/gal of emulsion, then this mix is less sensitive to the quantities of sand used in the mix than another mix which requires only 10 lb sand/gal of emulsion.

Two asphalt and two coal-tar emulsions were used to test mixes for studying the effect of freeze-thaw under two different conditions (wet and dry). In general it was observed that the first crack under wet conditions developed earlier than under dry conditions. Asphalt emulsion used in Mix #2 performed better under wet conditions than asphalt emulsion used in Mix #1. Also, the coal-tar emulsion with latex performed better than the emulsion without latex under wet conditions. The approximate ratio between the cycles to first crack under wet and dry conditions were 0.57-0.81 for these two mixes (Mix #1 and Mix # 2). Also, the levels of crack (assessed according to cracking scale, see Table 15-18) at the end of 10 cycles of freeze-thaw were higher for wet conditions than dry conditions. Again the ratio of these two levels was 1.72-1.80 for coal-tar emulsion mixes. These test indicated that there was a definite effect of moisture on the cracking characteristics of seal coat mixes.

No data were available to compare the performance of seal coats in the field with the performance of mixes prepared in the laboratory. But there were some indications that the laboratory results can be extrapolated to predict the performance of seal coat mixes in the field. There were some indications that the Ohio materials, which allowed only one mix to be acceptable in the laboratory, may also have some cracking problems in the field. On the other hand, Florida and Colorado materials, which tested well in the laboratory, had indications to perform better in the field also.

CONCLUSIONS

The conclusions of this study can be summarized as follows. It is important to remember that these conclusions are based on the data used in this study

1. Viscosity of seal coat mix is affected by the water, sand and additive content. But this property did not seem to have any apparent effect on the cracking characteristics of the mix.

2. The coarse fractions (passing sieve #8 and #16) present in the sand may cause adhesion problems in mixes which may otherwise be satisfactory. However, the mixes containing coarse fractions witnin the specified limits of FAA Item P-625 did not seem to have these problems.

3. Sand containing a high fraction passing sieve #40 tends to require a higher percentage of additive and lower percentage of sand to produce a desirable mix.

4. Laboratory tests described in FAA Engineering Brief No. 46 can be used to assess the performance of seal coat mixes in the field qualitatively. So far there are no data available to correlate directly the results of laboratory tests.

5. Wet freeze-thaw cycling was found to be more severe on laboratory samples. It reduced the potential life of samples to 50-80%. Also, the final levels of cracking under wet conditions were 70-80% higher than the cracking levels under dry

conditions (using the cracking scale of Engineering Brief No. 46).

6. Presence of rubber additive in coal-tar emulsion seal coat mix improved the wet freeze-thaw property of the mix. However, it did not completely eliminate the effect of wet conditions.

7. Laboratory test on asphalt emulsion seal coat mixes indicated that their freeze-thaw cycling characteristics were similar to those mixes which contained coal-tar emulsions. However, asphalt emulsion seal coats were not resistant to fuel.

8. It is important to remember that the additives (latex) used in the mix should be compatible with the emulsion. The manufacturer of the emulsion can provide information on this item. Also, when the additive was mixed with emulsion and water before mixing with the sand, it worked satisfactorily in the laboratory. When additive was added last in the mix, it did not mix properly in the laboratory samples.

9. The current quality control specifications cover the cases of hypothetical worst conditions. Actual performance of these seal coats will be different depending upon the site conditions. Specifications could be inhanced to accomodate site specific conditions and to predict the performance of seal coats through a more elaborate research effort.

CHAPTER VII
RECOMMENDATIONS

Based on the information collected in this study, the following recommendations are offered for consideration by FAA:

Field evaluation of five airport sites and laboratory tests of different seal coat mix formulations indicated that the use of coal-tar emulsions with latex is generally satisfactory in most places. However, if the fuel resistance characteristics of coal-tar emulsions are not important, seal coat mixes containing asphalt emulsions are likely to perform equally satisfactorily.

The fuel resistance characteristics of coal-tar emulsion were considered unimportant by an airport engineer because it caused the fuel to stay on the surface and make it slippery. Therefore, he preferred asphalt emulsion seal coat because it absorbed the spillage. The pavement repair needed for this case was not considered critical by this engineer.

The use of asphalt emulsion seal coats for taxiways and runways as a routine maintenance activity is likely to be satisfactory because the chance for fuel spillage on these pavements is minimal. Use of asphalt emulsion seal coat for runway and taxiway shoulders is also recommended for routine maintenance purposes.

Coal-tar emulsion seal coats have proven to be satisfactory for a service life of 2 to 3 years on all types of airfield pavements including aprons. However, the laboratory tests indicated that the mix design based on existing specifications are needed for each location to accommodate the variations in materials. The emulsions and additives should be checked for their compatibility as recommended by the manufacturer.

Sand should meet the current gradation requirements of FAA Item P-625 for coal-tar emulsion slurry seals. Excess amount of fraction retained on sieve #16 and #20 may cause adhesion problems. Similarly, excess amounts of fraction passing #40 may cause workability problems and require additional amount of additive.

Appropriate inspection procedures and their implementation during the construction of seal coats is needed to assure adherence to the specified job formula. Also, field samples are needed to check the properties of mix placed at the site. The performance of seal coats depends on correct proportions of ingredients used in the mix.

Provisions are to be made in the existing specifications for unusually wet conditions of the site. The mix design should be modified appropriately if these conditions are expected at any site.

Current specifications for asphalt emulsion mixes require coarser sand in the mix than used in coal-tar mixes. These mixes are likely to lose large particles during their service life which may result in premature failure of the seal coat. Therefore, sand gradation similar to the FAA Item P-625 should be considered for asphalt emulsions also. There are asphalt emulsions in the market which are formulated in the same manner as coal-tar emulsions. The performance of one of this emulsion was observed to be similar to the coal-tar emulsion mixes.

The sequence of mixing ingredients should be in the following order:

1. Emulsion,
2. Water,
3. Additive (if any), and
4. Sand.

It was observed in the laboratory samples that adding the additive last was not satisfactory.

In order to gain maximum benefits from seal coating, the seal coats should be applied before the existing surface is aged and cracked. The aged and cracked surface is likely to reflect the cracks on the seal coated surface. Also, the effect of aging will be reduced considerably if seal coating is applied during the early life of pavement. However, the seal coat should not be applied to a relatively new or newly overlaid pavements. Field observations have indicated that such seal coats tend to debond from the surface.

Although slurry seal coat using emulsions can be applied during any time of the year when temperatures are above 45° F, best results can be expected if the seal coat is applied in the beginning of the warm weather to take advantage of proper curing during the warm season. Seal coats should not be applied if the temperature is above 90 F and humidity is more than 85%.

Seal coating provides a protective layer against aging and water intrusion from the surface. Since aging takes place at all locations, seal coating is effective in almost every case. However, maximum benefits will be realized when the pavement is likely to be damaged by fuel also. The areas of heavy rainfall are likely to be benefitted more by seal coats than other areas.

Currently there are no procedures available to estimate the amount of additional life which can be gained from seal coating the surface. However, field observations of seal coated surface indicate that a pavement which has aged and cracked and could not be used in its current condition, can be brought back to reasonable condition for 2-5 years by seal coating. These observations are based on the field experience shared by airport engineers during our visit to their sites. At the present time, no information is available on the performance of seal coats placed on relatively new pavements, but it is expected that seal coating the pavements in early part of their life can prolong the life more than seal coating the pavements later.

Seal coats should not be applied immediately after overlaying a pavement. A curing period of at least 6 months should be allowed before seal coating.

Current FAA Engineering Brief No. 46 (see Attachment 1) recommends testing the mix for adhesion after testing the mixes for freeze-thaw cycling. Since freeze-thaw cycling can take as long as 20-days, while adhesion test requires only 24 hours curing, it is recommended that adhesion test should be conducted before freeze-thaw testing. This will eliminate any mix which is likely to fail the adhesion test after it has passed the freeze-thaw cycling test.

The requirements of fuel resistance test should be excluded from the asphalt emulsion slurry seal coats if it is decided by FAA to include testing procedures for asphalt emulsion seal coats in the current FAA Item P-626. This test should be substituted by a suitable test to check the permeability of the seal coated surface.

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18. "Guidelines and Procedures for Maintenance of Airport Pavements," Advisory Circular AC No. 150/5380-6, DOT, FAA, December 3, 1982.

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ENGINEERING BRIEF NO. 46

ITEM P-625 COAL-TAR PITCH EMULSION SEAL COAT

DESCRIPTION

625-1.1 This item shall consist of an application of a **[rubberized]** coal-tar emulsion seal coat, with or without mineral aggregate, **[and with the use of a latex rubber]** applied on an existing, previously prepared bituminous surface, in accordance with these specifications for the area shown on the plans or as designated by the Engineer. The material is intended for use as a fuel resistant sealer.

* *

Use of a rubberized seal coat may be specified by the Engineer by incorporating the words enclosed in brackets.

* *

MATERIALS

625-2.1 AGGREGATE. The aggregate shall either be a natural or manufactured angular aggregate and shall be composed of clean, hard, durable, uncoated particles, free from lumps of clay and all organic matter. The aggregate shall meet the gradation in Table 1, when tested in accordance with ASTM C 136.

TABLE 1. GRADATION OF AGGREGATES

Sieve Size	Percentage By Weight Passing Sieves
No. 8 (2.36 mm)	100
No. 16 (1.18 mm)	97-100
No. 20 (0.85 mm)	85-100
No. 30 (0.60 mm)	15-85
No. 40 (0.40 mm)	2-15
No. 50 (0.30 mm)	-
No. 100 (0.15 mm)	0-2

The gradation shown in Table 1 may be varied to conform with the recommendations of the latex supplier.

625-2.2 BITUMINOUS MATERIALS. The bituminous material shall be a coal-tar pitch emulsion prepared from a high temperature, coal-tar pitch conforming to the requirements of ASTM D 490, grade 11/12. Oil and water gas tar shall not be used even though they comply with ASTM D 490. The coal-tar pitch emulsion shall conform to all requirements of Federal Specification R-P-355 except that the water content shall not exceed 50 percent.

625-2.3 WATER. The water used in mixing shall be potable and free from harmful soluble salts. The temperature of the water added during mixing shall be at least 50 degrees F (10 degrees C). The pH of the water added during mixing shall conform to the requirements of the coal tar emulsion manufacturer.

625-2.4 LATEX RUBBER. The rubber shall be a copolymer latex containing 51-70 parts butadiene and 30-49 parts acrylonitrile or styrene with a minimum solids content of 40 percent. The rubber shall be compatible with the coal-tar pitch emulsion used by the Contractor and must mix homogeneously with the coal-tar emulsion, water, and sand in the proportions specified to produce a mixture that will adequately suspend the sand.

* *

The Engineer shall delete paragraph 2.4 if a rubberized coal-tar pitch emulsion is not specified.

* *

COMPOSITION AND APPLICATION

625-3.1 COMPOSITION. The **[rubberized]** coal-tar pitch emulsion seal coat shall consist of a mixture of coal-tar pitch emulsion, water, **[latex rubber]** and aggregate in proportions that fall within the ranges shown in Table 2.

625-3.2 JOB MIX FORMULA. For a rubberized seal coat, the Contractor shall submit the supplier's recommended formulation and application rate to a testing laboratory. The laboratory shall verify the proportions of emulsion, water, aggregate and rubber using the mix design procedures contained in Appendix A. The mix design shall be within the range shown in Table 2 and meet the requirements of Table 3. A copy of the mix design and test data shall be submitted to the Engineer for approval at least [ ] days prior to the start of operations. No seal coat shall be produced for payment until a job mix formula has been approved by the Engineer.

Rubberized coal-tar emulsion seal coat formulations are sensitive to the characteristics of individual latex additives. Not all products will provide satisfactory seal coat formulations for all combinations of coal tar emulsion, water, and rubber additive.

The job mix formula for each mixture shall be in effect until modified in writing by the Engineer.

For a non-rubberized seal coat the contractor shall submit the proportions of water, emulsion, and sand proposed for use to the Engineer at least 5 days prior to the start of operations. A copy of test data showing the results of the fuel resistance test in Appendix A shall also be submitted to the Engineer.

* *

Improper formulations of coal-tar pitch emulsion seal coats may produce coatings that crack prematurely or do not adhere properly to the pavement surface.

A minimum of 5 days is recommended for job mix approval.

* *

TABLE 2. COMPOSITION OF MIXTURE

Type of Seal Coat	**Composition and Quantities**			
	Water gal./gal. of emul.	Aggregate lbs/gal. of emul.	Rubber gal./gal. of emul.	Application Rate gal./sq.yd. (per application)
Rubberized Sand Slurry	0.80(max)	4-20	0.04-0.18	0.20-0.55
Rubberized Emulsion	0.80(max)	-	0.03-0.05	0.10-0.20
Sand Slurry	0.15(max)	2-5	-	0.15-0.20
Plain Emulsion	0.10(max)	-	-	0.08-0.10

TABLE 3 DESIGN CRITERIA

Test Property	Purpose	Criterion
Brookfield Viscosity poises @ 77F	Incompatibility between latex and coal tar	10-90
Brookfield Viscosity poises @ 77F	Workability of mix	10-90
Freeze-Thaw	Cracking	
@ 5 cycles		< 1
@ 10 cycles		< 3
Adhesion	Loss of adhesion	Rating = 5A
Fuel Resistance	Fuel penetration Loss of adhesion	No penetration or loss of adhesion

* *

Delete Table 3 if a non-rubberized seal coat is specified.

* *

625-3.3 APPLICATION RATE. [The rubberized coal-tar emulsion seal coat shall be applied in three coats. The first and second coats shall consist of a rubberized sand slurry; the third coat shall consist of a rubberized emulsion, if recommended by the manufacturer.] [The sand slurry coal-tar emulsion seal coat shall be applied in two coats.] The application rate submitted with the job mix formula shall be verified during placement of the test section and shall fall within the limits shown in Table 2.

* *

The Engineer shall incorporate the appropriate sentence in the project specifications, depending on whether the seal coat is rubberized or non-rubberized. When, in the opinion of the Engineer, an area will be subjected to heavy fuel spillage, a final application of plain emulsion , on a sand slurry seal coat, may be made at the rate of 0.075 to 0.10 gallons per square yard (0.36 to 0.5 liters per square meter).

* *

625-3.4 TEST SECTION. Prior to full production, the Contractor shall prepare a quantity of mixture in the proportions shown in the approved mix design. The amount of mixture shall be sufficient to place a test section a minimum of 250 square yards at the rate specified in the job mix formula. The area to be tested will be designated by the Engineer and will be located on a representative section of the pavement to be sealcoated. The actual application rate will be determined by the Engineer during placement of the test section and will depend on the condition of the pavement surface.

The test section shall be used to verify the adequacy of the mix design and to determine the application rate. The same equipment and method of operations shall be used on the test section as will be used on the remainder of the work.

[Viscosity tests shall be made to determine conformance with the requirements of Table 3. Test results shall be available within 2 days.]

If the test section should prove to be unsatisfactory, the necessary adjustments to the mix composition, application rate, placement operations, and equipment shall be made. Additional test sections shall be placed and evaluated, if required. Full production shall not begin without the Engineer's approval. Acceptable test sections shall be paid for in accordance with paragraph 625-7.1.

* *

The test section affords the Contractor and the Engineer an opportunity to determine the quality of the mixture in place as well as the performance of the equipment.

The application rate depends on the surface texture.

If operational conditions preclude placement of a test section on the pavement to be sealed, it may be applied on a pavement with similar surface texture.

* *

CONSTRUCTION METHODS

625-4.1 WEATHER LIMITATIONS. The seal coat shall not be applied when the surface is wet or when the humidity or impending weather conditions will not allow proper curing nor when the atmospheric or pavement temperature is below 50 degrees F (10 degrees C), unless otherwise directed by the Engineer.

625-4.2 EQUIPMENT AND TOOLS. The Contractor shall furnish all equipment, tools, and machinery necessary for the performance of the work.

a. Distributors. Distributors or spray units used for the spray application of the seal coat shall be self-propelled and capable of uniformly applying 0.15 to 0.55 gallons per square yard (0.69 to 2.5 liters per square meter) of material over the required width of application. Distributors shall be equipped with removable manhole covers, tachometers, pressure gauges, and volume-measuring devices.

The mix tank shall have a mechanically powered, full-sweep, mixer with sufficient power to move and homogeneously mix the entire contents of the tank.

The distributor shall be equipped with a positive placement pump so that a constant pressure can be maintained on the mixture to the spray nozzles.

b. Mixing Equipment. The mixing machine shall have a continuous flow mixing unit capable of accurately delivering a predetermined proportion of aggregate, water, emulsion **[and rubber]** and of discharging the thoroughly mixed product on a continuous basis. The mixing unit shall be capable of thoroughly blending all ingredients together and discharging the material to the spreader box without segregation.

c. Spreading Equipment. Attached to the mixing machine shall be a mechanical-type squeegee distributor, equipped with flexible material in contact with the surface to prevent loss of slurry from the spreader box. It shall be maintained to prevent loss of slurry on varying grades and adjusted to assure uniform spread. There shall be a lateral control device and a flexible strike-off capable of being adjusted to lay the slurry at the specified rate of application. The spreader box shall have an adjustable width. The box shall be kept clean; coal-tar emulsion and aggregate build-up on the box shall not be permitted.

d. Calibration. The Contractor shall furnish all equipment and materials and labor necessary to calibrate the equipment. It shall be calibrated to assure that it will produce and apply a mix that conforms to the job mix design. Commercial equipment should be provided with a method of calibration by the manufacturer. All calibrations shall be made with the approved job materials prior to applying the seal coat to the pavement. A copy of the calibration test results shall be furnished to the Engineer.

625-4.3 PREPARATION OF PAVEMENT SURFACE. Bituminous pavement surfaces which have been softened by petroleum derivatives or have failed due to any other cause shall be removed to the full depth of the damage and replaced with new bituminous concrete similar to that of the existing pavement. Areas of the pavement surface to be treated shall be in a firm consolidated condition. They shall be sufficiently cured so that there is no concentration of oils on the surface.

A period of [   ] days shall elapse between the placement of a bituminous surface course and the application of the seal coat.

* *

The Engineer shall specify the time period. In order to ensure adequate adhesion and minimize cracking and curling, the pavement surface must be sufficiently cured prior to applying the seal coat. Experience has shown that approximately 90 days of

hot weather (daytime temperatures of 70 degrees F) is needed for adequate curing.

* *

625-4.4 CLEANING EXISTING SURFACE. Prior to placing the seal coat, the surface of the pavement shall be clean and free from dust, dirt, or other loose foreign matter, grease, oil, or any type of objectionable surface film. When directed by the Engineer, the existing surface shall be cleaned with wire brushes and a power blower.

Where vegetation exists in cracks, the vegetation shall be removed and the cracks cleaned to depth of two inches where practical. Those cracks shall be treated with a concentrated solution of a herbicide approved by the Engineer. Cracks shall then be [ ]. Areas that have been subjected to fuel or oil spillage shall be wire brushed to remove any dirt accumulations. The area shall then be primed with shellac or a synthetic resin to prevent the seal coat from debonding.

* *

The Engineer shall specify the appropriate method of treating cracks depending on the frequency and severity. This may include filling or routing and filling with a compatible crack filler, filling with a rubberized slurry seal at the time it is applied to the pavement surface, milling, etc.

* *

625-4.5 TACK COAT. After the surface has been prepared, a tack coat of 3 parts water to 1 part emulsified binder, as specified in paragraph 625-2.2, shall be applied at the rate of 0.05 to 0.10 gal/sy of surface. A tack coat or adhesion promoter shall be applied only if recommended by the emulsion supplier.

When a tack coat is not specified the pavement shall be dampened with a fog spray of water if recommended by the supplier. No standing water shall remain on the surface.

625-4.6 APPLICATION OF PLAIN EMULSION. Plain emulsion shall be applied at a uniform rate with a distributor or spray unit at the rate as determined in paragraph 625-3.4. When it is necessary to dilute the emulsion in order to aid application, the emulsion may be diluted with clean water but not by more than 10 percent.

625-4.7 APPLICATION OF [RUBBERIZED] SAND SLURRY. The **[rubberized]** sand slurry shall be applied at a uniform rate with a distributor, spray unit, or squeegee at the rate determined in paragraph 625-3.4. When the emulsion, water, aggregate, **[and rubber]** are blended, the material shall be premixed to produce a homogeneous mixture of uniform consistency. The quantities of materials to be combined in each batch shall be in accordance with the approved mix design.

The mixing sequence of the various components shall be the same as indicated in the job mix formula. After all constituents are in the mixer, the mixing shall continue for approximately five minutes or longer, if necessary. The mixing shall produce a smooth, free flowing homogeneous mixture of uniform consistency. Slow mixing shall be continuous from the time the emulsion is placed into the mixer until the slurry is applied by distributor truck or poured into the spreading equipment. During the entire mixing process, no breaking, segregating, or hardening of the emulsion nor balling, lumping, or swelling of the aggregate shall be permitted. The slurry shall be applied at a uniform rate to provide the quantity determined during placement of the test strip.

When a spreader box is used, a sufficient amount of slurry shall be fed to the spreader box to keep a full supply against the full width of the squeegee, so that complete coverage of all surface voids and cracks is obtained.

Manufacturer's recommendations regarding application by spraying or squeegeeing should be followed. In areas inaccessible to equipment, the slurry may be applied by means of a hand squeegee.

Upon completion of the work, the seal coat shall have no pin holes, bare spots, or cracks through which liquids or foreign matter could penetrate to the underlying pavement. The finished surface shall present a uniform texture.

Each application shall be allowed to dry thoroughly before the next coat is applied.

625-4.8 CURING. The mixture shall be permitted to dry for a minimum of [ ] hours after the final application before opening to traffic and shall be sufficiently cured to drive over without damage to the seal coat. Any damage to the uncured mixture will be the responsibility of the Contractor to repair.

* *

A minimum of 24 hours is recommended.

* *

625-4.9 HANDLING. The mixture shall be continuously agitated from the initial mixing until its application on the pavement surface. The distributor or applicator, pumps, and all tools shall be maintained in satisfactory working condition.

QUALITY CONTROL

625-5.1 CONTRACTOR'S CERTIFICATION. The Contractor shall furnish the manufacturer's certification that each consignment of emulsion shipped to the project meets the requirements of Federal Specification R-P-355, except that the water content shall not exceed 50 percent. The certification shall also indicate the solids and ash content of the emulsion and the date the tests were conducted. **[The Contractor shall furnish the manufacturer's certification to the Engineer that the latex rubber shipped to the project meets the requirements of the material specified in paragraph 2.4. It shall also indicate that the latex and coal-tar emulsion proposed for use are compatible and that the latex is recommended for combining with the coal-tar emulsion, water, and aggregate.]** The **[certification] [certifications]** shall be delivered to the Engineer prior to the beginning of work. The manufacturer's certification for the emulsion **[and rubber]** shall not be interpreted as a basis for final acceptance. Any certification received shall be subject to verification by testing samples received for project use.

[The Contractor shall furnish manufacturer's certification that the combination of latex and coal tar emulsion proposed for use has been successfully used in coal tar emulsion seal coat mixtures for a minimum of three years. The Contractor shall also furnish a certification demonstrating their experience in the application of a rubberized coal-tar emulsion seal coat for a minimum of three years.]

625-5.2 INSPECTION. The Contractor shall have an independent technical consultant on the job site at the beginning of operations. The consultant shall have knowledge of the materials, procedures, and equipment described in this specification and shall assist the Contractor regarding proper mixing of the component materials and application of the seal coat. The consultant shall have a minimum of 3 years experience in the use of rubberized coal tar seal coats. Documentation of this experience shall be furnished to the Engineer prior to the start of operations.

625-5.3 SAMPLING. Four random samples of material, from each days production, shall be tested for viscosity to determine conformance with the requirements contained in Table 3. One random sample per day shall be tested for the other properties of Table 3. In addition, a one-quart sample will be obtained daily and stored in a glass container. The container shall be sealed against contamination and retained in storage by the Owner for a period of six months. Samples shall be stored at room temperature and not be subjected to freezing temperatures.

A sample of undiluted coal tar emulsion and latex shall be sampled from each consignment shipped to the job.

625-5.4 ENGINEER'S RECORDS. The Engineer will keep an accurate record of each batch of materials used in the formulation of the seal coat.

METHOD OF MEASUREMENT

625-6.1 The coal-tar pitch emulsion shall be measured by the gallon (liter) of undiluted emulsion.

625-6.2 The mineral aggregate shall be measured by the ton (kilogram).

625-6.3 The latex rubber shall be measured by the gallon (liter).

* *

Paragraph 6.3 shall be deleted if a rubberized seal coat is not specified.

* *

BASIS OF PAYMENT

625-7.1 Payment shall be made at the contract unit price per gallon (liter) for the coal-tar pitch emulsion, per ton (kilogram) for the mineral aggregate[,][.] **[and per gallon (liter) for the latex rubber.]** These prices shall fully compensate the Contractor for furnishing all materials; and for all labor, equipment, tools, and incidentals necessary to complete the items.

Payment will be made under:

Item P-625-7.1	Coal-Tar Pitch Emulsion -per gallon (liter)
Item P-625-7.2	Aggregate - per ton (kilogram)
Item P-625-7.3	Latex Rubber - per gallon (liter)

* *

Item P-625-7.3 shall be deleted if a rubberized seal coat is not specified.

* *

TESTING REQUIREMENTS

ASTM 136	Sieve or Screen Analysis of Fine and Coarse Aggregates

MATERIAL REQUIREMENTS

Fed. Spec.P-355	Pitch, Coal-Tar Emulsion (Coating for Bituminous Pavements)
ASTM D 490	Tars, (For Use In Road Construction)

Appendix A

MIX DESIGN PROCEDURE ITEM P-625
TEST METHODS
CRITERION

This procedure shall be used to determine the capability of the materials furnished by the contractor to produce a seal coat mix within the range of TABLE 2 and meeting the requirements of TABLE 3.

The formulation is a combination of coal tar pitch emulsion, water, sand, and latex rubber. The samples furnished by the contractor shall be combined in the proportions recommended by the supplier and subjected to a sequence of five tests designed to eliminate any materials or combination of materials which do not meet the test criteria. Unacceptable materials in the formulation shall be eliminated from further consideration.

BROOKFIELD VISCOSITY
Step 1 & Step 2

1. Scope

This method covers the determination of the Brookfield viscosity, using materials and recommended formulations provided by the Contractor. It is designed to detect formulations that have incompatible quantities of latex and coal tar emulsion, that might flocculate, that have viscosities too low to suspend sand, and to identify any incompatibilities created by introducing sand.

2. Definitions

2.1 Brookfield viscosity - the viscosity determined by this method. The viscosity is expressed in centipoises (100 centipoises = 1 poise). Its value may vary with the spindle speed (shear rate) due to the non-Newtonian behavior of the coal tar emulsion, additive, and the water added.

2.2 Total liquids - coal tar emulsion, additive, and water.

2.3 Composite system - total liquids and sand.

3. Apparatus

3.1 Brookfield digital viscometer (model DV-II) and stand.
3.2 Number 1 and 3 HB spindles for DV-II viscometer.
3.3 Paint cans
 3.3.1 quart capacity.
 3.3.2 gallon capacity.

4. Sample preparation for Step 1 (4.1-4.3) and Step 2 (4.1-4.4)

4.1 Allow components (coal tar emulsion, water, sand, and additive) to reach 77 degrees F. This should take approximately 24 hours.

4.2 Mix coal tar emulsion and water in container specified in 3.3.2 with 50 strokes of a large laboratory mixing spoon.

4.3 Introduce additive to the mixture with an additional 50 strokes of the laboratory mixing spoon.

4.4 Add sand to total liquids with 50 strokes of a large laboratory mixing spoon, for composite mixture. Sand must be added slowly to avoid trapping air in the mixture. Stir composite mixture for 5 minutes and immediately proceed to Step 2.

5. Procedure

Step 1

5.1 Fill quart paint can specified in 3.3.1 to within one inch of the top with the material prepared in accordance with 4.1 through 4.3.

5.2 Insert spindle No. 3 HB in the material until the mixture level coincides with the immersion groove on the spindle shaft.

5.3 Avoid trapping air bubbles underneath the spindle.

5.4 Adjust rotational speed on the Brookfield viscometer to 50 revolutions per minute (rpm).

5.5 Start motor and record viscosity value in centipoises after five seconds of rotation. If the viscosity reading is too low for spindle 3, repeat procedure 5.1 through 5.5, using spindle No. 1.

Step 2

5.6 Repeat 5.1 - 5.5 with the composite mixture prepared in accordance with 4.1 through 4.4.

5.7 If the composite mixture does not fall within the acceptance criterion of 10 to 90 poises the following procedure for combining materials shall be used.

5.7.1 Discard materials from Step 1.

5.7.2 Mix coal tar emulsion and water in container specified in 3.3.2 with 50 strokes of a large laboratory mixing spoon.

5.7.3 Add sand to the mixture with 50 strokes of the laboratory mixing spoon.

5.7.4 Introduce additive to the mixture with 50 strokes of the laboratory mixing spoon, for composite mixture. Stir composite mixture for 5 minutes and immediately proceed to Step 1.

6. Report

6.1 The report should include:

6.1.1 Date of test and complete identification of the coal tar formulation tested.

6.1.2 Spindle number and rpm setting.
6.1.3 Temperature of the sample tested.
6.1.4 Viscosity of total liquids in poises. (Step 1)
6.1.5 Viscosity of composite system in poises. (Step 2)

Step 1 Criterion: Viscosities between 10 and 90 poises are acceptable
Step 2 Criterion: Viscosities between 10 and 90 poises are acceptable

For materials to move into **Step 2** testing the viscosity range must be met in **Step 1**. Likewise **Step 3** will not be continued until viscosity range is met in **Step 2** testing. If a material fails to met testing criteria in any step it will be eliminated from further testing.

CYCLIC FREEZE THAW CONDITIONING
Step 3

1. **Scope**
   This method covers the analysis of crack development in a composite rubberized coal tar emulsion seal coat when exposed to multiple cycles of freezing and thawing.

2. **Apparatus**
   2.1 12" x 12" square 16 gauge sheet metal mask with an 11" x 11" square center removed.
   2.2 12" x 12" square section of aluminum panel 3/16" thick.
   2.3 Oven capable of maintaininq 140 degrees F.
   2.4 Freezer capable of maintaining 10 degrees F.

3. **Procedure**
   3.1 Using mask described in 2.1, apply uniform thickness of the composite rubberized coal tar emulsion mixture to a panel as described in 2.2.
   3.2 Allow material to cure at 77 $\pm$ 2 degrees F and 50 $\pm$ 10 percent relative humidity for 24 hours.
   3.3 Place sample in the 140 degree F oven for 24 hours.
   3.4 Remove sample and record crack development.
   3.5 Place sample in 10 degree F freezer for 24 hours.
   3.6 Remove from freezer; this constitutes one freeze-thaw cycle.
   3.7 Repeat procedures 3.3 through 3.6 for a total of 10 cycles.

3.8 Inspect the samples after 5 and 10 cycles and rate the cracking in accordance with the following scale:

0 - No cracking
1 - Hairline cracking
2 - Slight cracking
3 - Moderate cracking
4 - Severe cracking

4. Report

4.1 Report the crack rating at 5 and 10 cycles.

Step 4 Criterion: Rating of 1 or less at 5 cycles is required. Rating of 3 or less at 10 cycles is required.

Any materials not meeting this requirement shall be eliminated from **Step 4.**

ADHESION
Step 4

1. Scope

This method covers the determination of adhesion of a composite rubberized coal tar emulsion seal coat and retention of sand by applying pressure sensitive tape.

2. Apparatus

2.1 12" x 12" square 16 gauge sheet metal mask with
2.2 3" x 6" rectangular center removed.
2.2 12" x 12" aluminum panel 3/16" thick.
2.3 Razor sharp blade, scalpel, or other cutting device with cutting edge in good condition.
2.4 Steel straight edge.
2.5 One inch wide semi-transparent pressure sensitive tape
2.2 with an adhesion strength of 38$\pm$5 oz./in. when tested in accordance with ASTM D 3330.
2.6 Hard, small head rubber eraser.
2.7 Table lamp.

3. Procedure

3.1 Using the mask described in 2.1, apply a uniform thickness of the composite mixture to the aluminum panel as described in 2.2.
3.2 Allow mix to cure at 77 $\pm$ 2 degrees at 0 $\pm$ 10 percent relative humidity for 24 hours.
3.3 Select a representative area.
3.4 Make a horizontal cut of about 1.5 inches. Then make another cut of 1.5 inches about 40 degrees to the horizontal cut. The cuts should intersect each other at their centers. When making the cuts, use the

straight edge and cut through the coating to the substrate in on steady motion. Brush off dislodged materials.

3.5 Inspect the cuts for reflection of light from the metal substrate to establish that the coating has been cut through completely. If the substrate has not been reached, do not attempt to deepen the cut. Instead, make another "X" in a different location. Remove the dislodged materials by brushing lightly.

3.6 Remove two laps of the pressure sensitive tape from the roll and discard. Remove an additional length at a steady rate and cut a piece about three inches long.

3.7 Place the center of the tape at the intersection of the cuts with the tape running in the same direction as the smaller angles. Smooth out the tape in the area of the cuts and then rub firmly with the eraser.

3.8 Wait for 60 seconds, then rapidly pull one end of the tape back on itself with the non-stick surfaces touching and running parallel to each other.

3.9 Inspect the 'X" cut area for removal of the coating from the substrate and rate the adhesion in accordance with the following scale:

- 5A No Peelinq or removal
- 4A Trace peelinq or removal alonq incisions
- 3A Jagged removal along incisions up to 1/16 inch on either side
- 2A Jagged removal along most incisions up to 1/8 inch on either side
- 1A Removal from most of the area of the "X" under the tape
- 0A Removal beyond the area of the "X"

3.10 Inspect the tape for adhesion of sand.

3.11 Repeat the test in two other locations on the test panel.

4 Report

4.1 Report the number of tests, their mean value and range.

4.2 Report whether sand adhered to the tape as yes or no.

Step 5 Criterion: No sand can adhere to the tape. No debonding of the seal coat or the test medium is allowed (adhesion rating of 5A is required).

Any materials not meetinq this requirement shall be eliminated from being tested in **Step 5.**

FUEL RESISTANCE
Step 5

1. Scope

This method determines the resistance of the composite rubberized coal tar emulsion seal coat to kerosene.

2. Apparatus

2.1 2 6" x 6" square 16 gauge sheet metal masks with a 4" a 4" square center removed.
2.2 6" x 6" unglazed white ceramic tile with an absorption rate of 10-18 percent (determined in accordance with ASTM C 67).
2.3 Brass ring, 2" diameter and 2" high.
2.4 Kerosene meeting requirements of ASTM D 3699.
2.5 Silicone rubber sealant.

3. Procedure

3.1 Immerse the ceramic tile in distilled water for a minimum of ten minutes.
3.2 Remove excess water from the tile to produce a damp surface before applying the seal coat.
3.3 Using the mask described in 2.1 apply one layer of the coal tar emulsion mixture to the tile. Spread even with the top of the mask using a spatula or other straight edge.
3.4 Allow the sample to cure for 96 hours at 77 ± 2 degrees F. and 50 ± 10 percent relative humidity.
3.5 Position a second mask on top of the first mask.
3.6 Apply a second coat of coal tar emulsion mixture. Spread even with the top of the second mask.
3.7 Cure as in step 3.4.

3.5 After curing, affix the brass ring to the seal coat on the tile with silicone rubber.
3.6 Fill the brass ring with kerosene.
3.7 After 24 hours, remove the kerosene from the brass ring, blot dry and immediately examine the film for softness and loss of adhesion. Immediately after the film is examined, break the tile in half, exposing that part of the tile whose film was subjected to the kerosene.
3.8 Evaluate for penetration of kerosene through the sealer and loss of adhesion.

4. Report

4.1 Report the results as pass or fail. Visible evidence of leakage or discoloration shall constitute failure of the test.

Step 6 Criterion: A "pass" rating in the fuel resistance test is required.