Cairo University/Massachusetts Institute of Technology

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Evaluation of Methods to Improve the Characteristics of Asphalt Cements and Concrete Mixtures

By
The Performance of Paraffinic-Waxy Asphalt Cements in Egyptian Road Construction Project

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PERFORMANCE OF PARAFFINIC-WAXY ASPHALT CEMENTS IN EGYPTIAN ROAD CONSTRUCTION

EVALUATION OF METHODS TO IMPROVE THE CHARACTERISTICS OF ASPHALT CEMENTS AND CONCRETE MIXTURES

CU/MIT TECHNOLOGICAL PLANNING
PROGRAM
CAIRO UNIVERSITY

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FOREWORD

A four-year research program entitled, "Performance of Paraffinic-Waxy Asphalt Cements in Egyptian Road Construction," sponsored jointly by the United States Agency for International Development and a group of Egyptian road construction companies was initiated in June, 1979 by the Massachusetts Institute of Technology, MIT, and Cairo University, CU. The final objective of the project is to improve the performance of pavements constructed with the Egyptian paraffinic-waxy asphalt.

The first year research (July, 1979 to June, 1980) was mainly aimed at achieving a better understanding of the important factors affecting the use of Egyptian asphalts in road construction. The results of the first year research were published in two previous reports entitled:

1) Performance of Paraffinic-Waxy Asphalt Cements in Egyptian Road Construction: Literature Review and Background of the Problem in Egypt, TAP Report No. 80-4.

2) Performance of Paraffinic-Waxy Asphalt Cements in Egyptian Road Construction: Chemical and Physical Properties of Western Desert Asphalt Cements, TAP Report No. 80-5.

The work during the second phase included the following tasks:

1) Establish the basic chemical, physical and engineering properties of the pavement samples recovered during the first year from selected roadway sections;

2) Investigate methods of improving the performance of pavements constructed with Egyptian waxy asphalt; and

3) Design of a full scale field testing program.

The results of part 1 of the second phase were published in a previous report entitled: "Field and Laboratory Evaluation of In-Service Roadway Pavements," TAP Report No. 81-4.

This report presents the results of the second work item listed above. The work was supervised by Professors Abdel-Moneim Osman and Mohsen M. Baligh. The following individuals, listed alphabetically, have participated in the preparation of this report: A. Azzouz (MIT); F. Ebaid (Egyptian Petroleum Research Institute, EPRI); R. Elmitiny (CU); F. Ezzat (EPRI); A. Gadallah (CU); M. Noureldin (CU); L. Radwan (CU); M. Rushdy (EPRI); E. Sarhan (Ain Shams University); M. Talaat and S. El Beih (Roads and Bridges Authority). S. Noureldin and G. Darwish provided valuable assistance during the course of the study and the preparation of this report.

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The views and opinions expressed in this report are those of the authors and do not necessarily reflect those of the sponsors, CU/MIT Technological Planning Program, DRTPC, Cairo University, the Highways and Bridges Authority, or the Road Construction Companies.

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CHAPTER 1

INTRODUCTION

The performance of Egyptian roads constructed by means of paraffinic waxy asphalt cement produced from Western Desert crudes is often less than satisfactory. This report presents the results of a laboratory investigation to evaluate methods of improving the properties of these asphalt cements and their asphalt concrete mixtures.

Chapter 2 reviews existing experience and literature regarding the effect of additives on the behavior of asphalts and asphalt-concrete mixtures. Chapter 3 discusses the availability of additives in Egypt and presents a cost-analysis of various improvement methods. Chapter 4 describes the experimental design for this study and the basic properties of the materials used (asphalts, aggregates,...etc.). Chapter 5 presents the results of laboratory tests conducted to re-evaluate the effects of additives and aggregate types and gradation on properties. Chapter 6 summarizes the main conclusions of the study and provides recommendations for practice and for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 General:

A review of previous work conducted in the area of improving asphalt cements and/or their mix characteristics indicates that one of the most successful methods consists of utilizing additives. The additives may react with and/or substitute the asphalt binder or improve one or more of the weaker properties by changing the viscosity or thermal susceptibility. Furthermore, stress improvements can be achieved by adding to the bitumen a new material with elastic properties similar to those of the asphaltic concrete mixture but having a higher tensile strength, such as rubber. This literature review concentrates on additives that partially substitute or improve the behavior of the asphalt binder.

The most commonly used types of additives that improve the asphalt binder and consequently the mixture properties are sulfur, carbon black, rubber and resins. The previous experience with these four types of additives will be discussed in the following sections.

2.2 Sulfur Asphalt Mixture:

Sulfur was first used in the paving industry around 1935 in Ohio, U.S.A. (2). A paving brick filler (named Sulmor), consisting of asphalt and plasticized sulfur, was developed by

Lotehiser and Schofield (3). In 1936, Bacon and Bencowits (4,5) developed "The Texas Gulf" by basically adding as much as 50% of elemental sulfur in asphalt at 149°C and stirring the mixture vigorously.

Since 1960, significant advances in the use of sulfur in asphalt mixtures were achieved. One of the methods used was adding hot liquid sulfur, essentially as a filler, to a hot sand-asphalt mix during a second wet mixing cycle which occurs after the asphalt has been mixed with the aggregate (6). The addition of sulfur using the prescribed method transforms the mixtures containing poorly graded, unstable sands with low stability and produces mixtures of high stability. Cary (7) found that a significant increase in the stability of sand mixtures with poorly graded sands takes place. Mixing temperature ranged between 132°C. and 140°C. The final mixture was composed of sand, asphalt and sulfur with approximate weight ratios of 82, 6 and 12, respectively. The mechanical stability of the mixture was very high due to the solidified sulfur, which fills the internal voids and becomes part of the aggregate structure. In another method, sulfur was preblended with asphalt to produce sulfur extended asphalt. The hot sulfur extended asphalt binder was then mixed with the aggregates in the same way as asphalt alone (8). A third method attempted also to create a sulfur extended asphalt binder by the separate addition of the components and pugmill blending of sulfur and asphalt, rather than preblending (9, 11). The use of

this method has been described in detail by Kennepols, et al (10). This method can be used with a batch or a continuous type mix plant. This process is considered to be simpler than the preblending process.

2.2.1 Proportioning of Sulfur-Asphalt

The effect of sulfur in asphalt concrete mixtures depends on the sulfur concentration and the sulfur-asphalt ratio. At low sulfur asphalt ratios (less than 1 : 5, by weight), the sulfur modifies the chemical and rheological properties of the asphalt through chemical reactions, and the predominant reactions depend on temperature. At higher temperatures (above 240°C) dehydrogenation of the asphalt (similar to air blowing) takes place (14). At lower temperatures (below 140°C) sulfur combines with asphalt. In either case, the rheological properties of the asphalt (penetration, temperature susceptibility, ductility, etc...) are modified mainly due to the change in the asphaltene-resin ratio. With a ratio of sulfur to asphalt exceeding unity, the sulfur acts as a filler and a "structuring agent." At these high sulfur contents, the workability (at processing temperatures between 130°C and 160°C) and the mechanical strength (at service temperatures) of the mixture are improved. This permits the lowering of aggregate quality standards and the design of high quality mixtures using inexpensive poorly-graded materials, such as one-sized sands.

2.2.2 Effect of Sulfur on Asphalt Properties:

A series of laboratory tests were carried out by Dah-Jinn-Lee (15) to study the effect of adding different types of sulfur to asphalt cements with different penetration grades. Results showed that the addition of small amounts of sulfur at 149°C increased penetration and decreased the softening point and viscosity of the asphalt. The optimum sulfur content was 5-10% for tire sulfur and 15-20% for insoluble sulfur. Tests to determine the amount of bonded vs. free sulfur indicated that about 75% of the added sulfur remained in colloidal suspension (15). Only 5 to 20% of the sulfur reacted and actually entered the asphalt molecules. This low percentage of bonded sulfur compared with what was found by Petrossi (16) is thought to be due to differences in asphalt composition, especially in naphthene-aromatics, and in the reaction temperature.

Sulfurized asphalts were subjected to loss-on heating by the thin-film oven and durability tests (15). It was found that at low sulfur concentrations and under less severe weathering conditions, some improvement in aging characteristics takes place due to sulfur addition. At high sulfur concentrations and more severe aging conditions, sulfur caused no improvement and, in some cases, caused an increased hardening. This hardening was associated with an increase in the asphaltene content.

2.2.3 Mechanical Properties of Sulfur-Asphalt Concrete Mixtures

Dah-Jinn-Lee (15) added sulfur to asphalt at 150°C, before mixing with limestone aggregates. Test results indicated an increase in stability, immersion strength and cohesion (15). On the other hand, when sulfur was mixed with aggregates before adding the asphalt, no consistent results were obtained (15). At 7% asphalt, the optimum sulfur content, based on stability, cohesion and unit weight, was 5%. This sulfur content increased stability by 123%, immersion compression strength by 62%, cohesiometer value by 10% and the unit weight by 8%.

Kennedy and Haas (16) found that by adding up to 50% sulfur, all engineering properties, including the stiffness and fatigue characteristics, were significantly improved.

2.3 Carbon Black:

Commercial carbon products, in essentially pure form, range in properties from the very dense, hard and brilliant diamond, and in decreasing order of densities and crystallinity, through graphite, carbon black, coke and charcoal. Carbon black is unique amongst these materials in being the only one formed in the vapor phase from the decomposition of vaporized hydrocarbons, whereas the other carbon products (with the exception of crystalline diamonds) are produced by pyrolysis of solid organic substances.

Vapor phase pyrolysis is a smoke containing very small

size particles of carbon black having a high surface area and a carbon content of over 97%. The large surface area of the carbon black particles and their hydrophobic character makes carbon black, when properly dispersed, a part of the asphalt cement. The carbon black is of sub-micron size and, therefore, fine enough to become an integral part of asphalt and serves as a reinforcing agent. Studies carried out at the Matrecon Inc. laboratories by the Cabot Corporation from 1972 to 1976 (24) in the U.S.A. made the concept of reinforcing asphalt with carbon black practical by the development of a pelletized form of carbon black. Flux oil was used as a pelletizing agent in order to: (1) facilitate carbon black dispersion, and (2) balance its stiffening effect on asphalt (25).

The chemical and physical properties of carbon black were discussed by Donnet, Smith and Strokes (17,18,19). The important role of carbon black as a useful model to study the effects of filler dimensions and asphalt wettability has been recognized by Anderson and Goetz (20). The earliest work on using carbon black as a reinforcing agent for asphalt has been reported by Alliotti (21) and Martin (22).

In order to improve wear resistance of pavements, the Federal Highway Administration in the U.S.A. (FHWA) carried out a detailed experiment (23) to determine the marked differences between carbon black and conventional fillers in their effect on asphalt. Results showed significant improvements in the durability, wear resistance and temperature viscosity

characteristics of the asphalt achieved when certain types of carbon black were dispersed in asphalt at concentrations of 11 to 16 percent (by weight).

2.4 Rubber

The first attempt to modify bituminous binders by adding rubber was conducted in 1898 by de Caudenberg, who patented a process for manufacturing rubber-bitumen. Many difficulties were encountered in exploiting the patent and the process lapsed. This work was reported later by Freier (26).

The rubber industry used bitumen to modify rubber for various purposes, until the advent of rubber in granular and powder forms (about 1930), no significant progress was made to bitumen properties by the addition of small proportions of rubber. Work began in the Netherlands (27,30) and Great Britain (29,30,31), mainly on the assessment of the change in the rheological properties of the binders as measured in the laboratory. Full-scale road trials were carried out (34,35) and experimental rubberized sections showed improved performance.

In Great Britain, rubberized rolled-asphalt carpets were laid by Dussek in 1937 (38). The ground tyre-tread was of a coarse grading and intended to remain as discrete rubber particles rather than being blended in the bitumen.

From about 1950, research on the use of rubber in bituminous road surfaces was intensified. Laboratory research has shown clearly that quite small percentages of rubber,

incorporated in bituminous binders, have marked effects on the physical properties.

Synthetic rubbers, such as nitrile rubber, have also been suggested as materials for modifying bitumens. Research on the use of synthetic rubbers with bitumens has been carried out mainly in Great Britain (39). Rubber was first used in road construction in the form of solid blocks. In recent years, relatively small amounts of rubber are added to bituminous road mixtures.

2.4.1 Types of Natural Rubber Used in Bituminous Binders

The natural rubber molecule consists of a very long chain of many isoprene units ($[-CH_2-CH = C(CH_3)-CH_2-]n$) which are linked or coiled. The elasticity of rubber results from this form. Heating and milling lead to the degradation of rubber. The rate of degradation depends on the temperature and the material in which rubber is dispersed.

There are different forms of rubber available for use in bituminous binders. The following is a brief summary of commercially available natural rubber.

1. Latex: Latex consists of a suspension of rubber globules in a waterway serum. Natural rubber is extracted from the trees in the form of latex which is then concentrated and stabilized in various ways to give commercial products with varying dry-rubber contents, usually between 60 and 70%. The composition of the latex varies with the process used as well as the concentration and the stabilizing agents utilized.

Rubber latex is available in two forms: evaporated lates and centrifuged lates depending on the process used for concentrating the natural products.

2. Sheet Rubbers: Various forms of sheet rubbers made from coagulated latex are available.

3. Rubber Powder: Rubber powder is made by spray-drying the latex or by hammering lightly volcanized coagulum.

4. Ground Tyre-Tread: Tyres used are ground tyre-tread powder to improve permanent performance. The volcanized powders are more difficult to disperse in the mix, but are generally cheaper than unvolcanized powder which contains approximately 40 percent of inert filler.

2.4.2 Effect of Rubber on the Properties of Bituminous Binders

A number of theories are available to explain the effects of rubber on the rheological and physical properties of asphalts. Van Rooijen (40) proposed that, by absorbing some of the oily constituents from the bitumen, rubber grains swell to about five times their volume, disperse in the bitumen, and thus increase the bitumen hardness. De Decker and Nijveld (41) considered that at least part of the rubber dissolves into the bitumen and hence influences certain properties. Mason, Thrower and Smith (42) found that the changes in viscosity and brittleness of the bitumen take place due to molecular dispersion of the rubber.

Presently, no conclusive evidence exists to prove the

superiority of one hypothesis over the others, but it is clear that the degree of dispersion of the rubber has a profound effect on the resultant mixture (43).

The addition of rubber tends to increase the viscosity and reduce the brittleness of the bitumen (44). The degree of these changes depends on the bitumen and rubber types, and the method of preparation of the binder (44,45,46,47), the quantity of rubber used and the heat treatment of the mixture before testing. Smith (44) found that the increase in bitumen viscosity was more pronounced with softer bitumens and that, at 25°C, rubber content is proportional to the logarithm of viscosity.

The addition of rubber invariably increases the softening point of the binder (40,44,45). Experiments by Welborn and Babashak (46) found that the softening point increases due to the addition of up to 15% free sulfur with rubber latex.

In most cases, rubber reduces the penetration of the binder. However, there are a few exceptions. Using a bitumen of low asphaltene content, Lewis and Welborn (47) found that penetration increases with increasing rubber content. The addition of free sulfur with the rubber has also been found to increase penetration (41).

Rubber reduces the temperature susceptibility over all temperature ranges (48). The effect is more pronounced for the softer bitumens.

Rubber increases the elasticity of bitumens (44,45,47).

However, no improvement in ductility was observed unless up to 10% of sulfur is added to the rubber (46).

2.4.3 The Use of Rubber in Bituminous Mixtures

Experience indicates that, unless special precautions are taken, the effects of adding rubber will be negligible. A most effective method consists of dispersing rubber in the binder before mixing with the aggregates. Nevertheless, poor dispersion of the rubber in the binder produces unworkable mixtures and thus leads to difficulties in compaction operations of the road. Materials containing a high percentage of ground tyre-tread (5% of total mixture) were difficult to compact and disintegrated rapidly.

2.5 Resins:

The addition of small quantities of resin (say up to 5%) to the bitumen can improve its performance. No compatibility problems were encountered and the resin dissolved completely in the bitumen. Also, the resins increased the bitumen flexibility and resilience.

In Egypt, Bahram, Ezzat and Shaker (50) used resins to improve the poor temperature-susceptibility characteristics of selected bitumens. A series of experiments were undertaken to find out the possibility of increasing stability with the addition of resins (51). The type used was of the Escorez-3000, as denoted by ESSO Chemicals Co. of Egypt. Varying concentrations of the resins were mixed with different amounts of bitu-

men used in concrete mixtures. The addition of 5% resins to a sand-asphalt mix increased stability to a maximum of 710 lb.

2.6 Summary:

1. Sulfur can be used as an additive to improve bitumen properties and performance. At small sulfur contents (up to 20% by weight of the bitumen), sulfur acts as a modifier and the associated reactions depend primarily on the mixing temperature. At temperatures below 140°C, sulfur combines with the asphalt, and above 340°C, asphalt dehydrogenates. In either case, the sulfur modifies the rheological properties of the asphalt through chemical reactions, and changes the asphaltene/resins ratio. At high sulfur contents (e.g. above 20% by weight of bitumen), sulfur can be considered as a filler and a structural agent that generally improves the mixture workability at processing temperatures and its chemical properties at service temperatures.
2. When carbon black is properly dispersed in the bitumen, it becomes part of the binder and improves the bitumen durability, wear resistance and temperature susceptibility.
3. The effects of adding rubber to bitumen depend on the type of bitumen, the type of rubber and the preparation method used. Rubber increases bitumen viscosity and tends to decrease its brittleness, softening point, elasticity, penetration, and temperature susceptibility over all temperatures.

4. The addition of resins increases bitumen flexibility, resilience, and most notably, improves its temperature susceptibility. In Egypt, Escorez resin was found to increase asphalt mix stability without causing compatibility problems.

CHAPTER 3

AVAILABILITY OF ADDITIVES IN EGYPT AND COST ANALYSIS

The availability and unit costs of various additives in Egypt represent essential factors in finding practical solutions to the performance problems associated with the Egyptian paraffinic waxy asphalt cement (Alexandria asphalt). Field visits were therefore made to investigate the availability of additives in Egypt, as well as the quantities and unit prices of the imported and locally produced materials. Table 1 summarizes these data.

Figure 1 shows the increase in cost of the Alexandria asphalt cement due to the use of various additive types and contents*. Based on the price difference between the Suez asphalt (L.E. 27.5/ton) and Alexandria asphalt (L.E. 17.5/ton), an allowable percent increase in the price of Alexandria asphalt of 57.14% is considered reasonable. For example, when sulfur or air-blown asphalts (L.E. 60/ton) are utilized as additives, economical considerations require their proportions not to exceed approximately 20% by weight of Alexandria asphalt. Similarly, the petroleum coke content cannot exceed 14% whereas the other types of additive contents could not exceed 2% in order to keep the final product economically competitive with the Suez asphalt.

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* Prices and comparisons do not include transportation costs.

Additive		Quantity tons/year Imported	Locally Produced Existing	Expected	Producing Co.	Unit Price
1. Sulfur		20,000				
			5,500		El-Nasr Petroleum C., Alex. and General Petroleum Co. (Ras Gharib)	
				70,000	Suez Petroleum Co., and Mostorod Petrol Co.	L.E. 60/ton
2. Petroleum Coke				100,000	Suez Petroleum Co.	L.E. 72 to 100/ton
3. Propane Deasphalting tar Asphaltene				104,000	El-Nasr Petroleum Co. and Alex. Pet. Co.	L.E. 20/ton
4. Carbon Black	HAF			10,000	El-Nasr P.Co.	L.E.700/ton
	FEF					"
	SRE					"
	ISAF					"
5. Rubber						
Natural Raber	SBR					L.E.1800/ton
	NBR					L.E.1400/ton
Synthetic rubber	SBR			80,000	Egyptian Rubber Corporation	L.E.1150/ton
6. Resins						
No.3102					ESSO Chem.Co.	L.E. 400/ton
No.1200					ESSO Chem.Co.	L.E.1200/ton

HAR	high abrasion furnace	ISAF	Intermediate abrasion furnace
FEF	fine extraction furnace	SBR	Styrene butadiene rubber
SRE	Semi-reinforcing furnace	NBR	nitrile butadiene rubber

Table 1.: Quantities, Sources and Prices of Possible Asphalt Cement Additives

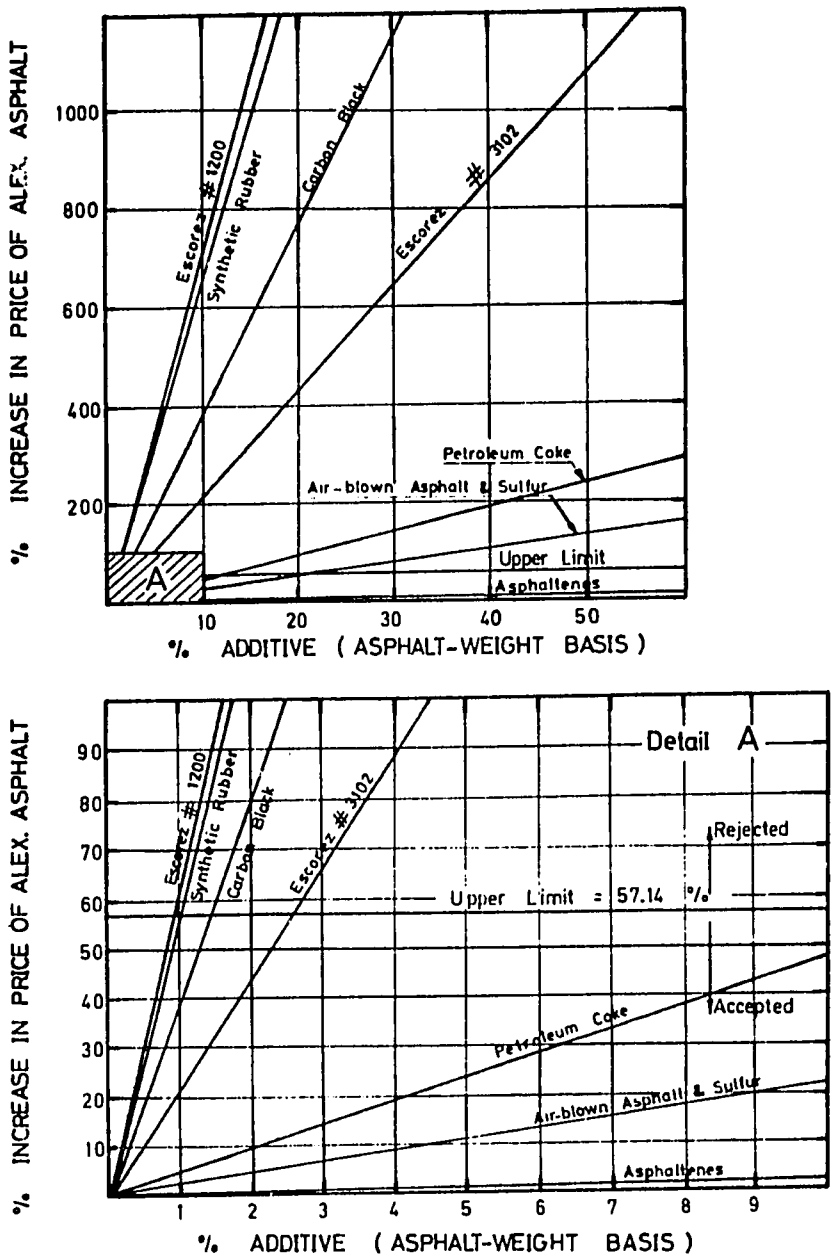


Figure 1 : Cost Analysis of Different Additives

CHAPTER 4

EXPERIMENTAL DESIGN AND BASIC PROPERTIES OF MATERIALS

4.1: Experimental Design

The experimental program of this study is divided into two main phases:

Phase 1: Investigation of mix component effects on the behavior of laboratory asphalt concrete mixtures.

Phase 2: Investigation of the effects of several additive types and their concentrations on the physical and chemical characteristics of asphalts and engineering properties of asphalt concrete mixtures.

4.1.1. Phase 1: Mix Component Effects:

Based on previous field experience, the severity of the waxy-asphalt cement performance problems appears to depend on two main factors related to mix components: (1) the coarse aggregate type; and (2) the gradation of the aggregate mix. Therefore, the experimental program in this phase of the study is designed to include the two coarse aggregate types available in Egypt (crushed limestone and basalt) and two surface mix aggregate gradations (4C dense and 3B coarse standard gradations, see ref. 1, table 8.10). Silicious sand and limestone dust are used as the fine aggregate and mineral filler, respectively.

Table 2 shows the arrangement of mixtures prepared to study the effects of the above mix components. Mix-

Mix No.	Coarse Aggregate		Aggregate Gradation		Asphalt Source		Asphalt Content	Number of Replicates	Number of Mix Samples
	lime-stone	Basalt	Dense[1]	Coarse[2]	Alex	Suez			
1	x		x		x		x x x x	3	12
2	x			x	x		x x x x	3	12
3		x	x		x		x x x x	3	12
4		x		x	x		x x x x	3	12
5	x		x			x	x x x x	3	12
6		x	x			x	x x x x	3	12

1) Asphalt Institute 4-C gradation of Surface mix
2) Asphalt Institute 3-B gradation of Surface mix

Table 2: Experimental Program: Investigation of Mix Component Effects.

tures number 5 and 6 are considered as a reference for comparisons and are prepared according to the common standards in Egypt utilizing the accepted Suez asphalt cement (60/70 pen. grade) and crushed limestone (Mixture No.5) or crushed basalt (Mixture No.6) as a coarse aggregate in the surface mix.

4.1.2: Phase 2: Additive Effects:

Based on available quantities in Egypt, and practical and economical considerations, the study involves four types of additives: (1) Sulfur; (2) petroleum coke; (3) air-blown asphalt; and (4) propane deasphalting tar (PDT).

The investigation of additive effects is divided into two phases. The first consists of a pilot study to determine the general effects of the various additives on Egyptian waxy asphalt cement properties and the second is aimed at selecting the different improved asphalt blends to be used in the large scale test track (additive type, concentration, preparation method,...etc.).

For each additive type, a complete laboratory testing program consists of determining the effects of three to four additive contents on the physical properties of the treated asphalt cement. The optimum content(s) are then utilized in the asphalt concrete mixtures to study the effects of additives on the engineering properties.

4.2: Testing Program:

The various tests conducted to evaluate the basic properties of materials and mixtures are given in Table 3.

4.3: Basic Properties of Materials:

Table 4 presents the physical properties of the two coarse aggregates investigated herein: limestone and basalt. As expected, limestone exhibits higher degree of absorption, disintegration, and wear whereas basalt has a markedly higher specific gravity. Table 5 gives the specific gravity of the fine aggregate and the mineral filler.

Tables 6 and 7 show the physical properties and structural components of Alexandria and Suez asphalt cements and Figures 2 and 3 compare their properties.

Table 6 clearly shows that the kinematic viscosity of the Suez asphalt is significantly higher than that of Alexandria asphalt at all test temperatures (60°, 100°, and 135°C), both before and after the thin-film-oven test. Further examination of Table 6 shows that the change in properties due to thin-film-oven testing are more pronounced in the Suez asphalt, compared to changes in Alexandria asphalt. This may be explained by the results shown in Table 7 which indicate that Suez asphalt has higher resin and asphaltene contents and, therefore, is more susceptible to the hardening conditions imposed during thin-film-oven testing. These results indicate that the Alexandria asphalt cement is less susceptible to hardening during plant mixing operations and, hence, suggest that pavements constructed with Alexandria asphalt cements will

TEST	Designation Number AASHO Standards	ASTM Standards
I. Aggregates		
- Bulk Specific Gravity of Coarse Aggregate	T85	C127
- Bulk Specific Gravity of Fine Aggregate	T84	C128
- Bulk Specific Gravity of Mineral Filler	T100	D854
- Bulk Specific Gravity-Saturated surface-dry basis		
- Disintegration in water		
- Los-Angeles test	T96	C131
- Sieve Analysis	T27	C136
II. Asphalt Cement		
- Penetration at 25°C,100g, 5 sec.	T 49	D1270
- Ductility at 25°C, 5cm per min.	T 51	D 113
- Softening Point	T 53	D2398
- Absolute Viscosity at 60°C	T202	D2171
- Kinematic Viscosity	T201	D2170
- Thin-Film-Oven Test	T179	D1759
- Specific Gravity	T228	D 70
III. Asphalt Concrete Mixtures		
- Marshall Test	---	D1559
- Hveem Cohesion Test	---	D1560

Table 3: Tests Conducted on Materials and Mixtures.

PROPERTY	Lime-stone	Basalt	Standard Specifica-tions
- Bulk Specific Gravity	2.539	2.853	---
- Bulk Specific Gravity (saturated surface-dry basis)	2.583	2.888	---
- Apparent specific gravity	2.663	2.957	---
- Percent absorption	1.88	0.80	5 max.
- Percent disintegration in water	0.46	0	---
- Percent wear (Los-Angeles test)	31.8	20	40 max.

Table 4: Physical Properties of Coarse Aggregates

Aggregate Types	Specific Gravity
Fine aggregates-silicious sand	2.680
Mineral Filler-Limestone dust	2.800

Table 5: Specific Gravities of Fine Aggregate and Mineral Filler

	Alex.	Suez	SPECIFICATIONS Egyptian	AASHTO	ASTM
I. Original Asphalt Cement					
Penetration, 0.1 mm					
at 5°C	9	9.2			
at 10°C	15	15			
at 15°C	25	24			
at 25°C	66	62	60/70	60/70	60/70
Ductility, cm	100+	100+	90+	100+	100+
Softening Point, °C	50.0	50.5	45/55		
Kinematic Viscosity, C.St.					
at 60°C	96,758	208,039			
at 100°C	1,792	3,185			
at 135°C	240	352	320*		
Specific Gravity at 60°C	1.018	1.020			
II. After Thin-Film Oven Test					
Penetration, % of original	59.1	59.7		54+	52+
Ductility, Cm.	100+	46.0		50+	50+
Softening Point, °C	51.2	57.8			
Kinematic Viscosity, C.St.					
at 60°C	252,810	941,078			
at 100°C	3,027	7,562			
at 135°C	336	664			
Weight Loss, %	0.14	0.7	1-	0.8-	

* Proposed to be included in the new Egyptian Specifications

Table 6: Physical Properties of Asphalt Cements and Standard Specifications

Asphalt Source	Wax Content,%	Oils Content,%	Resins Content %	Asphaltenes Content,%	Wax in Oil Fraction.%	Asphaltenes in Resinous Fraction,%
Alex.	7.5	33	51	16	22.73	23.9
Suez	5.68	23	55	22	24.70	28.6

Table 7: Component Analysis of Asphalt Cements.

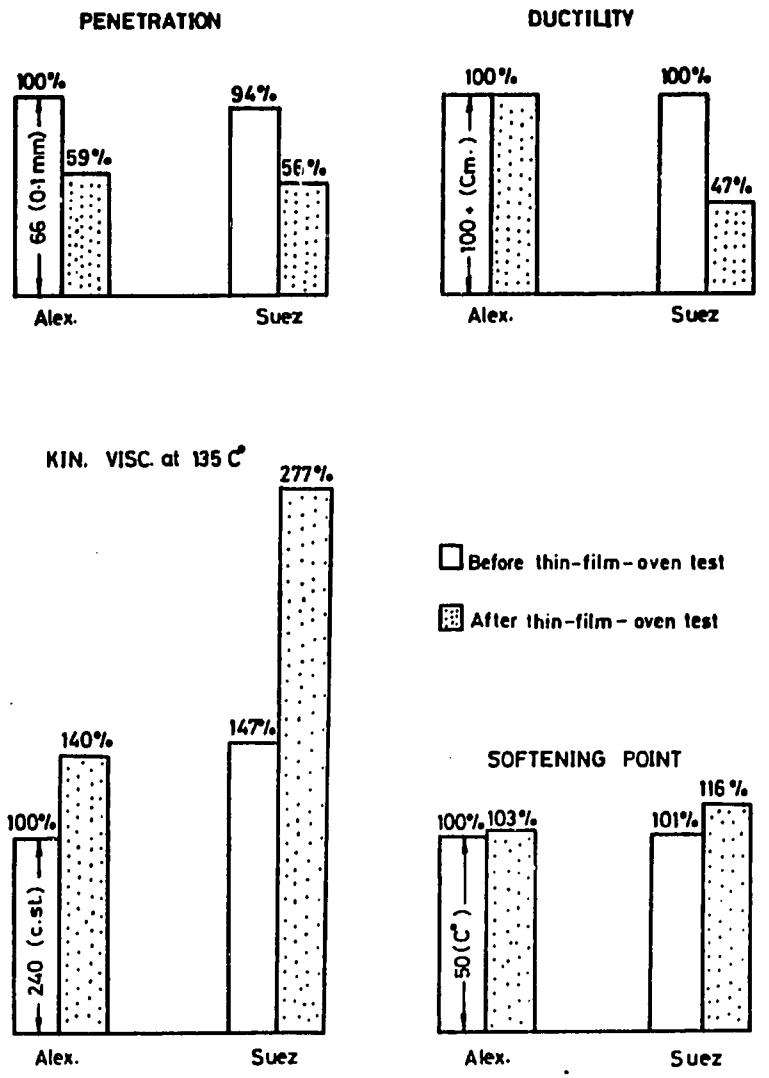


Figure 2 : Physical Properties of Alex. vs. Suez Asphalt Cements

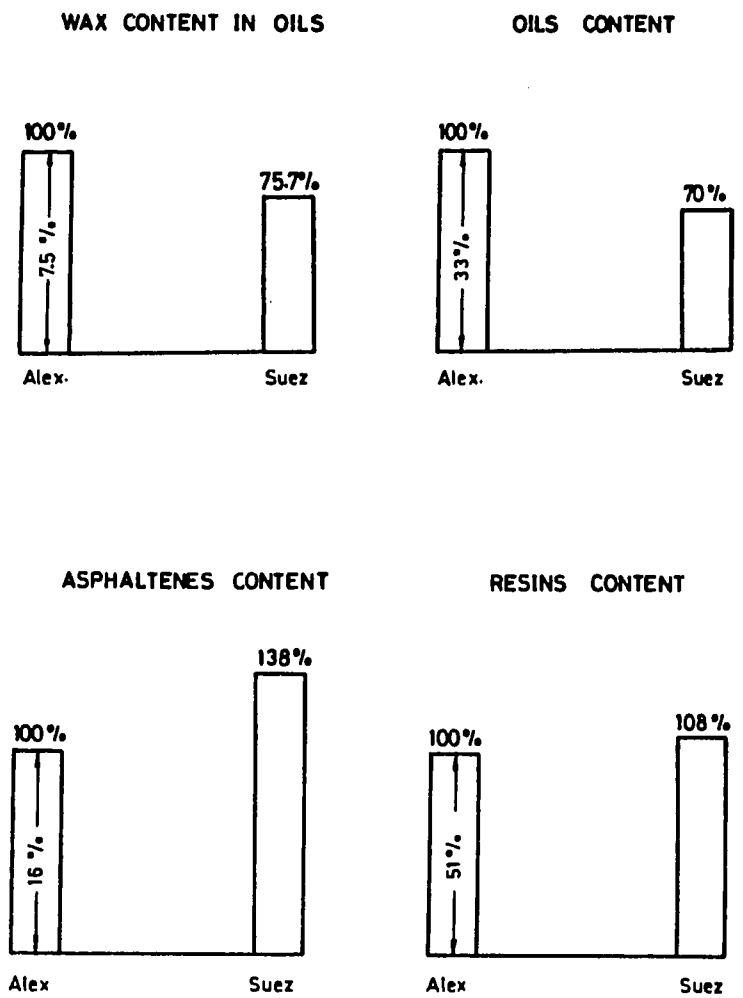


Figure 3 : Chemical Prporties of Alexandria vs. Suez Asphalt Cements

have a longer service life.

It is interesting to note that the percentage of wax in the oil fraction of the Alexandria asphalt sample tested herein (22.73% in Table 7) is relatively low when compared to results of tests conducted earlier on 24 different samples (ref. 1, Table 3-4). On the other hand, in the Suez asphalt this percentage (24.7%) is very high compared to previous test results (ref. 1). This suggests that the degree of improvements determined in the present testing program on Alexandria asphalts and their concrete mixtures represent a lower bound on improvements expected in the average Alexandria asphalt cements.

Figure 4 shows the "Bitumen Test Data Chart" suggested by Heukelom (52) to relate the consistency of asphalt with temperature. Results of penetration tests conducted at two or three different temperatures are plotted on the upper left part of the chart. Similarly, results of viscosity tests at two temperatures (usually 60°C and 135°C) are plotted on the lower part of the chart.

In order to compare the temperature susceptibility of the Suez and Alexandria asphalts, test data are plotted in Figure 4. Both asphalt cements deviate from the line of the hypothetical non-waxy asphalt. The higher slope of the Alexandria asphalt viscosity line together with the greater wax content of this asphalt (Table 7) clearly indicate its higher temperature susceptibility, as compared to the Suez asphalt.

4.4: Gradation of Aggregate Mixtures:

Table 8 and Figures 5 and 6 show the specification limits of the dense grading (4-C) and coarse grading (3-B) of aggregates according to the Asphalt Institute Specifications. For the purpose of this study, the required gradations are developed by controlling the proportions of the coarse aggregate, fine aggregate and mineral filler to exactly satisfy the midpoint of the specification limits in each case.

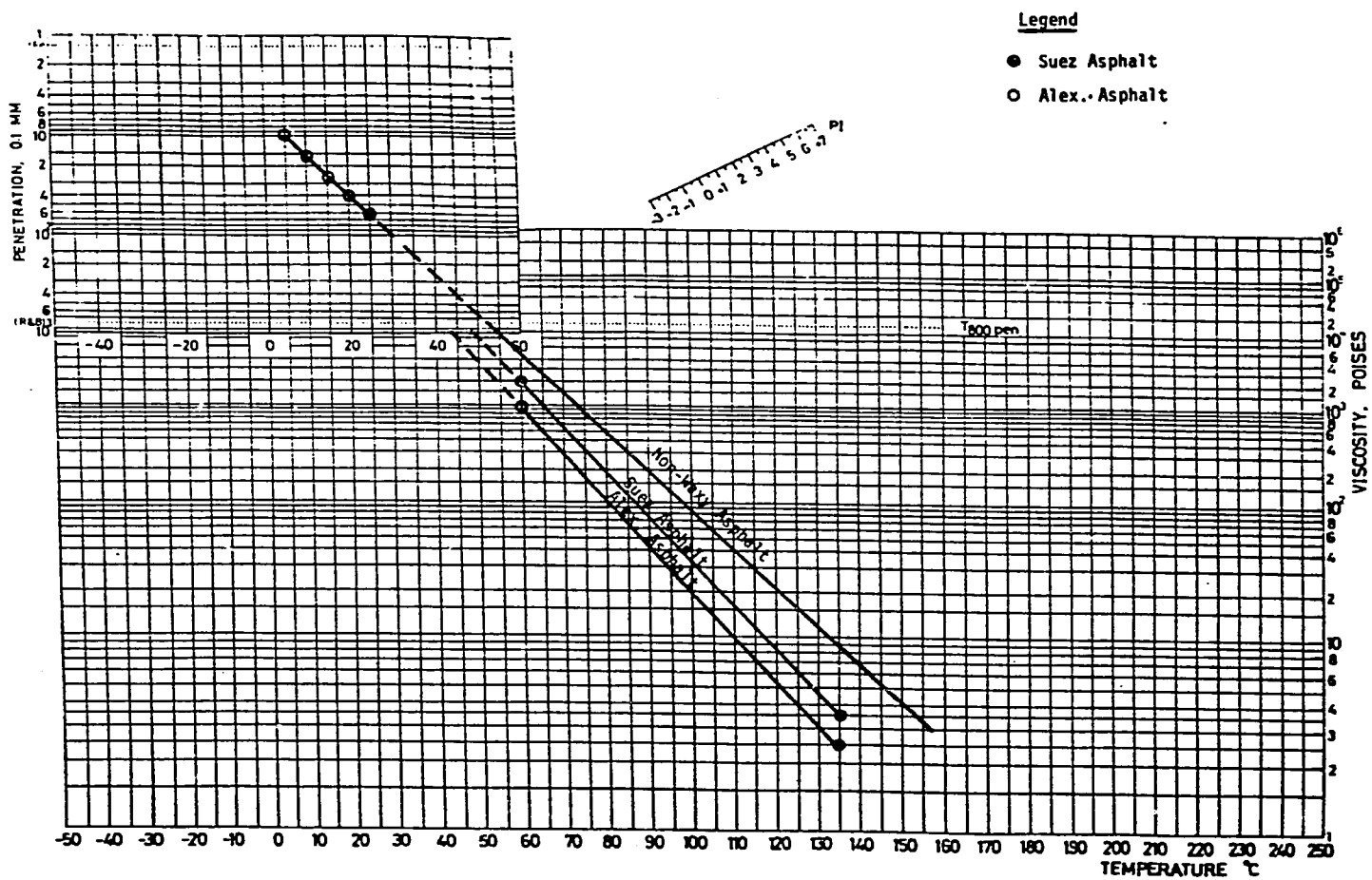


FIGURE 4 :HEUKELOM BITUMEN TEST DATA CHART

Sieve Size or Number	Coarse-Graded Mix		Dense-Graded Mix	
	Combined Grading,%	Specification limits (3-B)*	Combined Grading,%	Specification limits, (4-C)*
1-in.			100	100
3/4 in.	100	100	90.0	80-90
1/2 in.	87.5	75-100	---	---
3/8 in.	72.5	60-85	70.0	60-80
No.4	45.0	35-55	56.5	48-65
No.8	27.5	20-35	42.5	35-50
No.30	16.0	10-22	24.5	19-30
No.50	11.0	6-16	18.0	13-23
No.100	8.0	4-12	11.0	7-15
No.200	5.0	2-8	5.5	3-8

* Asphalt Institute Specifications

Table 8: Gradation of Aggregate Mixtures

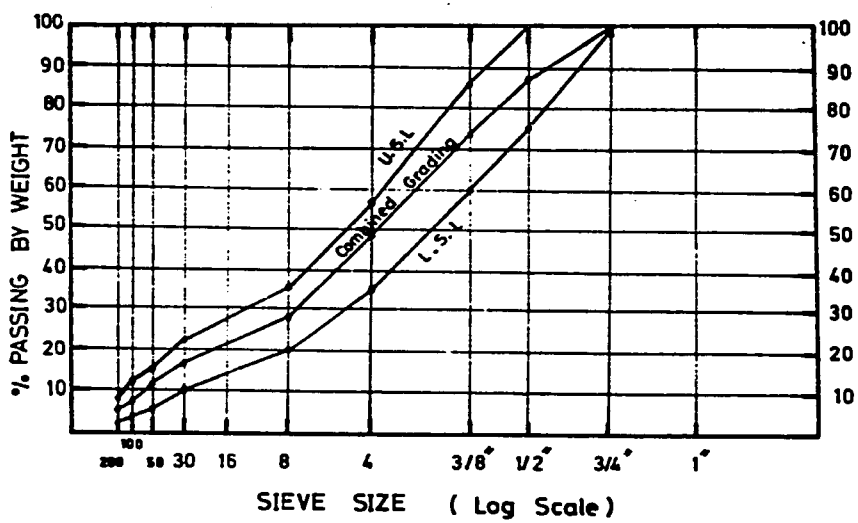


Figure 5 : Combined Grading and Specification Limits of Coarse Gradation (3-B).

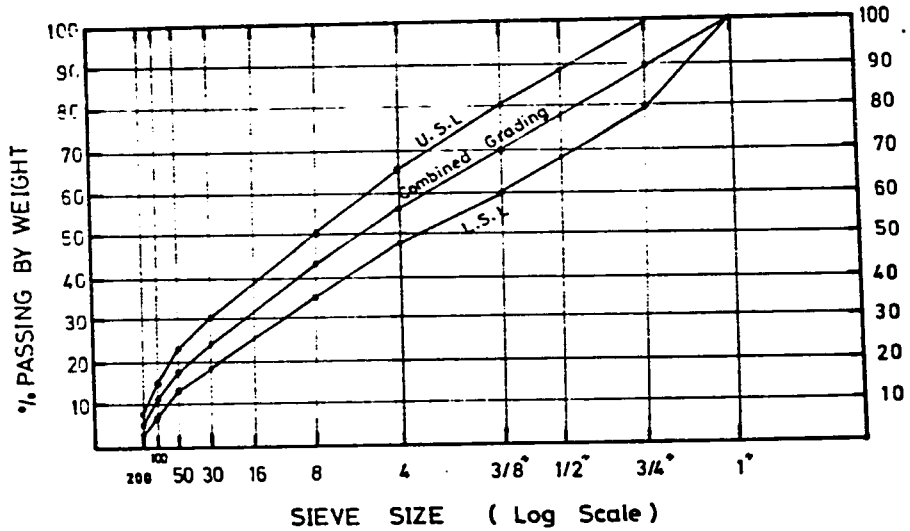


Figure 6 : Combined Grading and Specification Limits of Dense Gradation (4-C).

CHAPTER 5

TEST RESULTS AND DISCUSSIONS

5.1: INVESTIGATION OF MIX COMPONENT EFFECTS:

Table 9 summarizes the properties of mixtures tested to study the effect of coarse aggregate type and gradation as well as asphalt source on the behavior of asphalt concrete mixtures.

Figures 7 and 8 compare the properties of the six mixes at their optimum asphalt contents. These optimum asphalt contents are determined according to Marshall design criteria.

5.1.1. Effect of Asphalt Source

Figure 7 shows that both stability and cohesion of the Suez asphalt concrete mixtures are significantly higher than those of all Alexandria asphalt concrete mixtures. The higher asphaltene and lower wax contents of the Suez asphalt are probably the cause of its higher stability and cohesion.

5.1.2. Effect of Coarse Aggregate Type

Figure 7 shows that the Marshall stability and the Hveem cohesion of Alexandria asphalt concrete mixtures using limestone as an aggregate are considerably higher than basalt mixtures. This is believed to be caused by the higher porosity and absorption characteristics of limestone that tend to enhance the adhesion between Alexandria asphalt and the crushed limestone particles and, therefore, lead to better

Mix No.	Coarse Aggregate L(1)	Coarse Aggregate B(2)	Gradation D(3)	Gradation C(4)	Asphalt Source A(5)	Asphalt Source S(6)	Optimum Asphalt Content %	Marshall Stability, lb.	Unit Weight, PCF	Air Voids, %	Marshall Flow, 0.01 in.	Voids in Mineral Aggregates, %	Hveem Cohesion, gm/in.
1	x		x		x		5.62	1,640	147.2	3.1	10.5	15.5	381.0
2	x			x	x		5.00	1,810	145.3	4.7	9.5	15.5	345.7
3		x	x		x		5.30	1,220	153.0	4.4	11.5	16.2	267.0
4		x		x	x		4.75	1,160	152.4	6.3	11.0	17.1	149.4
5	x		x			x	5.60	2,310	146.0	4.0	9.7	16.1	428.3
6		x	x			x	5.20	2,480	154.0	3.8	13.0	15.6	479.3
Standard Specifications			Dense Agg. Mix				--	750+	--	3-5	8-16	13+	
			Coarse Agg. Mix				--	750+	--	3-8	8-16	14+	

(1) Limestone
(2) Basalt
(3) Dense Agg. mix (4-C)
(4) Coarse agg. mix (3-B)
(5) Alex. asphalt
(6) Suez asphalt

Table 9: Investigation of Mix Component Effects: Mixture Properties at Optimum Asphalt Contents

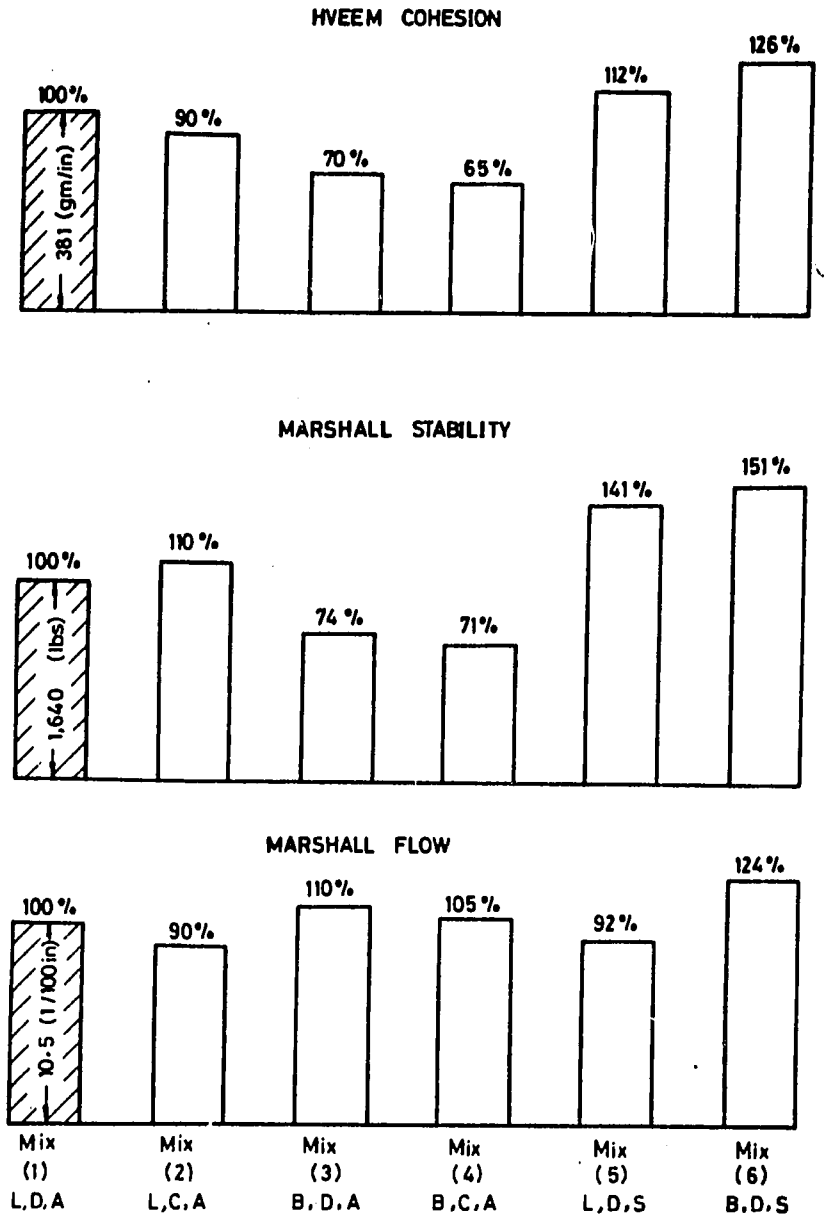


Figure 7 : Investigation of Mix Components Effects : Mix Properties at Optimum Asphalt Contents.

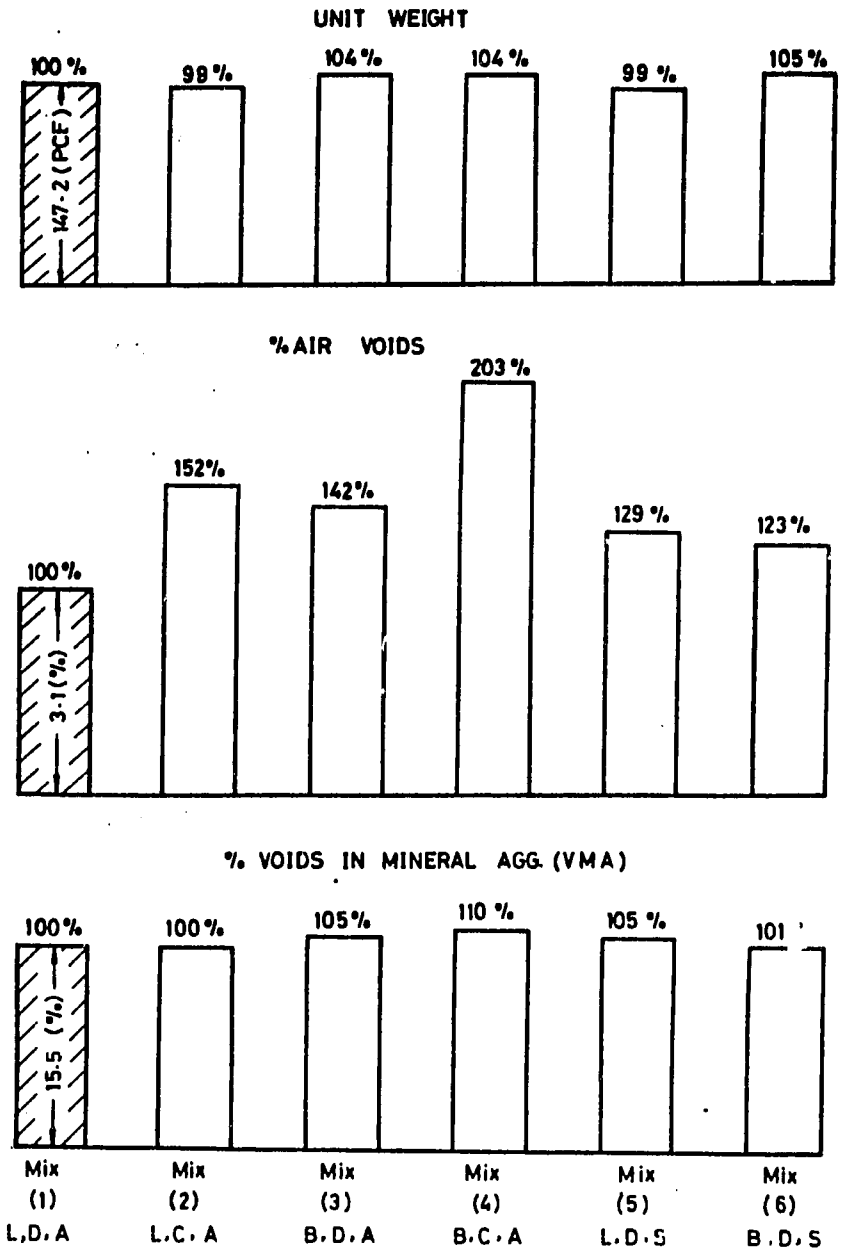


Figure 8 :Investigation of Mix Components Effects : Mix Properties at Optimum Asphalt Contents (Cont)

stability. The effect of coarse aggregate type on stability and cohesion of the Suez asphalt concrete mixtures is believed to be insignificant in view of the minor differences in the measured values.

Unit weights of basalt mixtures are slightly higher than those of limestone mixtures (Fig.8). This is due to the higher specific gravity of basalt aggregates.

Finally, by comparing the results of limestone versus basalt mixtures, no significant differences can be detected in the percent voids in the mineral aggregates (VMA).

5.1.3: Effect of Aggregate Gradation

Table 9 shows that the percent air voids of coarse aggregate mixtures are, as expected, higher than that of dense mixtures. On the other hand, the effect of aggregate on stability is not clear. For instance, the stability of the coarse-limestone mixture (Mix No.2) is 10% higher than that of dense limestone mixture (Mix No.1), whereas the stability of the dense-basalt mixture (Mix No.3) is slightly greater than that of the coarse-basalt mixture. The Hveem cohesion shows a more consistent trend whereby dense mixtures exhibit a higher cohesion than coarse mixtures.

No significant differences are observed between the flow values of dense and coarse mixtures.

5.2: Pilot Study on Additive Effects:

5.2.1: Sulfur

Experiences reported in the literature indicate that two

main factors are important in the use of sulfur as an additive to asphalt cements: (1) temperature and (2) time of mixing. A temperature of 140°C and a mixing time of 20 minutes were initially used in our experimental program. Required tests on materials and mixtures were conducted after 3 hours of mixing sulfur with asphalt.

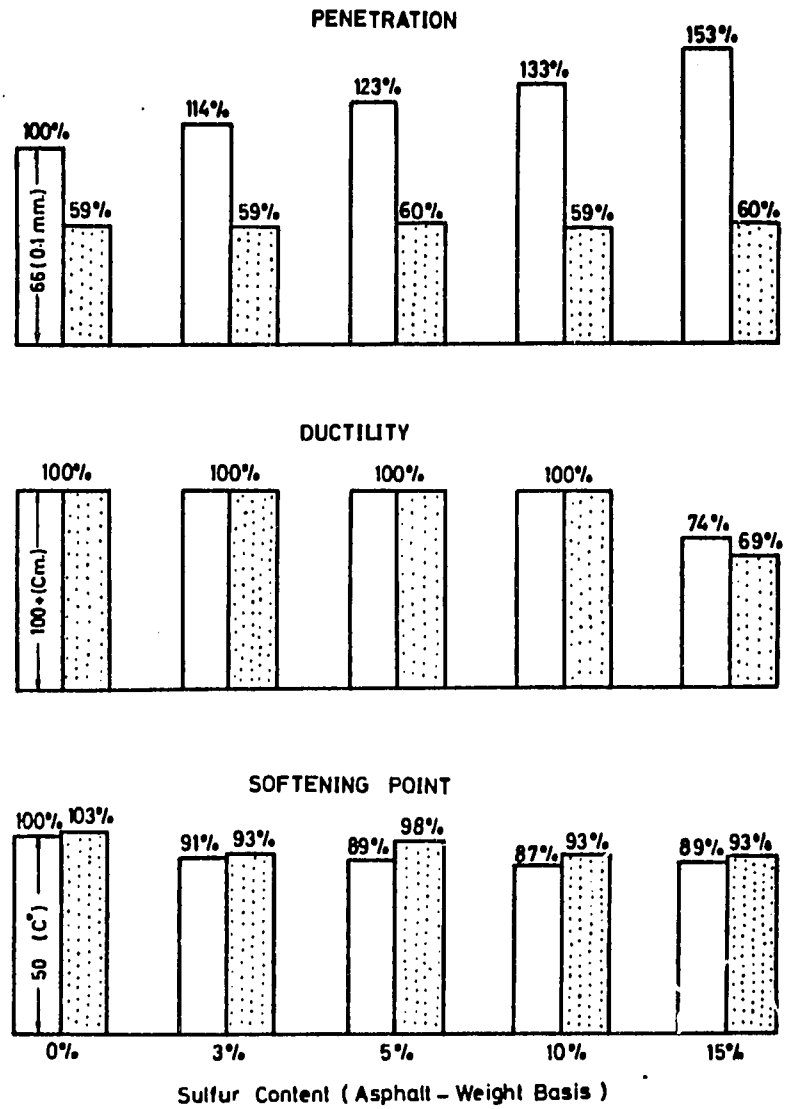
5.2.1.1: Effect of Sulfur on Physical Properties of Asphalt Cements:

Table 10 presents the results of physical tests performed on sulfur-asphalt blends. For comparison, properties of the original asphalt cement are also shown in the table.

Figures 9 and 10 provide the physical properties of asphalt-sulfur blends at various concentrations of sulfur before and after thin-film-oven test.

Penetration results show a consistent increasing trend with the increase of sulfur content. Except for 15% sulfur blends, the softening point and the kinematic viscosity gradually decrease as the sulfur content increases. These results clearly suggest that, at the concentrations used and under the mixing conditions employed, sulfur tends to soften asphalt significantly.

The specific gravity of sulfur-asphalt blends is slightly higher than that of the original asphalt cement. This is due to the higher specific gravity of sulfur (approximately twice as great as asphalt).



☐ Before thin-film-oven test

☐ After thin-film-oven test

Figure 9 :Investigation of Sulfur Effects on Physical Properties of Asphalt Cements

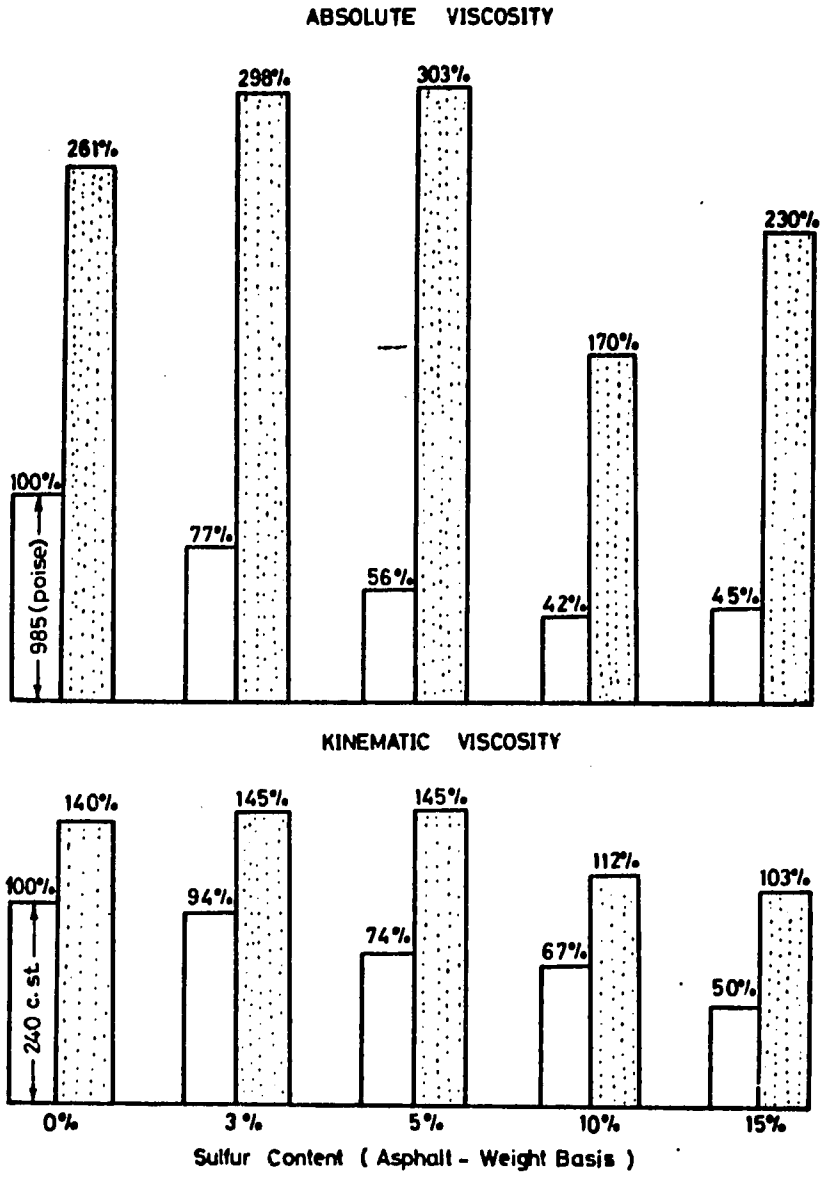


Figure 10 : Investigation of Sulfur Effects on Physical Properties of Asphalt Cements (cont.)

Properties of sulfur-asphalt blends after thin-film-oven test (TFOT) provide an indication of its susceptibility to hardening. Results in Table 10 show that the percent weight loss of all sulfur-asphalt blends exceeds the maximum specification limit of 1%. Also, except for the 3% sulfur blend, the percent of retained penetration after the TFOT is below the ASTM minimum limit of 52%.

This means that pavements constructed with these sulfur-asphalt blends would be susceptible to a relatively high degree of hardening during plant mixing operations and shortly after construction.

5.2.1.2: Effect of Sulfur on Mixture Properties

Table 11 presents the results of tests performed on sulfur-asphalt concrete mixtures at their optimum sulfur-asphalt contents. The table also includes the properties of the original mix (0% sulfur) for comparison. Figure 11 illustrates the comparisons between the mixture properties.

In general the addition of sulfur causes a pronounced decrease in cohesion of the asphalt concrete. On the other hand, the stability of mixtures increases by 16% when 5% sulfur is added. A relatively sharp reduction in the stability occurs when a blend of 10% sulfur (by weight of asphalt) is used. The Marshall flow is reduced at 3% sulfur content but increases gradually for 5% and 10% sulfur.

5.2.1.3: Further Work on Sulfur

Additional tests on sulfur blends include an increase in

Sulfur Content %	Pen. 0.1mm	Duct. cm	Soft. Pt. °C	Kin. Visc. C.St. 60°C	100°C	135°C	Spec. Grav. at 60°C	Pen. %	Duct. cm	Soft. Pt. °C	Kin. Visc. C.St. 60°C	100°	135°	Weight Loss %
	Before Thin-Film-Oven Test							After Thin-Film-Oven-Test						
0	66	100+	50.0	96,758	1,792	240	1.018	59.1	100+	51.2	252,810	3,027	336	0.14
3	75	100+	45.5	74,755	1,506	225	1.022	53.3	100+	46,7	288,790	3,214	348.5	1.27
5	81	100+	44.5	54,528	1,259	177	1.027	50.6	100+	49.0	293,155	3,279	349.0	1.88
10	88	100+	43.5	40,852	993	160	1.033	44.3	100+	46.7	163,988	2,075	267	2.44
15	101	73	44.5	43,499	709	120	1.046	39.1	69	46.4	222,431	2,158	247	3.22
Egyptian Specs.	60-70	90+	44-55			320								Max.1

* Asphalt - Weight Basis

** Proposed

Table 10: Physical Properties of Sulfurized Asphalt Cements

Mix No.	Sulfur* Content %	Optimum Asphalt Content %	Marshall Stability lbs.	Unit weight PCF	Air Voids %	Marshall flow 0.01 in.	Voids in Mineral Aggregates %	Hvee Cohesion gm/i
1	0	5.62	1,640	147.2	3.1	10.5	15.5	381.
6	3	5.5	1,640	146.4	3.7	9.0	15.5	224.
7	5	5.6	1,900	146.8	3.8	9.3	15.5	255.
8	10	6.0	1,140	146.8	4.5	11.2	16.4	204.

* Asphalt Weight Basis

Table 11: Investigation of Sulfur Effects:

Mixture Properties at Optimum Asphalt Contents

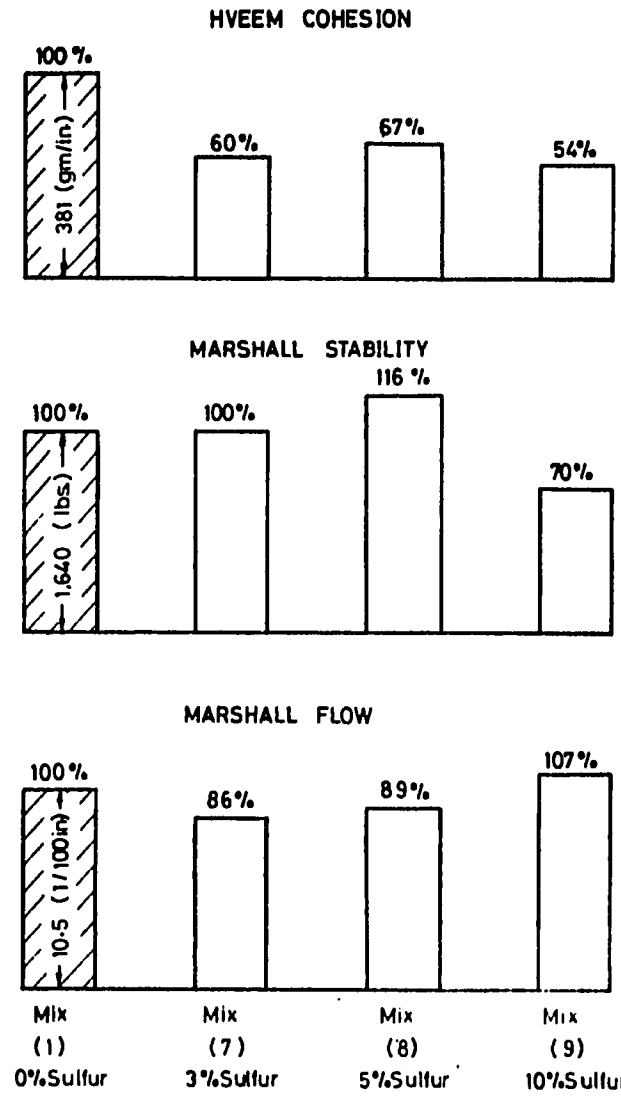


Figure 11 : Investigation of Sulfur Effects on Mix Properties at Optimum Asphalt Contents.

mixing temperature and mixing time. Results of physical tests indicate that better properties are obtained when mixing of sulfur and asphalt are carried out at a higher temperature of 160°C for 20 minutes. The absolute and kinematic viscosities of sulfur asphalt blends are markedly higher than those of the original asphalt and the blends prepared at lower temperatures. However, at the higher mixing temperature, sulfur fumes become more pronounced and are thus expected to cause significant problems in plant mixing and field operations.

5.2.1.4: Conclusions Regarding the Use of Sulfur

In conclusion, results of laboratory tests conducted to investigate sulfur as an additive indicate that at the low sulfur concentrations allowed by economic considerations in Egypt, sulfur does not give satisfactory improvements in the properties of western desert asphalt cements. Hence, sulfur-asphalt blends will not be studied in the Large Scale Test Track.

5.2.2 Petroleum Coke

Petroleum Coke is a by-product of the coking process performed on heavy petroleum products in order to produce light fractions. Large quantities of petroleum coke will be available in Egypt at very reasonable prices after coking plant operations commence in 1984. The chemical composition of petroleum coke is as follows:

Specific gravity = 1.2

Volatile matter at 800°C = 10% by weight

Ash content = 0.6%

Sulfur content = 4.8%

Carbon content = 89.9%

An examination of the chemical composition of petroleum coke indicates that coke exhibits strong similarities with "Carbon Black", another product marketed in the U.S. as an additive to improve asphalt properties. Based on experiences with Carbon Black as an additive, petroleum coke is expected to generally improve the performance of paraffinic Egyptian asphalts. On the other hand, Carbon Black increases the asphalt viscosity and reduces its penetration (i.e., causes hardening of the asphalt). Therefore, in the pilot study of petroleum coke as an additive, a higher penetration grade asphalt* (80/100 pen.) was selected such that, after the addition of coke, the improved asphalt grade will be 60/70 pen. asphalt representing the current standard production of the Alexandria refinery.

5.2.2.1 Effect of Petroleum Coke on Physical Properties of Asphalt Cements

The mixing of asphalt and coke is conducted at 140°C for 20 min. after grinding the coke to a fine powder (532 ft^2/lb. surface area and 73% passing sieve No. 200). Table 12 presents the results of physical tests performed on coke-

* Available at the Egyptian Petroleum Research Institute and produced by the Alexandria Refinery before 1976.

Coke* Content	Before Thin-Film-Oven Test							After Thin-Film-Oven-Test				
	Pen. 0.1mm	Duct. cm	Soft. Pt. °C	Kin. Visc.C.St. 60°C	100°C	135°C	Spec. Grav. at 60°C	Pen. %	Duct. cm	Soft. Pt. °C	Kin.Visc .C.St. 60°C	135°C	Weight Loss %
0	88	150	47.5	1,416		234	1.02						
7	70	57	48.0	1,592	2,976	348	1.032	60.00	26		8,808	583	0.15
10	63	49	49	1,880	3,242	364	1.038	61.90	21		10,350	613	0.15
15	54	35	49	2,035	3,604	402	1.047	70.40	17		14,795	777	0.15
Egyptian Spec. Limits	60-70	90+	45-55			*** 220+							Max.1%

* Asphalt Weight Basis

** Proposed

Table 12: Physical Properties of Coke-Asphalt Blends

asphalt blends. Properties of the original asphalt cement are also included in the table for comparison.

Figure 12 compares the physical properties of coke-asphalt blends at various concentrations of coke before and after thin-film-oven testing. Results in Fig. 12 show that the addition of petroleum coke sharply decreases the penetration and the ductility of the asphalt cement and increases its kinematic viscosity. At a coke concentration of 10% (by weight of asphalt), the asphalt penetration is reduced to 63 (i.e.,within the 60/70 pen. grade range) and its kinematic viscosity is increased to 364 C.St. This viscosity is clearly superior to the 240 C.St. corresponding to the 60/70 pen. grade asphalt cement produced by the Alexandria refinery (1). The ductility of the improved asphalt, however, does not satisfy the standard specifications (90 cm is the minimum). This is not surprising since, after adding coke, the ductility measured by the standard test is not representative. In order to prove this point, the carbon was extracted from the improved asphalt and its ductility was remeasured. Results indicate that the new ductility exceeds the minimum limit required by the standard specifications.

5.2.2.2.: Effect of Petroleum Coke on Mixture Properties

Dense-graded limestone aggregate mixtures (4C according to the Asphalt Institute Specifications) are utilized in the coke-asphalt concrete mixtures. Table 13 presents the properties of these concrete mixtures at their optimum asphalt

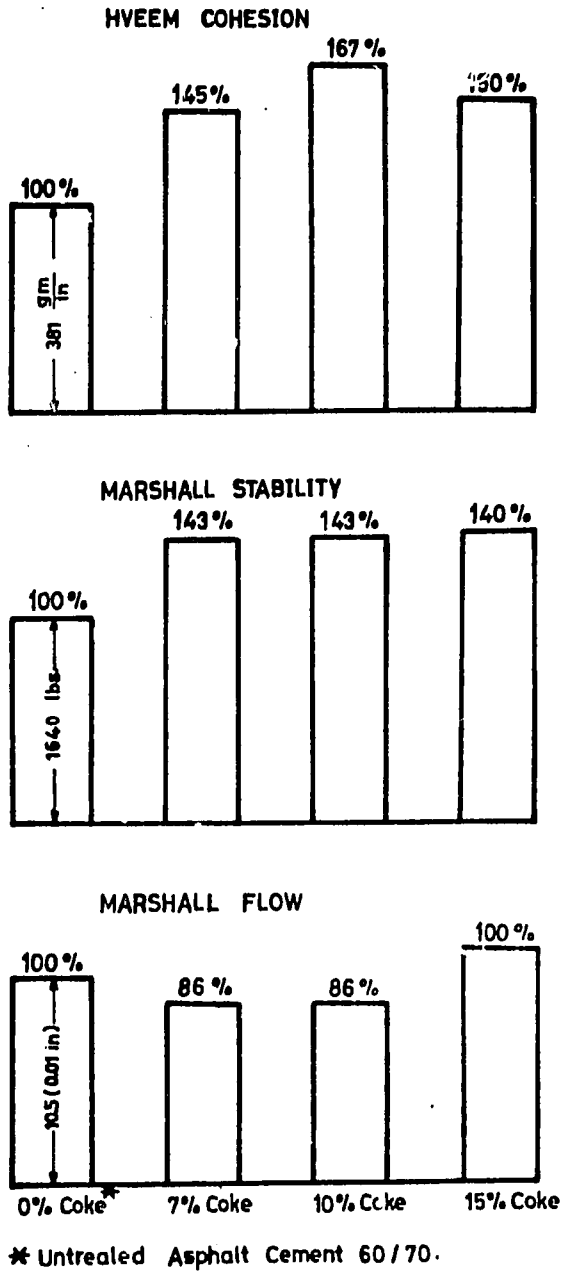
contents. The table also includes the properties of the untreated Alexandria (60/70 pen.grade) asphalt concrete mixtures for comparison. Figure 13 illustrates the comparison between the main mixture properties.

From Table 13 and Fig. 13, it is clear that Marshall stability of coke-asphalt concrete mixtures is approximately 40% higher than that of the untreated 60/70 pen. asphalt concrete mixtures. Furthermore, the addition of coke to the asphalt increases cohesion of the concrete mixtures by 45% to 67%.

5.2.2.3.: Conclusions Regarding the Use of Petroleum Coke as an Additive

Results discussed above indicate that the addition of petroleum coke to the 80/100 pen. grade western desert asphalt cement results in a distinct improvement in the measured properties. However, the penetration of the improved asphalt decreases and falls within a lower penetration grade range. A maximum concentration of petroleum coke of 10% (by weight of asphalt) should be used to keep the improved asphalt within the 60/70 pen. grade range.

In order to ascertain these results, a new batch of the 80/100 pen. asphalt cement was secured from the Alexandria refinery. This batch was manufactured especially for the purpose of this study in 1981 since the refinery does not currently produce this asphalt grade. Results of physical tests conducted on samples of this batch show that the kinematic viscosity of the new asphalt is much lower than that



* Untrealed Asphalt Cement 60/70.

Figure 13: Investigation of Petroleum Coke Effects on Mix Properties at Optimum Asphalt Contents

of the "old" 80/100 pen. asphalt cement (167 C.St. for the new 1981 sample compared to 234 C.St. for the old one). When 10% of petroleum coke was added to the "1981" 80/100 pen. grade asphalt, its penetration decreased from 85 to 57 and its kinematic viscosity increased from 167 C.St. to 219 C.St. These results follow the same trends exhibited by the "old" 80/100 pen. asphalt cement, but the improved "new" asphalt is still inferior to the 60/70 pen. asphalt cements produced by the refinery in 1979.

Finally, additional tests were performed to evaluate the various factors affecting the properties of the petroleum coke-asphalt blends. Results indicate that better homogeneity and more stable properties can be achieved if catalysts are utilized during mixing. For example, when 10% petroleum coke is added to the "1981" 80/100 pen. asphalt cement in the presence of 0.03% (by weight of asphalt) manganese stearate, test results indicate that the kinematic viscosity of the blend increases to 248 C.St., whereas penetration remains basically unchanged (58 compared to 57 in the previous trial).

5.2.3: Air-Blown Asphalt

The production of air-blown asphalt involves blowing air through a heated charge of asphalt cement at atmospheric pressure in either a still batch or a continuous column. These conditions cause oxidation of the asphalt and some of the hydrogen is removed in the form of water which leads to polymerization of the partially dehydrogenated molecules. The

oxygen content of the final product is slightly increased. As the oxidation reaction is exothermic, heating is only required to start the reaction, which then becomes self-supported and has to be carefully controlled by adjusting the rate of blowing.

In order to investigate the possibility of using air-blown asphalts to improve the properties of Egyptian paraffinic waxy asphalt cements, samples of air-blown asphalt with a penetration of 15 and a softening point of 115°C were secured from the Alexandria refinery (El-Nasr Company). Three concentrations of the air-blown asphalt (5,10 and 15% by weight of asphalt) were tested. The mixing was performed for 30 min. after heating the "new" 80/100 pen. asphalt cement produced in 1981 to 160°C and the air-blown asphalt to 200°C.

Results of physical tests are shown in Table 14. Clearly, the effects of adding air-blown asphalt are very similar to the effects of petroleum coke, namely a decrease in penetration and an increase in kinematic viscosity. Furthermore, in order to comply with the standard specifications of the 60/70 pen. grade, no more than 10% by weight of air-blown asphalt should be used.

% of Air-Blown Asphalt	Penetration (0.1 mm)	Kinematic viscosity (C.St.)	Softening point (C°)
0	85	167	46
5	66.5	200	48
10	60.0	233	50
15	57.0	256	50.5

Table 14 - Effects of Air Blown Asphalt on the Physical Properties of 80/100 pen. (new) Asphalt Cement.

5.2.4: Propane Deasphaltizing Tar, PDT

PDT is usually applied to the vacuum distillation residue during manufacture of lubricating oil to obtain an asphalt-free residue in order to avoid emulsion difficulties in the solvent treating step.

Two concentrations of the PDT were investigated in the pilot study: 10% and 15% by weight of asphalt. Mixing was performed for 30 min. after heating the 80/100 pen. "new, 1981" asphalt to 160°C and the PDT to 200°C.

Results of physical tests are shown in Table 15. Clearly, the PDT hardens the asphalt cement by significantly decreasing penetration and by increasing kinematic viscosity.

% of PDT (by weight of asphalt)	Penetration (0.1 mm)	Kinematic viscosity (C.St.)	Softening point (C°)
0	85	167	46
10	50	238	50
15	50	242	50

Table 15: Effects of Propane Deasphalting Tar on the Physical Properties of 80/100 pen. "New, 1981" Asphalt Cement.

5.3: Selection of Improved Asphalts for the Large Scale Test Track

Based on the results of the pilot study, the selection of improved asphalts to be evaluated in the Large Scale Test Track, (LSTT), can follow one of two approaches. The first consists of attempting to improve the properties of the 60/70 pen. asphalt presently produced by the Alexandria refinery and accepting the fact that the improved asphalt will belong to a lower penetration grade. The second approach consists of improving the properties of a higher penetration grade asphalt (80/100 pen., say) such that the improved asphalt belongs to the 60/70 pen. grade. Simply stated, the first approach utilizes the present product of the refinery, but leads to a harder improved asphalt, whereas the second approach requires a change in the current production of the refinery, but leads to an improved asphalt with a 60/70 penetration grade.

After careful examination of the laboratory data and in view of practical considerations related to asphalt production in the refinery, the first approach was selected. This decision was particularly influenced by the fact that test results obtained in the pilot study on improved stiff asphalt (40/50 pen. grade, say) indicate that, after thin-film-oven test, the absolute viscosity in poises at 60°C (140°F) is reasonably small [below the maximum limit of 10,000 poises specified in ASTM standards for this grade of asphalt (ref. 53)] and hence suggests that the use of stiff improved asphalts (40/50 pen. grade, say) will not necessarily lead to a reduction

in the service life of pavements constructed with Egyptian waxy asphalts. Therefore, a new batch of the 60/70 pen. asphalt cement was secured from the Alexandria refinery for the purpose of this phase of the study. Results of tests performed to evaluate the properties of this batch are shown in Tables 16 and 17. Table 18 presents the Marshall stability and Hveem cohesion of the asphalt concrete mixture (limestone, 4C dense gradation and 60/70 pen. asphalt cement).

Test results in Tables 16,17 and 18 show that the viscosity of the "new" (1981) 60/70 pen. asphalt are quite similar to those of the old (1979) 60/70 pen. asphalt tested earlier in this project [1]. However, the "new" (1981) asphalt has a higher wax content (8.9% vs. 7.5%), a slightly lower Marshall stability (1450 vs. 1640 lbs), and a much lower Hveem cohesion (113 vs. 381 gm/in). Therefore, the new (1981) 60/70 pen. asphalt was selected for the LSTT because, on one hand, it represents the latest available production of the refinery and, on the other, it is poorer in quality. Hence, the methods of improvements utilized with this asphalt can be applied to better quality asphalts produced by the refinery in the future provided that the performance of the improved asphalts in the LSTT are satisfactory.

Pen. (0.1 mm)	Kinematic Viscosity (C.St.)	Absolute Viscosity (Poise)	Softening Point (C°)
64	231	986	47

Table 16: Physical Properties of the "New" 60/70 pen. Asphalt Cement Presently Produced by the Alexandria Refinery (1981).

Asphaltenes,	25.2 %
Oils ,	35.6 %
Resins ,	47.2 %
Wax ,	8.9 %

Table 17: Component Analysis of the "New" 60/70 pen. Alex. Asphalt Cement (1981).

Marshall Stability, lbs.	1450
Hveem Cohesion, gm/in.	113
Flow, 0.01 in.	10
Air Voids	3.8
% Voids in Mineral Aggregates	16.8
Unit Weight. PCF	145.3

Table 18: Mechanical Properties of the "New" 60/70 pen. Asphalt Concrete Mixtures at Optimum Asphalt Contents (1981).

5.3.1: Petroleum Coke

Based on the results of the pilot study, a 10% petroleum coke concentration and 0.03% manganese stearate were utilized in the mix preparation. Results of tests performed to evaluate the physical properties of the new blend as well as properties of the original untreated 60/70 pen. asphalt cement are shown in Table 19.

Table 19 indicates that petroleum coke tends to considerably increase the kinematic viscosity and decrease penetration. The absolute viscosity after thin-film-oven test (3539 poises) is far below the ASTM limit of 8,000 poises and thus suggests that the reduction in penetration does not necessarily mean that the service life of the pavement is decreased.

Finally, test results on asphalt concrete mixtures prepared with this blend show that both Marshall stability and Hveem cohesion values of the petroleum coke-asphalt concrete mixtures (1650 lbs. and 261 gm/in., respectively) are considerably higher than those of the original 60/70 pen. asphalt concrete mixtures (1450 lbs., and 113 gm/in., respectively).

5.3.2: Air-Blown Asphalt

Based on the findings of the pilot study, blends of the "1981" 60/70 pen. asphalt were prepared with 10% air-blown asphalt concentration and 0.03% manganese stearate as a catalyst. Results of tests on this new blend are shown in Table 20.

Clearly, a considerable improvement in asphalt properties is observed and the absolute viscosity after thin-film-oven test (4,485 poises) is less than the critical limit specified by the ASTM standards (8,000 poises).

Test results on asphalt concrete mixtures prepared with this blend show much higher Marshall stability and Hveem cohesion values (1640 lbs, and 245 gm/in., respectively) as compared to those of the original untreated asphalt concrete mixtures (1450 lbs, and 113 gm/in., respectively).

Asphalt Sample	Penetration (0.1mm) at 25°C	Softening Point, C°	Viscosity poises at 60°C	Viscosity C.St. at 135°C
Original 60/70 pen. asphalt cement	64	47	986	231
Petroleum coke + 60/70 pen. asphalt + 0.03% manganese stearate	44	49.5	1,653	321

Table 19: Physical Properties of Petroleum Coke - 60/70 pen. 1981 Asphalt Cement Blends

Asphalt Sample	Penetration (0.1mm) at 25°C	Softening point, C°	Viscosity poises at 60°C	Viscosity C.St. at 135°C
Original 60/70 pen. asphalt cement	64	47	986	231
Air-Blown asphalt + 60/70 pen. asphalt cement + 0.03% manganese stearate	43	50	1,794	326

Table 20: Physical Properties of Air-blown asphalt - 60/70 pen. New Asphalt Cement Blends

5.3.3: Propane Deasphalting Tar (PDT)

Based on the results of the pilot study, blends of the 1981 60/70 pen. asphalt were prepared at a PDT concentration of 20% pen. asphalt in the presence of 0.03% manganese stearate.

Test results in Table 21 show that the effects of PDT on the physical properties follow the same trends as petroleum coke and air-blown asphalt: penetration decreases and kinematic viscosity significantly increases. Also, the absolute viscosity after thin-film-oven testing (4,567 poises) is less than the critical ASTM limit of 8,000 poises.

Asphalt Sample	Penetration (0.1mm) at 25°C	Softening point, C°	Viscosity poises at 60°C	Viscosity C.St. at 135°C
Original 60/70 pen. asphalt cement	64	47	986	231
PDT + 60/70 pen. asphalt cement + 0.03% manganese stearate	42	52	2,665	360

Table 21: Physical Properties of Propane Deasphalting Tar - 60/70 Pen. New Asphalt Cement Blends

5.3.4: The 40/50 pen. Grade Asphalt Cement

Results of the experimental program on additives described above suggest that another method of improving the performance of Egyptian paraffinic-waxy asphalt cements consists of using a lower penetration grade of the asphalt cement: the 40/50 pen. grade. This is basically due to the fact that the three additives discussed earlier tend to harden the 60/70 pen. grade and increase its kinematic viscosity to an acceptable limit (e.g. 320 C.St. suggested by the experts of the Egyptian Roads and Bridges Authority). A study performed to investigate the properties of the western 40/50 pen. grade asphalt cement shows that this grade may have the same desired properties of the improved 60/70 pen. asphalt. Test results of the 40/50 pen. asphalt are shown in Tables 23

and 24.

These results show that the 40/50 pen. grade has a kinematic viscosity that exceeds the 320 C.St. limit. Also, the absolute viscosity after thin-film-oven test is far below the limit of 8,000 poises. Both stability and cohesion are higher than the 60/70 pen. asphalt concrete mixtures. Therefore, the 40/50 pen. grade asphalt cement will be evaluated in the LSTT.

Before Thin - Film - Oven Test					After TFOT	
Pen. 0.1mm	Ductility cm	Soft. Pt. C°	Kin. Vis. C.St.	Absol. Visc. Poise	Pen. %	Absol. Visc., Poise
44	150	54	321	1885	66	4000

Table 22: Physical Properties of the Western 40/50 Pen. Asphalt Cement (June 1980)

Asphaltene, %	18.8
Resins , %	53.5
Oils , %	27.5
Wax , %	7.5

Table 23: Component Analysis of the Western 40/50 Pen. Asphalt Cement (June 1980)

Type of Coarse Aggregate	Opt. A.C. Content,%	Marshall Stability lbs.	Unit Weight PCF	% Air Voids	% Voids in Mineral Aggregates	Marshall Flow 0.01 in.	Hveem Cohesion gm/in.
Basalt	5.4	1730	154.9	3	14.7	10.8	267
Limestone	5.6	1805	146.2	4.2	15.6	10.0	300

Table 24: Mechanical Properties of the 40/50 pen. Western Asphalt Concrete Mixtures (June 1980).

CHAPTER 6

SUMMARY AND CONCLUSIONS

This report presents the results of a study aimed at investigating the various methods of improving the properties of paraffinic-waxy asphalt cements and their concrete mixtures. These methods can be divided into:

1. Changes in mix components; and 2. The use of additives.

1. Effects of Mix Components

Based on field experience, the severity of the waxy asphalt performance problems appears to depend on two factors related to mix components: (1) the type of coarse aggregate, and (2) the gradation of the aggregate. Therefore, two coarse aggregate types (crushed limestone and basalt) and two aggregate gradations (dense and coarse surface mix gradations, Asphalt Institute 4-C and 3-B gradations, respectively) were investigated. For comparison purposes, two standard mixes were also prepared according to the common practice in Egypt utilizing the accepted Suez asphalt cement. The first utilizes limestone as an aggregate and the second uses basalt.

Results of tests indicate that in Alexandria asphalt concrete mixes:

1. Limestone aggregates lead to higher stability and cohesion than basalt aggregates. This is probably caused by the higher absorption characteristics of limestone compared to basalt.
2. Coarse versus dense aggregate gradations do not have a consistent trend of stability, whereas the Hveem cohesion of dense-graded mixtures is higher than the coarse mixtures.
3. Suez asphalt concrete mixtures exhibit a higher stability and a higher cohesion than Alexandria asphalt concrete mixtures. These superior properties of the Suez mixtures are believed to be due to the higher kinematic viscosity of Suez asphalts and their better adhesive qualities.

2. Investigation of Additives

Based on available quantities in Egypt, practical and economical considerations, the study involves four types of additives:

1. Sulfur; 2. Petroleum coke; 3. Air-blown asphalt; and 4. Propane deasphalting tar (PDT).

The investigation of additive effects is divided into two phases: the first consists of a pilot study to determine the general effects of the various additives on Egyptian waxy asphalt properties and the second is aimed at selecting the different improved asphalt blends to be used in the Large

Scale Field Test Track (additive type, concentration, preparation method,...etc.).

2.1 Pilot Study of Additive Effects

a) Sulfur: Pesults of laboratory tests conducted to investigate sulfur as an additive indicate that, at the low sulfur concentrations allowed by economic considerations in Egypt, sulfur does not cause satisfactory improvements in the properties of western desert asphalt cements. Hence, sulfur-asphalt blends will not be studied in the Large Scale Test Track.

b) Petroleum Coke: Petroleum coke is a by-product of the coking process performed on heavy petroleum products in order to produce light fractions. Large quantities of petroleum coke will be available in Egypt at very reasonable prices after coking plant operations in 1984.

An examination of the chemical composition of petroleum coke indicates that coke exhibits strong similarities with "Carbon Black", another product marketed in the U.S. as an additive to improve asphalt properties.

Based on experiences with Carbon Black as an additive, petroleum coke is expected to generally improve the performance of paraffinic Egyptian asphalts. On the other hand, Carbon Black increases the asphalt viscosity and reduces its penetration (i.e., causes hardening of the asphalt). Therefore, in the pilot study of petroleum coke as an addi-

tive, a higher penetration grade asphalt (80/100 pen.) was selected such that, after the addition of coke, the improved asphalt grade is 60/70 pen. asphalt representing the current standard production of the Alexandria refinery.

Laboratory test results indicate that the addition of petroleum coke sharply decreases the penetration and increases the viscosity. Mechanical tests conducted to investigate the mixture properties at optimum asphalt contents indicate that both Marshall stability and Hveem cohesion values of coke-asphalt concrete samples utilizing the dense graded limestone mixtures are markedly higher than those obtained by means of the untreated 60/70 pen. asphalt concrete mixtures.

Additional tests were performed to evaluate the various factors affecting the properties of the petroleum coke-asphalt blends. Results indicate that better homogeneity and more stable properties can be achieved if catalysts are utilized during mixing. Results of these tests indicate that 0.03% of manganese stearate (by weight of asphalt) acts as a proper catalyst hence the kinematic viscosity of the coke-asphalt blends increases whereas penetration remains basically unchanged.

c) Air-Blown Asphalt

In order to investigate the possibility of using air-blown asphalts to improve the properties of Egyptian paraffinic waxy asphalt cements, samples of air-blown asphalt with a penetration of 15 and a softening point of 115°C were

secured from the Alexandria refinery (El-Nasr Company). The mixing was performed for 30 min. after heating the 80/100 pen. asphalt cement to 160°C and the air-blown asphalt to 200°C.

Results of physical tests show that the effects of adding air-blown asphalt are very similar to the effects of petroleum coke, namely a decrease in penetration and an increase in kinematic viscosity. Furthermore, in order to comply with the standard specifications of the 60/70 pen. grade, no more than 10% by weight of air-blown asphalt should be used.

d) Propane Deasphalting Tar, PDT

Two concentrations of the PDT were investigated in the pilot study: 10% and 15% by weight of asphalt. Mixing was performed for 30 min. after heating the 80/100 pen. asphalt to 160°C and the PDT to 200°C.

Results of physical tests indicate that PDT hardens the asphalt cement (i.e., penetration decreases and kinematic viscosity increases).

2.2 Selection of Improved Asphalts for the Large Scale Test Track

Based on the results of the pilot study, the selection of improved asphalts to be evaluated in the Large Scale Test Track (LSTT) may follow one of two approaches. The first consists of attempting to improve the properties of the 60/70 pen. asphalt presently produced by the Alexandria refinery taking into consideration that the improved asphalt will have

a lower penetration grade. The second approach consists of improving the properties of a higher penetration grade asphalt (80/100 pen., say) such that the improved asphalt belongs to the 60/70 pen. grade. Simply stated, the first approach utilizes the present product of the refinery, but leads to a harder improved asphalt, whereas the second approach requires a change in the current production of the refinery, but leads to an improved asphalt with a 60/70 penetration grade.

After careful examination of the laboratory data and in view of practical considerations related to asphalt production at the refinery, the first approach was selected. This decision was particularly influenced by the fact that test results obtained in the pilot study on improved stiff asphalt (40/50 pen. grade, say) indicate that after thin-film-oven testing, the absolute viscosity is reasonably small (below the maximum limit of 8,000 poises) and hence suggests that the use of stiff improved asphalts (40/50 pen. grade, say) will not necessarily lead to a reduction in the service life of pavements constructed with Egyptian waxy asphalts. Therefore, a new 60/70 pen. asphalt cement batch was secured from the Alexandria refinery for the purpose of this phase of the study.

a. Petroleum Coke

Based on the results of the pilot study, a 10% petroleum coke concentration and 0.03% manganese stearate were utilized in the mix preparation. Results of tests performed to evalu-

ate the physical properties of the new blend indicate that petroleum coke tends to considerably increase the kinematic viscosity and decrease penetration. The absolute viscosity after thin-film-oven test (3539 poises) is far below the ASTM limit of 8,000 poises and thus suggests that the reduction in penetration does not necessarily mean that the service life of the pavement is decreased.

Finally, test results on asphalt concrete mixtures prepared with this blend show that both Marshall stability and Hveem cohesion values of the petroleum coke-asphalt concrete mixtures (1650 lbs. and 261 gm/in., respectively) are considerably higher than those of the original 60/70 pen. asphalt concrete mixtures (1450 lbs. and 113 gm/in., respectively).

b. Air-Blown Asphalt

Based on the findings of the pilot study, blends of the 60/70 pen. asphalt cement were prepared with 10% air-blown asphalt concentration and 0.03% manganese stearate as a catalyst. Results of tests on this blend show a considerable improvement in asphalt properties and the absolute viscosity after thin-film-oven test is less than the critical limit specified by the ASTM standards.

Test results on asphalt concrete mixtures prepared with this blend show much higher Marshall stability and Hveem cohesion values (1640 lbs., and 245 gm/in., respectively) as compared to those of the original untreated asphalt concrete

mixtures (1450 lbs, and 113 gm/in., respectively).

c. Propane Deasphalting Tar (PDT)

Based on the results of the pilot study, blends of the 60/70 pen. asphalt cement were prepared at a PDT concentration of 20% in the presence of 0.03% manganese stearate.

Test results show that the effects of PDT on the physical properties follow the same trends as petroleum coke and air-blown asphalt: penetration decreases and the kinematic viscosity significantly increases. However, the absolute viscosity after thin-film-oven test is less than the critical ASTM limit of 8,000 poises.

d. The 40/50 Pen. Grade Asphalt Cement

Results of the experimental program on additives suggest that another method of improving the performance of Egyptian paraffinic-waxy asphalt cements consists of using a lower penetration grade of the asphalt cement: the 40/50 pen. grade. This is basically due to the fact that the three additives investigated tend to harden the 60/70 pen. grade and increase its kinematic viscosity to an acceptable limit (e.g., 320 C.St. suggested by the experts of the Egyptian Roads and Bridges Authority). A study performed to investigate the properties of the western 40/50 pen. grade asphalt cement shows that this grade may have the same desired properties of the improved 60/70 pen. asphalt. Tests on the 40/50 pen. asphalt were therefore conducted.

Results show that the 40/50 pen. grade has a kinematic viscosity that exceeds the 320 C.St. limit. Also, the absolute viscosity after thin-film-oven test is far below the limit of 8,000 poises. Both stability and cohesion are higher than the 60/70 pen. asphalt concrete mixtures. Therefore, the 40/50 pen. grade asphalt cement will be evaluated in the LSTT.

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