

EFFECTS OF ANTI-STRIPPING ADDITIVES

By

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CHAPTER I

INTRODUCTION

Over ten million tons of road oils, cutback asphalts, and penetration grade asphalt cements, derived from petroleum residuums, are used annually in the United States. The primary use of these products is for surfacing roads, streets, and airport runways (1). The more heavily traveled transportation facilities are usually surfaced with asphalt-concrete, which is a mixture of well graded aggregate and asphalt cement.

These asphaltic-concrete pavements should be stable, durable, skid resistant, and economical. Stripping of the asphalt cement from the surface of the aggregate can be detrimental to all of the foregoing desirable pavement properties--particularly the durability characteristics.

Stripping occurs where there is a loss of adhesion between the asphalt and the aggregate in the presence of water, i.e., the bond at the asphalt-aggregate interface is disrupted by the action of water. While the presence of moisture is a primary element, there are a number of other factors that can affect the stripping tendencies of a given paving mixture. These factors are aggregate properties, asphalt cement characteristics, environment of the pavement, and construction procedures.

To decrease the stripping tendencies in an asphalt-aggregate mixture, a number of anti-stripping additives have been employed. Some of these products are used to improve certain characteristics of the asphalt,

while others are designed to improve the surface properties of the aggregate. During recent years the use of these additives has gained a fair acceptance by paving technologists (2). A good additive should be effective on the mixture used, be completely miscible with the asphalt, have good heat stability, and have little or no effect on other properties of the mixture (2, 3).

In many asphaltic pavements throughout Oklahoma, where limestone aggregates have been used, a serious problem of skid resistance has developed. This is due to the tendency of the limestone aggregate particles at the road surface to polish. In an attempt to remedy this situation, the Oklahoma Highway Department sponsored, in 1972, a research project to analyze bituminous mixes incorporating small amounts of siliceous aggregates obtained from several different sources in Oklahoma. This study was carried out by Oklahoma State University in cooperation with the Oklahoma Highway Department.

Siliceous aggregates which have a lower tendency to polish than that of limestone, have not been popular with the paving industry because of their poor adherent properties with asphalt cement. Due to this poor adhesion, there is a greater tendency for stripping when this type of aggregate is employed in the paving mixture.

The preliminary phase of the Oklahoma Highway Department project consisted of analyzing the effects of incorporating eleven different siliceous aggregates in a standard asphalt-aggregate mixture. The mix was designed to meet the Oklahoma Highway Department specifications for a type B surface course mixture.

This report concerns a subsequent phase of this project. The objective of this phase of the research was to check the effects of

several anti-stripping additives or treatments on mixtures containing three different types of siliceous aggregates and to determine the approximate amounts of these additives to use for optimum results.

Hydrated lime and a latex rubber were the anti-stripping additives employed. A cationic emulsion pre-coating treatment was also used.

A laboratory study and evaluation of some properties of the asphalt-aggregate mixtures such as stability, cohesion, and stripping resistance, are reported and compared with non-additive mixtures. A modified Immersion-Compression Test (4), and two types of stripping tests were employed to determine the effectiveness of the anti-stripping additives and precoating treatment.

CHAPTER II

REVIEW OF LITERATURE

Asphaltic pavement mixtures are basically composed of two materials, the binder (asphalt cement) and the mineral aggregate (sand, screenings, and coarse aggregates). The two substances are proportionally mixed to form what is known as asphalt-concrete. An asphalt-concrete pavement should be stable, i.e., it should resist deformation under loads, and be durable, skid resistant, and economical (5).

The principle function of the asphalt in such a mixture is to serve as a strong glue or adhesive. The asphalt cement adheres to the aggregate particles and forms a strong bond at the interface.

If an improper bond condition exists between the binder and the aggregate particles, the results may be serious, leading to a premature failure of the pavement mixture. A proper bond is normally expected in a bituminous-aggregate system in which a suitable binder and a dry, clean aggregate have been used. Therefore, once an appropriate adhesive bond is formed between both materials, the interface failure between the binder and aggregate is improbable, barring the action of water (2, 4). This loss of adhesion between the asphalt and aggregate, due to the action of water, is known to road design engineers as stripping.

Stripping is not a new phenomenon. It has been known since asphalt-paving came into existence (2). Its presence has resulted in

the reduction of pavement performance. In order for stripping to occur, there must be a loss of adhesion between the binder and the aggregate particles. There are numerous variables which tend to affect this adhesion. Some of these are: aggregate and binder properties, environment, surface contamination of the aggregate, and pavement construction techniques (2, 4, 6, 7).

Factors That Affect Stripping

Aggregate Properties

The mineralogical composition of the aggregates is important to know. Aggregates have unbalanced surface charges with energy needs that must be filled. Due to these energy demands, the aggregate will form a strong bond with a binder which satisfies its needs. When two adhesive substances are compared, the one best filling the aggregates energy needs will displace the other, e.g., water displacing asphalt, resulting in stripping.

Aggregates can generally be placed in one of two categories--hydrophobic or hydrophilic. Hydrophobic, which are usually calcareous in nature, have a high affinity for asphalt. On the other hand, hydrophilic, which are siliceous aggregates, have a stronger attraction to water. This is why siliceous aggregates tend to strip more readily than limestone aggregates.

Surface roughness of the aggregate influences the strength of the aggregate binder bond. As the roughness of the surface increases, the strength of the bond generally increases as well. This is the reason that more surface area is exposed for the binder to attach to, resulting in lower stress at the interface.

Porosity of the aggregate can also influence the adhesion of the binder. The space in a rock, which is unoccupied by solid matter, gives the binder an opportunity to penetrate the pores and form an interlocking bond.

Surface contamination on the aggregates, i.e., clay, dust, or moisture, tend to produce a weak aggregate bond. Clay and dust reduce the spreading and wetting of the binder on the aggregate surface. Moisture, referring to the absorbed water molecules that exist within the aggregate, is the main cause of stripping.

Binder Properties

Surface tension is an important binder property. It has to do with the forces of attraction between molecules in the binder. Interior molecules are equally attracted in all directions while surface molecules are only inwardly attracted, causing a state of tension at the surface. This is why surface tension is one of the principle factors affecting the wetting and spreading of the binder on the aggregate surface. In other words, if the surface free energy of the adhesive is greater than that of the adherent, the binder will tend to bulk, slowing wettability (2).

Viscosity of the binder influences its ability to flow. As the temperature increases, viscosity decreases, so that the binder will flow more readily, coating the aggregate surfaces. Extreme caution should be taken when the binder is heated to high temperatures though, as it may undergo physical and chemical changes. Mathews (8) also found that the higher the viscosity of the binder, after coating is

achieved, the more it will resist, to some extent, the disruption of the asphalt-aggregate bond by water.

The durability of the binder is extremely important. The initial properties should remain constant after being exposed to service conditions. Also, the composition and source of the binder should be examined. Not all binders exhibit similar properties. Each binder may exhibit different degrees or amounts of stripping.

Environment

Environment plays an important role in stripping. When it rains, the liquid enters the pavement through the available pores or cracks in the surface. This water tends to disrupt the asphalt aggregate bond and eventually leads to stripping. Water is said to be one of the major causes of adhesion failures. The rate and amount of loading may fracture or crack the pavement. These fractures tend to increase stripping by giving the water more possibilities to penetrate in the pavement.

Vehicles also affect the binder-aggregate bond. They tend to spill small amounts of fuel (gasoline, diesel, and oil) on the pavement. This fuel tends to dissolve the asphalt, therefore weakening the asphalt aggregate bond.

Construction

Following good construction procedures, a high quality road can be produced. The most critical phase of construction, according to Marker, especially as far as the durability and service life of the completed pavement is concerned, is the compaction of asphalt concrete pavement (9). It has been found that in a well compacted, hot-rolled, asphalt

mix having extremely low permeability to water, stripping has not been significant (2).

Stripping Tests

Presently there are a number of tests that try to evaluate the amount of stripping of a binder-aggregate sample. In some of the tests stripping is visually inspected, while in others a reduction in strength between wet and dry compacted specimens gives the indication that stripping has taken place. Another test which was developed by Ford (4) is able to quantitatively evaluate the amount of aggregate surface stripped. Following is a discussion of the Immersion-Compression Test, the Static Immersion Test, the Dynamic Immersion Test, and the Surface Reaction Test.

Immersion-Compression Test (I-C)

There has been extensive research in this area since the first report on such a test procedure appeared in 1943. Ford made a very extensive review of all the available literature concerning the Immersion-Compression Test (4).

After several years of research in this area, the test was standardized by ASTM under the test designation: D 1075-54, "The Effect of Water on the Cohesion of Compacted Bituminous Mixtures." For this test, six specimens (4 inches in diameter by 4 inches high) are molded following the recommended ASTM procedure. The specimens are then cured at 140 F for 24 hours. Then the bulk specific gravity of the specimen is measured so they can be sorted into two groups having about the same average specific gravity.

Three specimens are tested dry at 77 F under axial compression at a rate of .05 inches per minute for each inch of specimen height. The other three are immersed for four days at 140 F. They are then transferred to a 77 F water bath for two hours before their compressive strength is determined. Then, the percentage of loss in strength can be determined by dividing the compressive strength of the wet samples by the compressive strength of the dry samples. This strength loss gives an indication that the sample has been stripped.

Dynamic Immersion Stripping Test (DIS)

Nicholson (2) devised this method to empirically measure the degree of stripping. The test procedure is as follows: (a) An aggregate is fully coated with bitumen and immersed in a bottle filled with distilled water; (b) The bottle is then mechanically agitated or in some cases rotated, at a specified speed for a stated period of time; (c) The content of the bottle is then visually inspected to check for stripping on the aggregate surfaces. Several small modifications of this test have been made by other authors trying to simulate traffic loading conditions (2, 4, 10).

Static Immersion Stripping Test

This standard method test was adopted by ASTM under the designation: D 1664-64T. The method consists of coating 100 grams of the aggregate in question with 5.5 grams of bitumen. The aggregates used for this test must pass through the 3/8 inch sieve and be retained on the 1/4 inch sieve. The coated samples are then immersed in a jar filled with distilled water at 77 F for 16 to 24 hours. The distilled water used

must have a pH of 6 to 7. The percentage of coated aggregate surface is then determined by visual inspection.

Surface Reaction Test (SRT)

This test is credited to Ford (4). He found that there was a need for a test that would eliminate an operator's visual judgment in reporting degrees of stripping. The test results, in other words, would give a quantitative measure of stripping.

The procedure followed was to measure the stripped surface area of an aggregate sample by determining the gas pressure generated in a chemical reaction. To do this, Ford found that certain acids could be used to react with various types of aggregate. This reaction generated gas and heat. These reaction products were considered to be proportional to the exposed surface area of the aggregate.

There are several factors that need to be considered for the SRT. First, a suitable reagent (acid) is needed for this test, one that will cause a chemical reaction, creating a measurable gas pressure but not so strong as to deeply etch the aggregate surface. Second, the acid when in contact with asphalt cement coated aggregates (100 percent) should not create a significant pressure. Third, the sample used for this test should be dry.

The equipment Ford used for this test was a pressure vessel that would contain the reaction between the acid and the aggregate. The pressure in the vessel was measured by a pressure transducer. The temperature was monitored by using a thermistor and remote sensing thermometer unit. This instrumentation was attached to a strip chart recorder that simultaneously recorded pressure, temperature, and time.

Anti-Stripping Additives

Purpose

Earlier in this chapter the different factors that affect stripping were enumerated. One can see that new techniques are needed to overcome stripping failures. Anti-stripping additives may be used to improve pavement mixtures to protect against the aggression of water. That is, stripping can be reduced by the use of a suitable additive in the proper amount (11).

There has been extensive laboratory work done on the use of additives, especially in the area of blending rubber and asphalt. But there is a lack of results being published concerning field performance or the effects of anti-stripping additives on asphalt aggregate mixtures.

Requirements

Numerous anti-stripping additives have been used to increase adhesion and reduce stripping. These additives can be classified as binder or aggregate additives. In other words, some additives are designed to improve the properties of the binder while others are designed to improve the characteristics of the aggregate surface.

An additive must satisfy several requirements (8). First, the additive should be stable at high temperatures, i.e., the elevated temperatures used in mixing, transporting, and construction of hot-mix bituminous pavements should not change the additive properties (10). Second, the additive must be efficient when present in small amounts (11). Third, the additive must prove to be economical or the additional

expenditure must be justified (13). Sometimes, repair or maintenance work may be less expensive than the initial cost of the additive. Fourth, the incorporated additives should not produce undesirable side effects on the mix (14). Another, and one of the most important requirements, is that additives be able to withstand the aggression of water (10, 13, 14).

Several authors have found that when aggregate additives are employed, the results are most successful. The only problem with this is that the method has proven to be expensive (2, 15). Binder additives have also proven to give good results. In either case, it is essential that accurate and reliable tests be conducted to determine the proper type and quantity of additive to be used, as well as the correct mixing procedure. Additives are usually too expensive to be wasted.

Types of Available Additives

During recent years, the use of anti-stripping additives has gained fair acceptance by paving technologists. Majidzadeh and Brovold have summarized several anti-stripping additives that have been used in bituminous mixtures (see Table I). They also made comment on the results of their usage in several research reports (2).

Due to time restrictions, only a few of the available additives or treatments could be investigated. After reviewing the available data, two additives and a treatment procedure, proven to be most successful, were selected and used in this study. These were a latex rubber, hydrated lime, and precoating with a cationic emulsion.

TABLE I
ADDITIVES USED IN BITUMINOUS MIXTURES

Additive	Remark
Filler-hydrated lime, portland cement, 1 to 2 percent by weight	May reduce or prevent stripping Good for improvement of wet or cold aggregate
Acid	Type and quantity not well established
Polar material (organic acids or alcohols)	Added to binder, attractive from a theoretical viewpoint but often inadequate experimentally Seldom adequate
Surface-active chemicals	Reduce interfacial energy between binder and water, seldom adequate practically
Surface-active chemicals (soaps, calcium, lead, iron)	May improve adhesion, but often inadequate
Cationic surface-active agents	Strongly adsorbed at the binder aggregate interface reinforcing adhesion; expensive
Cationic, cetyl pyridinium bromide	Good laboratory performance but poor field performance
Organic amines	Effective in surface treatments, used extensively in Sweden and Great Britain, minimum quantity not established Very powerful, cationic surface-active agents
Amines or diamines of long-chain hydrocarbons	Maximum useful percentage 1.5 percent by weight, more may decrease adhesion
Road tar, 10 percent by weight	Slight improvement
Oil or soot (thin layer deposited on surface)	Questionable
Fly ash	Questionable
Precoating aggregate with silicone or metal salt solution	Improves adhesion, may compare economically with cationic additives to binder, needs confirmation by field performance
Precoating with diesel oil and 1 percent solution of oleic acid, naphthenic acid, tar, and bitumen	Improves adhesion significantly in laboratory detachment test
Precoating with 1 percent undiluted bitumen or tar at 250 C	Safest method to ensure 100 percent adhesion in the laboratory detachment test
Addition to binder of "stearine pitch," oleic acids, naphthenic acid	Improves resistance to detachment

Source: Majidzadeh, K. and Brovald, F. N. "State of the Art: Effect of Water on Bitumen-Aggregate Mixtures." Highway Research Board Special Report No. 98, Washington, D.C. (1968), p. 57.

Rubber Additive. Commercial rubber additives have been used recently by numerous highway agencies. One type, "Pliopave" (emulsified latex rubber) is manufactured by Goodyear Rubber Co. This rubber can be added to the asphalt aggregate mixture in two ways. One way is by blending it with the bitumen prior to adding the aggregate. The second is by introducing all the materials at the same time.

According to Goodyear publication (16), the addition of Pliopave latex increases stability and percent density of asphalt-concrete. Several advantages of this additive have also been noticed in construction operations. It brings about changes in asphalt properties, for example prolonging life and improving weatherability. Goodyear has also stated that the use of Pliopave produces a great increase in adhesion properties. Normally, about 3 to 5 percent rubber, based on asphalt cement content is sufficient to improve the physical properties of the binder (16).

Mineral Filler. There has been a lot of work done in this area. The most frequent types of filler used in research have been hydrated lime, fly ash, organic amines, and others (2). Of these major alternatives, hydrated lime appeared to have the best possibilities.

O'Harra found that using 2 percent lime on several silicious aggregates of the state of Arizona, a higher index of retained strength in the I-C test was encountered (16). Eager (13) also reports of a study made by Swanson using hydrated lime that produced similar results to those of O'Harra. Several other authors have found that when the aggregate was treated with lime and cured in moisture for several days, better results were achieved (13, 15, 17).

Precoating the Aggregate. Majidzadeh and Brovold mentioned several research reports that have been investigated concerning precoating treatments (2). Karius and Dalton reported that precoating the aggregate with a solution of tar, bitumen, silicones, and emulsions, often improved adhesion and reduced stripping (18).

Precoating of the aggregate with a cationic emulsion seems to give good results. Several authors feel this is because cationic emulsions tend to displace water from the surface of the aggregate.

CHAPTER III

ASPHALT CEMENT, MINERAL AGGREGATES AND ADDITIVES

Asphalt Cement

The asphalt cement used in this research came from the Allied Materials Corporation plant at Stroud, Oklahoma. The physical properties of this asphalt are shown in Table II.

TABLE II
PHYSICAL PROPERTIES OF ASPHALT CEMENT

Characteristics	Test Value ¹
Penetration, 77 F, 100 g, 5 sec.	88
Ductility, 77 F, cm	150+
Viscosity at 275 F, Kinematic, cst	400
Specific gravity, 77 F	1.003
Softening Point, degrees F	118
Flash Point, degrees F	580+

¹Obtained using standard ASTM test methods.

Aggregates

In previous work, Ford (4) studied the relative stripping tendencies of eleven different Oklahoma aggregates. Ten of these aggregates were primarily siliceous in nature and included gravels, sandstones, siliceous limestones and a crushed chert material. With some consideration as to their resistance to stripping, three of these aggregates, typifying the various sedimentary types employed by Ford, were selected for this investigation.

For the purposes of this study, these siliceous aggregates were incorporated in the coarse aggregate portion of a type B surface course mixture. Proportioning was made on the basis of obtaining 30 percent acid insoluble residue material (OHD-L-25) in the coarse aggregate fraction. A relatively pure limestone from Cooperton, Oklahoma, and a river sand were used as the basic ingredients of this standard mixture.

The various aggregate materials employed are identified by the town name adjacent to the source location. The location of the source by county and a brief description of the aggregate is included under each heading.

Some of the physical properties of the coarse aggregate are listed in Table III. These values are based on those obtained by the Oklahoma Highway Department.

Cooperton

This aggregate is a gray to mottled gray limestone rock. The quarry is located in Kiowa County in southwestern Oklahoma. The rock

TABLE III
AGGREGATE PHYSICAL PROPERTIES

Sample	Average Bulk Specific Gravity	Acid Insoluble Residue Percentage	Water Absorption	Los Angeles Abrasion
Cooperton	2.67	1.2	0.8	24
Asher	2.46	99.8	3.2	25
Miami	2.56	95.4	1.2	23
Onapa	2.47	92.1	4.1	35

Source: Rowland, T. L. "Chemical and Physical Properties of Selected Oklahoma Crushed-Stone Products." Oklahoma Geology Notes, Vol. 32, No. 5. The University of Oklahoma, Norman, Oklahoma (October 1972), p. 152.

consists of 98 percent limestone and 2 percent silica, with traces of magnesium and iron.

Arkholá Sand

This aggregate is a reddish-brown sand obtained from Arkansas River deposits near Muskogee, Oklahoma.

Asher

This aggregate is a light red to brown gravel rock, obtained from a conglomerate of the Prairie Plains Homocline. The quarry is located in Pottawatomie County in central Oklahoma. The rock consists of 94 percent banded chert and 6 percent cherty limestone.

Miami

This aggregate is a whitish-gray chert rock. It comes from waste stockpiles from the Eagle-Picher Zinc Mine in Ottawa County in northeastern Oklahoma. The rock consists of 92 percent chert, 6 percent limestone, and 2 percent dolomite with traces of zinc and iron.

Onapa

This aggregate is a grayish-tan siliceous sandstone obtained from the Arkoma Basin. The quarry is located in McIntosh County. The rock consists of 68 percent quartz grains, 31 percent chert and 1 percent miscellaneous materials.

Additives

The additives used in this research were hydrated lime, latex rubber and cationic emulsion. Their selection was based on the results reported by several authors (2, 16, 20), which were summarized in Chapter II.

Reports from the additive manufacturers were examined to determine their physical and chemical properties. These are given in the following descriptions.

Hydrated Lime

The chemical formulation of this additive is nominally, Ca(OH)_2 . It is manufactured by the St. Clair Lime Company at their plant in Sallisaw, Oklahoma. A chemical analysis of the material by Mr. G. L. Griffin, chemist for the St. Clair Company, indicated that the sample contained 90 percent of available CaO .

The gradational analysis of the lime showed 99.8 percent passing the No. 30 sieve, 94.6 percent passing the No. 100 sieve and 85.1 percent passing the No. 200 sieve.

Pliopave

This additive is manufactured by Goodyear Tire and Rubber Company of Akron, Ohio, under the trade name Pliopave L-165K. This material is a cationic (positively charged) styrene/butadiene rubber in latex form. Properties of Pliopave L-165K latex are shown in Table IV.

According to Goodyear, the material consists of particles of unvulcanized synthetic rubber in a water emulsion system. These particles are very small and uniform and well dispersed in the latex form.

TABLE IV
PROPERTIES OF PLIOPAVE L-165K

Characteristics	Test Value
Solid Content, Min percent	60
Solid Content, Min lbs/gal	5.0
Coagulum on 80 mesh screen, max percent	0.1
Mooney Viscosity of Polymer (M1 4 @ 212 F) min	100
pH of latex	5.5
Surface Tension, dynes/cm	28-40
Brookfield Viscosity, cps	1500 max

Source: The Goodyear Tire and Rubber Company. "Tech Book Facts: Pliopave Types and Products." Goodyear Chemicals, Akron, Ohio (Revised, February, 1968) P. T.T.

The latex rubber, when blended with the asphalt cement, is supposed to reduce penetration, increase viscosity, and increase ductility of the asphalt cement (21). The effect of various percentages of rubber on the penetration of the AC used in this study is shown in Table V.

TABLE V
RESULTS OF PENETRATION OF THE BASE AC
BLENDED WITH PLIOPAVE

Penetration Blended with 85-100 pen AC	Test Values
1 1/2 percent rubber, by wt of AC	77
3 percent rubber, by wt of AC	74
4 1/2 percent rubber, by wt of AC	71

Emulsion

The type of emulsion used was a CRS-1 cationic asphalt emulsion distributed by Okmulgee Refining Co., Inc., of Okmulgee, Oklahoma. Some of the properties of the emulsion and the base asphalt cement are shown in Table VI.

TABLE VI
EMULSION (CRS-1) AND ITS
BASE AC PROPERTIES

Characteristics	Test Values
<u>(CRS-1)</u>	
Viscosity, SFV @ 122 F	33.0
Seven Day Settlement Test	2.5
Particle Charge	Pos.
Residue by Dist.	66.0
<u>Base AC</u>	
Flash Point, (COC), F	500+
Penetration 100 g @ 77 F	94
Penetration Ratio	33
Viscosity @ 275 F	195
Ductility @ 77 F	150+

Source: Briscoe, R. F. "Certificate of Analysis on CRS-1 Cationic Asphalt Emulsion." Okmulgee Refining Co., Inc., Okmulgee, Oklahoma (Personal Communication, June, 1973).

CHAPTER IV

LABORATORY TEST PROCEDURES

Mix Design

The aggregate-asphalt mix used for this research was the Oklahoma Highway Department (OHD), type B surface or base course mixture (19). The upper and lower specification limits as well as the midpoint gradations are shown in Table VII.

TABLE VII
OHD TYPE B MIX SPECIFICATIONS

Sieve	Percent by Weight Passing	
	Specifications	Midpoint Gradation
3/4 inch	100	100
1/2 inch	80-100	90
3/8 inch	70- 90	80
#4	50- 70	60
#10	35- 50	42.5
#40	15- 30	22.5
#80	10- 20	15
#200	3- 9	6

Source: "Standard Specifications for Highway Construction," Oklahoma State Highway Commission, 1967, Soc. 708.01.

The gradation of the test specimen mixtures was controlled to achieve the desired midpoint of the OHD standard mix. The coarser aggregates (3/4 inch sieve to #10 sieve) were obtained from the Cooperton aggregate. Arkhola sand was used for the fine aggregate (#40 sieve to #80 sieve); and Cooperton dust, or mineral filler, was used for the minus #200 sieve material. These aggregates were the basic ingredients for the standard mix. Only the coarser fraction (minus 3/4 inch to plus #10 sizes) of the siliceous aggregates were incorporated in the standard mix. The amounts of each aggregate incorporated were based on their percent acid-insoluble residue (OHD-L-25) and replaced like amounts of the Cooperton limestone. The proportions were set to obtain 30 percent acid-insoluble residue in the mix as was done by Marr (12). Each sample was identified by the coarse aggregate used.

Three of the siliceous aggregates previously investigated (4, 12) were used in this study. They were the Asher chert gravel, the Miami chert and the Onapa sandstone. These aggregates seemed to be representative of the group and were selected on this basis. Asphalt contents of 4, 4 1/2 and 5 percent by weight of mix were used for the test series of specimens made for each of these aggregates. With the exception of the precoating treatment, three different percentages of each additive were incorporated in these test specimens.

Sample Preparation

The three additives used were hydrated lime, latex rubber and a cationic emulsion. The description and properties of these additives were presented in Chapter III. The additives were introduced to the

mix by varying procedures, each of which will be discussed later in this section.

Mixing and Molding

Pans containing 1000 grams of the sized aggregates were heated to $250\text{ F} \pm 10\text{ F}$. A predetermined amount of hot asphalt at $250\text{ F} \pm 10\text{ F}$ was poured into the hot aggregate. The samples were then mixed using a Hobart C-100 mixer with a wire whip attachment. The mixing time necessary to coat all the samples was approximately 3 to 5 minutes. During the mixing a bunsen burner was used to keep the mixture from cooling.

After the samples were mixed they were placed in an oven and brought to $250\text{ F} \pm 10\text{ F}$ prior to molding. The asphalt aggregate mixtures were then molded and compacted using the Texas Highway Department method, Tex-206-F part II (20). An explanation of this procedure follows.

The aggregate in the oven was removed and placed in a hot gyratory mold in three approximately equal layers. The mold containing the mixture was placed in a motorized gyratory-shear compactor for compaction. The mold was then gyrated one cycle (three revolutions) at 50 psig pressure. This cycle was continued until one stroke on the pump gave a pressure of 100 psig on the mixture. Then a leveling pressure of 2500 psig was applied for final compaction. The mold was then removed from the compactor and the samples dislodged from the mold and left to cool.

Additive Introduction

The additives were introduced to the aggregate mixtures prior to mixing and molding. The different procedures used are as follows.

Hydrated Lime. The hydrated lime was received from the manufacturer in powder form in 10 pound cans. It was added to the samples in various percentages (1, 1 1/2 and 2) by weight of the total aggregate, as a mineral filler.

As a check for loss of weight due to water evaporation, samples of the lime were placed in an oven at 250 F for a twelve hour period. This resulted in no significant weight loss.

Lime was added to the sized aggregate sample and then heated, mixed and molded following the procedure already stated. However, the mixing time was slightly greater than that of the stated procedure. This may be attributed to the increased surface area of the hydrated lime samples.

Pliopave. The rubber additive used in this research was Goodyear Pliopave, L-165K. This latex emulsion contained 62.1 percent solids (rubber). This additive was incorporated by blending it with the asphalt cement. The various percentages of 1 1/2, 3 and 4 1/2 percent rubber by weight of asphalt-cement were tested.

The procedure used to blend the Pliopave with the asphalt was determined by experimentation. In the first trial procedure the asphalt was heated to $250\text{ F} \pm 10\text{ F}$ and then poured into a can containing a prescribed amount of latex emulsion. The amount of emulsion was based on its solids (rubber) content to obtain the desired rubber percentage in the asphalt cement. Then this mixture was stirred by hand. This method proved ineffective due to the fact that all water could not be

removed and it appeared that the rubber was not well blended or dispersed in the asphalt cement.

After consulting with the manufacturer, a second procedure was tried. Following their recommendations, the asphalt cement was heated to $300\text{ F} \pm 15\text{ F}$ and a mechanical mixing method was devised to blend the two materials. In this procedure, the hot AC was placed in a deep container, stirred in a manner such that a vortex was created, and then the Pliopave was slowly added, a few drops at a time. A 15 inch bench drill press, with an "L" shaped metal stirring rod was used as the blender. For safety reasons, a pan was placed under the container with a hot plate below this in an effort to keep the temperature of the asphalt constant. The purpose of the pan was to keep the asphalt contained.

The Pliopave was poured very slowly into the center of the vortex as the contact of the two resulted in immediate foaming. The "L" shaped stirring rod was moved up and down in the container during mixing to insure a thoroughly blended mixture as well as to facilitate removal of the available water in the Pliopave emulsion. The difficulty of blending increased as the percentage of rubber increased.

After mechanically stirring the AC and Pliopave mixture the blended material was returned to the oven and the temperature raised to $300\text{ F} \pm 15\text{ F}$. After attaining this temperature, it was manually stirred as a final check for the presence of water.

The mixing and molding of the test specimens containing the rubber additive blended into the asphalt, following the same procedure as that previously described, with the exception of temperature. This was raised

to $280\text{ F} \pm 10\text{ F}$, as the mixture was easier to work with at a higher temperature.

Handling the blended rubber AC was laborious and tedious as the added rubber made the AC more elastic and tended to stick to the equipment used while mixing and molding.

Precoating Treatment. Rapid curing cationic asphalt emulsion was used for the precoating treatment. Only the siliceous aggregates used in the standard OHD type B mix were precoated. This treatment consisted of coating these aggregate particles with a thin film of asphalt ($1\text{ percent} \pm 0.25\text{ percent}$).

Several trials were made in order to achieve the desired amount of coating. The final selected procedure was as follows. The asphalt emulsion was procured in a 5 gallon bucket. When stored in this type container the emulsion formed a protective skin or crust at the air-emulsion interface. To avoid disturbing this crust or film and including clots of separated asphalt in the emulsion used for precoating, the necessary amounts for each treatment were withdrawn from the bucket using a vacuum pump arrangement. Distilled water was then added to dilute the emulsion, to obtain the desired proportion of 70 percent distilled water, 30 percent emulsion. The siliceous aggregate was then placed in a tea strainer and dipped into the diluted emulsion, making certain that all aggregate particles were immersed. The particles were then drained, transferred to a pan, and placed in a 140 F oven to remove any moisture present in the coated particles. The mixing and molding procedure for the test specimens containing these precoated aggregates was the same as that previously described.

Test Procedures

After the samples were molded, they were marked with an identification number and cooled to room temperature. The average height of the compacted specimens was then measured followed by measuring the bulk specific gravity. The procedure used in measuring this specific gravity followed test procedure OHD-L-14, method B (19).

Stability Test

The stabilometer test, ASTM Designation: D 1560 (21), was used to determine stability, which is the ability of the samples to resist deformation. A Hveem stabilometer, which is a triaxial compression device, is used to determine the transmitted horizontal pressures developed in a compacted asphalt-aggregate mixture when subjected to vertical pressure.

The testing and evaluation of results followed ASTM and OHD procedures (21, 19). Briefly the test procedure was as follows: Prior to testing, the samples were brought to $140\text{ F} \pm 5\text{ F}$, and held at that temperature for at least two hours. Then the stabilometer was calibrated and the head speed of the compression testing machine was adjusted to 0.05 inch per minute. The samples to be tested were then placed in the stabilometer, and then both placed in the compression machine for testing.

Cohesion Test

The cohesiometer test, ASTM Designation: D 1560 (21), was performed on the specimens previously tested for stability. This test provides a measure of the cohesive resistance or tensile strength of a

compacted asphalt-aggregate mixture. The cohesion of a compacted specimen is determined by measuring the force required to break or bend the specimen as a cantilever beam by means of the Hveem cohesiometer. The cohesiometer value, C, is a numerical value expressed as weight in grams of lead shot required to break, in tension, a test specimen equivalent to 3 inches in height and 1 inch in width.

After the samples were tested for stability, they were placed in a $140\text{ F} \pm 5\text{ F}$ oven and held at that temperature for a minimum of 2 hours. After this, they were placed in the cohesiometer cabinet which had been previously calibrated to release 1800 ± 20 grams per minute of lead shot and tested for cohesion.

Immersion-Compression Test

In order to utilize the available laboratory equipment, and from previous work done by Ford (4), a modified I-C test was employed in this study.

Ford found that by following the ASTM procedures, the test did not show any significant results. The ASTM procedures were presented in Chapter II. Ford therefore modified the test so he could get more percent voids in the remolded compacted specimens. Using a motorized gyratory-shear compactor, the mold was gyrated one cycle (three revolutions) at 50 psig pressure and leveled for final compaction to a pressure of 800 psig. This decrease in compactive effort resulted in higher air void contents and thus greater water penetration in the remolded specimens. After the cohesiometer tests, the same samples were remolded, oven cured, vacuum saturated, water cured, tested and evaluated using Ford's outlined procedures (4).

Dynamic-Immersion Stripping Test (DIS)

This test was conducted on only the siliceous aggregates--Asher, Miami, and Onapa. The object of this test was to accelerate the stripping action of water on the additive-asphalt coated aggregates.

The test samples were prepared by weighing out approximately 1700 grams of each of the above mentioned aggregates which passed the 3/8 inch sieve, but were retained on the 1/4 inch sieve. The aggregates were then washed, dried, resieved, and quartered to obtain 16 representative samples each weighing 100 ± 2 grams. The number of rock particles were counted so that the samples could be paired by approximately equal number of particles. Duplicate samples were tested using each percent of additive studied. The two remaining samples were uncoated and used for the surface reaction test.

All the 100 gram samples were brought to 250 F, except for those to be used with the Pliopave additive. These aggregate samples were heated to $280 \text{ F} \pm 10 \text{ F}$ to facilitate coating with the asphalt containing the latex rubber. All the samples were fully coated with 6 grams of AC. For samples using Pliopave, 6 grams of AC plus Pliopave were used. The additives for this test were introduced in the same manner as for the compacted specimens. That is, the hydrated lime was added to the aggregate sample prior to coating with the AC; the Pliopave was blended with the AC; and the aggregate samples were coated with this blended material. The precoated aggregate samples were handled in a slightly different manner. These samples already contained 1 percent \pm 0.25 percent by weight of asphalt in this coating so only an additional amount of asphalt necessary to make a total of 6 grams was required.

The samples were then placed in jars with 600 ml of chilled distilled water and tested in a dynamic stripping machine. They were then visually inspected at 1, 2, and 4 hours for stripping using Ford's comparison charts (4). The water in the jars was changed during the course of the DIS test, at the end of 2 hours with cold water to prevent the particles from bulking (sticking together). The water in the jars containing Pliopave treated samples was changed twice, because the coated particles had a greater tendency to bulk.

Surface-Reaction Test (SRT)

The purpose of this test was to evaluate in a more quantitative manner, the amount of asphalt that was stripped from an initially fully coated aggregate surface. This test was performed on the samples which were previously used in the DIS test.

Following the DIS test, the samples were placed in a pan and left to dry at laboratory temperature. The samples were then tested and evaluated following Ford's procedure, with the exception of the hydrofluoric acid concentration and the laboratory temperature. The hydrofluoric acid was not diluted with distilled water as previously done by Ford for several reasons. Using the fully concentrated acid, a stronger reaction was achieved. This made the pressure and temperature recordings easier to read and evaluate. Also, the procedure was simplified by eliminating the dilution process and the extra handling of this highly dangerous acid. The laboratory temperature was approximately 26 C when the DIS and SRT testing was performed. This was approximately 6 C higher than when Ford did his testing. The higher temperature was attributed to

the change of seasons and the poor air conditioning facilities in the laboratory.

Percent Density Determinations

Rice's method was used to determine the maximum specific gravity of the compacted specimens. This is an ASTM standard test procedure, ASTM Designation: D 2041.

The testing was performed on duplicate compacted samples at each asphalt content used in this study. Briefly, the procedure was as follows. The samples were brought up to $250\text{ F} \pm 10\text{ F}$, after which they were broken down into individual asphalt coated particles and allowed to cool. The samples were then transferred to a calibrated flask and weighed. The flask was then filled with deaired distilled water treated with a wetting agent so that the particles were covered. This was then subjected to approximately 29 inches of Hg vacuum for 15 minutes. It was agitated vigorously several times during this period. After the flask was filled with deaired distilled water it was placed in a $77\text{ F} \pm 0.9\text{ F}$ water bath for 10 minutes. The flask containing the aggregate and deaired distilled water was then weighed. The specific gravity was then determined using the ASTM outlined formula (21).

The percent density of the compacted specimens was then calculated by dividing the bulk specific gravity by the maximum specific gravity (Rice's Method). The quotient factor of this was then multiplied by 100.

CHAPTER V

TEST RESULTS AND DISCUSSION

The purpose of this study was to investigate the effects of introducing anti-stripping additives into a standard asphalt paving mix containing small amounts of siliceous aggregates. The siliceous aggregates (Asher, Miami, and Onapa) in this paving mixture were proportioned on the basis of obtaining 30 percent acid insoluble material in the coarse aggregate fractions.

The test procedures discussed in Chapter IV were used to obtain the values reported in this chapter. The results of the various tests are presented in tabular form. In some cases, graphs were drawn for comparative purposes. These graphs are incorporated in the appendices.

Stability and Cohesion Tests

Tables VIII through XI show the bulk specific gravity, maximum specific gravity by Rice's method, percent density, stability, and cohesiometer values of the compacted specimens for each of the aggregates used, both with and without additives. The values shown in Table VIII for the standard mix with no additives are the results of a second series of specimens and not the results reported by Marr (12).

TABLE VIII
STANDARD MIX TEST RESULTS

Test	% Asphalt	No Additives	Additives Incorporated					
			Lime			Pliopave		
			1%	1 1/2%	2%	1 1/2%	3%	4 1/2%
Bulk Specific Gravity	4	2.468	2.460	2.445	2.420	2.457	2.458	2.449
	4 1/2	2.473	2.460	2.449	2.441	2.460	2.463	2.455
	5	2.462	2.447	2.444	2.440	2.453	2.450	2.445
Maximum Specific Gravity by Rice's Method	4	2.504	2.497	2.494	2.490	2.498	2.497	2.497
	4 1/2	2.483	2.480	2.477	2.483	2.481	2.482	2.474
	5	2.467	2.461	2.459	2.456	2.470	2.460	2.448
% Density	4	98.6	98.5	98.0	97.2	98.4	98.4	98.1
	4 1/2	99.6	99.2	98.9	98.3	99.2	99.2	99.2
	5	99.8	99.4	99.4	99.3	99.3	99.6	99.9
Hveem Stability	4	41	49	48	50	39	36	41
	4 1/2	23	28	30	31	30	21	28
	5	15	14	11	15	17	16	17
Hveem Cohesimeter	4	381	455	449	499	442	459	476
	4 1/2	396	468	405	530	478	473	516
	5	330	400	402	420	431	439	439

TABLE IX
30% ASHER TEST RESULTS

Test	Percent Asphalt	No Additives	Additives Incorporated						
			Lime			Plifopave			Emulsion
			1%	1 1/2%	2%	1 1/2%	3%	4 1/2%	1% Coating
Bulk Specific Gravity	4	2.361	2.407	2.412	2.407	2.412	2.417	2.396	2.398
	4 1/2	2.372	2.417	2.412	2.408	2.421	2.417	2.410	2.413
	5	2.395	2.408	2.403	2.406	2.409	2.407	2.404	2.411
Maximum Specific Gravity by Rice's Method	4	2.468	2.463	2.463	2.460	2.458	2.459	2.460	2.461
	4 1/2	2.455	2.444	2.441	2.439	2.443	2.441	2.436	2.446
	5	2.435	2.438	2.426	2.426	2.427	2.423	2.419	2.431
% Density	4	95.7	97.7	97.9	97.8	98.1	98.3	97.4	97.4
	4 1/2	96.6	98.9	98.8	98.7	99.1	99.0	98.9	98.7
	5	98.3	98.8	99.1	99.2	99.3	99.3	99.4	99.2
Hveem Stability	4	38	43	41	48	36	33	35	38
	4 1/2	36	28	26	25	30	24	28	28
	5	31	19	26	17	17	15	16	16
Hveem Cohesion	4	177	535	580	469	452	499	459	260
	4 1/2	212	544	547	511	489	516	566	320
	5	219	502	439	444	398	420	456	372

TABLE X
30% MIAMI TEST RESULTS

Test	Percent Asphalt	No Additives	Additives Incorporated						
			Lime			Pliopave			Emulsion
			1%	1 1/2%	2%	1 1/2%	3%	4 1/2%	1% Coating
Bulk Specific Gravity	4	2.388	2.425	2.412	2.417	2.429	2.428	2.415	2.426
	4 1/2	2.394	2.426	2.419	2.426	2.437	2.439	2.427	2.438
	5	2.416	2.430	2.427	2.428	2.436	2.432	2.425	2.438
Maximum Specific Gravity by Rice's Method	4	2.487	2.479	2.478	2.483	2.486	2.482	2.472	2.489
	4 1/2	2.469	2.558	2.462	2.462	2.465	2.458	2.460	2.465
	5	2.449	2.454	2.445	2.445	2.453	2.443	2.434	2.453
% Density	4	96.0	97.8	97.3	97.3	97.7	97.8	97.7	97.5
	4 1/2	97.0	94.8	98.3	98.5	98.9	99.2	98.7	98.9
	5	98.6	99.0	99.3	99.3	99.3	99.5	99.6	99.4
Hveem Stability	4	40	49	50	50	40	39	38	37
	4 1/2	40	36	32	28	31	34	31	32
	5	37	17	17	18	20	21	19	18
Hveem Cohesimeter	4	140	471	474	538	538	465	389	327
	4 1/2	164	434	473	523	523	482	483	427
	5	230	443	429	467	467	454	433	425

TABLE XI
30% ONAPA TEST RESULTS

Test	Percent Asphalt	No Additives	Additives Incorporated						
			Lime			Pliopave			Emulsion
			1%	1 1/2%	2%	1 1/2%	3%	4 1/2%	1% Coating
Bulk Specific Gravity	4	2.342	2.391	2.400	2.387	2.403	2.400	2.411	2.400
	4 1/2	2.360	2.402	2.403	2.405	2.412	2.411	2.407	2.405
	5	2.385	2.402	2.404	2.404	2.411	2.406	2.408	2.407
Maximum Specific Gravity by Rice's Method	4	2.484	2.473	2.472	2.480	2.465	2.476	2.470	2.477
	4 1/2	2.462	2.454	2.442	2.446	2.452	2.456	2.445	2.450
	5	2.428	2.436	2.431	2.444	2.433	2.443	2.432	2.436
% Density	4	94.3	96.7	97.1	96.2	97.5	96.9	97.6	96.9
	4 1/2	95.8	97.9	98.4	98.3	98.4	98.2	98.4	98.2
	5	98.2	98.6	98.9	98.9	99.1	98.5	99.0	98.8
Hveem Stability	4	42	52	51	47	44	46	45	45
	4 1/2	39	40	37	33	37	40	37	40
	5	37	24	17	17	19	31	24	24
Hveem Cohesimeter	4	168	477	498	481	445	438	581	315
	4 1/2	180	507	485	478	553	470	594	419
	5	260	530	479	480	475	509	528	427

Hydrated Lime

All of the tested mixtures exhibited critical tendencies, i.e., a slight increase in asphalt content resulted in a drastic drop in stability (see graphs in Appendix A). No definite peak of the stability versus asphalt content curve could be established for any of the samples containing, 1 1/2 or 2 percent hydrated lime. Only the Miami aggregate mixes without additives exhibited a peak or maximum of the stability versus asphalt content curve.

By comparing the mixtures with a lime additive to those without lime from a stability point of view, there was an improvement noted. The trend followed by the standard mix (Cooperton) with lime added indicated that the improvement in stability values decreased as the percent asphalt content increased. The mixtures containing 4 percent AC with lime showed higher stability values than those without lime. As the asphalt content increased, the stability values for mixtures with lime decreased faster than those without, with the exception of Cooperton, as mentioned above. There was no consistent trend followed by samples with incorporated lime as far as the percentage added was concerned. Therefore it is difficult to assign a specific advantage of one percentage over any other.

The stability value of a compacted specimen is greatly affected by the surface characteristics, mineralogical composition, and particle shape of the aggregates. Therefore, the variance in stability values between the four aggregates is to be expected.

Gradation of the Cooperton and the three siliceous aggregates was discussed in Chapter IV. An adjustment of the gradation, i.e., increasing

the coarser aggregates (plus No. 10 sieve) at the expense of the fine aggregates, would improve the stability values making them less critical. Another adjustment that could be made is to substitute crushed screening (limestone or siliceous aggregates) for the rounded river sand. This change in gradation will increase the voids in the mineral aggregate.

The tensile strength or cohesive resistance of a compacted bituminous specimen is greatly influenced by the inherent cohesive properties of the bitumen. The adhesive forces that develop at the asphalt-aggregate interfaces contribute, but in small amounts, to the cohesive strength. The cohesiometer test values for all the compacted samples with lime were approximately double those of the samples without lime, with the exception of Cooperton. With Cooperton, the values of the samples with lime were only slightly higher than those without. However, all the specimens were higher than the recommended cohesiometer value of 50 (see graphs in Appendix B). Again, there was no consistent trend in these values with regard to the amount of lime added to the compacted samples for maximum cohesion. Therefore, it is impossible to choose one percentage of lime that would be consistently superior to the others.

Kallas, Puzinauskas, and Krieger (22) made a study of incorporating different mineral fillers in an asphalt paving mixture, with hydrated lime being one of the fillers studied. They found that hydrated lime showed a stability increase as the filler-asphalt ratio increased. As far as the cohesiometer values were concerned, their tests showed an increase as the filler-asphalt ratio increased.

Pliopave

All the mixtures containing the latex rubber additive exhibited the same trend in stability as those containing hydrated lime. In other words, the stability values drastically decreased as the asphalt content increased (see graphs, Appendix A), and no stability peaks were found. However, the rate of decrease in stability was much less than for the mixes containing lime, indicating that the rubber had some stiffening effect on the mixtures. Changing the mix gradation, as explained in the foregoing section, would increase the stability values.

In all of the percentages of rubber used, there was no significant trend developed in the stability and cohesiometer values, making it difficult to decide which percentage would give the best results. The cohesiometer values were all well above the minimum cohesiometer value of 50 (see graphs, Appendix B).

In a report prepared for Goodyear Tire and Rubber Co. on the "Effects of Pliopave on Physical Design Properties of Hot-Mix Asphaltic Concrete" (23), Jimenez found similar trends of stability to those found in this study. In other words, as the asphalt cement was increased without altering the percent of Pliopave, a slight decrease in stability was shown.

Precoating

Only the siliceous aggregates were precoated with a cationic emulsion. The trend followed by these treated mixtures, as far as stability was concerned, showed that as the percent AC increased, the stability values drastically decreased. The Onapa treated mixtures showed a

definite improvement at 4 and 4 1/2 percent AC. The other siliceous aggregates showed relatively lower stability values when compared to the no additive mixtures (see Appendix A). Also, a gradation change in the mix may increase stability values as previously explained.

The cohesiometer test values for all the compacted specimens treated with the emulsion were approximately double those of the samples without the treatment. However, all the specimens were higher than the recommended cohesiometer value of 50 (see graphs, Appendix B).

Immersion-Compression Test

Tables XII through XV show the bulk specific gravity, percent air voids, dry strength, and percent retained strength values for the compacted aggregate samples remolded following the procedures outlined for the immersion-compression test.

Hydrated Lime

By comparing the results of the percent retained strength of the Cooperton aggregate samples and the three siliceous aggregate samples with and without additives, it can be noted that the different amounts of lime incorporated in the compacted specimens generally increase the percent retained strength at all asphalt contents. However, there was no consistent increase in strength as the percent of lime increased.

The percent retained strength of all the compacted specimens with no additives increased as the percent AC increased. This was not true with the mixtures containing the lime additive, e.g., Asher with 4 percent AC and Miami at 4 1/2 percent AC were higher at all lime contents; standard

TABLE XII
IMMERSION-COMPRESSION TEST RESULTS
(STANDARD MIX)

Test	Percent Asphalt	No Additives	Additives Incorporated					
			Lime			Pliopave		
			1%	1 1/2%	2%	1 1/2%	3%	4 1/2%
Remolded Bulk Specific Gravity	4	2.358	2.359	2.316	2.316	2.360	2.350	2.356
	4 1/2	2.372	2.378	2.371	2.360	2.377	2.377	2.375
	5	2.394	2.382	2.381	2.384	2.394	2.391	2.395
% Air Voids	4	8.100	5.500	6.000	7.000	5.500	5.900	5.600
	4 1/2	6.400	4.100	4.300	5.000	4.200	4.200	4.000
	5	4.700	3.200	3.200	2.900	3.100	2.800	2.200
Dry Strength	4	322	260	246	303	309	259	294
	4 1/2	312	268	220	301	300	275	291
	5	319	237	219	270	288	258	287
% Retained Strength	4	86	106	110	106	101	105	98
	4 1/2	92	104	117	104	105	102	106
	5	96	104	101	104	96	99	106

TABLE XIII
IMMERSION-COMPRESSION TEST RESULTS
(30% ASHER)

Test	Percent Asphalt	No Additives	Additives Incorporated						
			Lime			Pliopave			Emulsion
			1%	1 1/2%	2%	1 1/2%	3%	4 1/2%	1% Coating
Remolded Bulk Specific Gravity	4	2.270	2.314	2.321	2.309	2.341	2.317	2.308	2.310
	4 1/2	2.288	2.339	3.334	2.335	2.348	2.334	2.335	2.335
	5	2.326	2.341	2.351	2.353	2.371	2.368	2.353	2.348
% Air Voids	4	8.000	6.000	5.800	6.100	4.800	5.800	6.100	6.100
	4 1/2	6.800	4.300	4.400	4.300	3.900	4.400	4.300	4.500
	5	4.500	4.000	3.100	3.000	2.300	2.300	2.900	3.400
Dry Strength	4	409	279	289	286	365	287	282	234
	4 1/2	402	258	263	269	385	277	293	231
	5	395	236	234	233	308	279	279	221
% Retained Strength	4	84	106	112	104	110	98	102	104
	4 1/2	102	100	103	103	104	98	94	110
	5	106	104	100	100	106	96	100	99

TABLE XIV
IMMERSION-COMPRESSION TEST RESULTS
(30% MIAMI)

Test	Percent Asphalt	No Additives	Additives Incorporated						
			Lime			Pliopave			Emulsion
			1%	1 1/2%	2%	1 1/2%	3%	4 1/2%	1% Coating
Remolded Bulk Specific Gravity	4	2.282	2.335	2.311	2.314	2.337	2.323	2.322	2.324
	4 1/2	2.295	2.347	2.345	2.345	2.352	2.343	2.348	2.350
	5	2.325	2.364	2.357	2.359	2.361	2.362	2.368	2.361
% Air Voids	4	8.200	5.600	6.700	6.800	6.000	6.400	6.100	6.600
	4 1/2	7.000	8.200	4.800	4.800	4.600	4.700	4.600	4.700
	5	5.100	3.700	3.600	3.500	3.800	3.300	2.700	3.800
Dry Strength	4	381	280	290	276	375	289	278	236
	4 1/2	370	252	272	264	360	266	273	233
	5	304	243	261	246	353	260	251	199
% Retained Strength	4	85	104	103	109	102	96	94	102
	4 1/2	95	107	110	109	110	105	97	106
	5	102	104	104	102	102	105	109	115

TABLE XV
IMMERSION-COMPRESSION TEST RESULTS
(30% ONAPA)

Test	Percent Asphalt	No Additives	Additives Incorporated						
			Lime			Pliopave			Emulsion
			1%	1 1/2%	2%	1 1/2%	3%	4 1/2%	1% Coating
Remolded Bulk Specific Gravity	4	2.267	2.299	2.284	2.280	2.202	2.291	2.308	2.292
	4 1/2	2.280	2.330	2.309	2.313	2.321	2.321	2.322	2.317
	5	2.305	2.340	2.329	2.323	2.337	2.328	2.337	2.326
% Air Voids	4	8.700	7.000	7.600	8.000	6.600	7.400	6.600	7.500
	4 1/2	7.400	5.100	5.400	5.400	5.300	5.500	5.000	5.400
	5	5.100	3.900	4.200	5.000	3.900	4.700	3.900	4.500
Dry Strength (psi)	4	316	282	280	278	312	286	331	219
	4 1/2	294	271	270	252	294	275	314	221
	5	256	271	259	241	288	256	315	210
% Retained Strength	4	86	98	103	96	97	94	80	101
	4 1/2	89	99	109	109	103	95	93	101
	5	108	100	101	102	100	105	95	115

mix with 4 percent AC was higher at 1 and 2 percent lime; Onapa at 4 1/2 percent AC was higher for 1 1/2 and 2 percent lime.

From the test results, it can be concluded that lime improves the cohesion of the compacted specimens subjected to water action. No optimum lime content, within the range of contents tested, can be determined for the various siliceous aggregate mixtures from the results shown in Tables XII to XV. This is due to the irregularity of the data and the fact that practically all the values were within about 9 percentage points of each other. The value difference can be attributed to the effect of lime on the gradation of the mix design.

Pliopave

By reviewing the results of the aggregate mixtures with Pliopave, it can be noted that generally a decrease in retained strength occurred (except Miami at 5 percent AC) when the rubber additive content was increased. This indicates that smaller amounts of Pliopave were most effective on the tested compacted specimens.

Except for the Asher specimens at 4 1/2 and 5 percent AC with 3 and 4 1/2 percent rubber and Onapa at 5 percent AC with 1 1/2, 3, and 4 1/2 percent rubber, all the aggregate mixes showed an increased percent retained strength when the rubber additive was used. This implies that the Pliopave was not as effective with Asher as it was with Onapa and especially with Miami.

In some cases the effectiveness of the rubber was also influenced by the asphalt content. The percent retained strength decreased as the AC increased (see Cooperton 1 1/2 and 3 percent; Asher 1 1/2, 3, and 4 1/2 percent). Cooperton with 1 1/2 and 3 percent Pliopave at 5

percent asphalt content showed some loss in strength even though the 4 and 4 1/2 percent did not show this loss. Ford (4) obtained similar results with some of his aggregate mixtures without additives. He attributed this loss in strength not to cohesion loss, but to a loss in density of the compacted specimens. This density loss occurred due to swelling and the consequent excessive amounts of water absorbed by these specimens during vacuum saturation.

In review, it can be stated that the lower percent (1 1/2 percent) of rubber additive used was more effective than the higher percentages of rubber tested (3 and 4 1/2 percent). Also, the rubber additive was not as effective with Asher as with the other aggregates tested.

Precoating

The results of the I-C test on the siliceous aggregates with an emulsion treatment, except for Asher at 5 percent AC, showed that the percent retained strength increased with an increase in asphalt content. Comparing the results of treated aggregates with nontreated aggregates, except for Asher, all treated mixtures displayed a significantly higher percent retained strength.

In retrospect, it can be said that the precoating treatment is an effective way to increase cohesion in compacted specimens subjected to water action. Lower percentages of emulsion treatment such as 0.25 to 0.75 percent coating should be investigated for their effectiveness as the 1 percent proved to be more than adequate.

Film Stripping Tests

The film stripping resistance of the three siliceous aggregates with and without additives, was evaluated by the Dynamic Immersion Stripping (DIS) test. The procedure followed for this test was outlined in Chapter IV.

After the DIS test, the same samples were subjected to the Surface Reaction Test (SRT). The SRT test was used for the purpose of obtaining a quantitative evaluation on the amount of stripping.

Dynamic-Immersion Stripping Tests

The results of the DIS test for the three siliceous aggregates used in this study, both with and without additives, are shown in Table XVI. The results after four hours of rotation were used for comparative purposes.

Hydrated Lime. The samples were rotated for four hours using the dynamic stripping machine as discussed previously. A visual examination of all the samples containing various percentages of lime was made at the end of one, two and four hours. After one hour of tumbling, all the samples retained 99 percent of their original asphalt coating. At the end of two hours, the samples retained 80 percent or more of their original coating. After four hours of tumbling, the samples displayed values ranging from 57 to 80 percent retained coating.

By comparing the results of the visual inspection of the aggregates with lime to those without additives, only the Miami aggregate showed an improvement in retained coating after four hours. However, the "No Additive" results were obtained from Ford's study and any comparison or

TABLE XVI
DYNAMIC IMMERSION STRIPPING
TEST RESULTS

Aggregate	Time (hrs)	No Additives	% Retained Coating (Visual Inspection)						
			Additives Incorporated						
			Lime			Rubber			Emulsion
			1%	1 1/2%	2%	1 1/2%	3%	4 1/2%	1% Coating
Asher	1	95	99	99	99	99	99	99	99
	2	90	90	92	92	98	98	98	97
	4	80	75	76	76	80	89	95	80
Miami	1	95	99	99	99	99	99	99	99
	2	85	92	93	93	95	96	98	96
	4	75	78	80	80	85	90	95	90
Onapa	1	95	99	99	99	99	99	99	99
	2	90	83	92	80	96	98	96	98
	4	85	57	71	75	83	90	83	96

interpretation must take into account the factor of operator judgement. Also, there seemed to be a definite trend as the percentage of lime was increased, i.e., the percent retained coating increased as the percent of lime increased.

Pliopave. The visual inspection procedures for these aggregate samples coated with asphalt containing Pliopave were the same as for those incorporating hydrated lime. At the end of one hour of rotating, the results showed all the aggregates retained 99 percent of their original asphalt coating. After two hours, the samples showed 95 percent or more, and at the end of four hours the values ranged from 80 to 95 percent retained coating.

The aggregates showed a definite improvement in retained coating with the addition of Pliopave in all the percentages of rubber tested with the exception of Onapa. The Asher and Miami aggregates showed that as the percent of rubber was increased, a greater percent of the original asphalt coat was retained. Only the 3 percent Pliopave treatment of the Onapa aggregate resulted in a higher percentage of retained coating than was evidenced by the untreated sample.

Precoating. By comparing the emulsion treated aggregate samples with those having no additive, the results indicated that Miami and Onapa aggregates had a substantially higher percent retained coating with the precoating treatment. The asher aggregate showed that the percent retained coating with the precoating treatment was essentially the same as when the emulsion treatment was not used.

Surface Reaction Test

After the samples were subjected to the DIS test, they were left to dry at room temperature for 24 hours. At the end of this time, the Surface Reaction Test was performed on each of the aggregates under study.

Each aggregate was tested both uncoated and partially coated with asphalt. Duplicated samples were used in all cases. These samples were placed in the pressure vessel and 200 ml of concentrated hydrofluoric acid was added in order to obtain the desired pressure and temperature of the reaction on a strip chart recorder. The test pressures were then adjusted to 68 F. This was necessary because of the difference in temperatures between tests.

The retained coating of the asphalt on the aggregate samples was calculated using the following equation developed by Ford (4).

$$RC = 100 - \frac{\Delta P_s}{\Delta P_u} \quad 100$$

where RC = retained coating in percent

$\Delta P_s = P_2 - P_1$ for the stripped sample

(P_1 = initial pressure after 15 seconds)

(P_2 = final pressure after 5 minutes of reaction time)

$\Delta P_u = P_2 - P_1$ for the uncoated sample.

The SRT values that are shown in Table XVII are adjusted values. This adjustment was necessitated due to two reasons. First, the highly concentrated hydrofluoric acid reacted with the asphalt giving a higher pressure reading than expected, since it had been assumed that the acid would not react with the asphalt. Since Ford tested with diluted

TABLE XVII
SURFACE REACTION TEST RESULTS

Aggregate	Conditions	No Additives	% Retained Coating (Visual Inspection)						
			Additives Incorporated						
			Lime			Rubber			Emulsion
			1%	1 1/2%	2%	1 1/2%	3%	4 1/2%	1% Coating
Asher	ΔP	0.08	0.08	0.04	0.03	0.05	0.06	0.05	0.11
	ΔP^S	0.31	0.61	0.61	0.61	0.61	0.61	0.61	0.61
	%u	74	87	93	95	92	90	92	82
Miami	ΔP	0.08	0.07	0.08	0.10	0.05	0.09	0.10	0.05
	ΔP^S	0.20	0.33	0.33	0.33	0.33	0.33	0.33	0.33
	%u	60	79	76	70	85	73	70	85
Onapa	ΔP	0.06	0.08	0.09	0.09	0.02	0.08	0.09	0.03
	ΔP^S	0.19	0.31	0.31	0.31	0.31	0.31	0.31	0.31
	%u	68	74	71	71	94	74	71	90

hydrofluoric acid, he did not find the acid to react with the asphalt. Because of this dilution, the boiling point of his reagent solution was higher than for the concentrated acid.

Secondly, Ford's test conditions varied somewhat from the conditions under which these tests were made. The laboratory temperature at the time Ford tested averaged 6 C lower than during this testing period. The change in acid concentration and this increased temperature were enough to cause the acid to give an additional pressure reading while running the tests in this study. This extra pressure reading was caused by the evaporation of the acid at the higher test temperature (boiling point being 19.6 C).

The adjustment used to correct the values in Table XVII involved subtracting the pressure due to the acid-asphalt reaction on all of the partially stripped aggregate samples.

No corrections were used for the increase in pressure created by the boiling of the acid as it was assumed that this was equal in both the partially coated and uncoated aggregate samples being tested, since the test temperatures were approximately the same.

The SRT test gave a quantitative evaluation of the amount of stripping of the aggregate samples. All aggregates showed an improvement in percent retained coating when the additives were used. Miami and Onapa, both with 1 percent lime and Asher with 2 percent lime gave best results when the lime additive was incorporated. When the aggregates containing rubber were tested, the higher percent retained coatings were obtained with the lowest percent of Pliopave additive used. The emulsion treatment showed definite improvements in all three cases.

By comparing the DIS and SRT test results, one can see that the figures disagree. This can be attributed to several factors. The visual inspection of the DIS is subject to human error as it is a personal judgement. The darker colored aggregates tended to result in higher percent retained coating estimates than the lighter colored ones. Prior to the SRT test, the samples were left to dry in a pan for a 24 hour period. During this time, the coatings softened to the extent that the particles stuck to the pan. This loss of asphalt was greatest when particles coated with the asphalt-rubber additive were tested.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In reviewing the data collected during this study, the following conclusions can be made:

1. As far as stability is concerned, only lime showed a noted improvement of the additives being tested. However, by modifying the gradation of the mix, higher stability can be achieved. With higher stability, a better judgement can be made as to any effect the additives have on the mix.
2. By incorporating the different percentages of additives in the aggregate mixture, the cohesiometer values were doubled. In all cases however, all of the compacted samples, both with and without additives, were well above the recommended minimum value of 50.
3. The immersion-compression test values showed improvement when the additives were incorporated. With lime, it was difficult to find the optimum percentage due to the irregularity of the data. Plio-pave gave best results when incorporated at low percentages. The emulsion treatment of 1 percent precoating proved to be more than adequate.
4. There was no correlation found between the DIS and the SRT test results of the aggregates used in these tests. But both test

methods did show that the addition of additives tended to improve the stripping resistance of the siliceous aggregates.

5. There was an insignificant difference found in this study between the various percentages of additives used in an aggregate mixture. Therefore, only a general conclusion may be drawn, that the addition of these additives (in any of the tested percentages) will reduce stripping.

Recommendations

1. A valuable increment to this study would be to perform field evaluations to further test the performance of these additives. Only then can one accurately correlate the laboratory results to actual performance.
2. There are many other additives that could be tested for their ability to improve stripping resistance of the aggregate. Some of these are mentioned in Chapter II.
3. The SRT test should be run in a well air conditioned laboratory or in the cooler months of the year. This condition will reduce the chances that the hydrofluoric acid will boil and create erroneous pressure readings.

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APPENDIX A

PLOTS OF HVEEM STABILITY VERSUS ASPHALT CONTENT

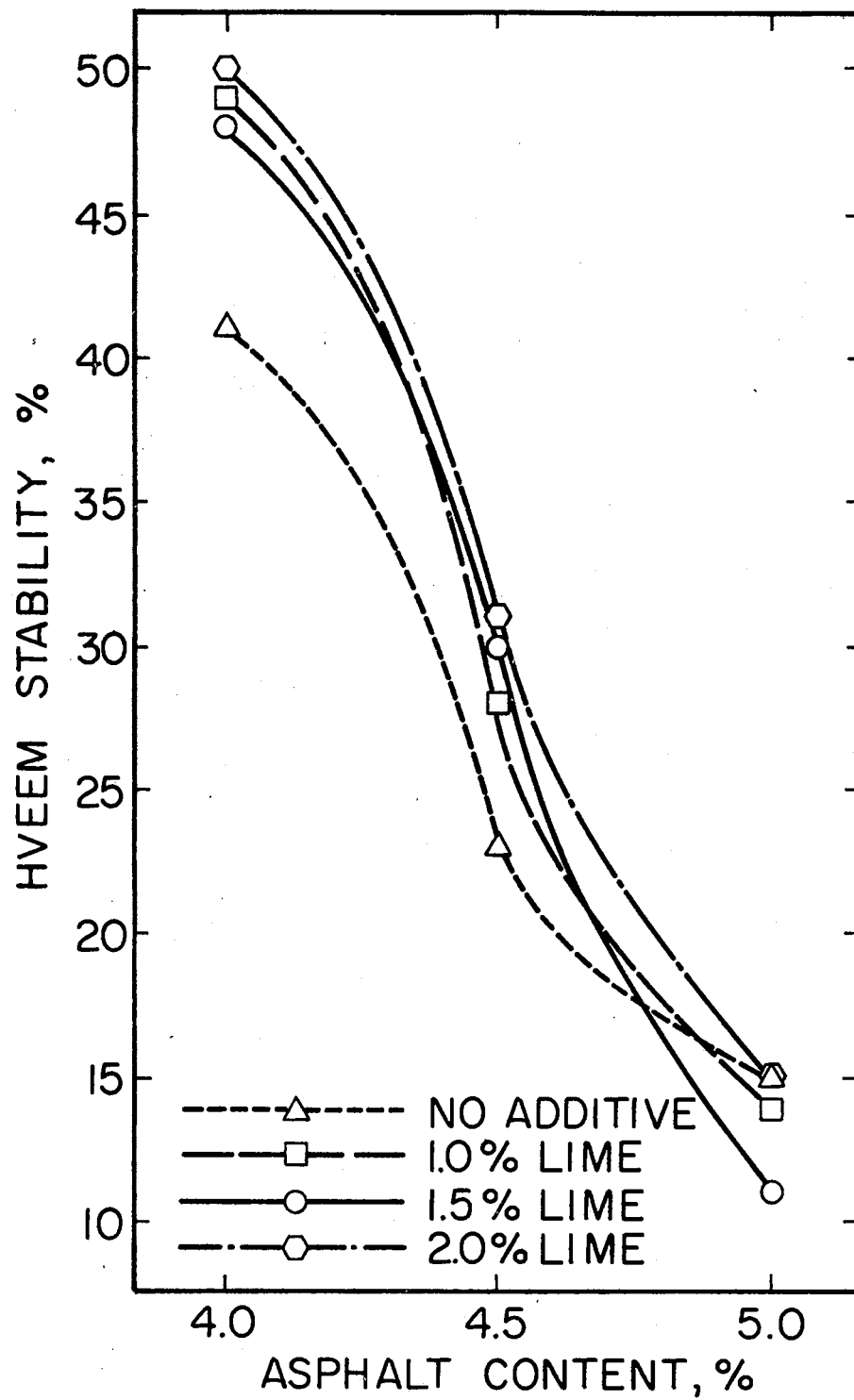


Figure 1. Hveem Stability Versus Asphalt Content for Standard Mix with Lime

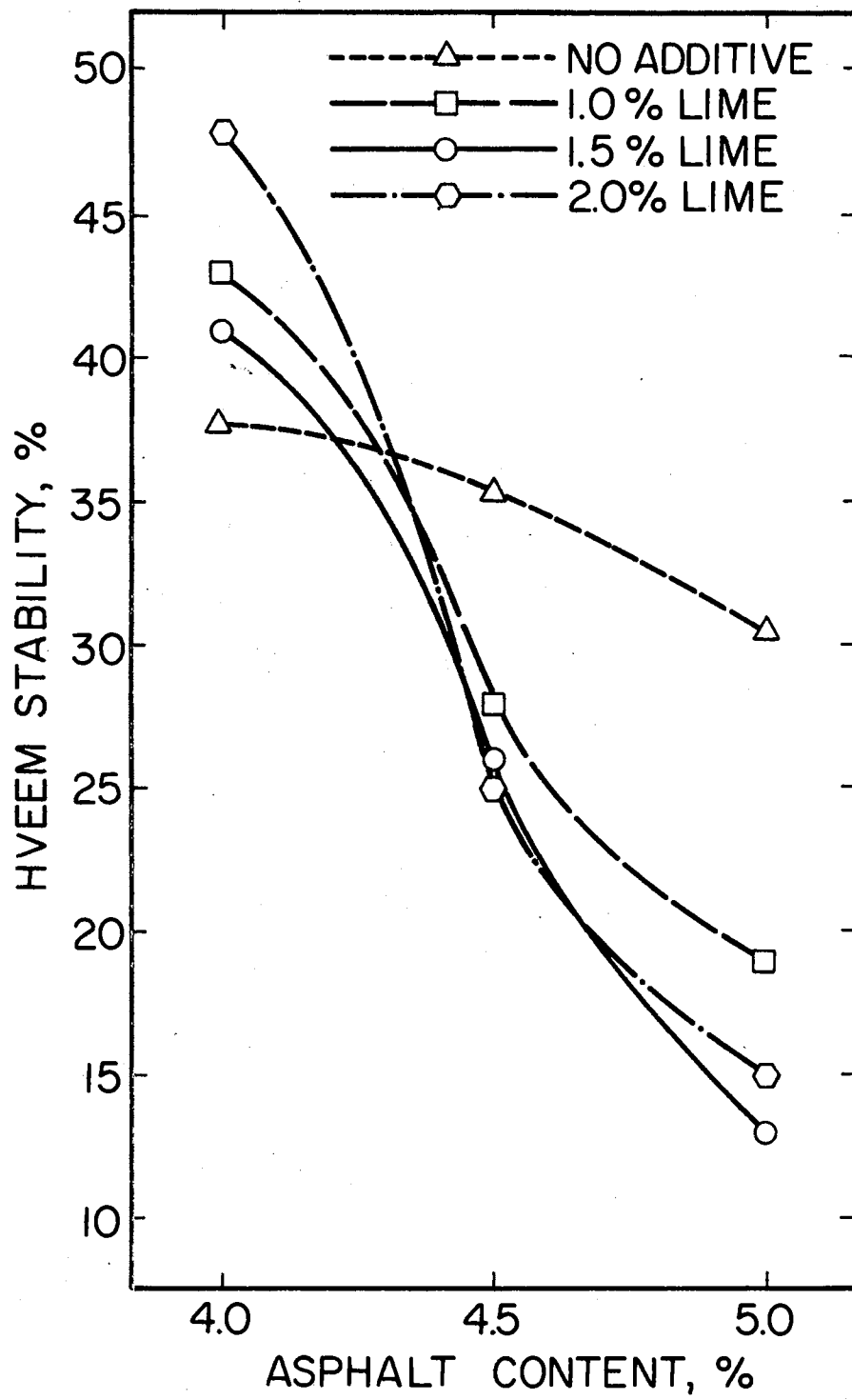


Figure 2. Hveem Stability Versus Asphalt Content for Asher with Lime

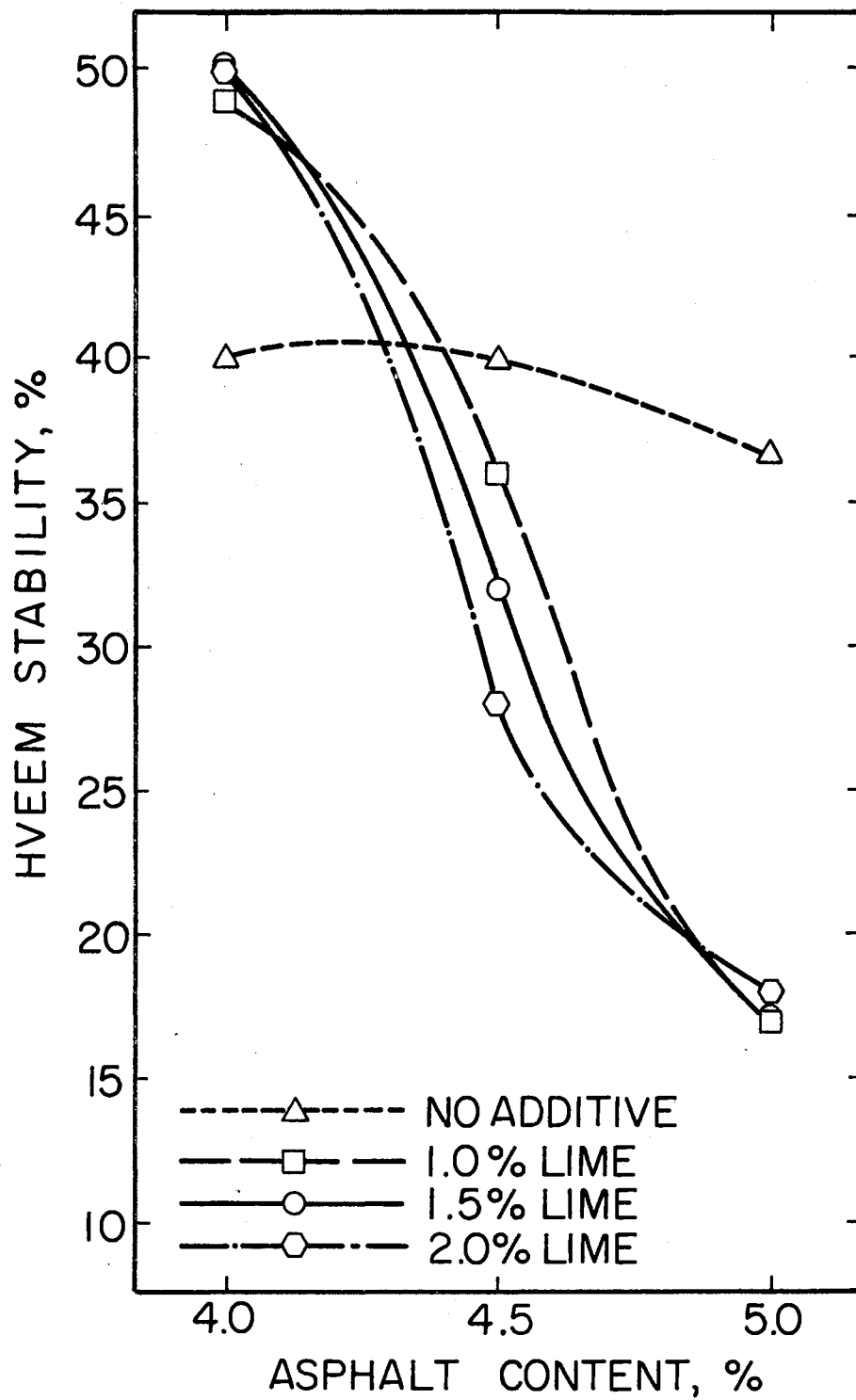


Figure 3. Hveem Stability Versus Asphalt Content for Miami with Lime

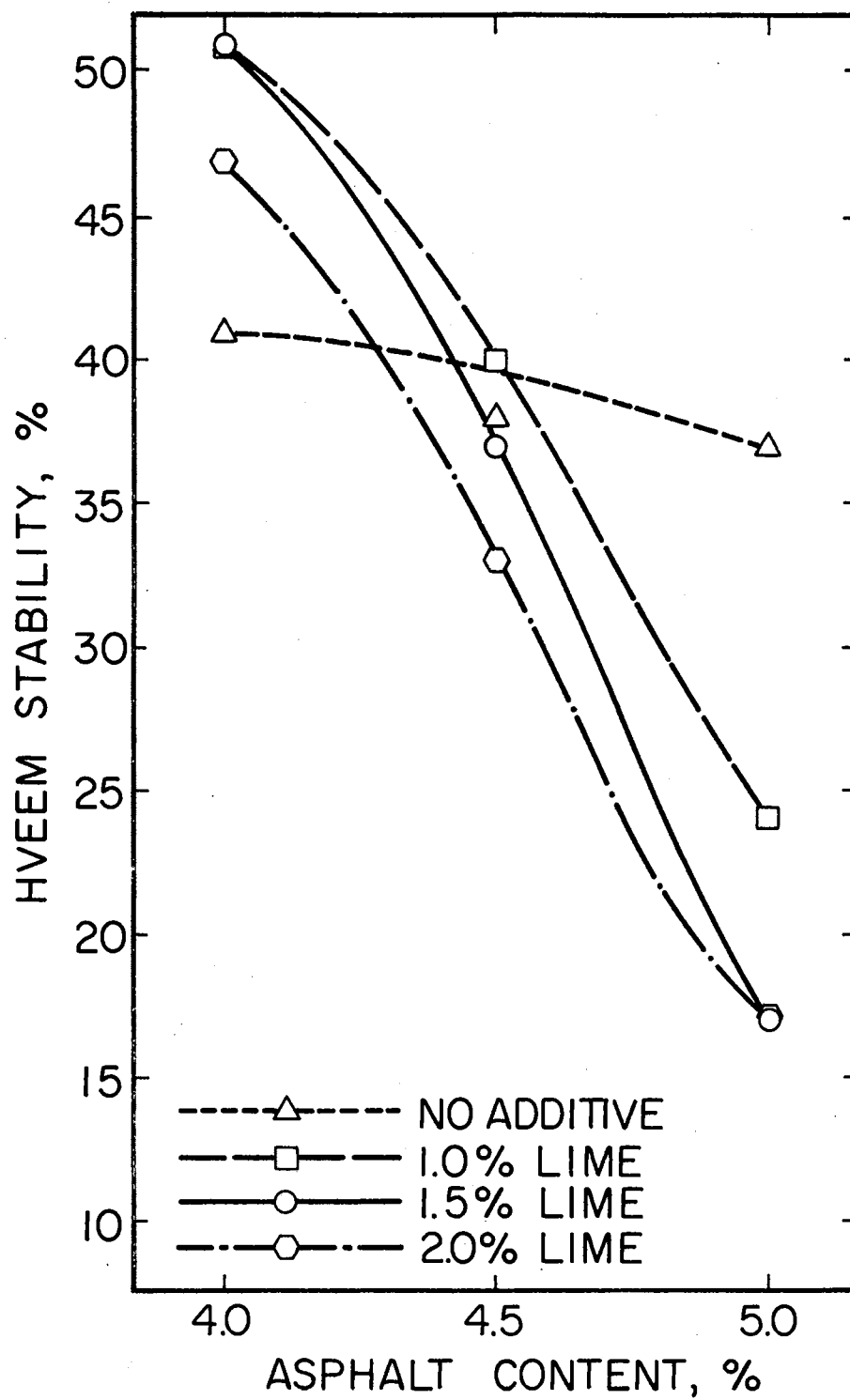


Figure 4. Hveem Stability Versus Asphalt Content for Onapa with Lime

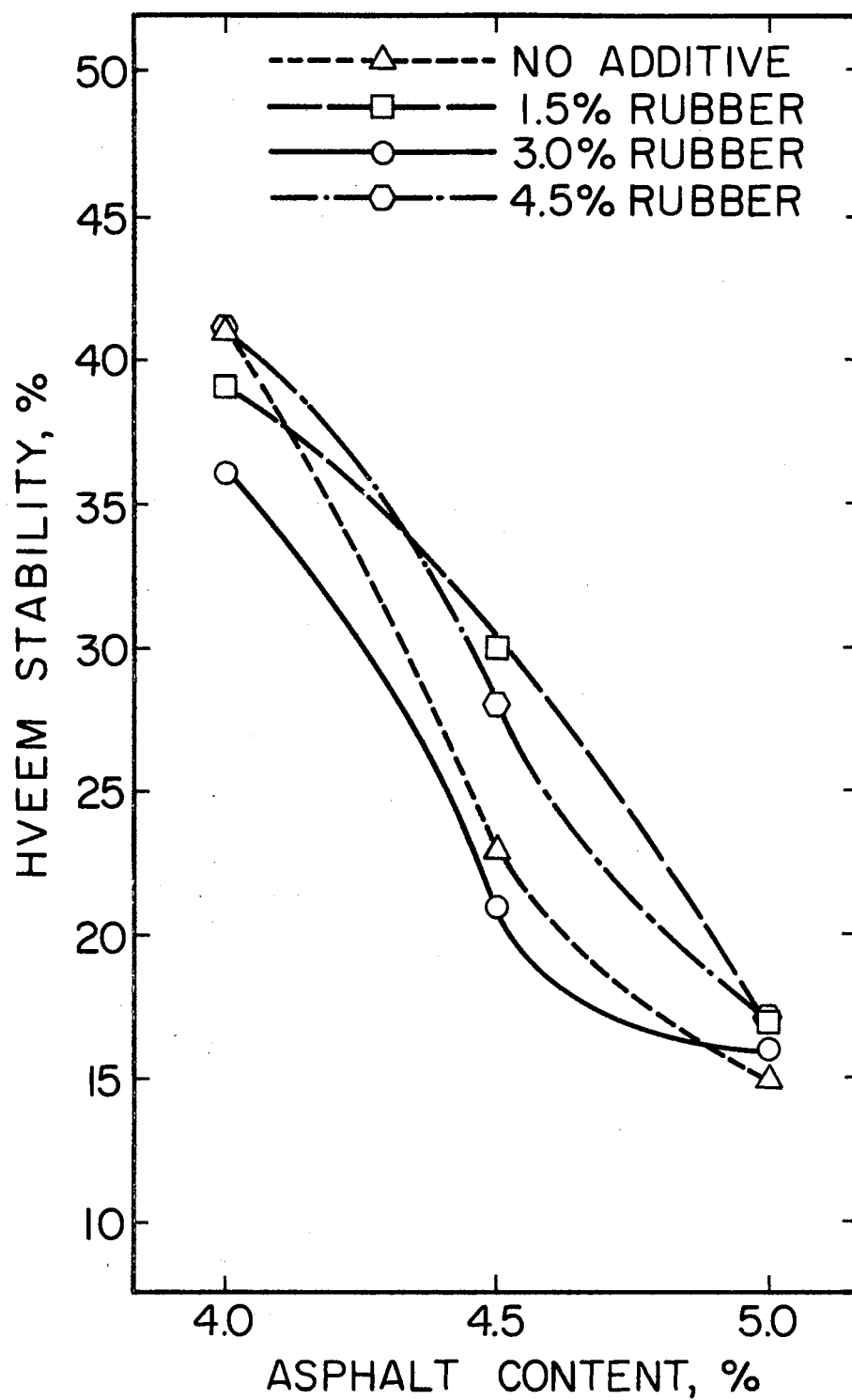


Figure 5. Hveem Stability Versus Asphalt Content for Standard Mix with Pliopave

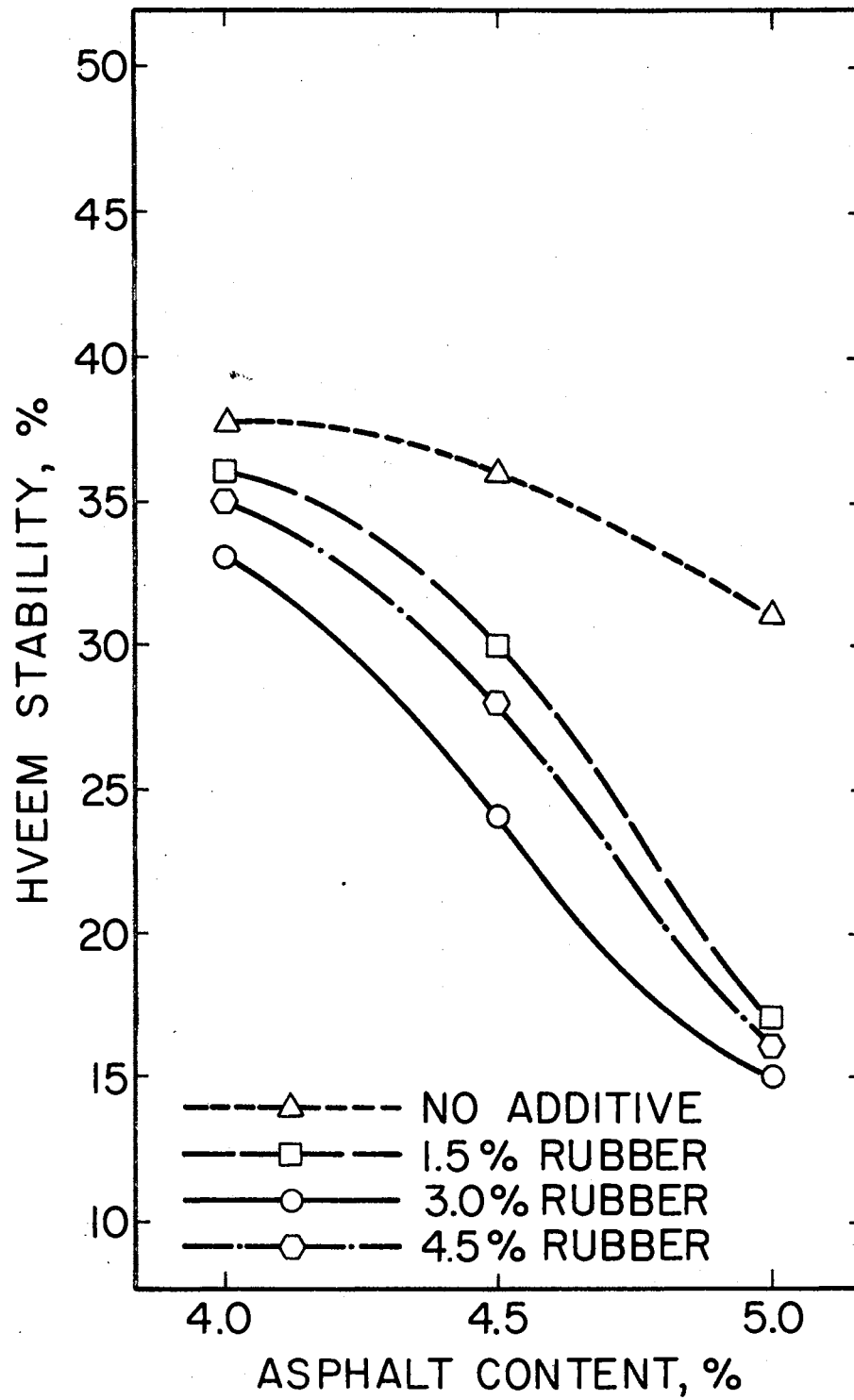


Figure 6. Hveem Stability Versus Asphalt Content for Asher with Pliopave

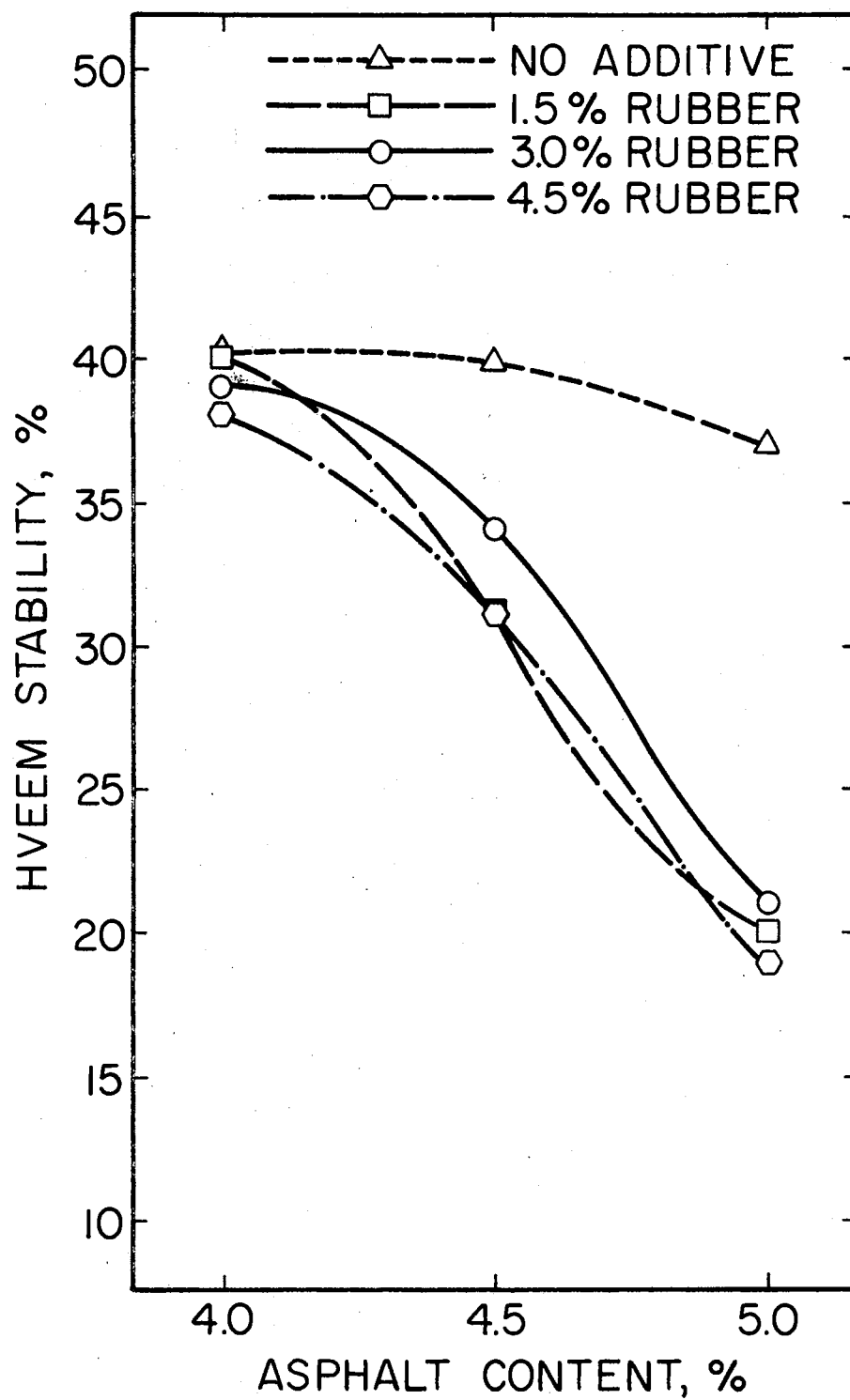


Figure 7. Hveem Stability Versus Asphalt Content for Miami with Pliopave

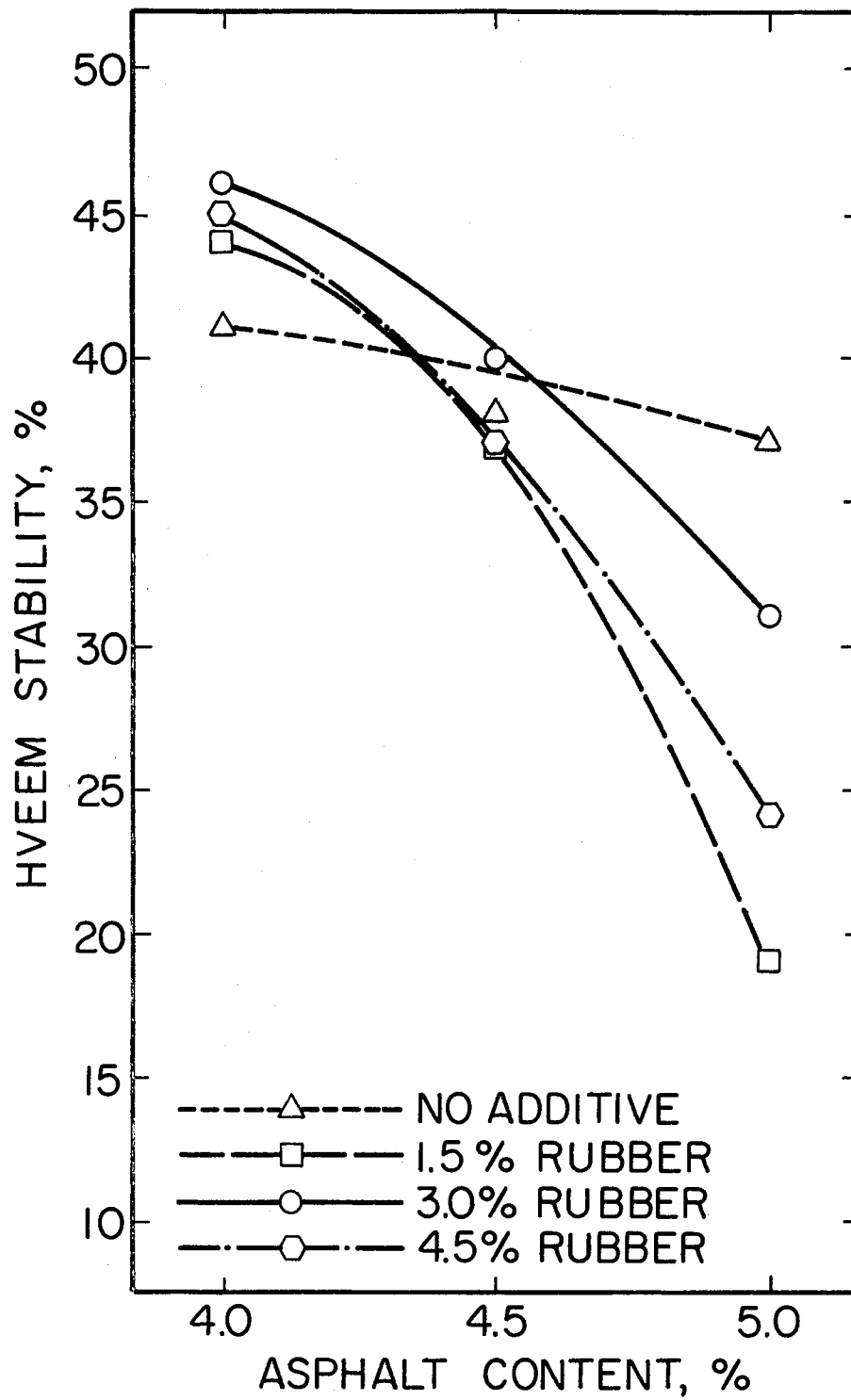


Figure 8. Hveem Stability Versus Asphalt Content for Onapa with Pliopave

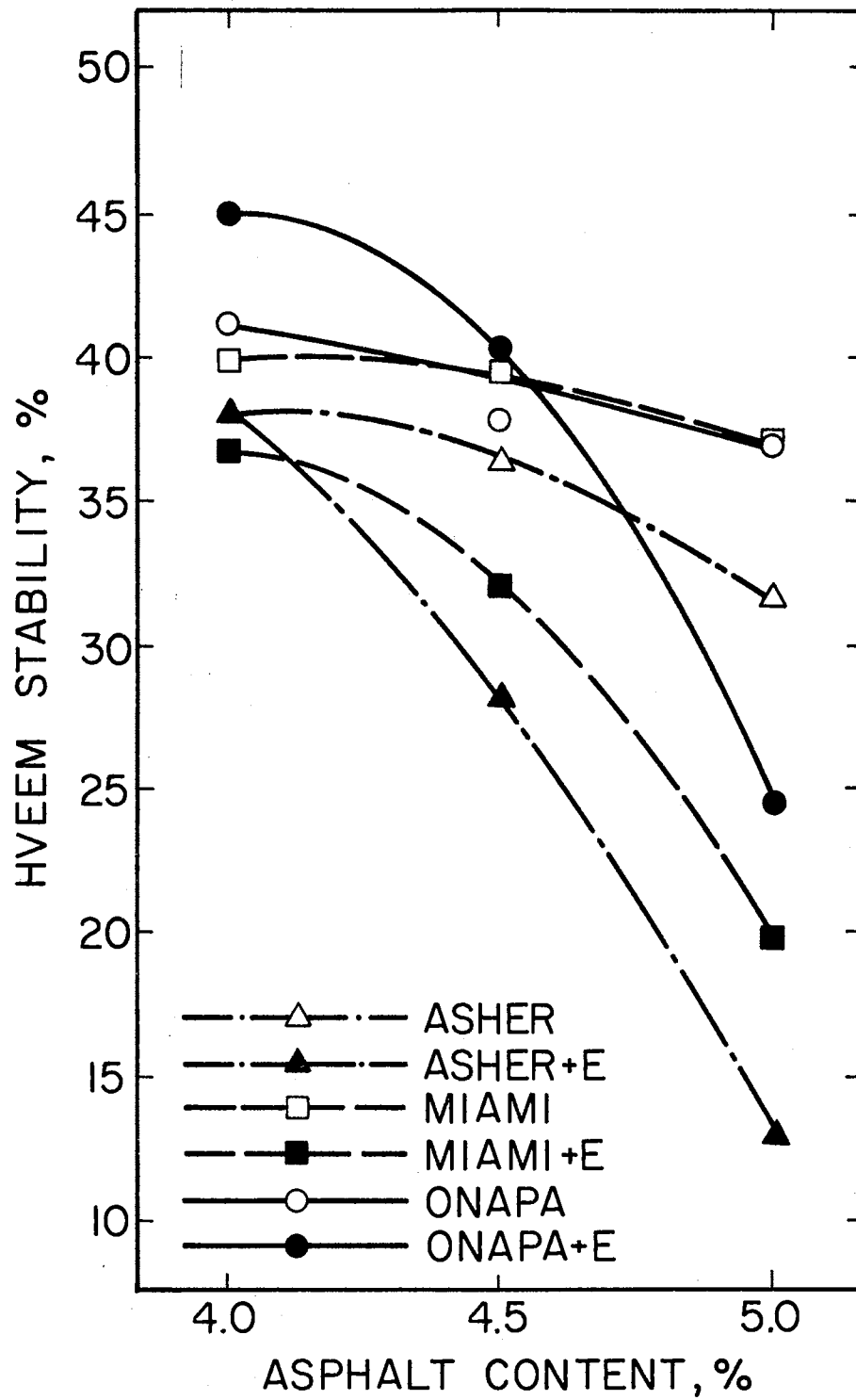


Figure 9. Hveem Stability for Asher, Miami and Onapa with an Emulsion Treatment

APPENDIX B

PLOTS OF HVEEM COHESIOMETER
VERSUS ASPHALT CONTENT

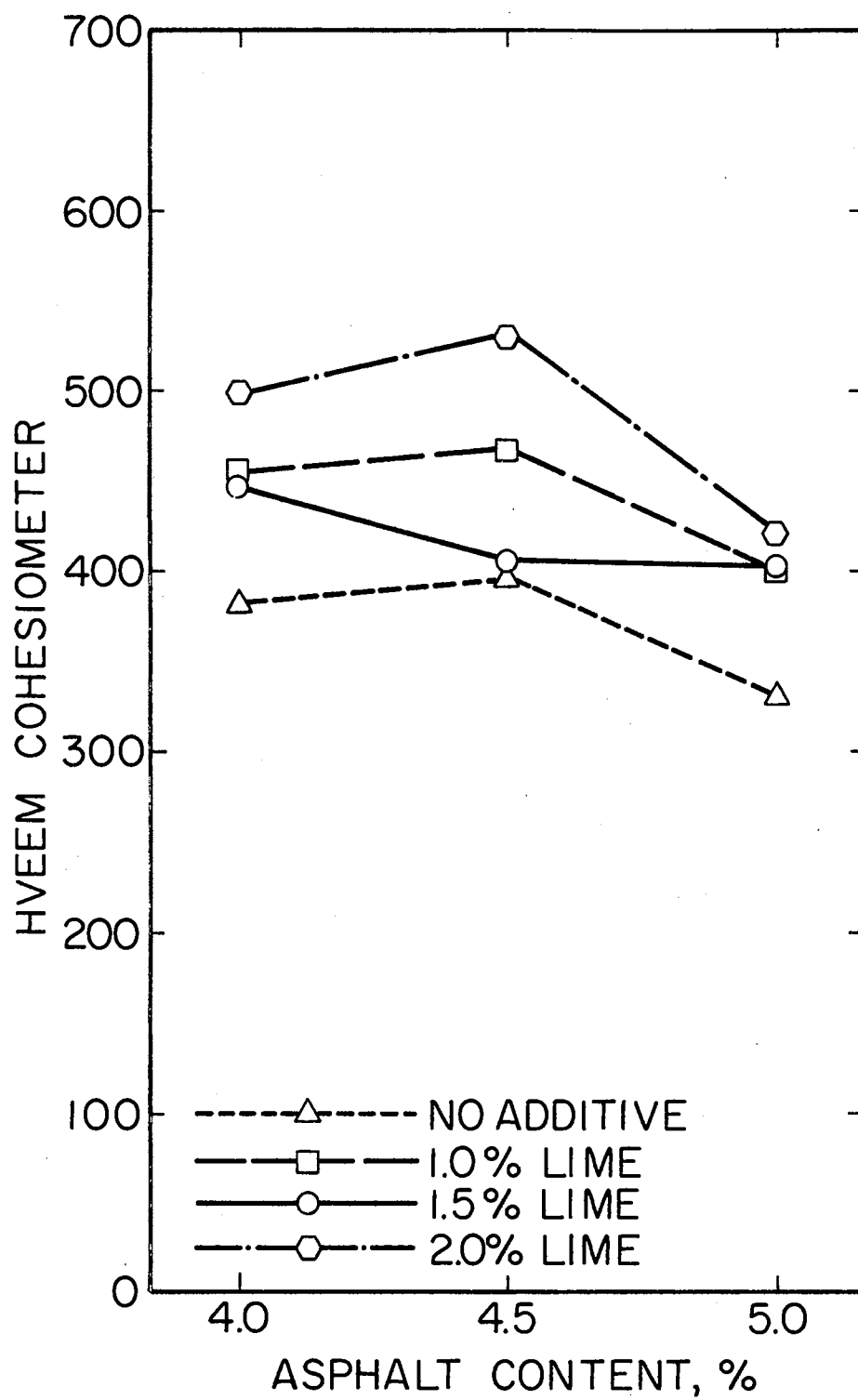


Figure 10. Hveem Cohesimeter Versus Asphalt Content for Standard Mix with Lime

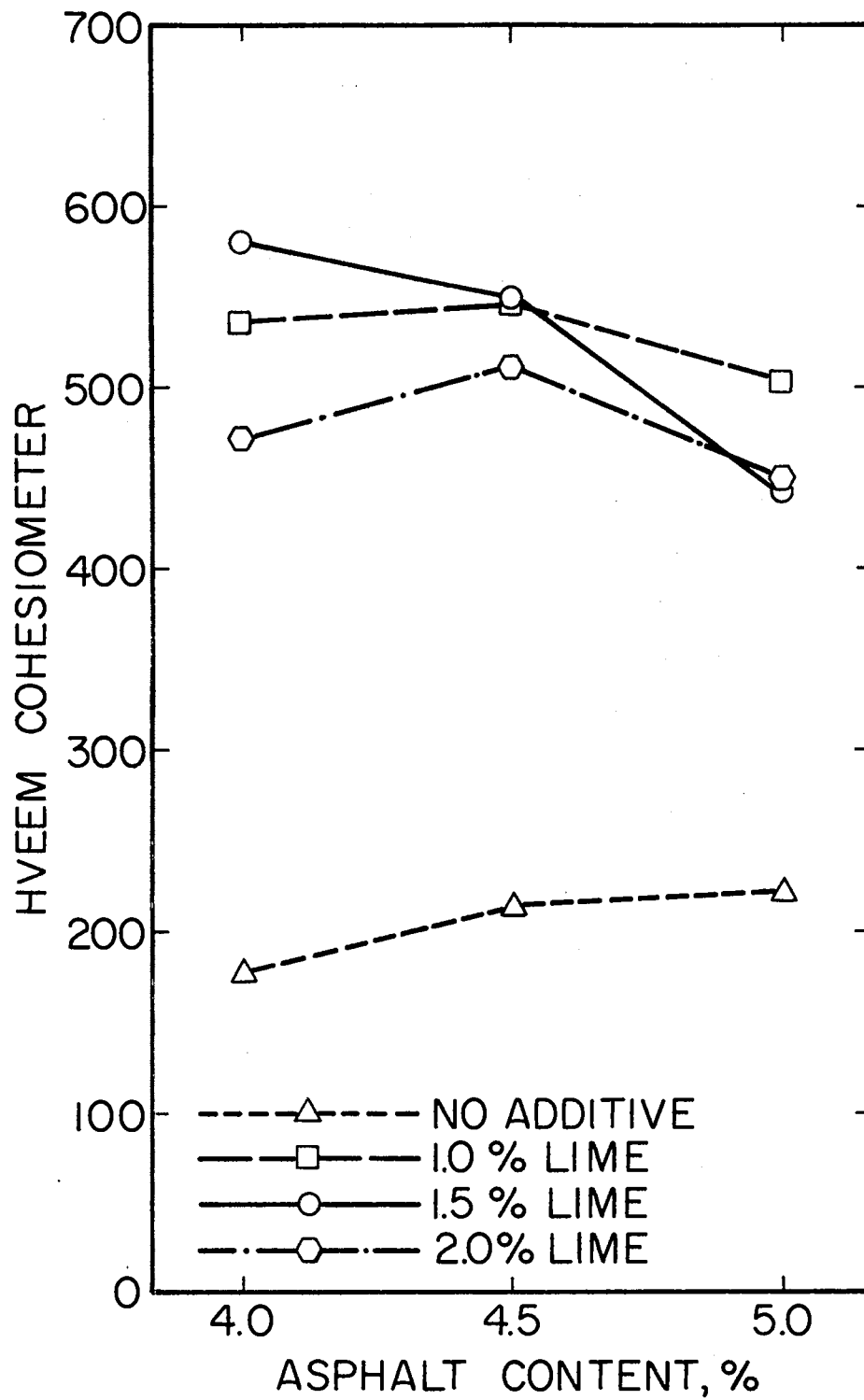


Figure 11. Hveem Cohesimeter Versus Asphalt Content for Asher with Lime

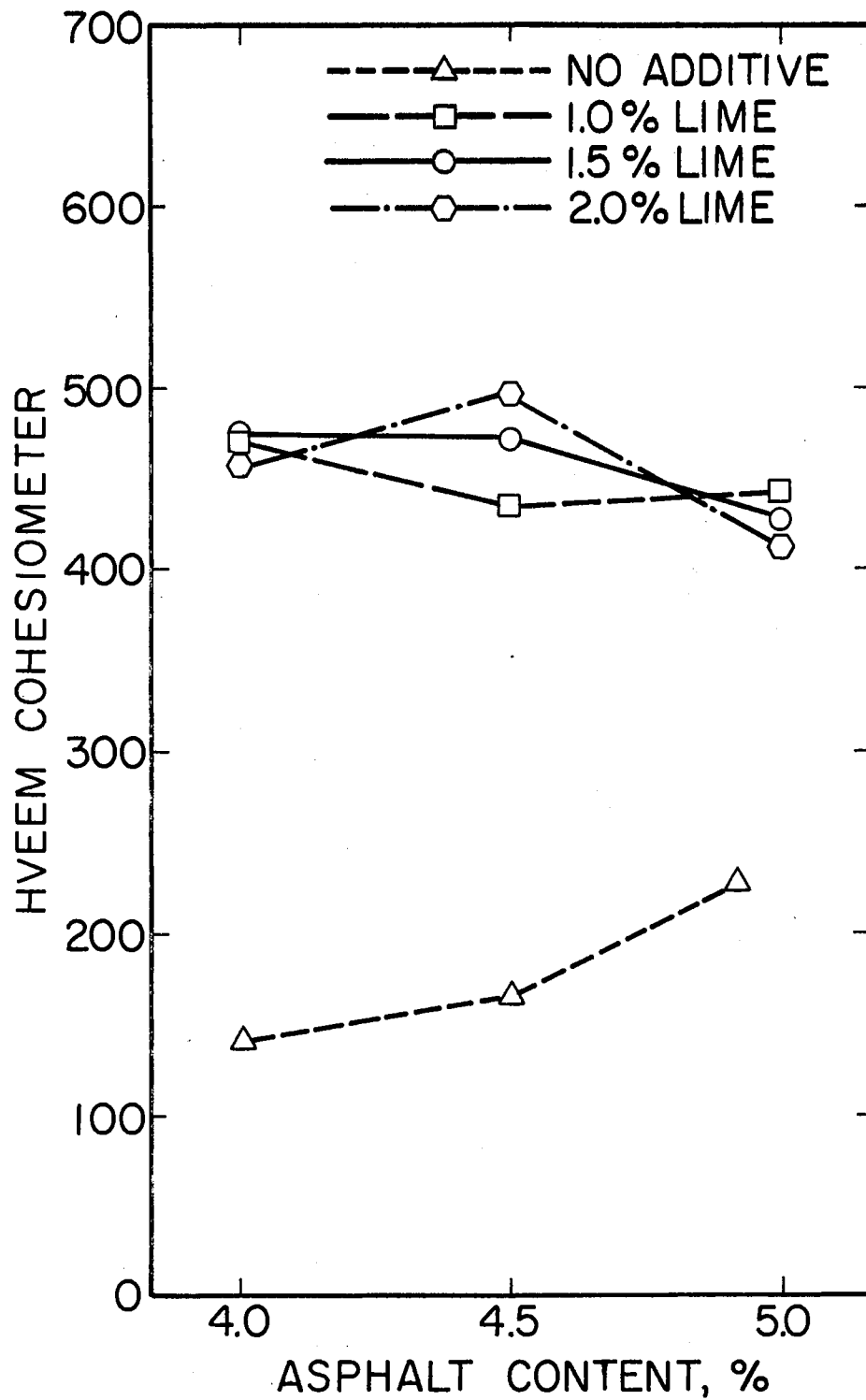


Figure 12. Hveem Cohesimeter Versus Asphalt Content for Miami with Lime

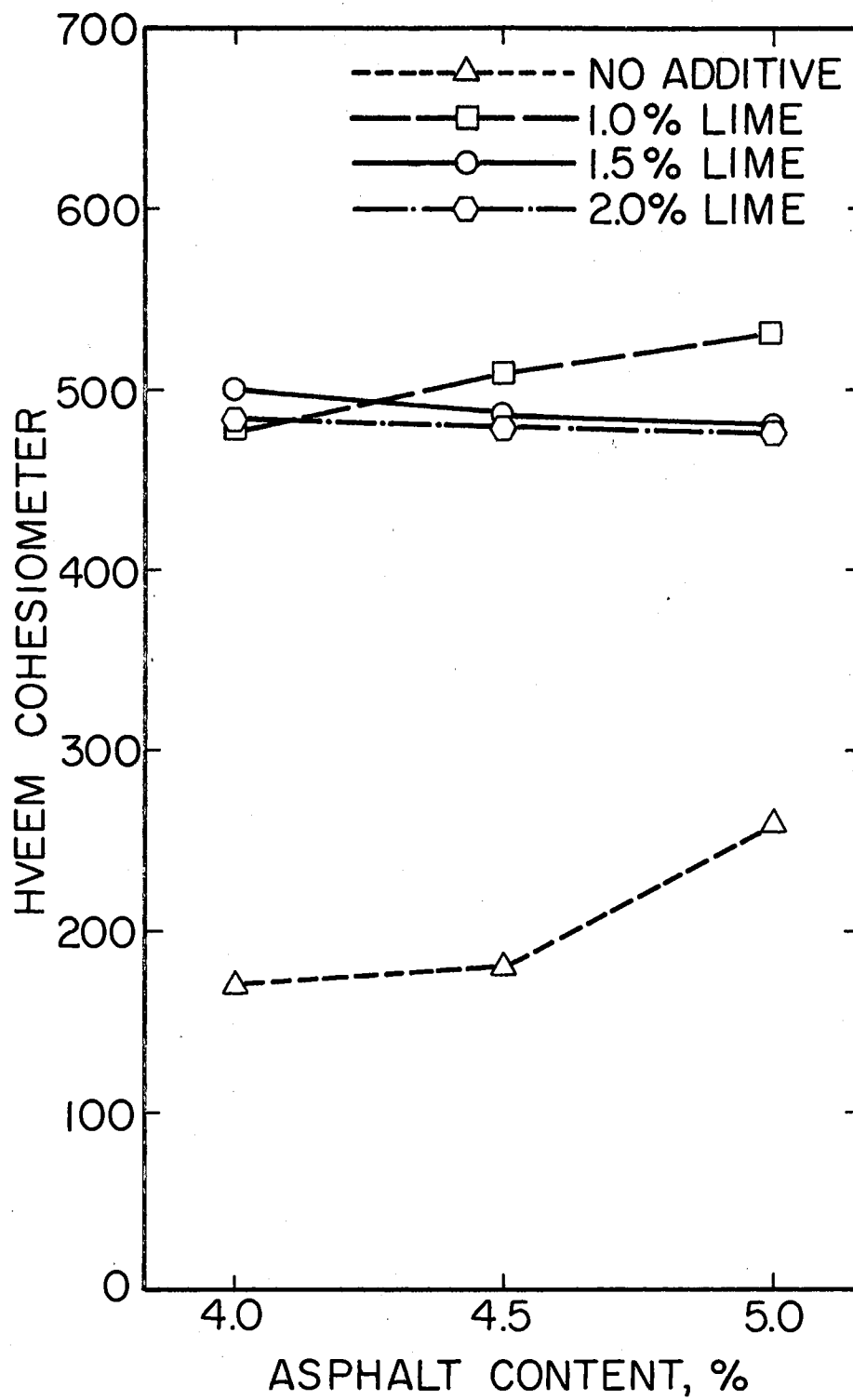


Figure 13. Hveem Cohesimeter Versus Asphalt Content for Onapa with Lime

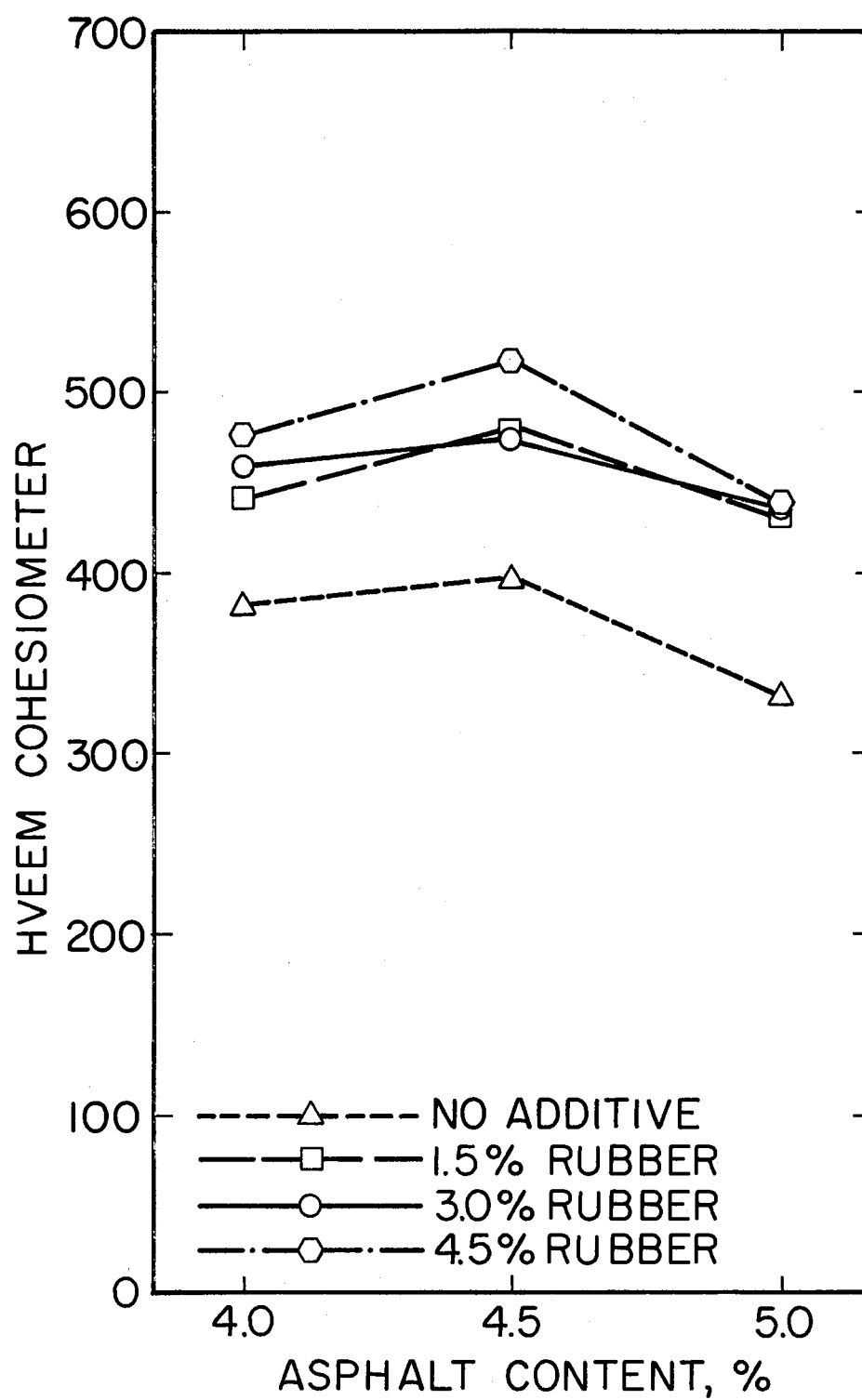


Figure 14. Hveem Cohesimeter Versus Asphalt Content for Standard Mix with Pliopave

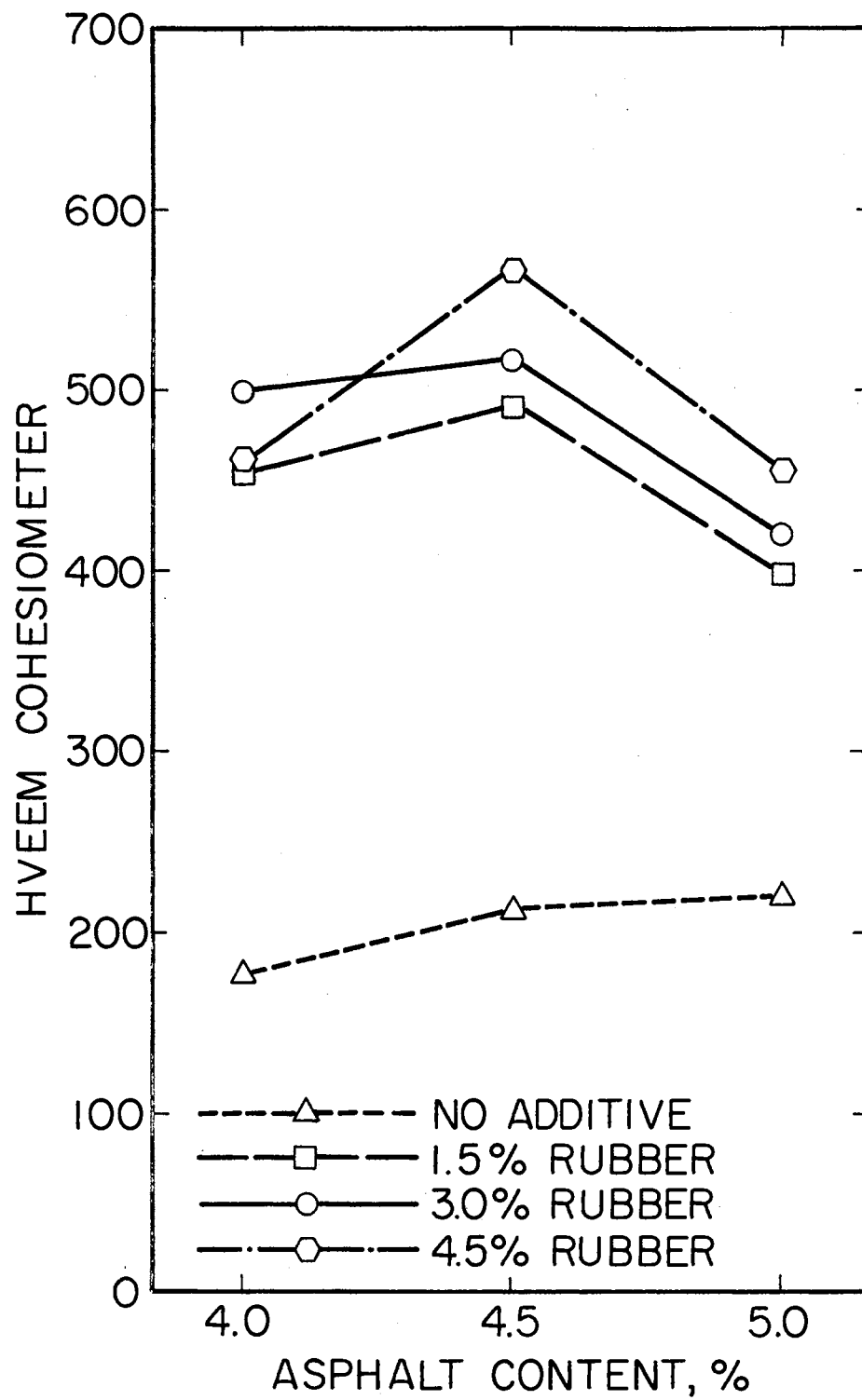


Figure 15. Hveem Cohesimeter Versus Asphalt Content for Asher with Pliopave

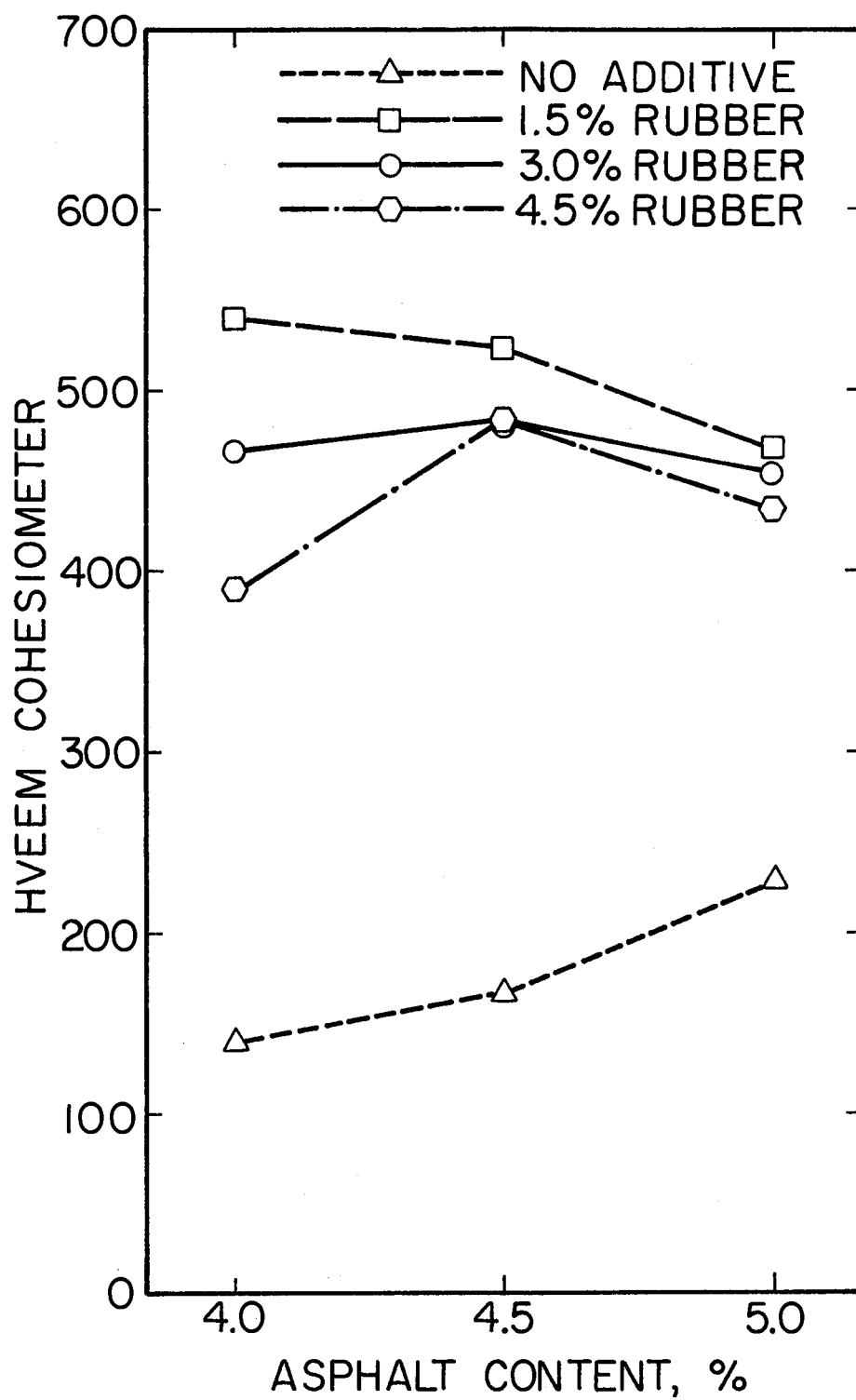


Figure 16. Hveem Cohesimeter Versus Asphalt Content for Miami with Pliopave

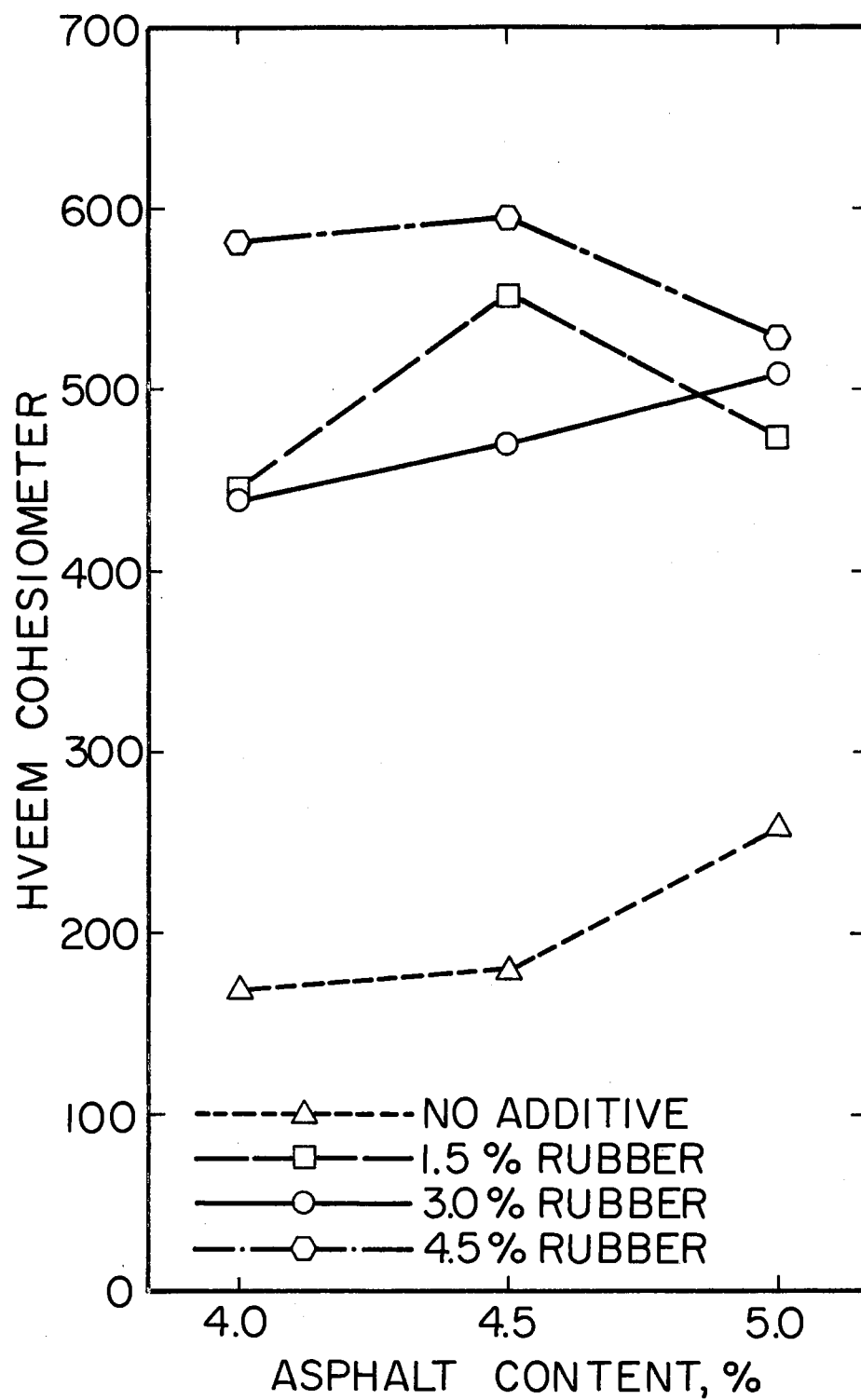


Figure 17. Hveem Cohesimeter Versus Asphalt Content for Onapa with Pliopave

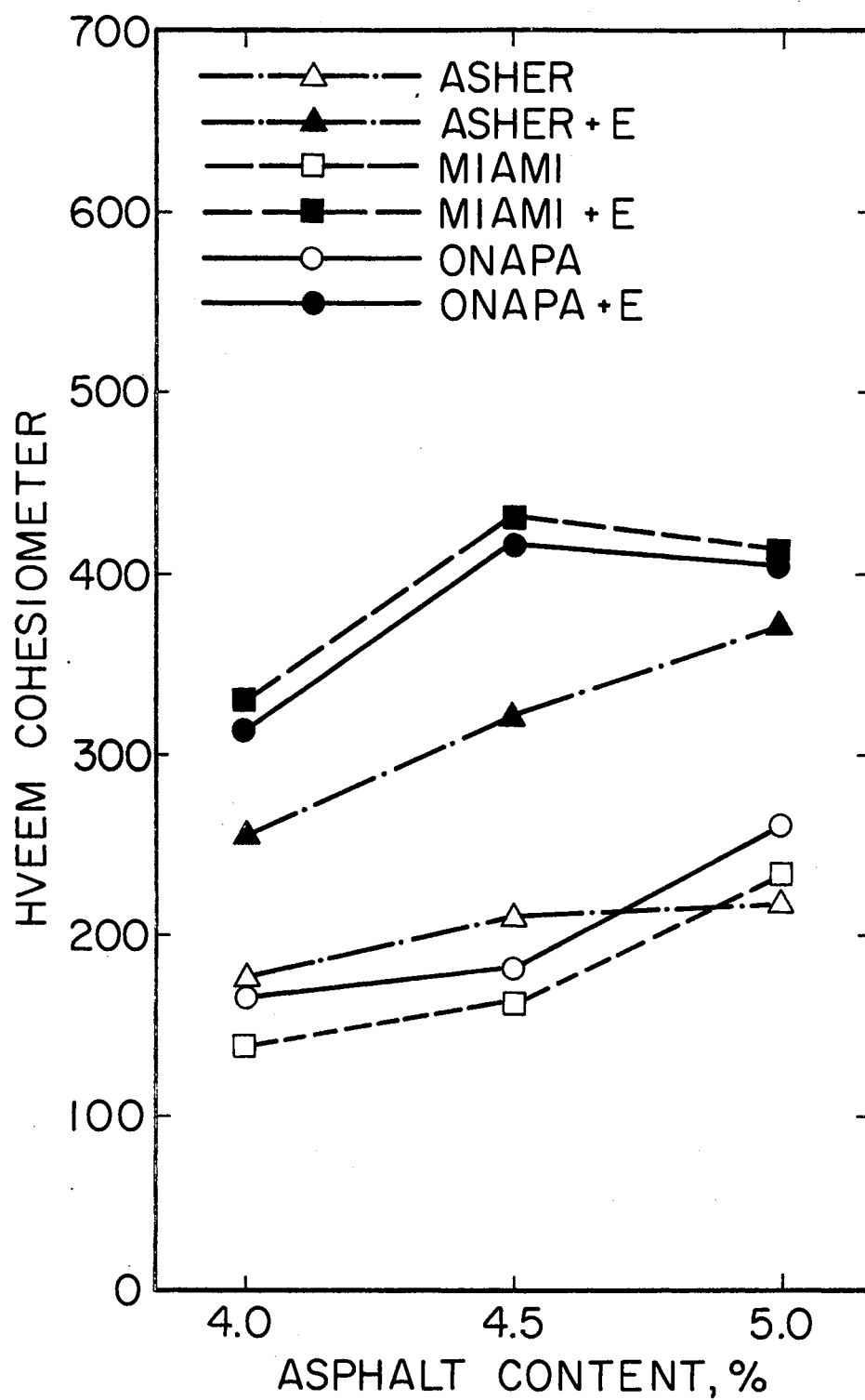


Figure 18. Hveem Cohesimeter Versus Asphalt Content for Asher, Miami and Onapa with an Emulsion Treatment

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