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Analysis of sand asphalt mixtures

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ANALYSIS OF SAND ASPHALT MIXTURES

BY

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A

THESIS

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ABSTRACT

The objective of this investigation was to determine the optimum percent of asphalt which should be added to the sand asphalt mixture. Also the effects of filler on the properties of the sand-asphalt mixture were evaluated.

The variables in this study were mineral filler, asphalt cement, and asphalt content. The sand used in this study was sub-rounded, and uniformly graded. The asphalt was asphalt cement with two different penetrations, one of 85-100 penetration grade and the other of 120-150 penetration grade.

Three different groups of mixtures of sand-asphalt were prepared. The first group consisted of adding 85-100 penetration asphalt to a mixture of sand and filler. The second group consisted of adding 85-100 penetration asphalt to sand only. The third group consisted of adding 120-150 penetration asphalt to sand. All mixes were prepared by the Harvard Compaction machine and tested in an unconfined compression machine.

The physical properties analyzed were compressive strengths, unit weight and air voids in the mineral aggregate. It was found that an asphalt content of four percent appears to be an optimum percentage for the three groups of mixtures tested. It was found also that filler increased the desirable properties of sand-asphalt mixture.

ACKNOWLEDGMENT

The author wishes to extend his sincere appreciation to his advisor, Dr. Thomas S. Fry for the suggestion of the research topic and for his continued guidance and counseling through the preparation of this thesis.

Thanks are also offered for the assistance given by members of the staff of the Civil Engineering Department of the University of Missouri at Rolla.

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I. INTRODUCTION

Sand-asphalt stabilization has been accomplished by the addition of bituminous material in the proper quantities to sand.(1) In the stabilization of cohesionless soil with asphalt, the mixture serves a dual purpose of binding soil particles together to give cohesion to the mass, and of water-proofing the mixture. (2)

The asphalt-stabilized materials are generally used for:

1. The construction of bases for surface-treated roads with low traffic volume:

2. The construction of bases of main roads having concrete or bituminous surfacing:

3. The water-proofing of subgrade to preserve its stability. (3)

In the United States there are now more than seven thousand miles of sand-asphalt stabilized base course and sub-base which have performed with varying degrees of success. A considerable amount of sand-asphalt stabilization has been performed in the Province of Manitoba, Canada. (4)

Soil stabilization by the incorporation of admixtures has been subjected to many research projects, particularly in recent years. At present, sand-asphalt mixtures are being investigated by practically all agencies concerned with pavement design and construction. The extent of investigation ranges from comprehensive reviews of published literature, through long-term performance studies of existing facilities, to intensive laboratory research projects on specific problems associated with the stabilization process.

In addition to the conventional use of sand-asphalt for the construction of bases and sub-bases for highways, it is also used for the construction of rainwater reservoirs. The U.S. Government, Department of the Interior, is conducting research in this field, especially in the area of New Mexico, where the results showed that a rainfall of six inches or more a year can be stored on a base of sand-asphalt and used economically for irrigation and water supply purposes.

Until recently, the major portion of work in sand-asphalt stabilization has been of a practical nature to arrive at a set of empirical design standards and construction procedures suitable for use in a particular locale. Increased efforts have been made during the past few years to investigate sand-asphalt stabilization on a more scientific basis and to provide information on fundamental mechanisms.

Due to the large number of factors which influence the strength and durability of a sand-bituminous mixture, any single investigation must necessarily restrict the number of variables as much as possible. Therefore, in this investigation only one type of sand and a hard asphalt with two different penetrations were used. Also, only one method of mixing and compacting was used throughout the testing program. The unconfined compression test was used to measure the stress-strain relationship of the samples. It was chosen for its simplicity.

With these factors in mind, the purpose of this research is to investigate the relationship between the percentage of asphalt used and the compressive strength of the mixture, and to determine the influence of the filler on the strength of the sand-asphalt mixture.

II. REVIEW OF LITERATURE

A. Case History

In 1957 and 1958 the South Carolina State Highway Department was concerned with the construction of a four lane, divided highway between Conway and Myrtle Beach on U.S. Route 501. The base consisted of 10 inches of hot sand-asphalt containing 4.0% asphalt-cement. The sand was dark gray in color due to a high percentage of organic matter and graded as follows:

Pass No. 10	100%
Pass No. 40	71%
Pass No. 80	13%
Pass No. 200	2%

The base was placed in two 5-inch layers. Although there were no stability requirements on this project, a mixture made in the laboratory with soil from the pit with 4% asphalt cement gave 160 lbs. marshall stability.

This road has a yearly average of 5,002 vehicles per day and a summer average of 9,100 vehicles, and except for considerable rutting is apparently in good condition. It is believed that the surface could be covered and brought to a uniform cross-section with a treatment of 150 pounds per square yard of asphaltic concrete. (5)

B. Stabilization Methods

Asphalt is one of many types of stabilizing agents. Depending on the mechanisms of stabilization these stabilizers may be subdivided into three general groups.

The first group includes materials which cement the soil particles.

These materials, capable of reactions within themselves or with certain soil constituents in the presence of water, produce strong inter-particle bonds which can support high intensity loads. Typical representatives of this group are cements, lime, and more recently acidic phosphorus compounds.

A second group of stabilizers could be termed the soil modifiers or conditioners. Lime, calcium, or sodium chlorides, and a number of surface active materials are typical of this group.

The third group embraces the water-proofing agents. Asphalt, certain resinous materials, and coal tars are representative of this group. The stabilizers coat individual soil particles or their agglomerates, and thereby prevent or hinder the penetration of water into the stabilized soil layer.

The role of an asphalt film in stabilizing a soil mass depends to a great extent on the properties of the soil. In the case of non-cohesive soils (sands and silts) the asphalt film serves a double purpose in that it water-proofs the soil mass and it binds the soil particles together producing a cohesive material.

C. Mechanics of Asphalt Stabilization

The most important objective of soil stabilization is the elimination of the dependency of soil engineering properties on moisture content. The most obvious way in which the water sensitivity of soils can be eliminated is to coat the individual soil particles with film of stable, water-insoluble resinous substance which will prevent water from reaching the particle surfaces, and/or prevent water from migrating by capillarity into a consolidated porous soil mass. The use of a resinous material provides additional advantages in that it causes the individual particles to adhere to one another, and thus contributes to the shear strength of the compacted mass.

Asphalt as a soil stabilizer is, however, limited by certain physical properties both of the asphalt and of the soil. The three most important factors limiting its effectiveness as a stabilizer are believed to be:

1. the difficulty of distributing asphalt uniformly throughout a material such as clay or fine sand,

2. the inability of asphalt to adhere to wet soil particles, and

3. the sensitivity of the asphalt-soil bond to destruction by water.

To facilitate distribution of asphalt through soils, and thus to improve its stabilizing action by minimizing the first factor cited above, three basic approaches have been followed in practice. The fluidity of the asphalt at normal temperatures can be increased by diluting it with volatile solvent. The viscosity can be decreased by heating or emulsification with water in the presence of an emulsifying agent. All of these processes yield mobile liquids which can be admixed with soil more effectively. (4)

D. Stabilization of Sand with Cutback Asphalt

At the present time, cutbacks appear to be the most practical asphalts for sand stabilization. So-called road oils are equivalent to cutbacks made with fuel oil. These road oils are usually prepared as direct residuals from fractional distillation and they are the lowest cost asphalts.

Medium-curing cutbacks (MC) and rapid-curing cutbacks (RC) seem to be suitable types of liquid asphalt for soil stabilization. The choice between (MC) and (RC) depends largely on climate, soil type, and construction practice. Different grades of cutbacks are designated from 0-5, depending on the percent solvent contained. MC-0 and RC-0 each contain about 50 percent solvent, and the percentage decreases to about 18 percent solvent for MC-5 and RC-5. A harder asphalt after curing contributes to better binding in the compacted and cured mix.

The higher grades of RC cutbacks may harden before mixing is completed; lower grades contain more solvent and cure more slowly.

The choice of grade of MC and RC also depends on mixing conditions; usually the more solvent, the greater the ease of mixing. Solvents cost about the same as the asphalt and do not contribute directly to the final strength because they evaporate during the curing process. The use of high solvent content cutback asphalts may greatly prolong the curing time. For these reasons MC-0 and RC-0 are seldom used and MC-2 or 3 and RC-2 or 3 represent usable products. The final choice is made on the basis of proper consideration of laboratory test results on the soil to be used and of the climate conditions prevailing at the time of construction. (6)

E. Functions of Fillers in Bituminous Mixes

For the purpose of this discussion the term "filler" will be restricted to that fraction of a mineral aggregate, flour or dust, present in a bituminous mixture that passes the No. 200 sieve.

A filler can perform several functions in the performance of a bituminous mixture. One of the functions is that of filling voids in coarse aggregates. This increases the density, stability, and toughness of a conventional bituminous paving mixture. Another is the creation of asphalt mixes in which the filler particles of dust either are individually coated with asphalt or are incorporated into the asphalt mixture mechanically in the form of a collodial suspension. The effect of fillers in a conventional-type mix is quite pronounced. Excessive quantities of filler tend to increase stability, brittleness, and susceptibility to cracking. Deficiency of filler tends to increase the void content, lower stability and soften the mix.

Although there has been much theorizing, there has been a lack of study and literature pertaining to the actual behavior and specific functions of fillers of various sizes, shapes, and sources, mineral composition, and their effect on the paving mixture. Unquestionably all of these factors have some effect on the functioning, behavior, and effects of a filler.

Two fundamental theories, based on the results of studies, observations, and experience, have emerged regarding the functions of fillers in bituminous mixes. One of these theories referred to herein as the filler theory, postulates that the filler serves to fill voids in the mineral aggregates and thereby creates a denser mix. The other theory, referred to as the mastic theory, proposes that the filler and asphalt combine to form a mastic which acts to fill voids and also bind aggregate particles together into a dense mass.

The filler theory presumes that each particle of the filler is individually coated with asphalt and that coated particles, either discrete or attached to an aggregate particle, serve to fill the voids in the aggregate. By virtue of such filling of voids, mixes of higher stability and density can be attained.

Studies and tests have verified the fact that increasing quantities of filler tend to increase the stability and density of the mix.

There is however, a limit to the beneficial effects of increasing filler content. Fillers may function and behave in many different ways depending on mixing procedure and the properties of the filler used in preparing the mix. In mixes prepared in the conventional manner, fillers serve predominantly to fill voids. (7)

F. Hot Mixed Sand-Asphalt

From a practical viewpoint, hot mix stabilization of sand is seldom practiced; however, the laboratory work in this area is considered desirable as a basis for strength comparisons. The use of hot mix methods appeared to work very well to distribute the asphalt in the preparation of laboratory specimens, but the resultant strength values were quite low. (2)

So far as the writer has been able to ascertain, no work has been done to study the effect of using hard asphalt cement with 85-100 penetration grade in the laboratory.

III. PROCEDURE AND RESULTS

A. General

The primary objectives of this investigation of sand-asphalt design were the following:

1. To determine optimum percentage of asphalt with 85-100 penetration, when added to sand and filler.

2. To determine the optimum percentage of asphalt with 85-100 penetration when added to sand only.

3. To determine the optimum percentage of asphalt with 120-150 penetration when added to sand only.

The variables in this investigation were asphalt content, asphalt penetration and filler.

B. Material

1. Soil - The soil selected for this project was fine river sand (Dioxin)! obtained from a sand pit located at Pacific, Missouri. The angularity of this material varied from sub-round to sub-angular. Table I contains a summary of the grain size distribution of this material. A standard specific gravity test indicated that the average specific gravity of the solid constituents is 2.68.

2. Asphalt - Asphalt having two penetrations were used in this investigation. The one with an 85-100 penetration was obtained from American Bitumuls and Asphalt Company in San Francisco, California, and one with 120-150 penetration was obtained from Chevron Asphalt Company in Cincinnati, Ohio.

3. Filler - Fly ash with a gradation having 100% passing the No. 200 Sieve was used as filler. It was obtained from Walter N. Handy

Company, Inc., Springfield, Missouri. The specific gravity of this fine grained material was found to be 2.60.

C. Equipment

1. A Harvard Compaction machine was used for preparing the samples. The mold size was 1.312 inches inside diameter by 2.816 inches high. The volume of the mold was 1/454 cubic feet.

2. An electric oven was used for the heating of the sand. A hot plate was used both for melting the asphalt and keeping the sand asphalt mixture within the desirable temperature range during specimen preparation.

3. An unconfined compression apparatus with a modification for temperature control during testing was used for the testing of the specimens.

D. Preparation of Specimens

1. The sand was heated in the electric oven for 90 minutes at a temperature of 250°F. The required amount of oven dried sand was then determined on the basis of 1000 gm. total weight of mixture.

The asphalt was heated on the hot plate until it softened, then the required amount of asphalt was added to the sand. The mixture was placed on the hot plate and mixed by hand thoroughly for three to four minutes.

2. The temperature of the batch was kept between 230° - 250°F during the compaction of the five specimens. The temperature had to be carefully watched because of the volatile nature of the asphalt. The mold was pre-heated on the hot plate before the compaction. Uniform static pressure was applied to each of the three layers of the

specimen. The total pressure applied to the specimen was 115 lb/in . After compaction both the specimen and the mold were cooled for a period of 12-15 minutes, and then the specimen was extracted carefully from the mold and cured for a minimum of 24 hours before testing.

3. The specimens were weighed and the average weight of each group was determined as shown in Table 2.

E. Types of Mixtures

By using the previous method of mixing and molding, three different sand-asphalt mixtures were prepared at several different asphalt percentages. The first series involved the preparation of five specimens for each of seven different percentage of 85-100 penetration asphalt. The percentages used were 3, 4, 5, 6, 7, 8, and 9 percent asphalt. Five percent filler (by weight of the total mix) was used for this group of tests.

The second series of mixes involved the preparation of five specimens for each of five different percentages of the 85-100 penetration asphalt with no mineral filler. The asphalt percentages used were 3, 4, 5, 7, and 9 percent.

The third series of tests were performed on specimens having five different percentages of 120-150 penetration asphalt without mineral filler. The asphalt percentages used were 3, 3 1/2, 4, 4 1/2, and 5 percent.

An attempt was made to use 200-250 penetration asphalt. The asphalt in this case was thick viscous liquid, using it in the mixture didn't contribute to the strength of the particles of sand, consequently no adequate stress-strain curves were developed.

F. Testing Procedure

All specimens were immersed in a water bath for a minimum of 30 minutes before testing. The temperature of the water was kept within the range of 21.2°C to 21.8°C.

A standard unconfined compression apparatus modified for temperature control was used for testing. The sample was immersed in water during the testing by inserting the specimen into a hollow water filled cylinder made from Plexiglas. A Plexiglas compression block was placed over the steel compression disc of the machine to keep the steel from being immersed in the water during the testing. It was felt that the Plexiglas used in this manner would minimize any temperature change in the water surrounding the sample. A thermometer was kept in the water to detect any temperature change. The temperature of the bath was kept within the range of 21.2°C to 21.8°C during the test period. The load was applied at a constant rate of 0.032 inches per minute. The load applied to the specimen was measured by means of a proving ring having a capacity of 500 pounds. An extensionometer was attached to the machine for reading the sample deformation.

G. Results

1. Loads for unconfined compression test samples were taken from calibration curves prepared for the 500 pound proving ring.

2. An area correction table was prepared and the area determined from the initial diameter and unit strain. This assumed a deformation at a constant volume, that is:

$$A = \frac{A_o}{1 - \epsilon}$$

where: A = Final area

Ao = Initial area

ϵ = Unit Strain

A sample calculation is shown in Table 3. The relationship between weights, percentage of asphalt and strength of specimens in PSI is shown in Table 4.

Thermo-control precautions were taken only after many failures to get satisfactory results. Prior to the thermo-control precautions, the same group of specimens prepared from the same batch would give a very wide range of stress values. An investigation was made of these failures and two factors were suspected as causes. The first factor was that by leaving the batch on the hot plate for a period of time during the compaction of specimens, the temperature of the mixture became much higher at the end of the period than it was at the beginning. This caused more volatile materials to leave the asphalt and resulted in the hardening of the asphalt which in turn gave higher results for the stress-strain relationship for specimens compacted at the end of the period. This was indicated by the testing of the labeled specimens. The difficulty seemed to be minimized by controling the temperature of the batch, and by shortening the period of compaction.

The second factor was the change of room temperature during the testing of the specimens. No matter how small the change, some variations in the results of stress-strain relationships were noted. This second reason was made more evident by the satisfactory results obtained after the use of the water bath and the procedure of testing the sample while it was immersed in water.

In-spite of all the previous precautions, some specimens in some groups showed rather wide differences in results and as a result were eliminated from the analysis of the data.

Curves were plotted for each group of specimens as shown in Fig. 1 through 20. Part (a) of each figure is a plot of the stress-strain data for the individual specimens. Part (b) of each figure represents an average of the curves which are shown in Part (a) of the figure.

The averaging of the curves was accomplished by calculating Youngs Modulus (E_i) for the elastic (initial) portion of each curve. The average (E_i) was calculated and the inclination of the initial portion of the stress-strain curve was calculated or measured and drawn as shown in part (b) of each figure.

An imaginary tangent was drawn for each linear part of the curve in part (a) of the figure until it intersected the strain axis. This point of intersection was then considered as the origin point for that curve, and all of the other calculations were altered to fit the corrected curve.

Three other points were chosen on the strain axis. One of these points involved the determination of the average peak stress and the average strain at which this stress occurred. The other two points were concerned with the average stress that occurred at a given strain.

The angle and the three computed points were plotted in part (b) of the figures, then a smooth curve was drawn to the angle and the three points.

Table 1. Sieve Analysis

Sieve Size	% Passing
30	99.30
50	40.10
100	3.76
200	0.58

APPENDIX I

Figures 1 through 29

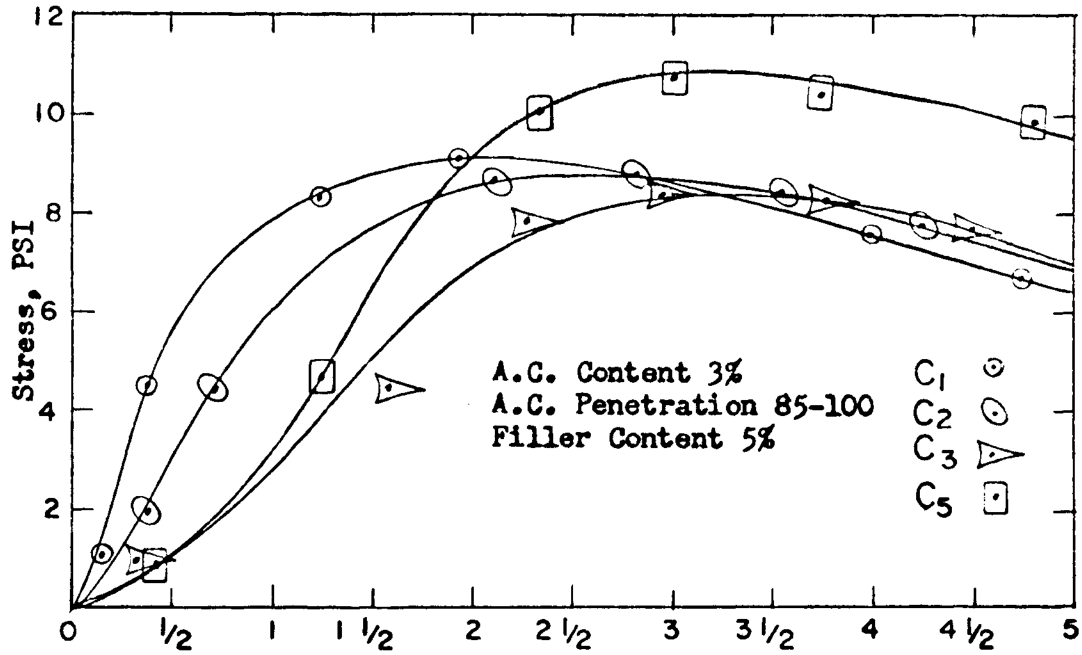


Figure 1a. Stress-Strain Relationship

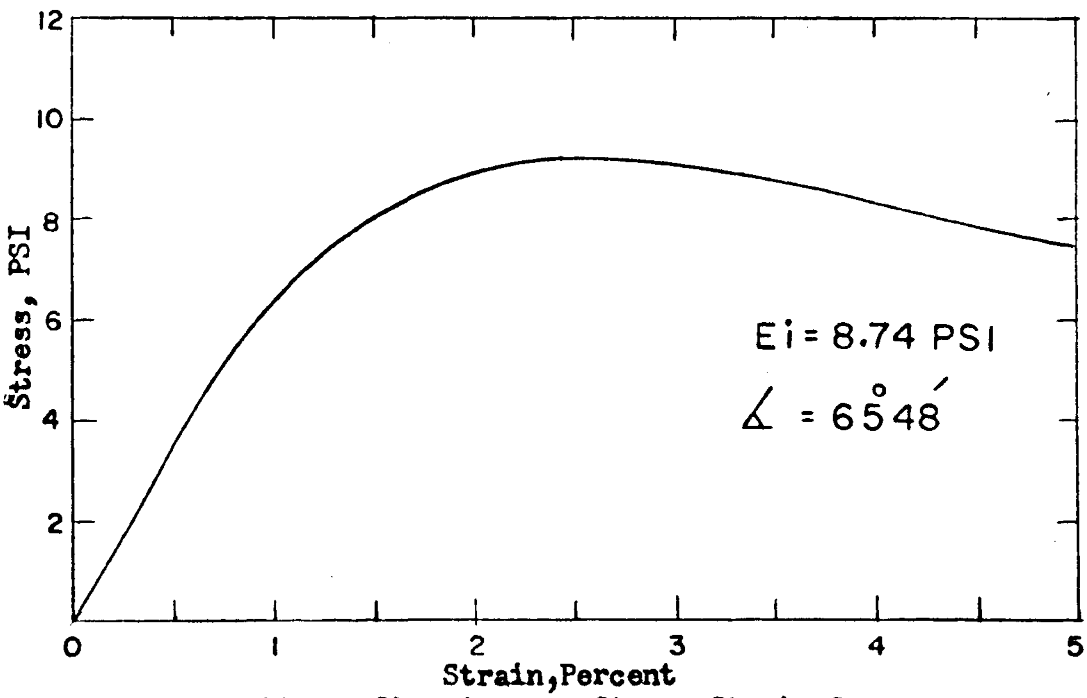


Figure 1b. Average Stress-Strain Curve

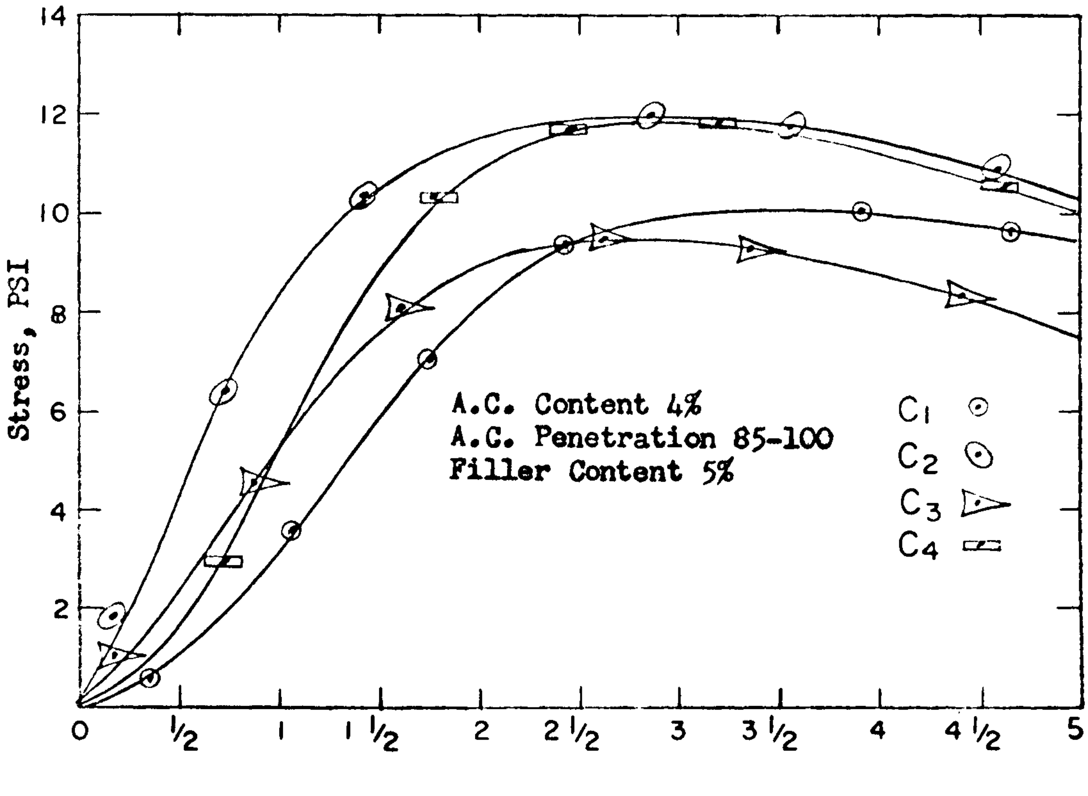


Figure 2a. Stess-Strain Relationships

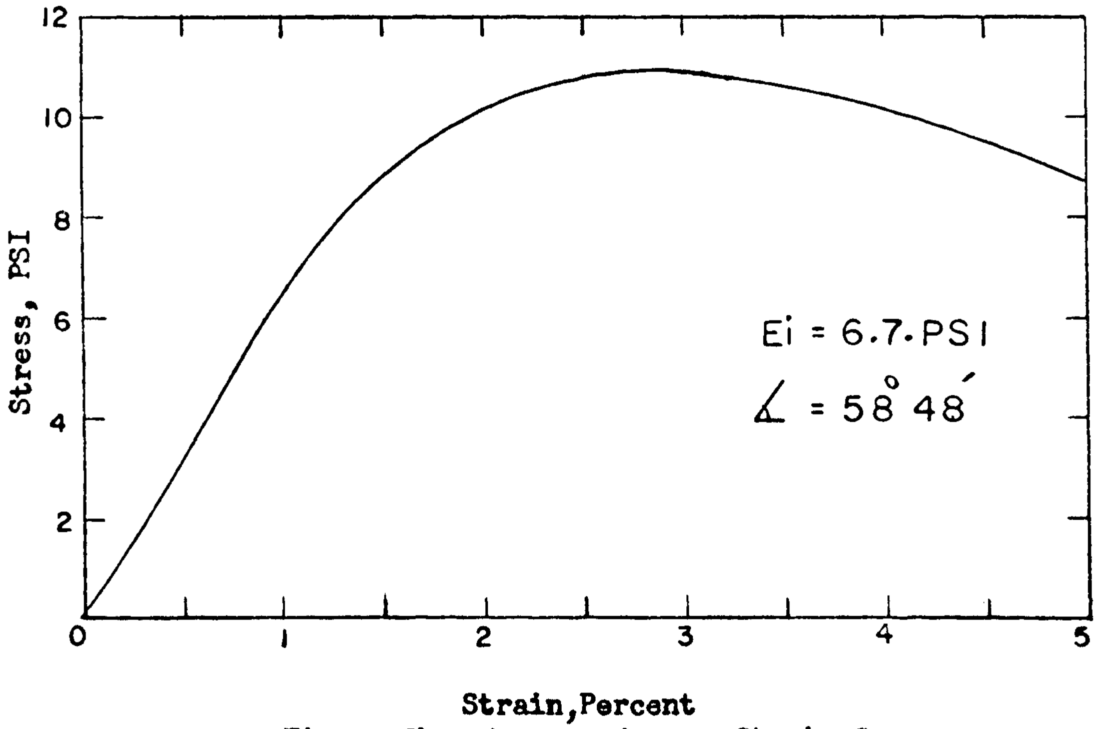


Figure 2b. Average Stress-Strain Curve

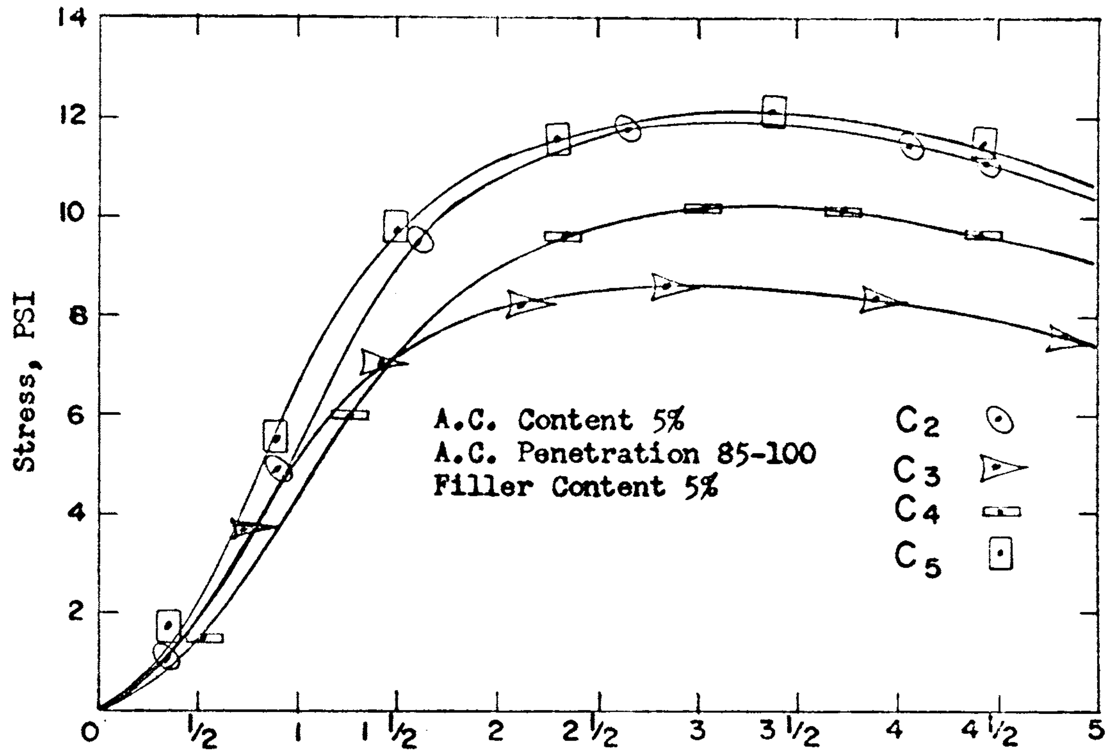


Figure 3a. Stress-Strain Relationships

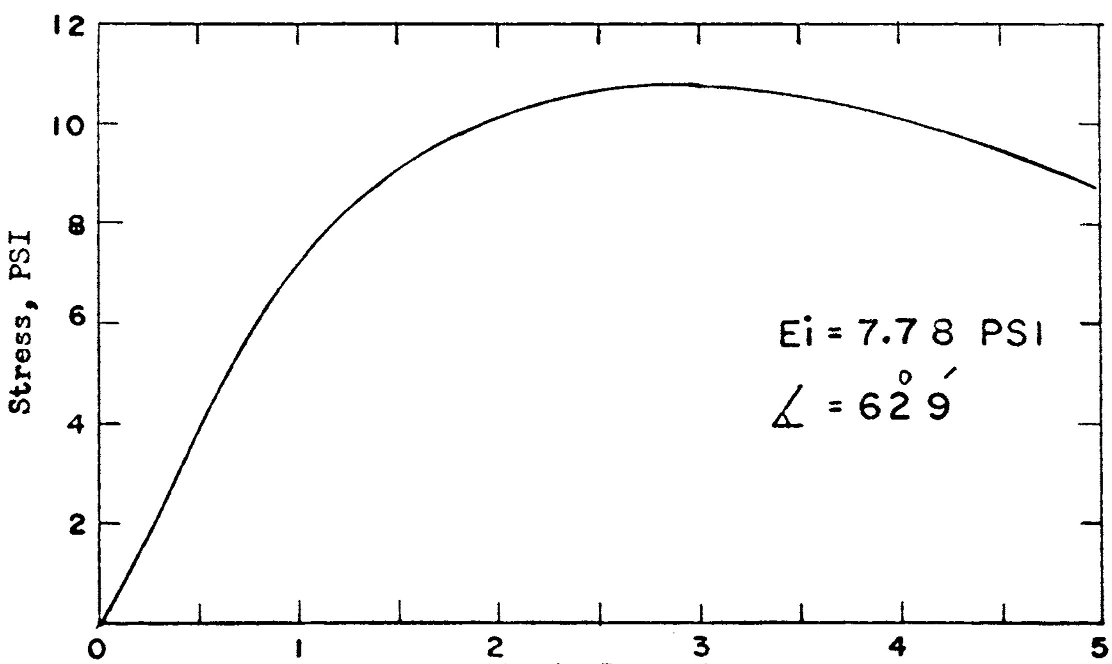


Figure 3b. Average Stress-Strain Curve

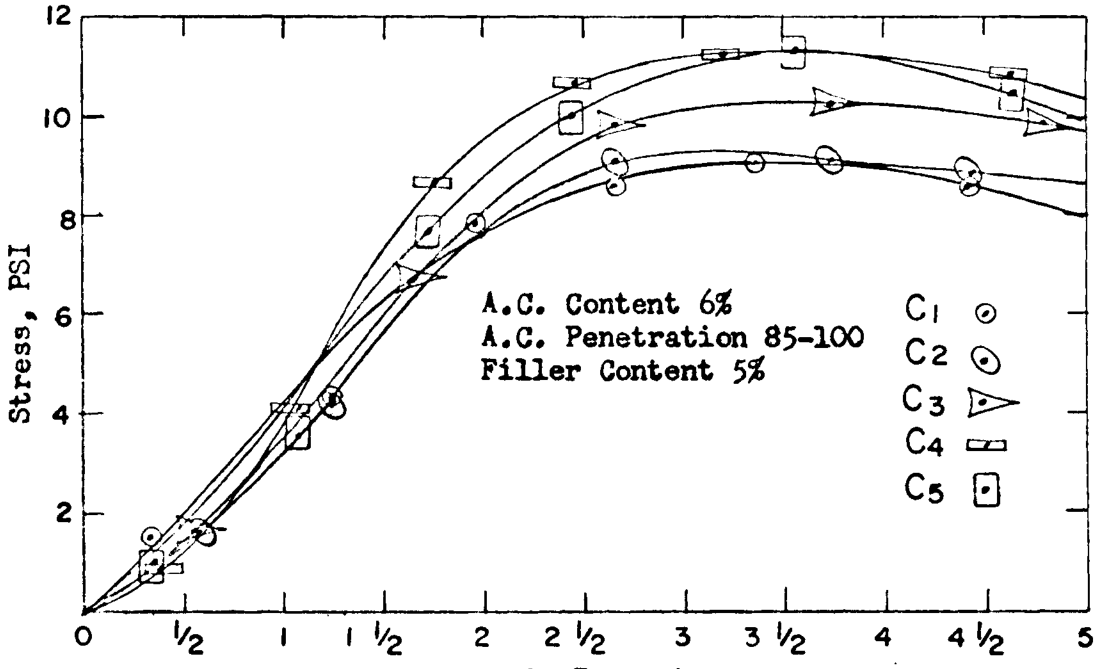


Figure 4a. Stress-Strain Relationships

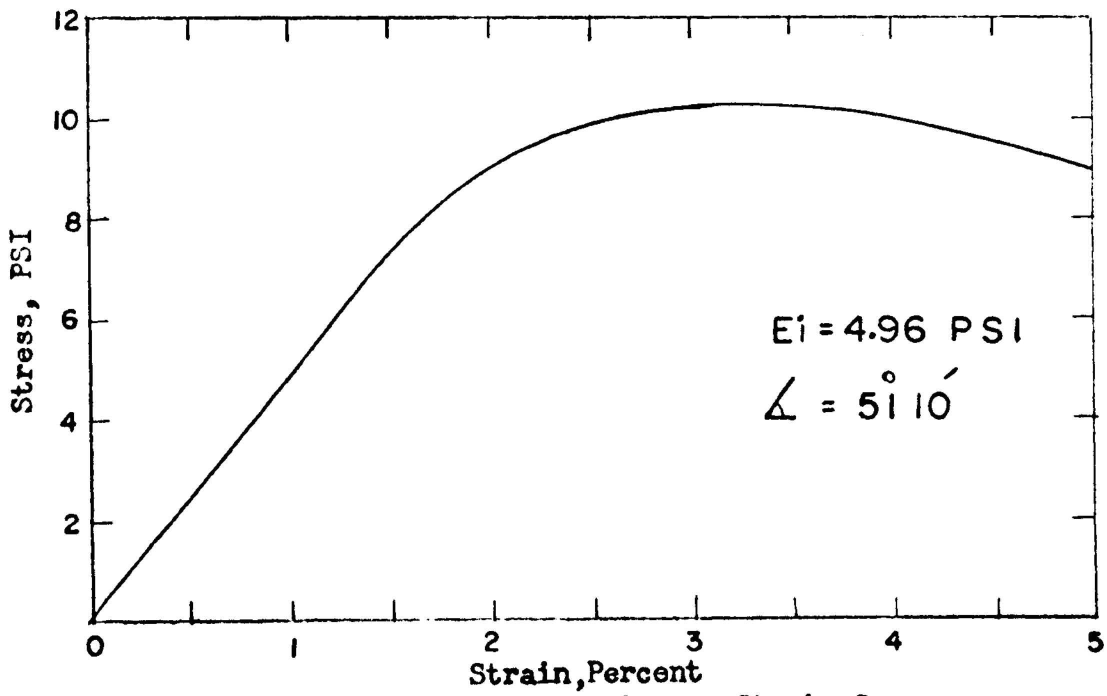


Figure 4b. Average Stress-Strain Curve

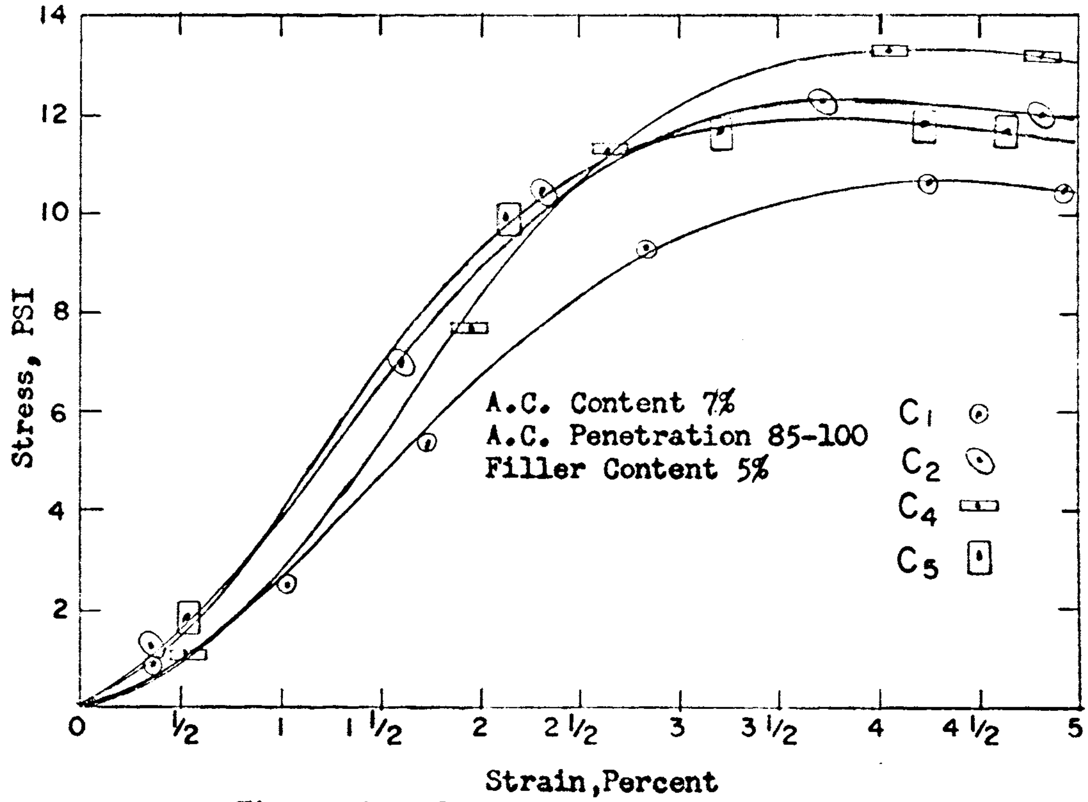


Figure 5a. Stress-Strain Relationships

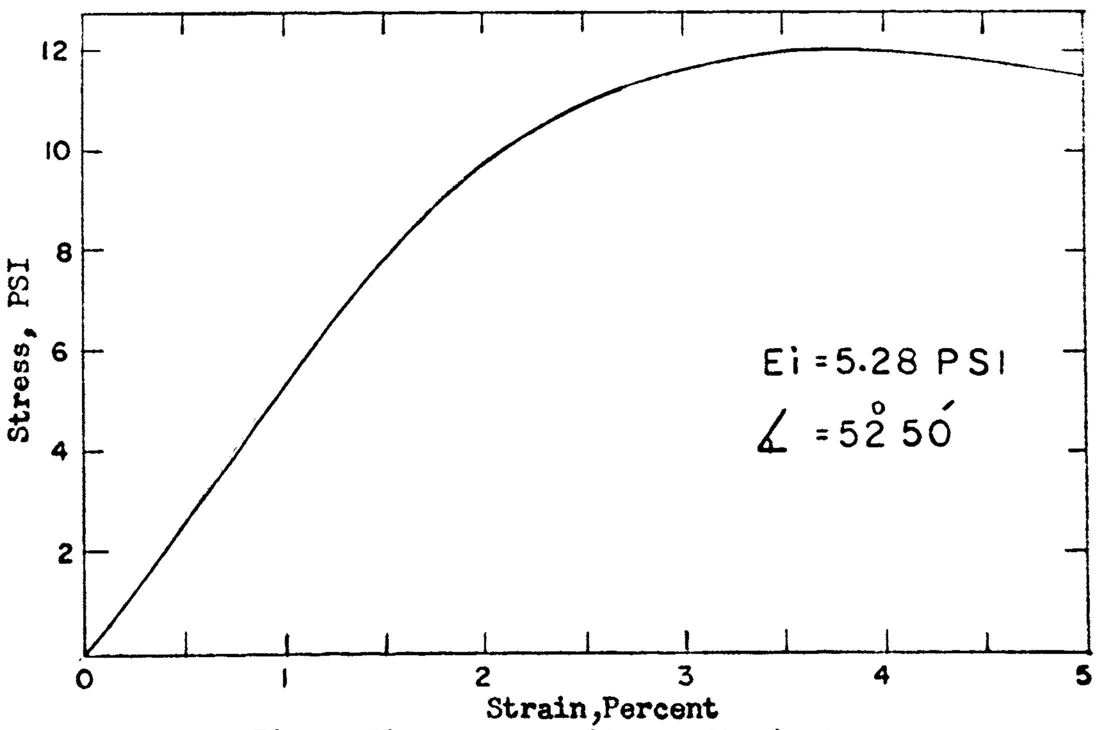


Figure 5b. Average Stress-Strain Curve

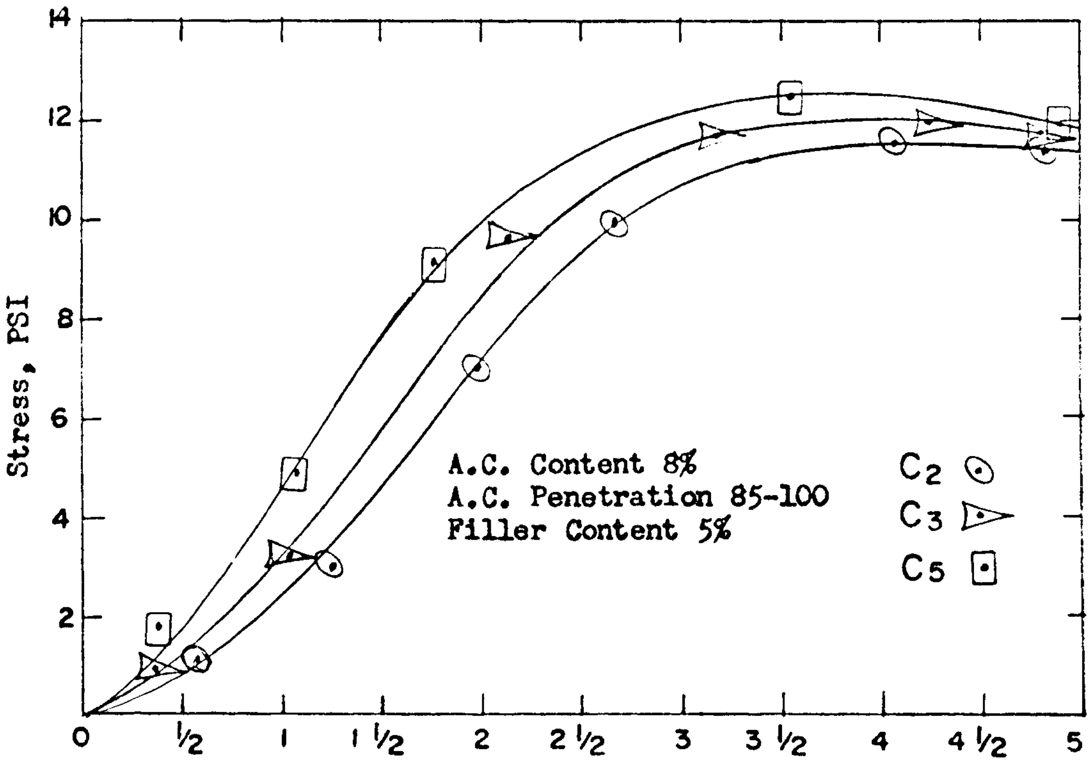


Figure 6a. Stress-Strain Relationships

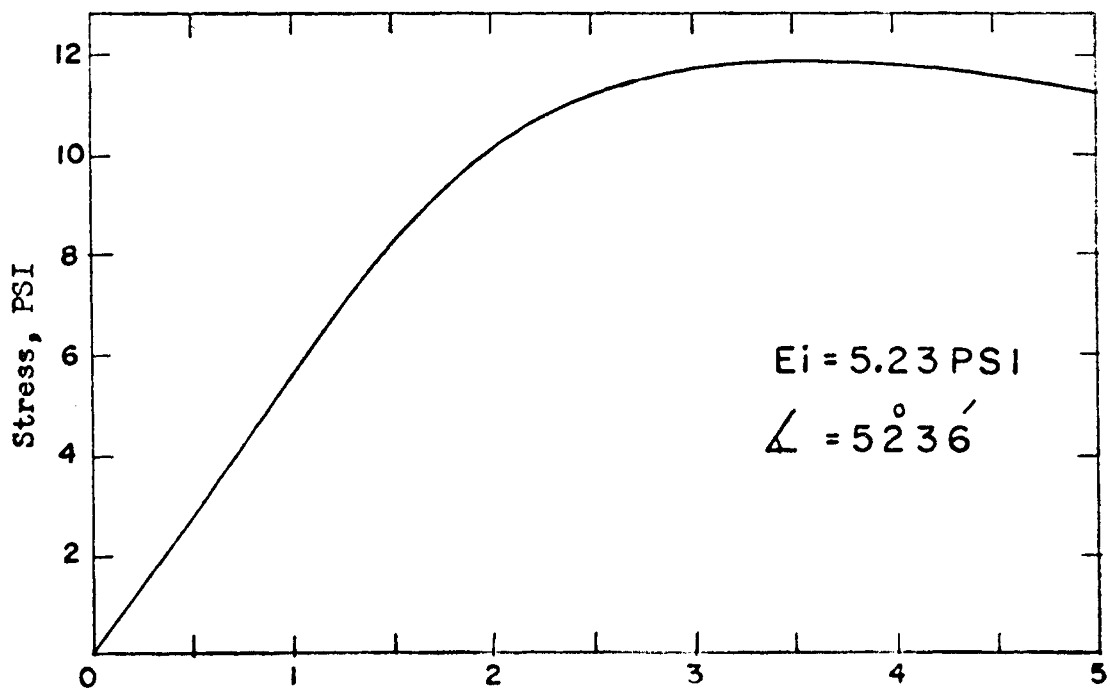


Figure 6b. Average Stress-Strain Curve

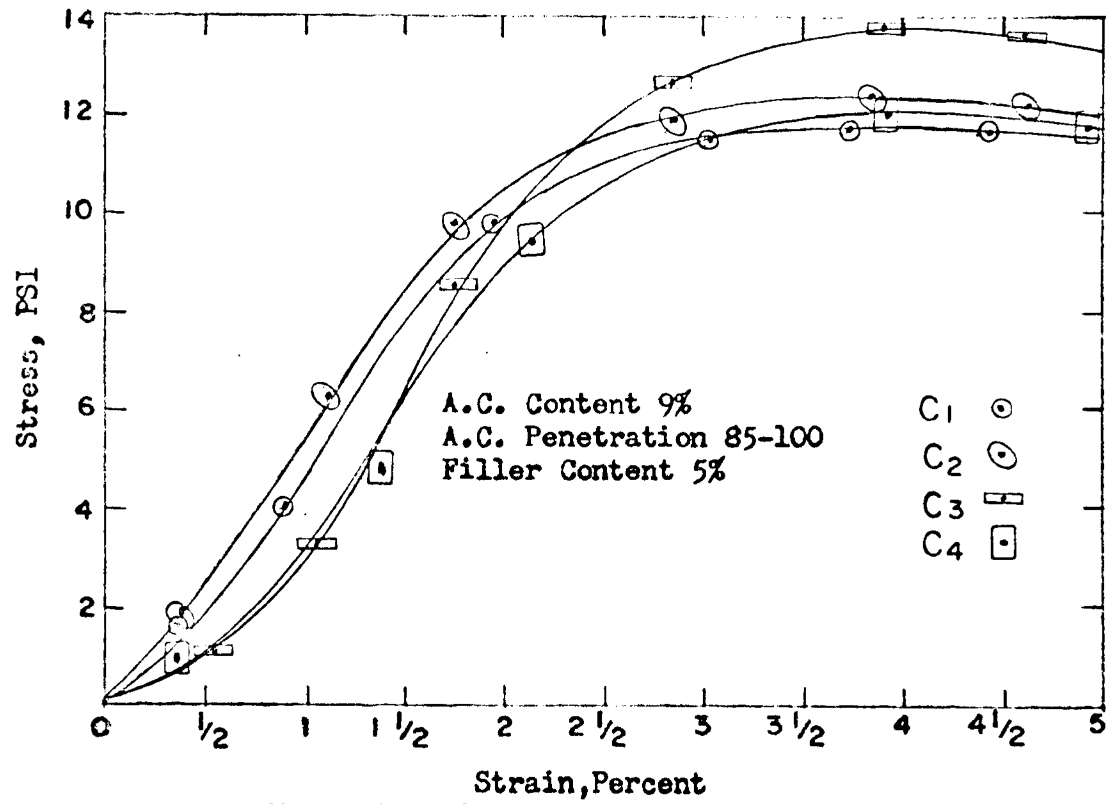


Figure 7a. Stress-Strain Relationships

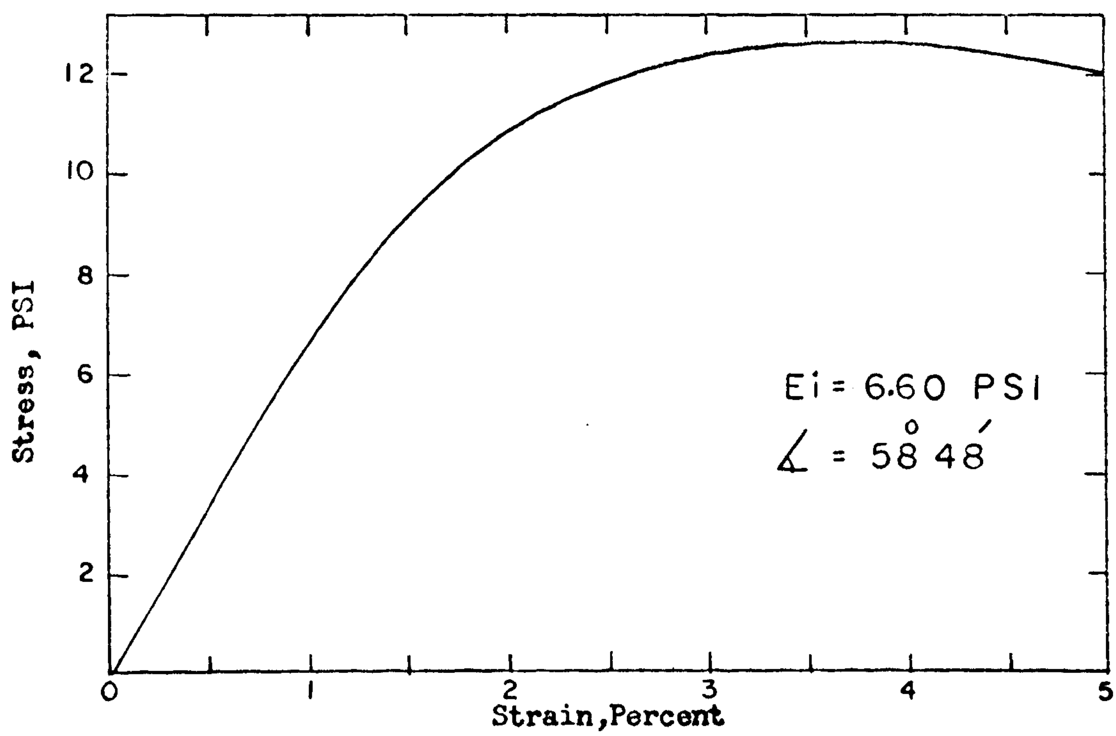


Figure 7b. Average Stress-Strain Curve

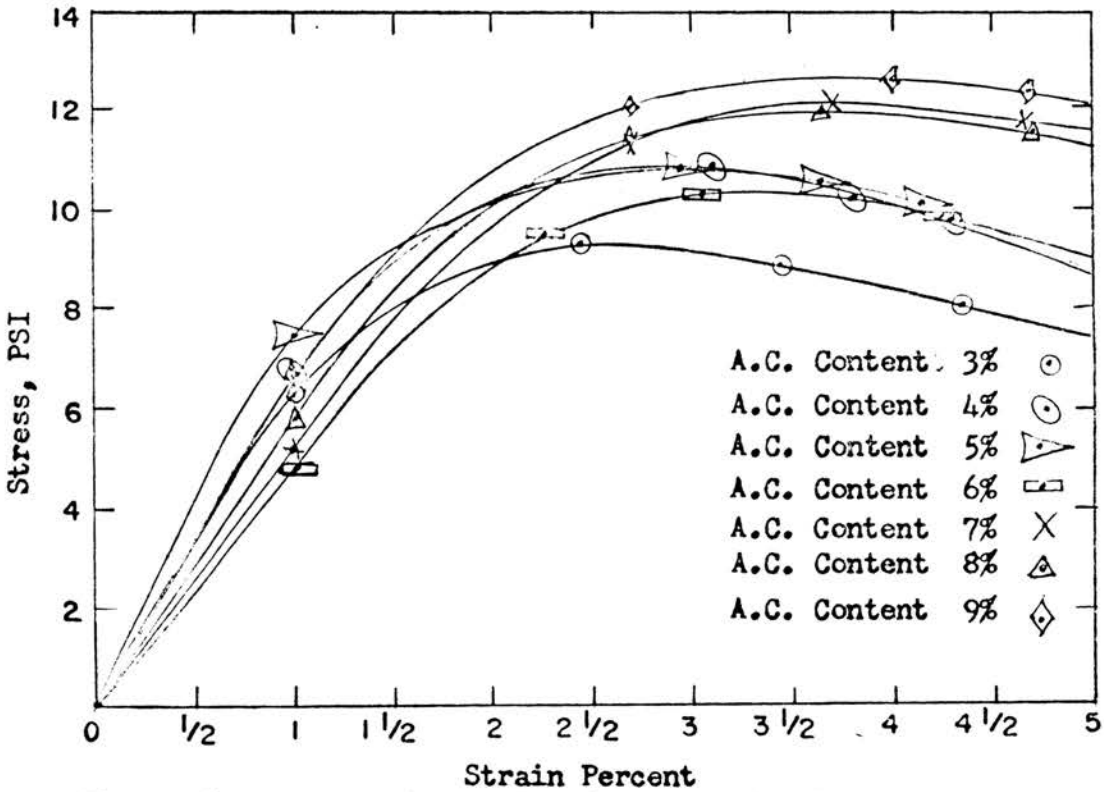


Figure 8. Average Stress-Strain Curves for Group A Mixtures

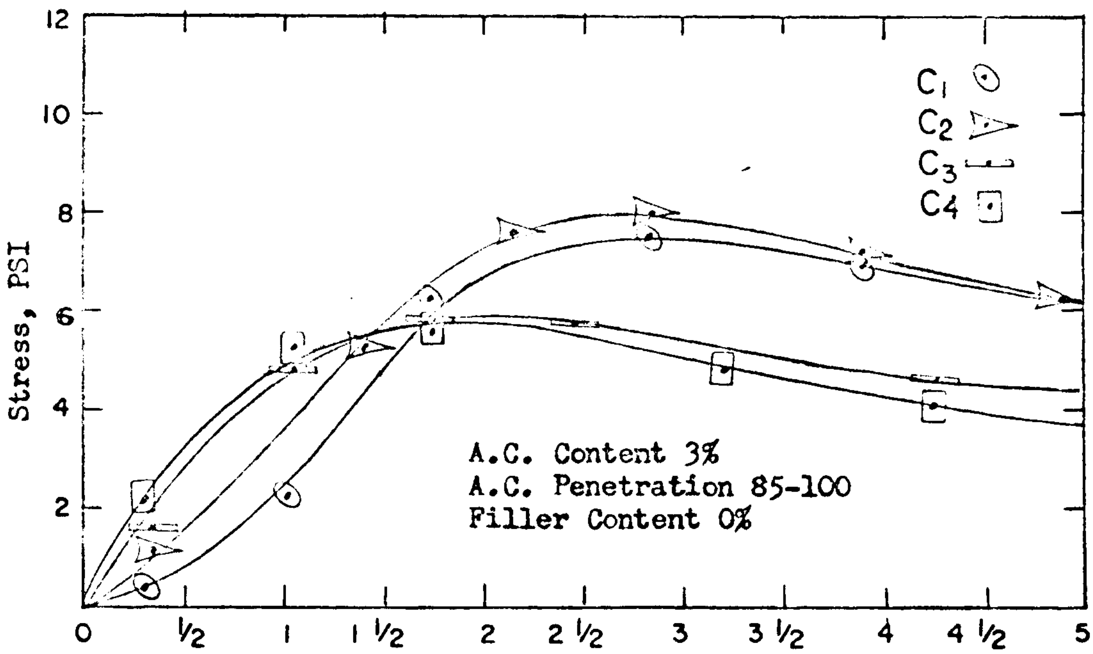


Figure 9a. Stress-Strain Relationships

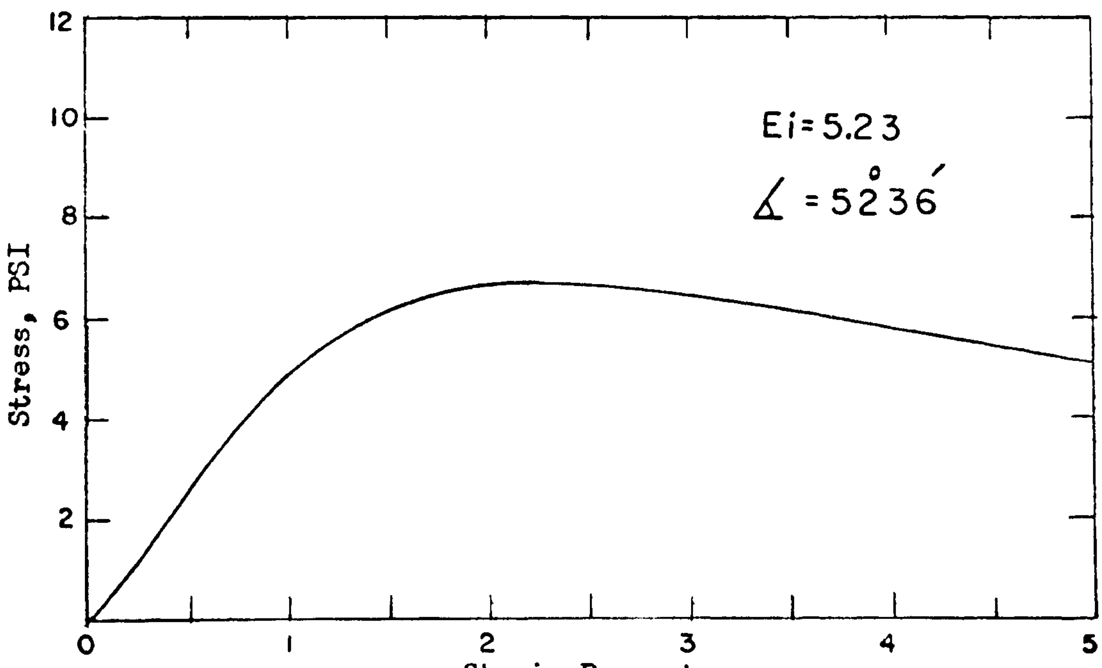


Figure 9b. Average Stress-Strain Curve

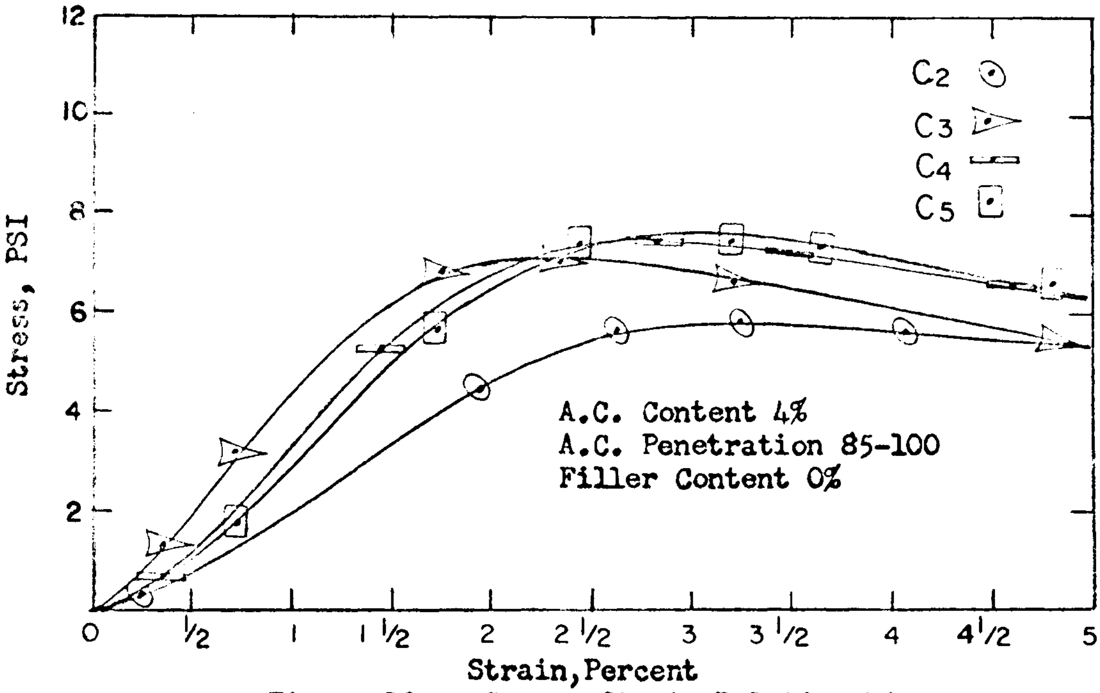


Figure 10a. Stress-Strain Relationships

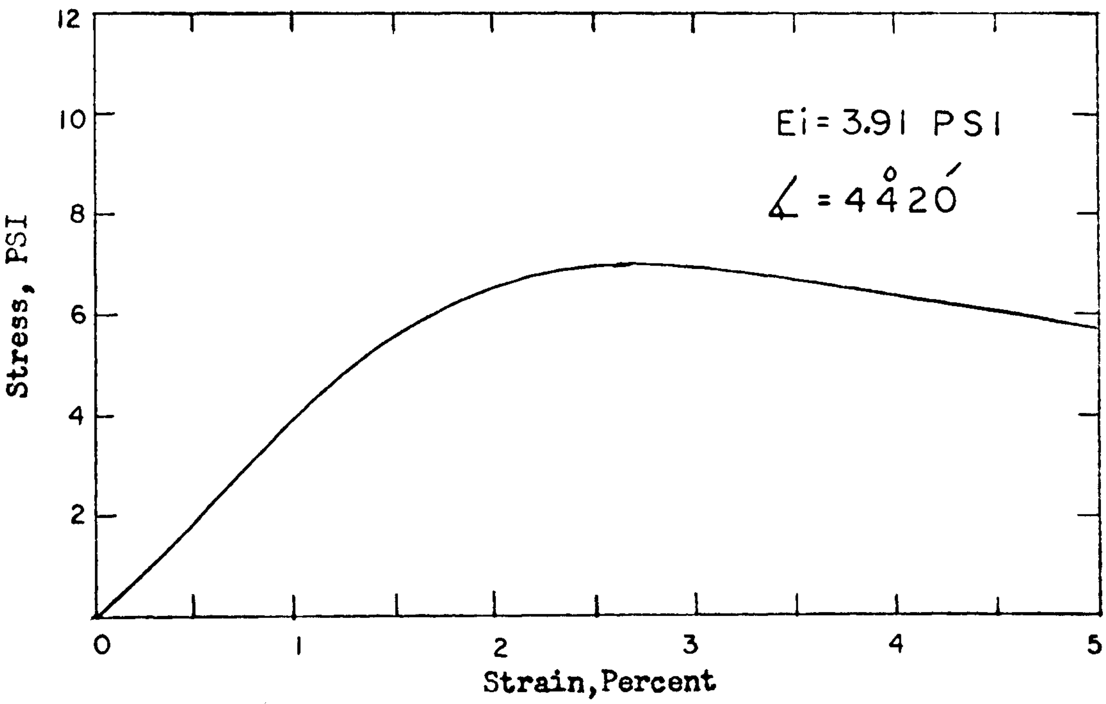


Figure 10b. Average Stress-Strain Curves

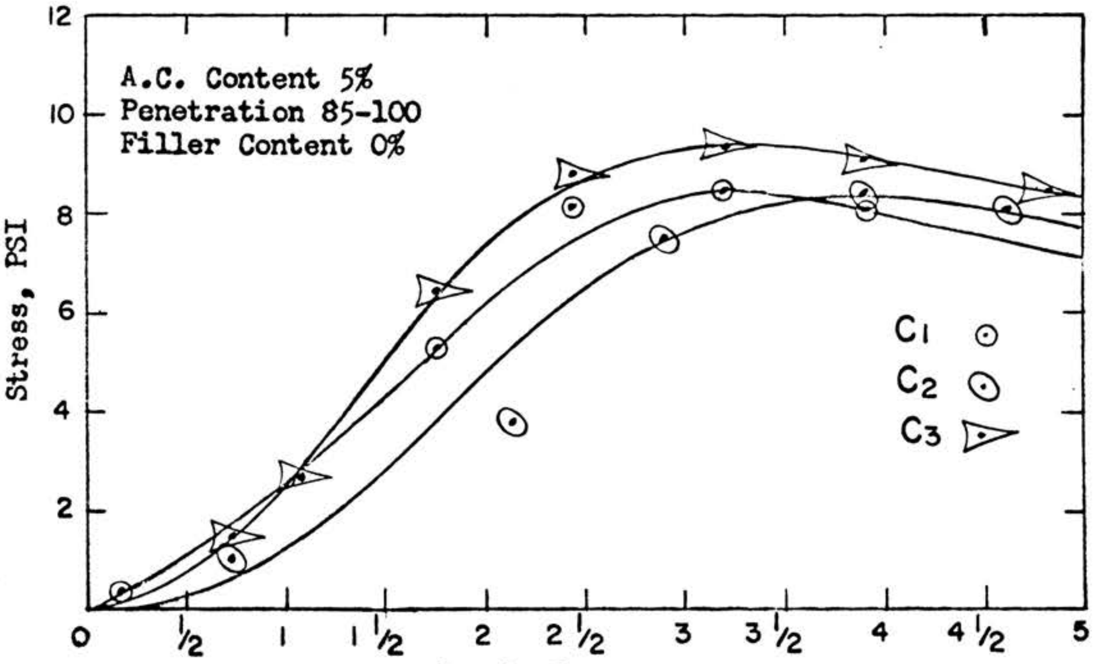


Figure 11a. Stress-Strain Relationships

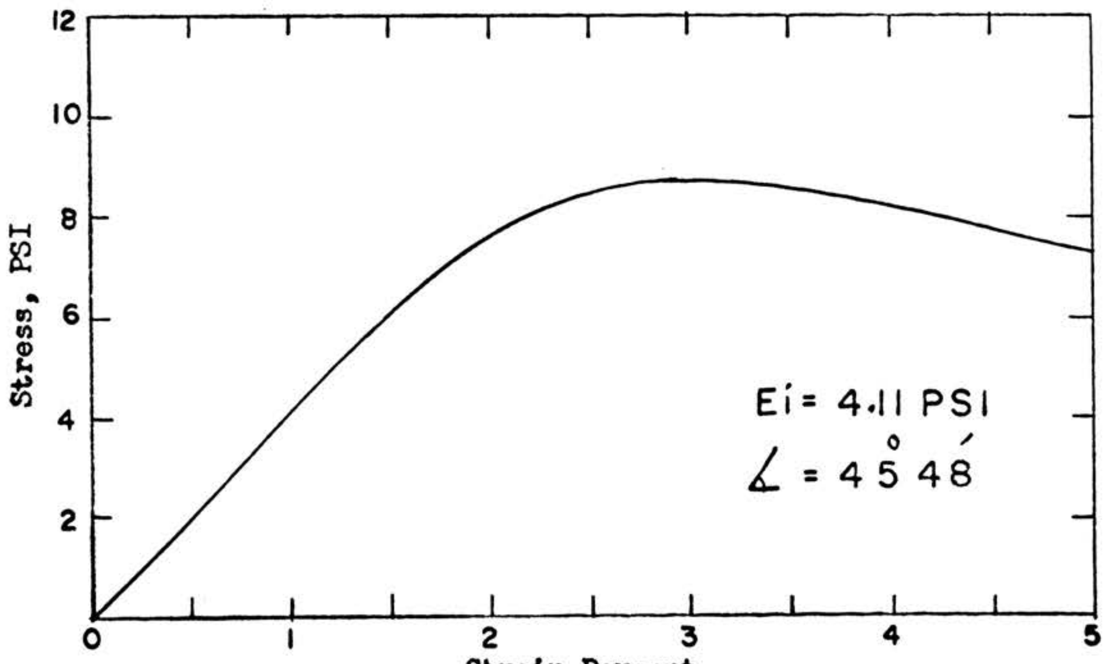


Figure 11a. Average Stress-Strain Curve

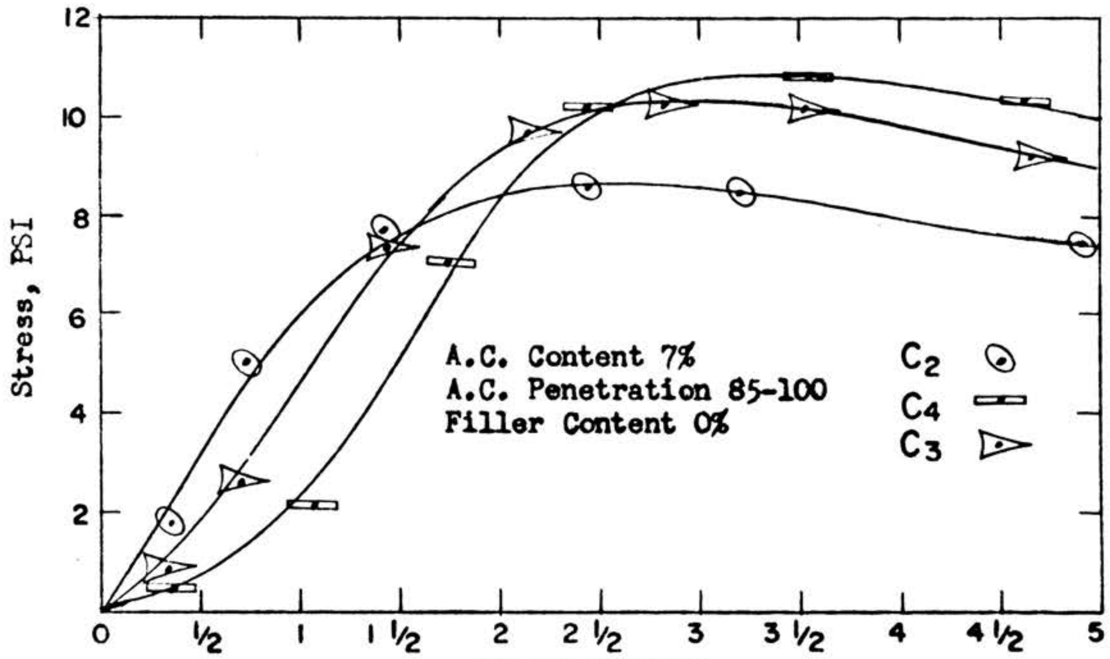


Figure 12a. Stress-Strain Relationships

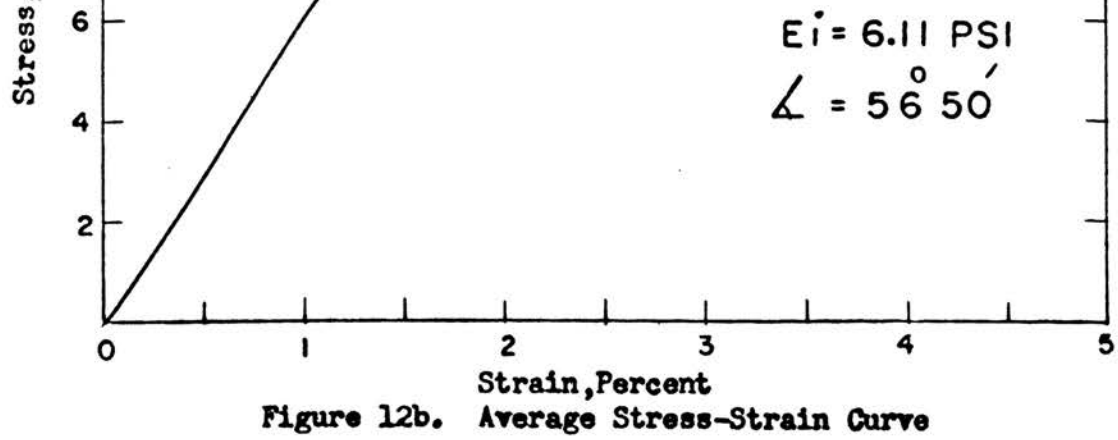


Figure 12b. Average Stress-Strain Curve

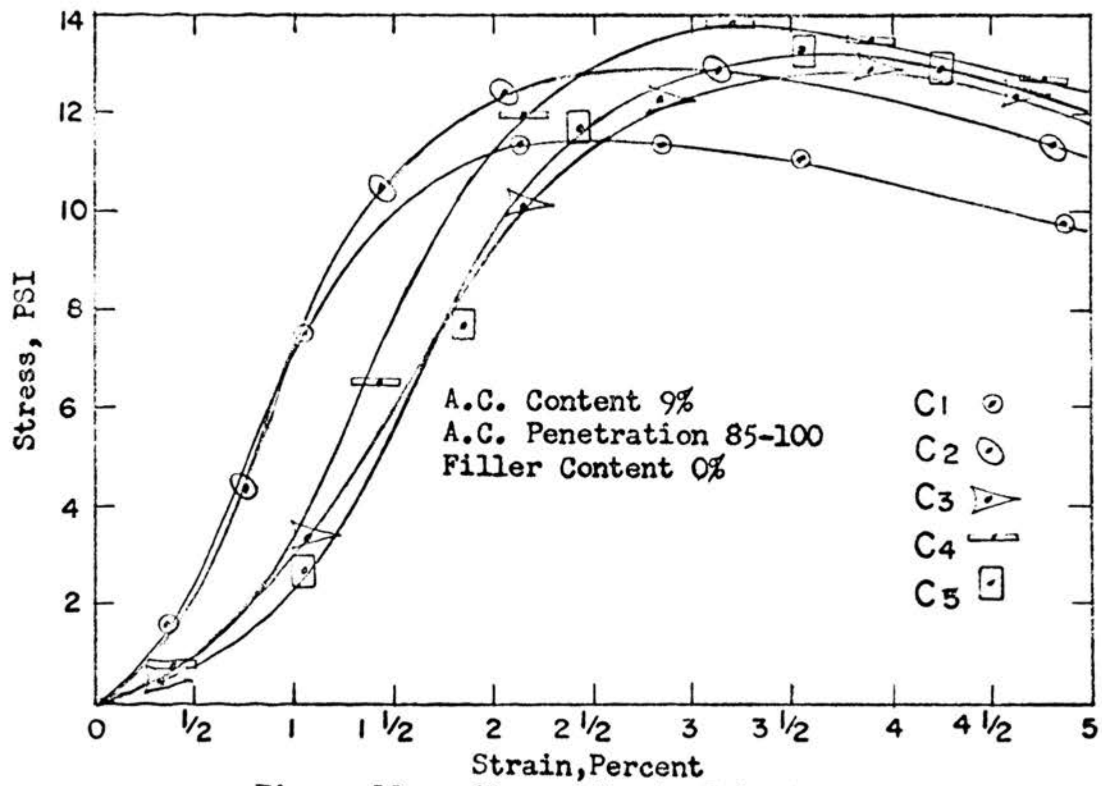


Figure 13a. Stress-Strain Relationships

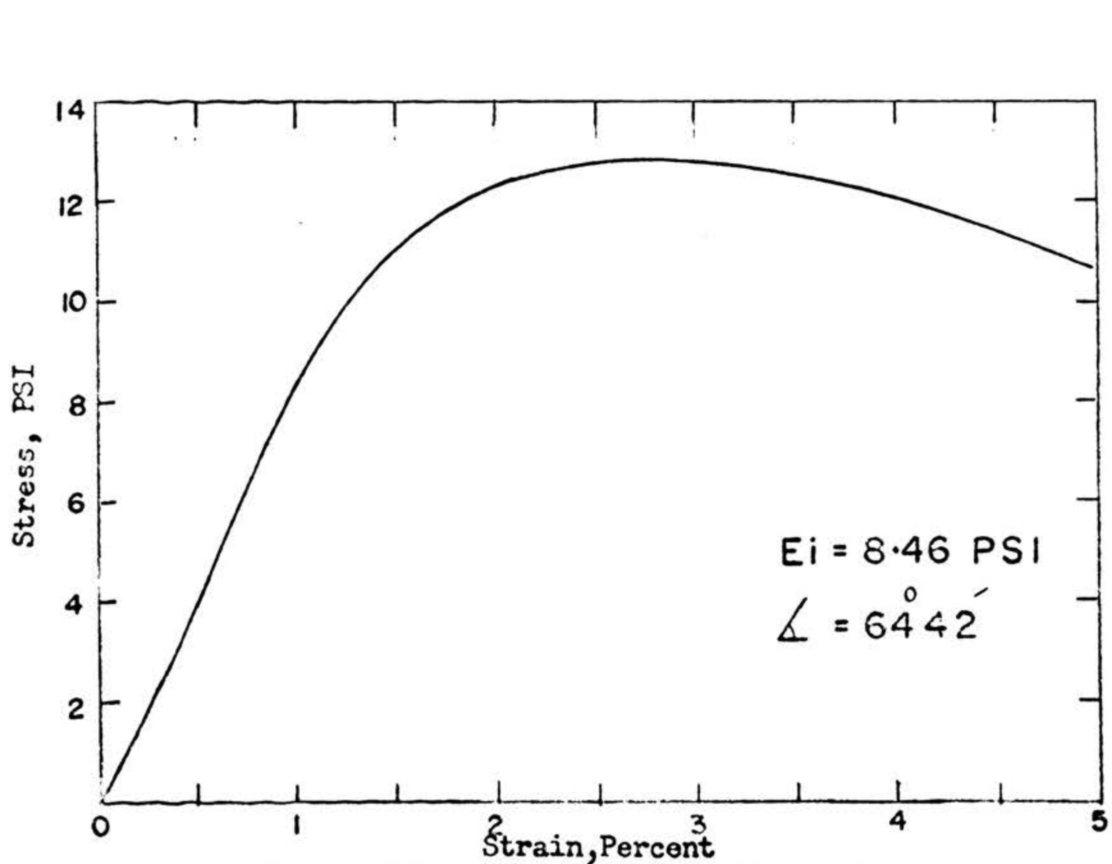


Figure 13b. Average Stress-Strain Curve

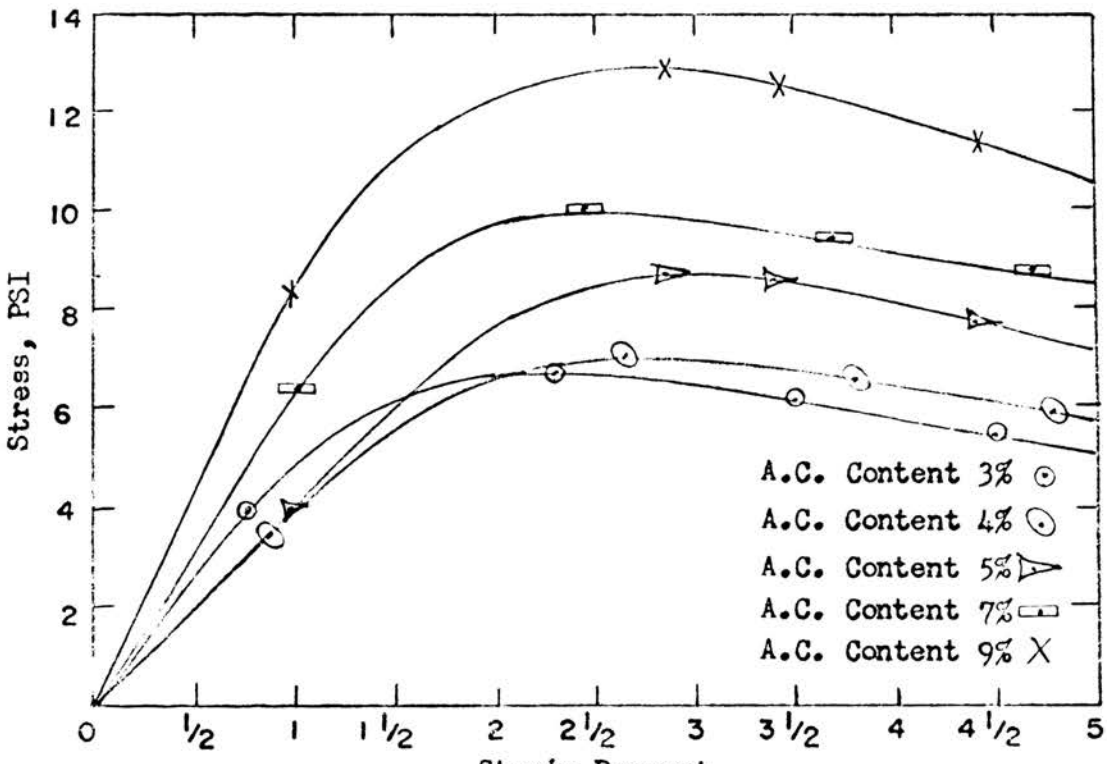


Figure 14. Average Stress-Strain Curves for Group B Mixtures

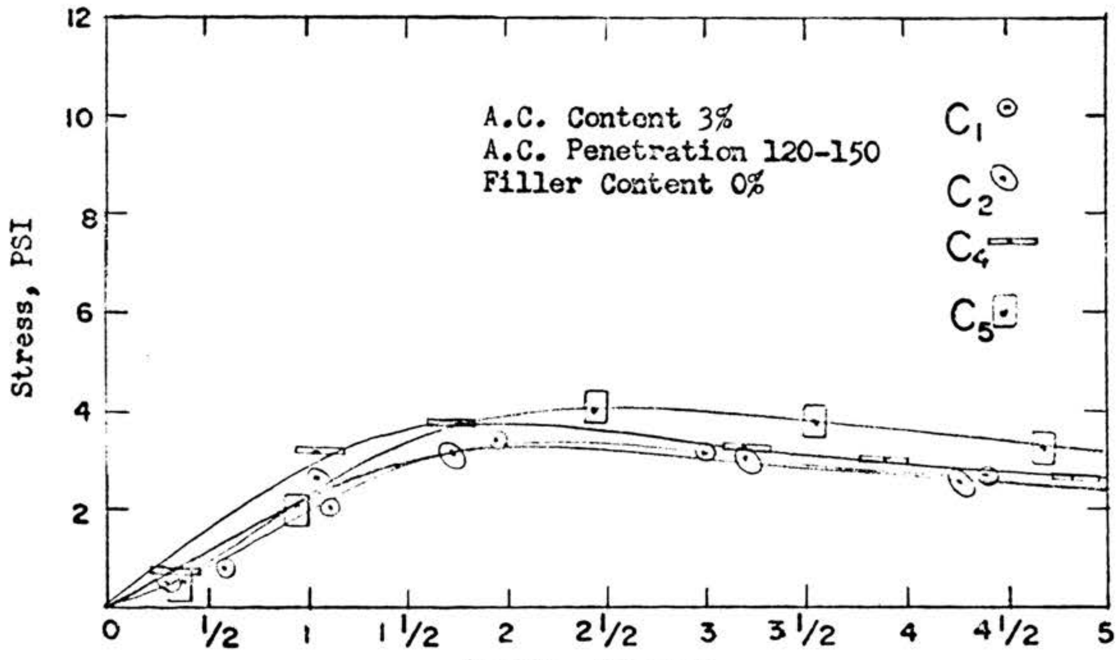


Figure 15a. Stress-Strain Relationships

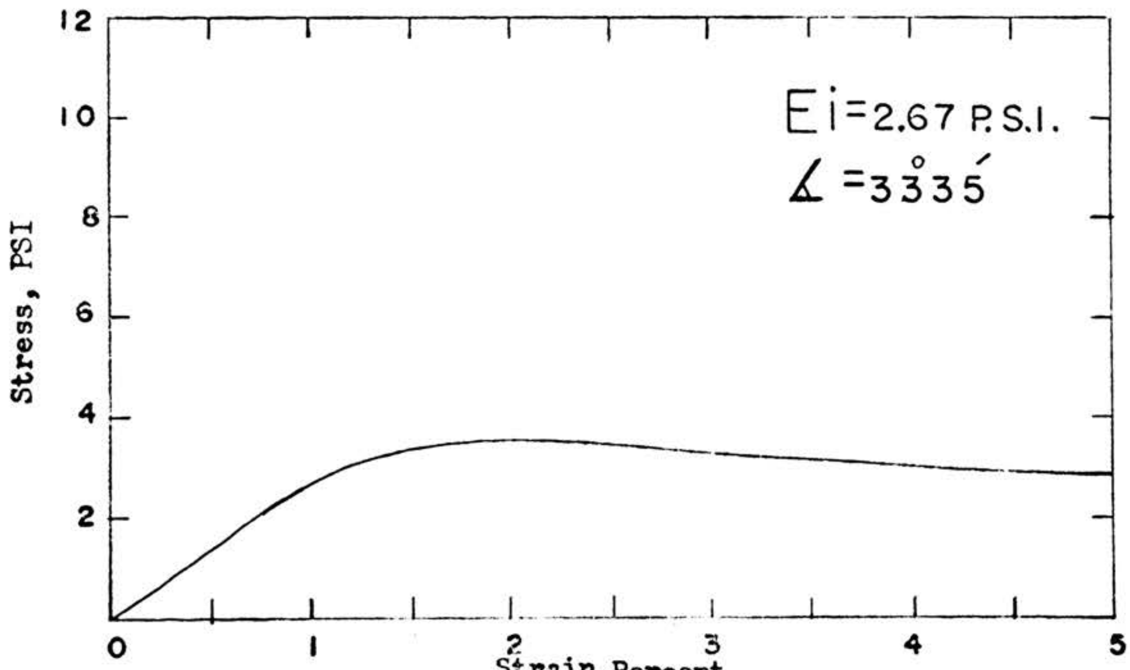


Figure 15b. Average Stress-Strain Curve

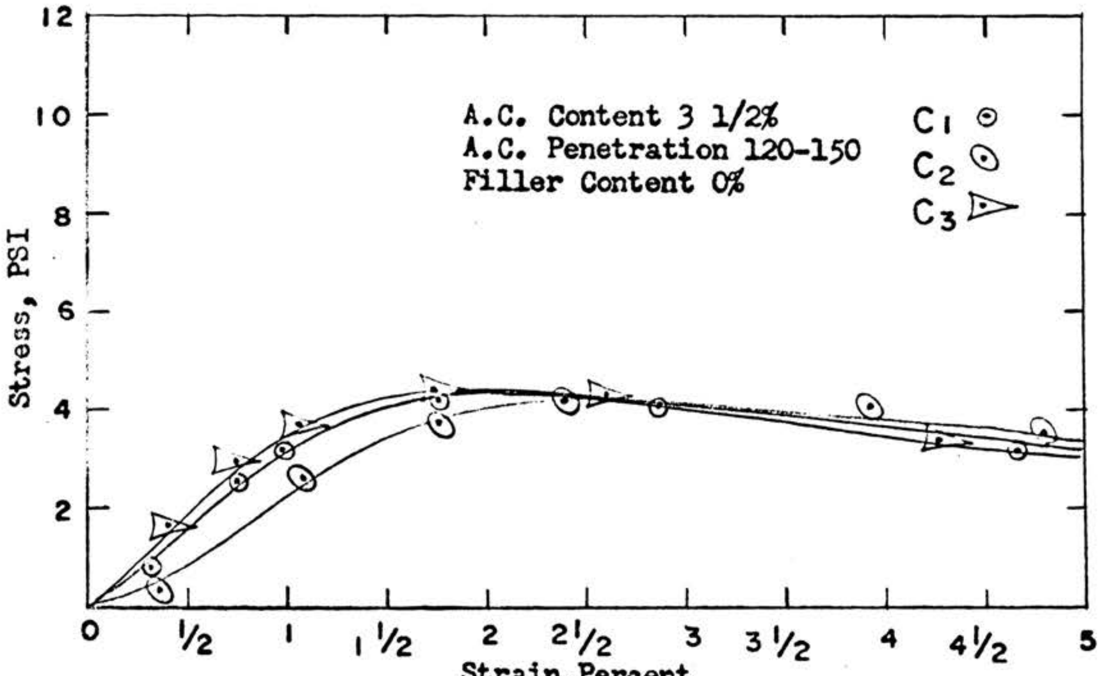


Figure 16a. Stress-Strain Relationship

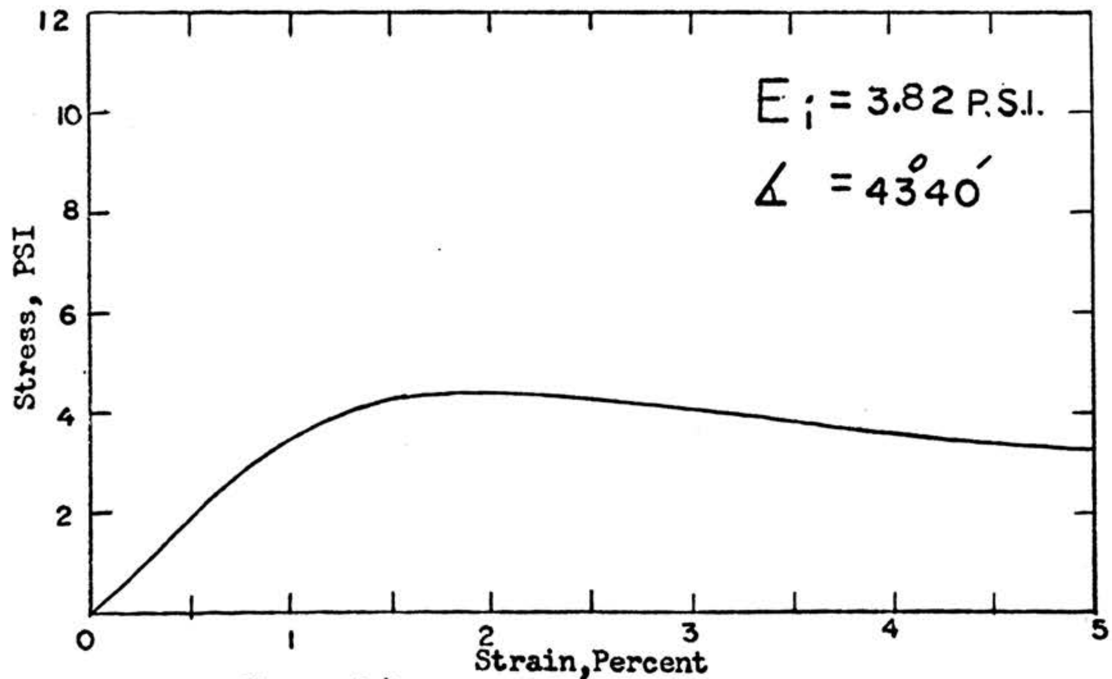


Figure 16b. Average Stress-Strain Curve

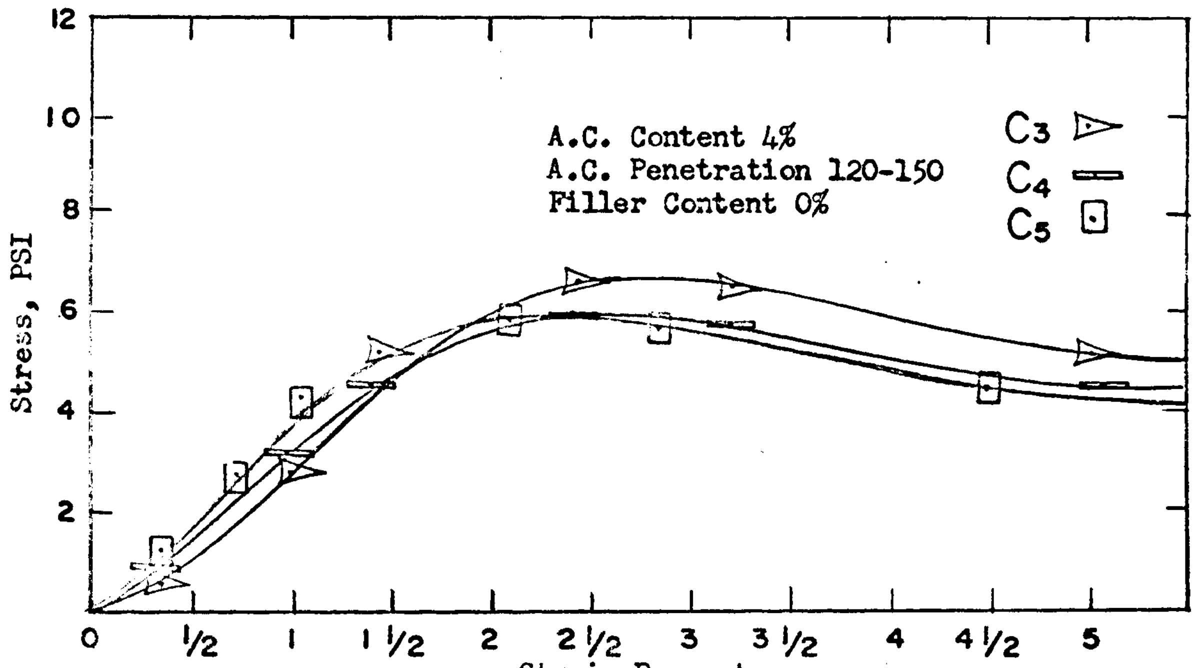


Figure 17a. Stress-Strain Relationships

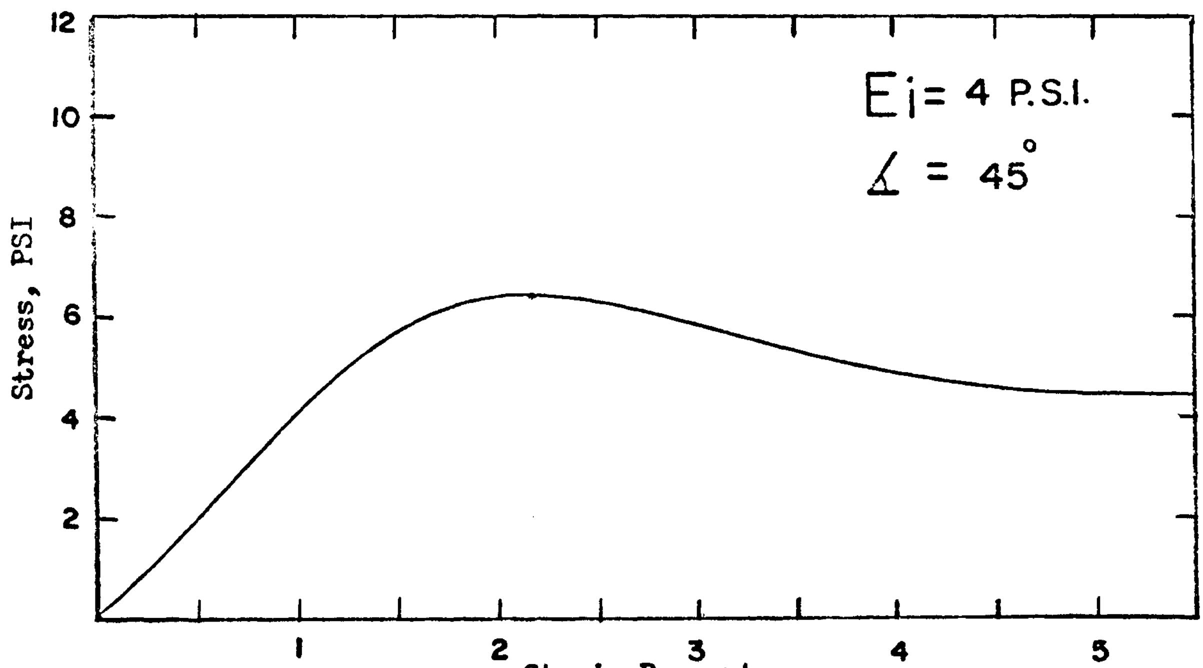


Figure 17b. Average Stress-Strain Curve

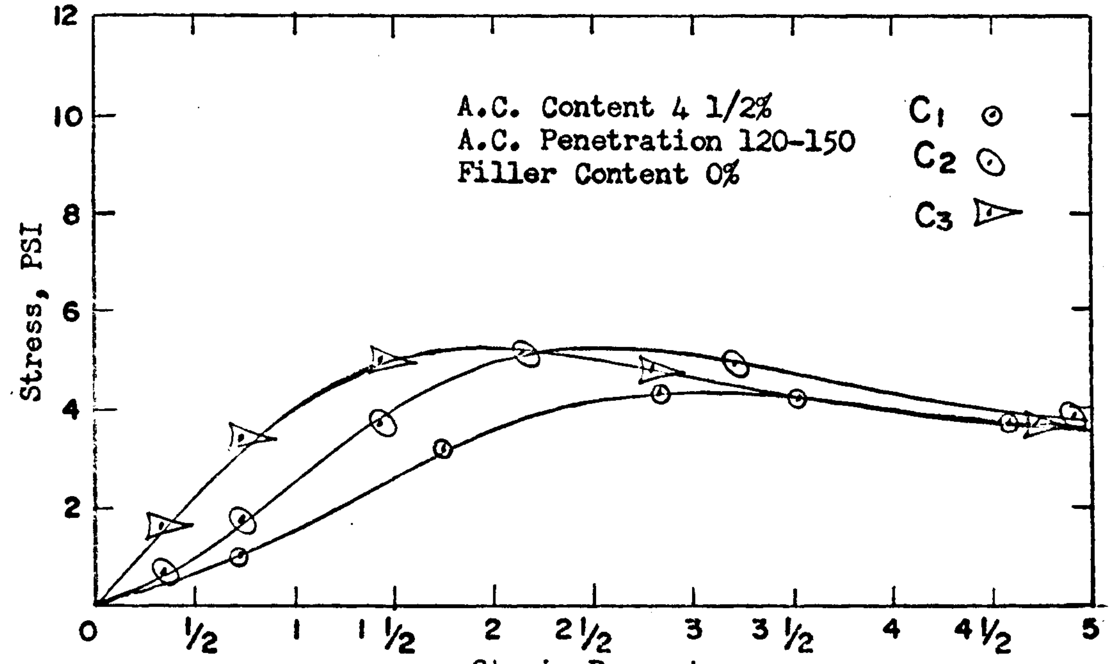


Figure 18a. Stress-Strain Relationship

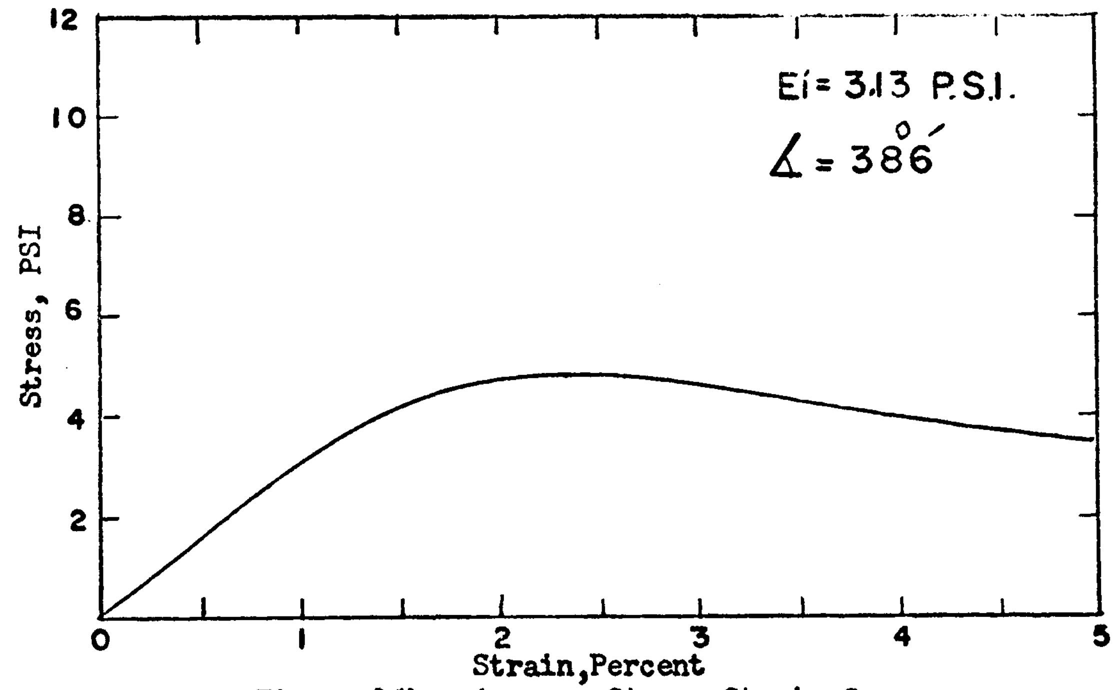


Figure 18b. Average Stress-Strain Curve

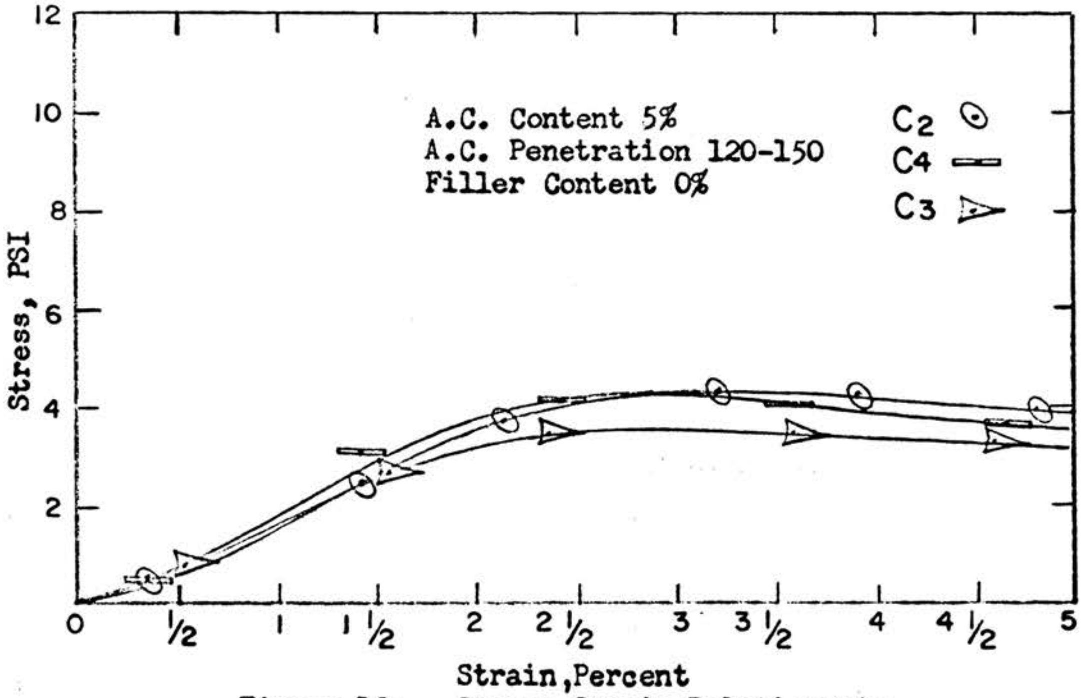


Figure 19a. Stress-Strain Relationship

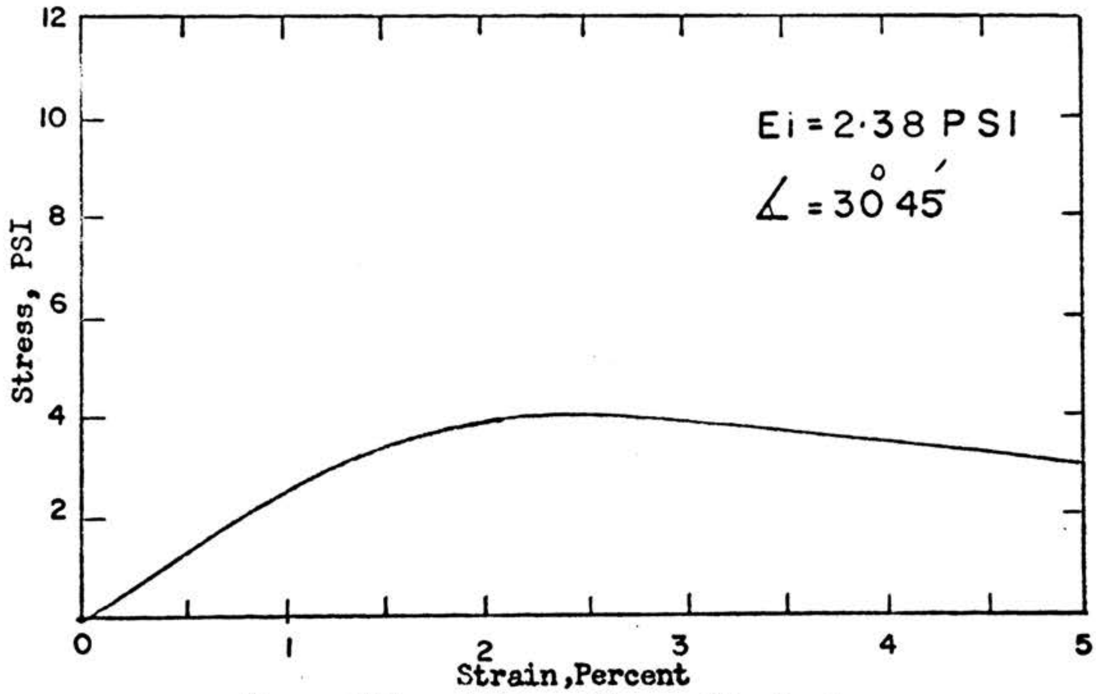


Figure 19b. Average Stress-Strain Curve

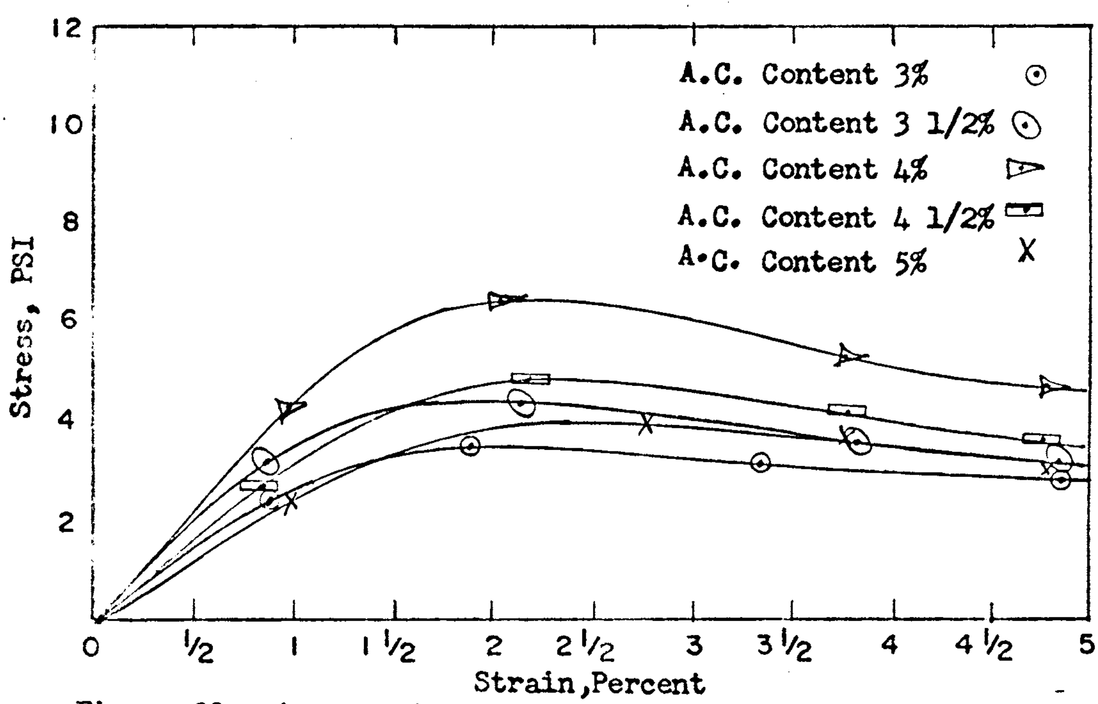
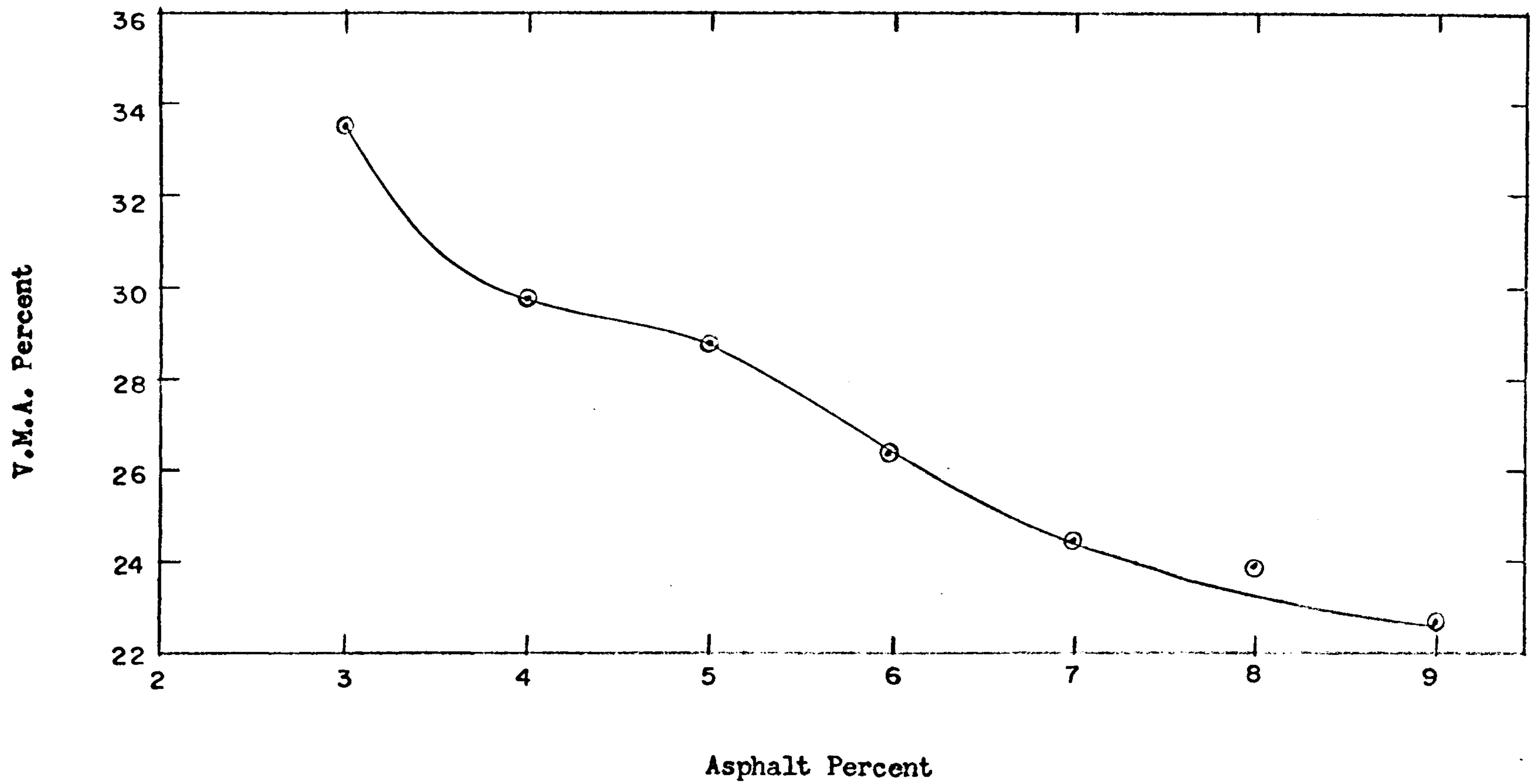
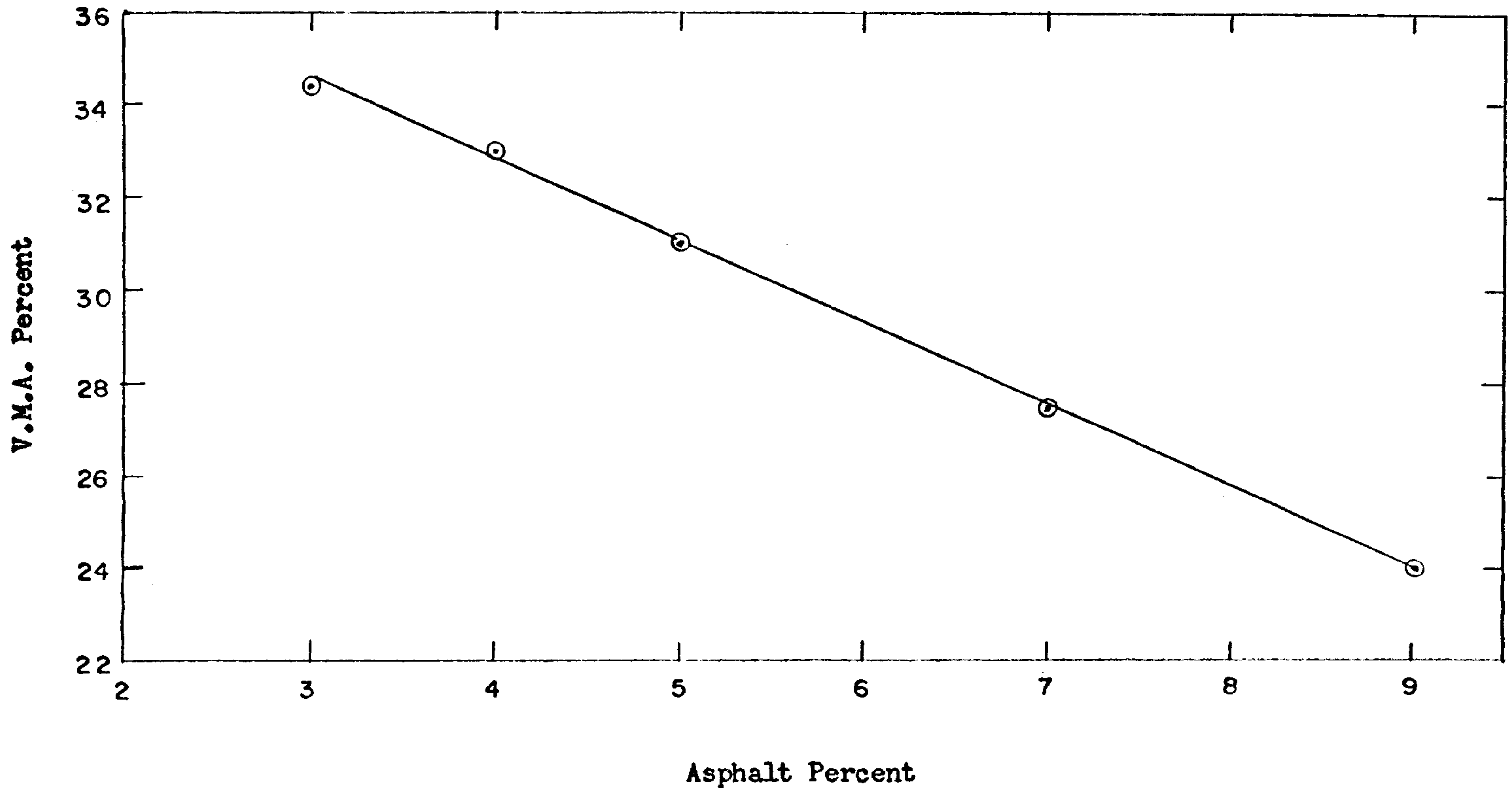


Figure 20. Average Stress-Strain Curves For Group C Mixtures



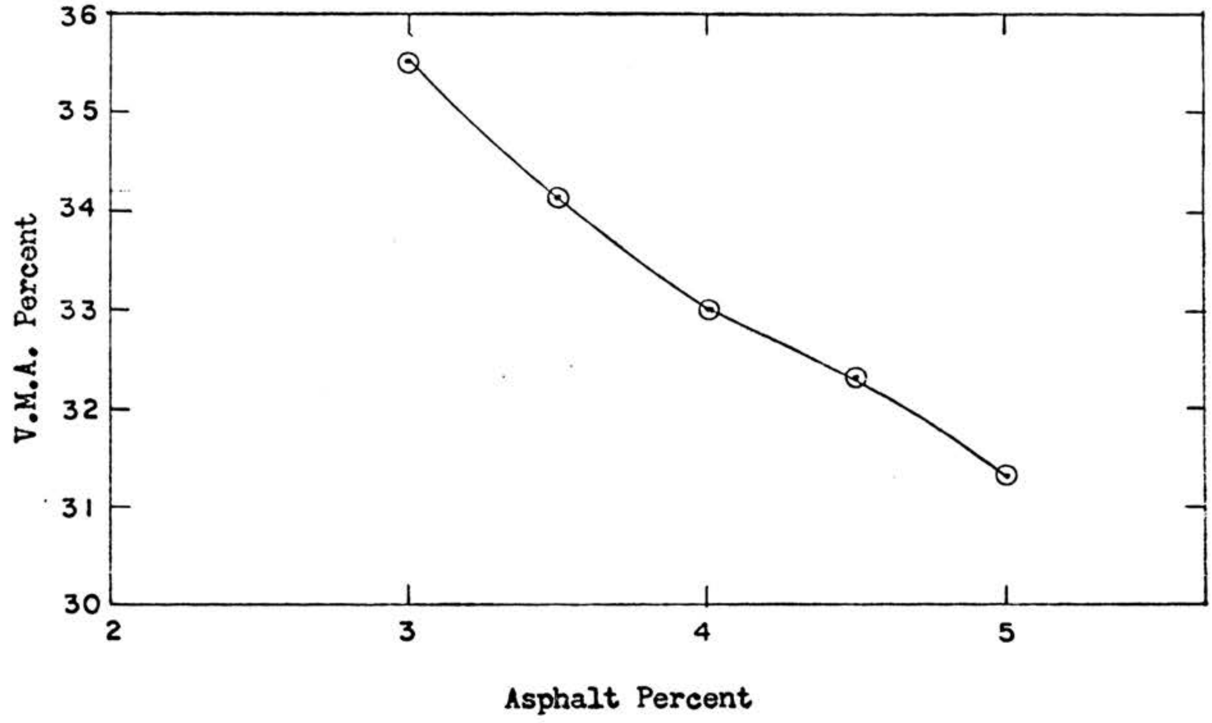
Group A Mixtures

Figure 21. V.M.A.-Asphalt Percent Relationship



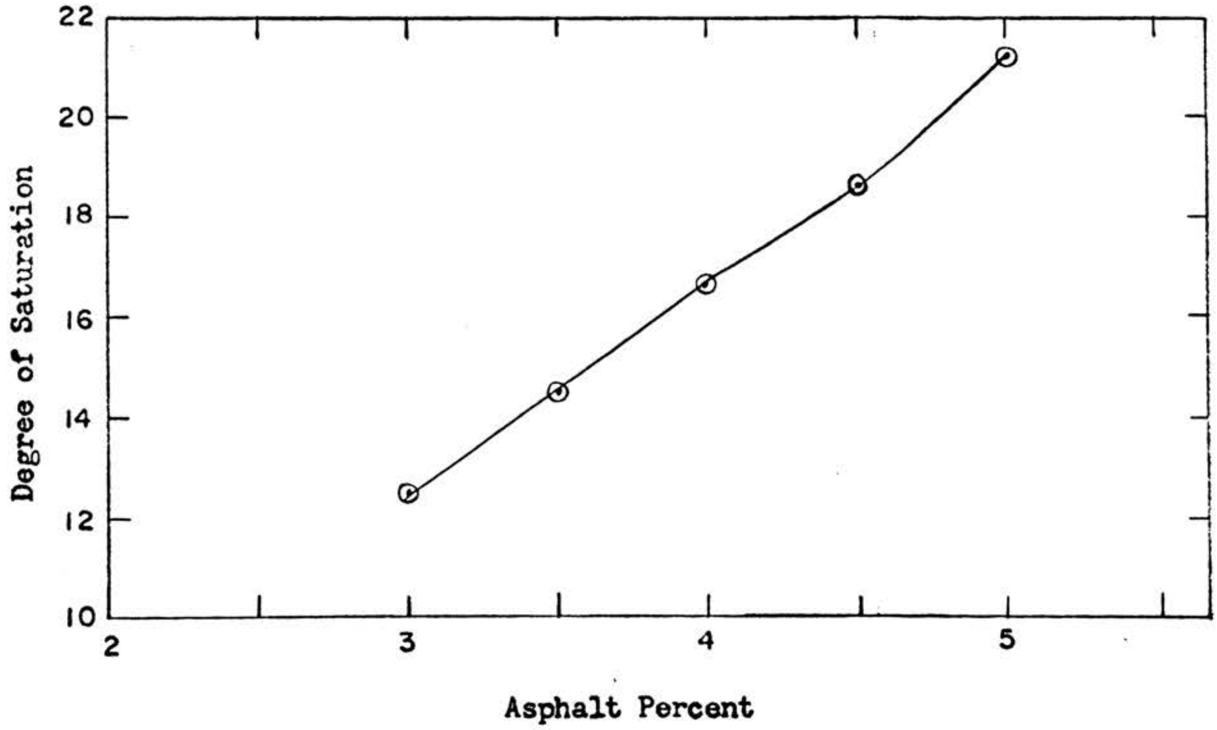
Group B Mixtures

Figure 22. V.M.A.-Asphalt Percent Relationships



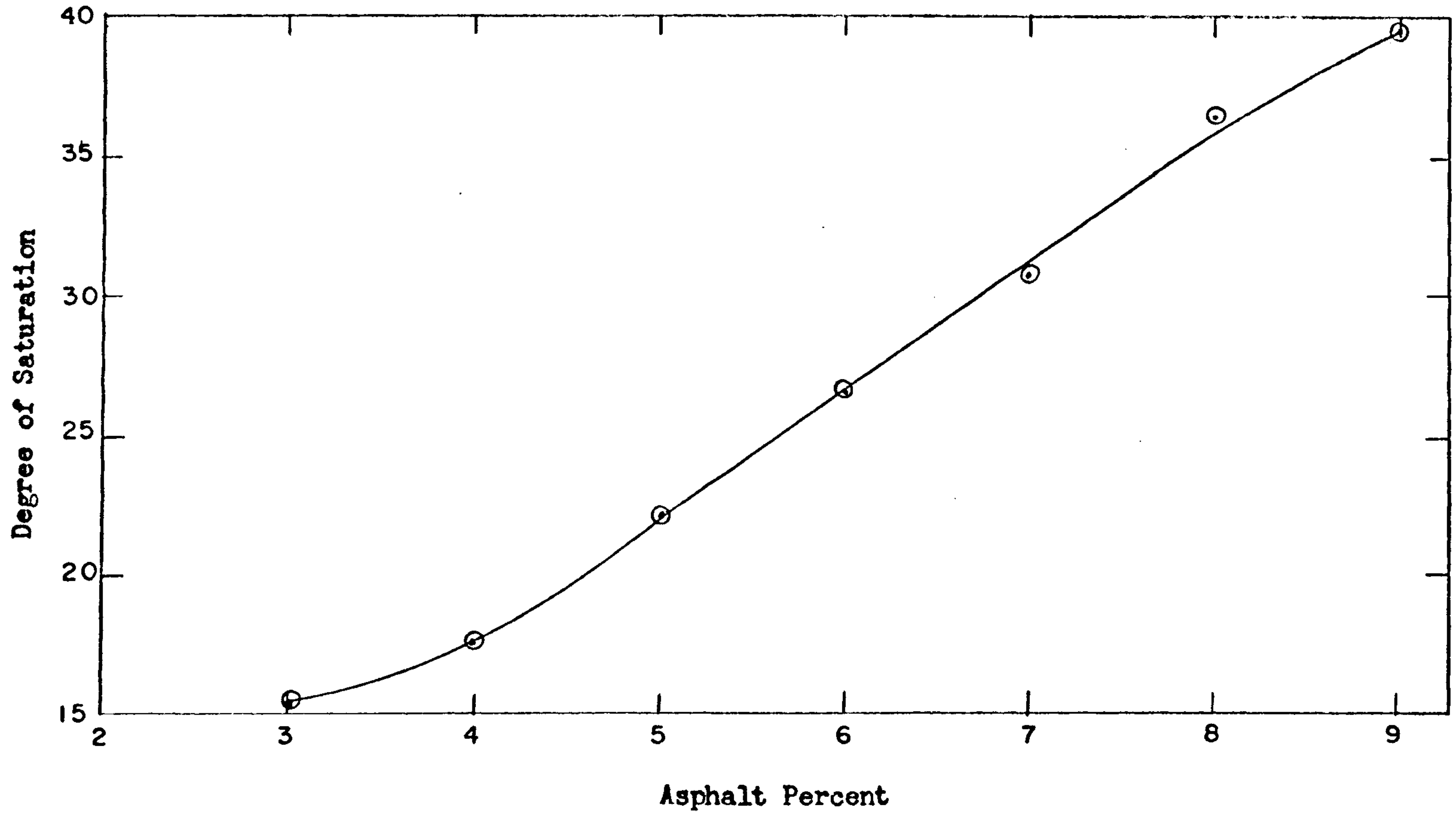
Group C Mixtures

Figure 23. V.M.A.-Asphalt Percent Relationships



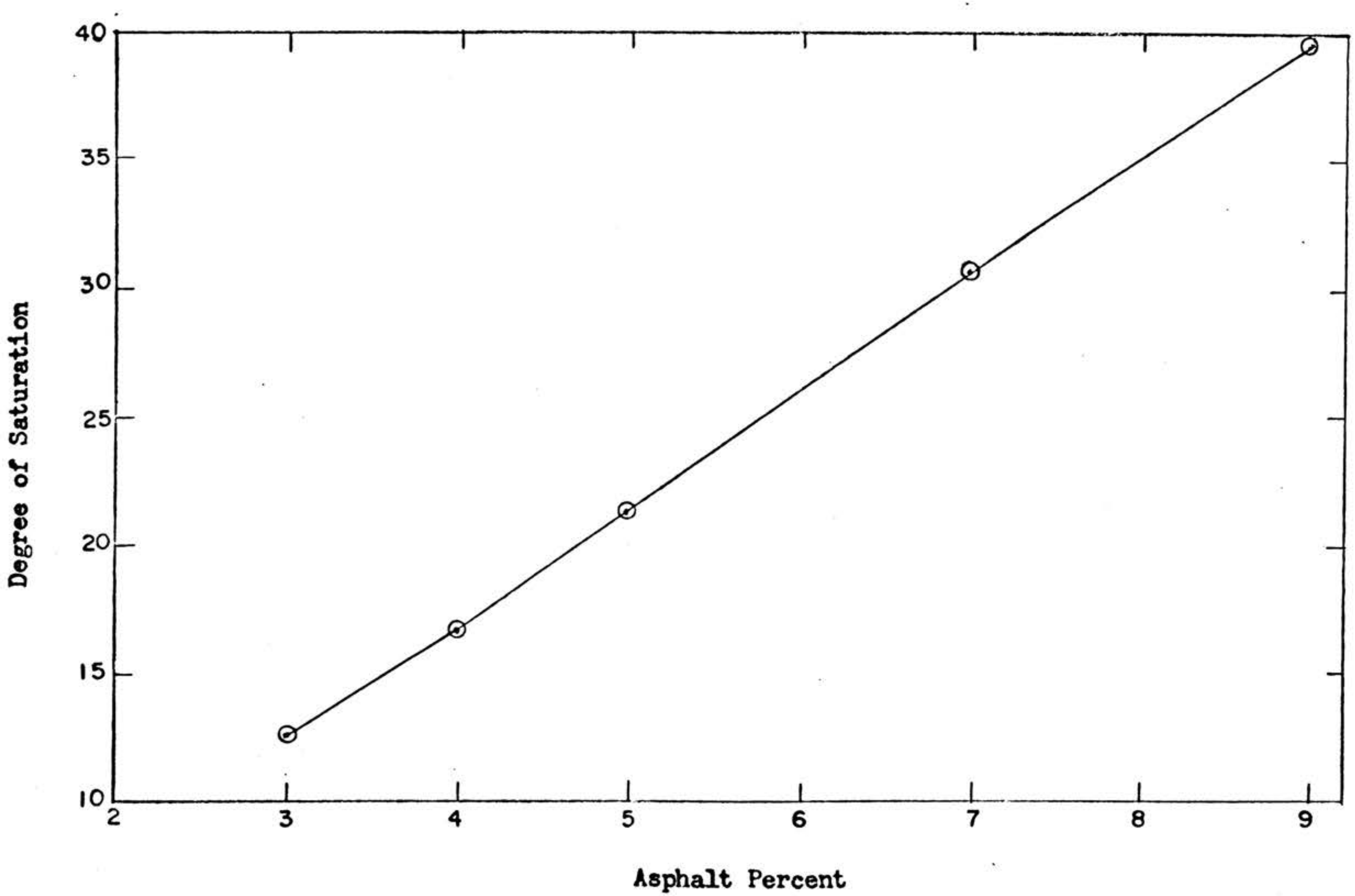
Group C Mixtures

Figure 24. Saturation-Asphalt, Percent Relationships



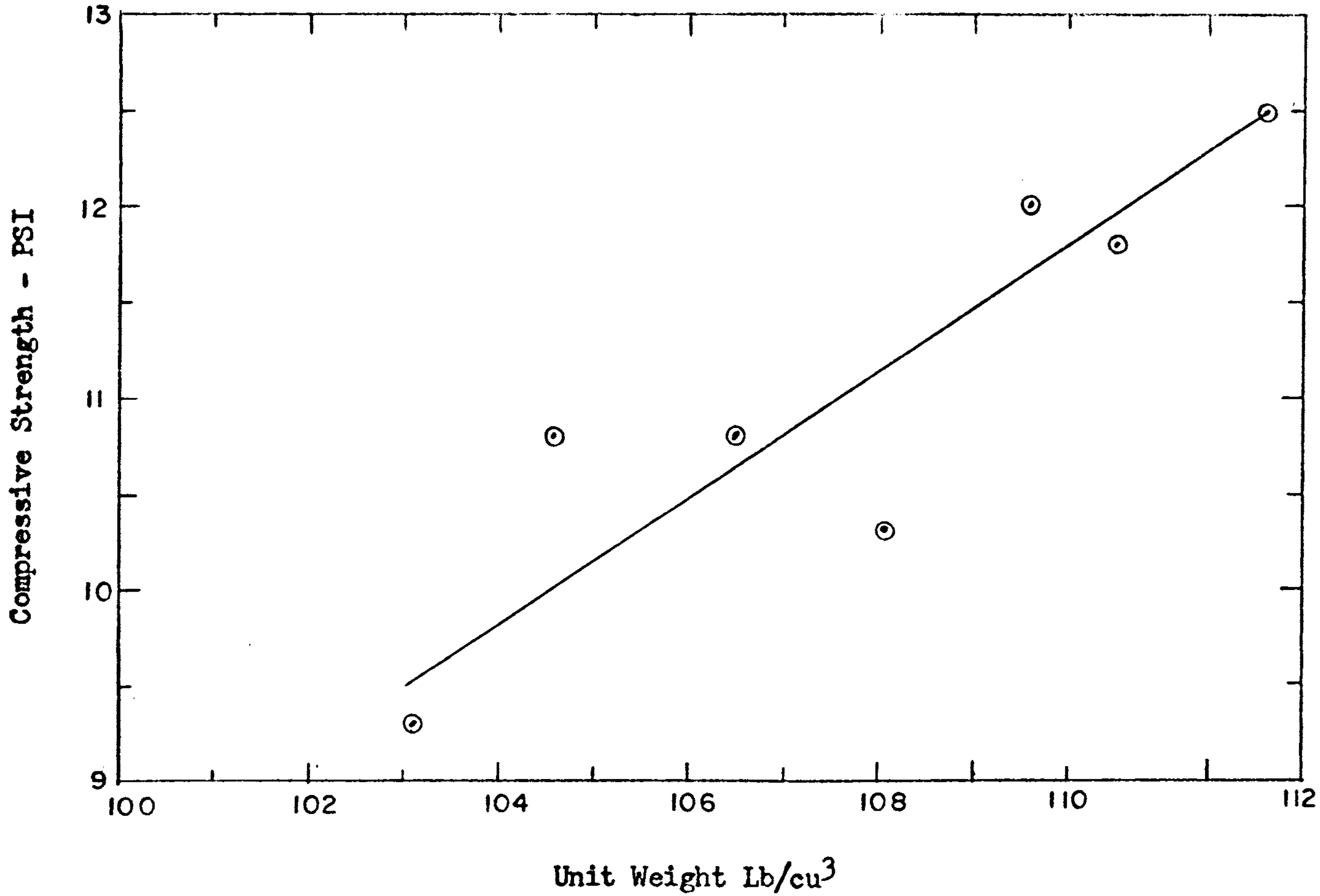
Group A Mixtures

Figure 25. Degree of Saturation-Asphalt Percent Relationships



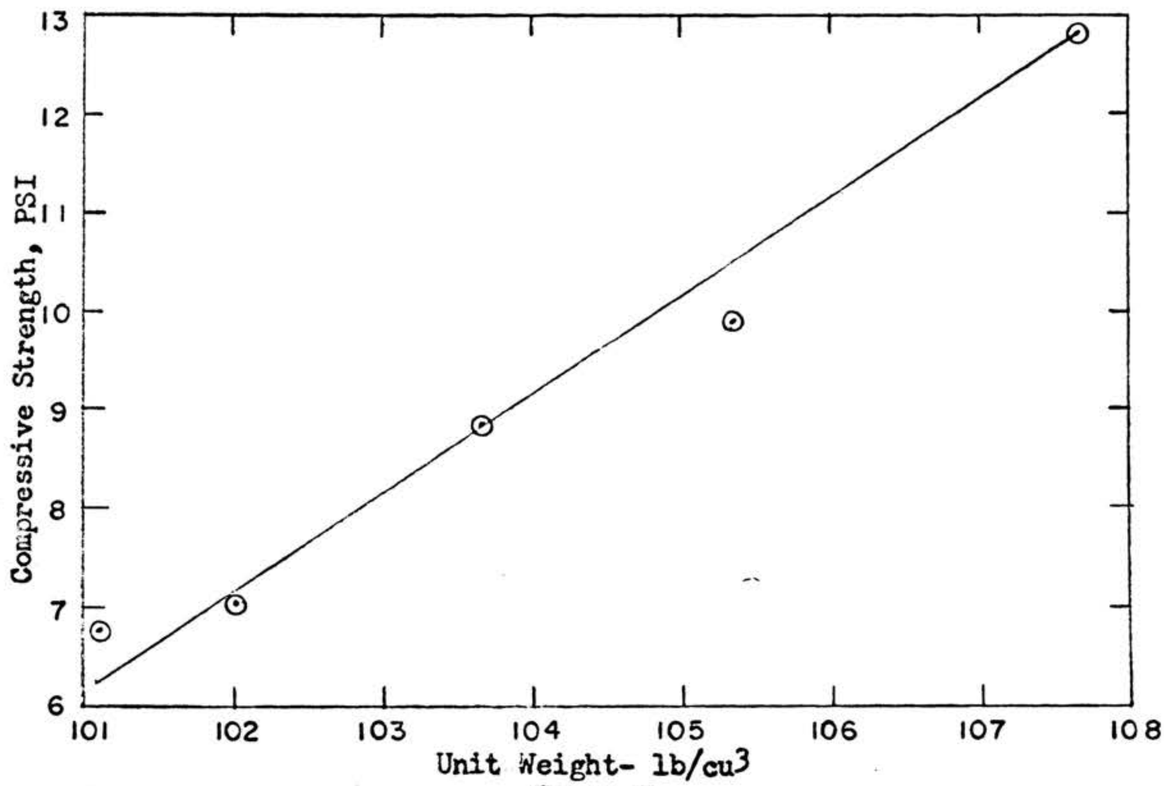
Group B Mixtures

Figure 26. Degree of Saturation-Asphalt Percent Relationships



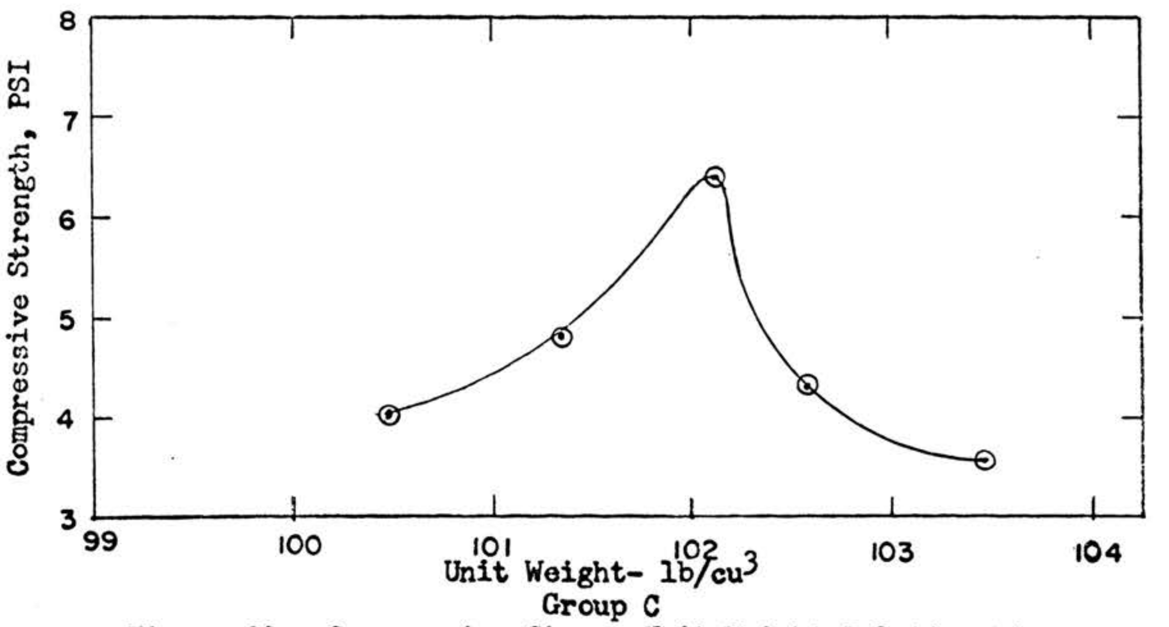
Group A Mixtures

Figure 27. Compressive Stress - Unit Weight Relationships



Group B

Figure 28. Compressive Stress-Unit Weight Relationships



Group C

Figure 29. Compressive Stress-Unit Weight Relationships

APPENDIX II

Tabulation of Data

Table 2. Weight of Specimens

Specimens Consisting of Sand + Asphalt with 85-100 Penetration + 5% Filler

No. of Specimens	Wt. in gms. With 3% Asphalt	Wt. in gms With 4% Asphalt	Wt. in gms. With 5% Asphalt	Wt. in gms. With 6% Asphalt	Wt. in gms. With 7% Asphalt	Wt. in gms. With 8% Asphalt	Wt. in gms. With 9% Asphalt
1	103.16	104.87	106.72	108.00	110.19	110.71	112.66
2	102.88	104.67	107.27	108.05	109.50	109.66	112.35
3	103.48	104.26	106.11	107.87	110.67	110.95	112.95
4	102.80	104.57	106.21	107.72	108.81	110.70	112.18
5	103.16	104.57	106.25	108.72	109.03	110.54	110.34
Av. Wt. in gms.	103.10	104.59	106.51	108.07	109.64	110.51	112.10

Table 2

(Continued)

Specimens Consisting of Sand + Asphalt with 85-100 Penetration

No. of Specimens	Wt. in gms. With 3% Asphalt	Wt. in gms. With 4% Asphalt	Wt. in gms. With 5% Asphalt	Wt. in gms. With 7% Asphalt	Wt. in gms. With 9% Asphalt
1	101.75	101.43	103.48	105.61	107.55
2	101.93	101.95	103.48	105.00	107.93
3	101.60	102.00	102.93	105.53	106.87
4	101.94	102.40	103.63	105.00	108.34
5	101.80	102.12	105.26	105.63	107.72
Av. wt. in gms.	101.80	101.98	103.76	105.35	107.68

Table 2

(Continued)

Specimens Consisting of Sand + Asphalt with 120-150 Penetration

No. of Specimens	Wt. in gms. With 3% Asphalt	Wt. in gms. With 3 1/2% Asphalt	Wt. in gms. With 4% Asphalt	Wt. in gms. With 4 1/2% Asphalt	Wt. in gms. With 5% Asphalt
1	99.74	101.33	102.47	102.87	103.29
2	100.53	102.00	102.38	102.00	103.26
3	100.30	101.10	102.15	102.20	103.65
4	101.15	100.70	101.83	102.88	103.61
5	100.74	101.63	101.63	102.83	103.51
Av. Wt. in gms.	100.49	101.35	102.15	102.56	103.46

Table 4

Relationship Between Weights, Percentages of Asphalt and Maximum Stress in PSI

Specimens Consisting of Sand + Asphalt 85-100 Penetration + 5% Filler			Specimens Consisting of Sand + Asphalt 85-100 Penetration			Specimens Consisting of Sand + Asphalt 120-150 Penetration		
% Asphalt	Weight in gms	Compressive Strength in PSI	% Asphalt	Weight in gms	Compressive Strength in PSI	% Asphalt	Weight in gms	Compressive Strength in PSI
3	103.10	9.30	3	101.80	6.75	3	100.49	4.00
4	104.59	10.80	4	101.98	7.00	3 1/2	101.35	4.80
5	106.51	10.80	5	103.98	8.80	4	102.15	6.40
6	108.07	10.30	-	------	----	4 1/2	102.56	4.30
7	109.64	12.00	7	105.35	9.90	5	103.46	3.55
8	110.51	11.80	-	------	----			
9	112.10	12.50	9	107.68	12.80			

APPENDIX III

Sample Calculations

Table 3

Sample Calculations For Specimens Containing Sand + 6% 85-100 Penetration Asphalt + 5% Filler

		STRAIN			STRESS	
No. of Specimens	Deformation In inches	Strain Per.	The Final Area (in^2)	Load-Dial Reading	Load in Pounds	Stress In PSI
1	0.010	0.356	1.355	2.1	1.57	1.157
	0.035	1.242	1.368	8	6.00	4.380
	0.055	1.955	1.378	14.5	10.90	7.920
	0.075	2.670	1.388	16	12.00	8.620
	0.095	3.380	1.399	16.8	12.60	9.010
	0.115	4.080	1.409	16.6	12.45	8.840
	0.125	4.440	1.413	16.2	12.10	8.560
2	0.010	0.356	1.355	2.1	1.58	1.165
	0.025	0.890	1.362	6.1	4.57	2.350
	0.055	1.955	1.378	15.0	11.25	8.180
	0.075	2.670	1.388	16.9	12.70	9.160
	0.095	3.380	1.399	17.1	12.80	9.160
	0.105	3.730	1.403	17.1	12.80	9.130
	0.125	4.440	1.413	16.6	12.45	8.800

Table 3

(Continued)

No of Specimens	Deformation In Inches	STRAIN Strain Per.	The Final Area (in^2)	Load-Dial Reading	STRESS Load in Pounds	Stress in PSI
3	0.010	0.533	1.359	2.9	2.17	1.603
	0.035	1.242	1.368	8.5	6.37	4.630
	0.055	1.955	1.378	15.2	11.40	7.720
	0.075	2.670	1.388	18.3	13.70	9.880
	0.105	3.730	1.403	19.261	14.40	10.260
	0.125	4.440	1.413	19.0	14.25	10.080
	0.135	4.800	1.418	18.7	14.00	9.890
4	0.010	0.356	1.355	1.9	1.42	1.048
	0.030	1.065	1.365	7.5	5.62	4.120
	0.050	1.775	1.375	16.0	12.00	8.730
	0.070	2.430	1.385	18.2	13.65	10.750
	0.090	3.200	1.396	20.9	15.70	11.240
	0.110	3.910	1.405	20.9	15.45	11.200
	0.130	4.620	1.418	20.6	15.45	10.900

Table 3

(Continued)

No of Specimens	STRAIN Deformation In Inches	Strain Per.	The Final Area (in^2)	STRESS Load-Dial Reading	Load In Pounds	Stress In PSI
5	0.010	0.356	1.355	1.8	1.35	0.996
	0.030	1.065	1.365	6.5	4.87	3.560
	0.050	1.775	1.375	14.0	10.50	7.640
	0.070	2.430	1.385	18.5	13.90	10.030
	0.100	3.560	1.400	20.1	15.75	11.240
	0.120	4.270	1.410	20.0	15	10.640
	0.130	4.620	1.418	19.9	14.92	10.530

Table 5

Sample of Calculations

V.M.A. and Degree of Saturation

5% Asphalt Content - Without Filler

Sand specific gravity = 2.68

Asphalt specific gravity = 1.02

Asphalt content total weight = 5%

Average weight of the mix in the specimen = 103.76 gms.

The volume of the mold = 60.6 cm^3.

Asphalt by weight in the specimen = 103.76 x 0.05 = 5.18 gms.

Sand by weight in the specimen = 103.76 x 0.95 = 98.5 gms.

Asphalt by volume in the specimen = $\frac{5.18}{1.02}$ = 5.08 cm^3.

Sand by volume in the specimen = $\frac{98.5}{2.68}$ = 36.75 cm^3.

Volume of sand + Asphalt = 36.75 + 5.08 = 41.83 cm^3.

Volume of voids = 60.5 - 41.83 = 18.77 cm^3.

$$\text{V.M.A.} = \frac{18.77}{60.60} \times 100 = 31\%$$

Total volume of voids = 60.60 - 36.75 = 23.85

$$\text{Degree of saturation} = \frac{\text{Volume of asphalt} \times 100}{\text{Total volume of voids}}$$

$$= \frac{5.08 \times 100}{23.85} = 21.3\%$$

IV. DISCUSSION

A. General

As mentioned previously the variables in this investigation are asphalt content, type of asphalt cement and mineral filler. Prior to discussing the effects of the variables on the ability to predict the physical properties of a mix, it is desirable to evaluate the role of each of these variables in the sand bituminous mix.

The asphalt cement performs a dual role by acting as a cementing agent, thereby increasing the cohesive properties of the mix, and as filler by partially filling the voids in the mineral aggregate. The mineral filler frequently performs a dual role, but the effect is somewhat less obvious. Filler particles increase the number of interparticle contacts thereby increasing the internal friction and some of the finer particles of mineral filler are in suspension in the asphalt cement and they either coat the larger particles or have an apprciable effect on the apparent viscosity of the asphalt. (8)

The results of this study indicate that there is a direct relationship between the physical properties of a design asphalt mixture and the type and quantity of the asphalt. They also indicate the effects of the filler on the properties of sand-asphalt mixture. These relationships are shown in Figure 8, 14, 20, 21, 22, and 23. The numerical data for these relationships are summarized in Tables 2 and 4.

B. The Effect of Asphalt

A continuous increase occurs in the compressive strength as a result of increasing the percentage of asphalt (85-100 penetration) in the mixture. This is due to the action of the asphalt as a filler and to the high viscosity of this type of asphalt.

Asphalt with a 120-150 penetration causes an increase in compressive strength for up to four percent asphalt added. An appreciable decrease in strength was found for the 4 1/2% and the 5% asphalt in the mixture. For the three different percentages of asphalt (3%, 3 1/2, and 4%) the asphalt acted as a binder and coater to the particles of the sand. It gave the mixture cohesiveness and strength, and it filled portions of the voids between the particles. But, with an increase in the percentage of this asphalt to 4 1/2 and 5 percent the low viscosity of this type of asphalt causes a lowering of the compressive strength. The changes in strength that occur with varying asphalt content appear to be a function of the thickness of the film that coats the particles. As the film thickness increases the relatively low viscosity of the asphalt makes it easier for the sand particles to move with respect to each other and as a result the strength of the mix approaches a lower limiting value which is the viscosity of the asphalt cement.

C. The Effect of Filler

Both the compressive stress and the unit weight of the mixture are increased due to the dual action of the filler. The filler increases contact between the particles of the sand and this results in more shearing resistance. Also, due to a filling of the voids the unit weight is increased. The void ratio decreased due to the use of filler in the mixture. The effect of filler has been demonstrated in this investigation by comparing two different groups of mixtures, one with filler and the other without it. The one to which filler was added yielded higher compressive strengths and higher unit weights.

D. Stress-Strain Relationship

1. Group A Mixtures:

This group of mixtures consisted of 85-100 penetration asphalt added in seven different percentages (3% through 9%) to a mixture of sand containing 5 percent filler material.

In Figure 1 through 8, it is shown that by increasing the asphalt percent in the mixture, a higher maximum stress was achieved and the maximum strain before failure increased simultaneously with the increase in stress. The increase in the maximum stress was rather small for mixtures having asphalt contents ranging from seven to nine percent. The maximum stresses for the mixtures containing 4%, 5% and 6% asphalt were very close to each other too, as shown in Figure 8.

The E_i (Young's Modules) for this group did not change directly with the stress-strain relationship. The highest E_i value in this group was for the mixture which contained 3% asphalt.

2. Group B Mixtures:

This group of mixtures consisted of 85-100 penetration asphalt added to sand without filler in five different percentages (3, 4, 5, and 9). The increase in the percent of asphalt added was always accompanied by an increase in the maximum stress and maximum strain before failure as shown in Figure 9 through 14.

The (E_i) was increased simultaneously with the increase in the percent of asphalt from 4% through 9%.

3. Group C Mixtures:

This group consisted of asphalt having a 120-150 penetration range added to the sand in five different percents (3, 3 1/2, 4, 4 1/2, and 5). The maximum stress was increased by increasing the percent of of asphalt added, up to the 4% where it began to decrease with an increase in asphalt content. The relationships are shown in Figure 15 through 20. The strain corresponding to the maximum stress was increased or decreased according to the increase or decrease in maximum stress.

The (E_i) of this group was higher for the mixture which yielded higher maximum stress and lower for the one which yielded lower maximum stress.

E. Relationship Between Asphalt Content and Unit Weight

The unit weight of the mixture in each of thes groups was increased with an increase in the percent of asphalt added (see Table 4). This is because the asphalt acted as a filler for a portion of the voids in the mixture. Figures 21 through 23 indicate that by increasing the percent of asphalt, the V.M.A. (the voids in mineral aggregate) were decreased continuously. By increasing the percent of asphalt added to the mixture, the degree of saturation for the voids was increased as shown in Figure 24 through 26.

F. Unit Weight - Compressive Strength Relationship

The unit weight - compressive strength relationship followed the same trends as the relationship between percentage of asphalt and stress. This is shown in Table 4 and Figures 27 through 29. For the mixes of both groups A and B there was a general increase in the compressive strength when the unit weight of the mixture was increased. For group C the unit weight-strength relationship was non-linear as indicated in Figure 29.

G. Evaluation of Results

1. Group A:

For this group the maximum stress-strain, and unit weight were increased simultaneously with the increased percent of asphalt added, and the V.M.A. decreased at the same time. This resulted from the asphalt working as an adhesive material and binding the sand particles together and providing more cohesiveness to the mix. Also, the asphalt acted as a filler for a portion of the voids, this was especially true in mixtures where a rather high percent of asphalt was used. This conclusion is supported by the curves shown in both Figures 21 and 25. In Figure 21, the curve which shows the V.M.A. and asphalt content relationship started taking a straight line shape between the 5% and 7% asphalt contained. The degree of saturation and asphalt contained followed a straight line relationship above the 5% asphalt contained as shown in Figure 25. Because of the high V.M.A. of the mixture in this investigation, the straight line of the curves in the previous two figures indicated that the asphalt contained in excess of 5% had been acting as filler. From this, it can be concluded that in a mixture in which the V.M.A. is low, a condition which could be brought about by increasing the compaction effort and using well graded sand, the asphalt in excess of 5% will not be needed. By referring to Figure 8, it can be seen that no increase in maximum stress resulted when the percentage of asphalt was increased from 4 to 5. From the previous results and discussion, the 4% asphalt content could be considered as the optimum percentage of asphalt used in this group if the V.M.A. is kept within the desirable limits.

2. Group B:

In this group of mixtures, the maximum stress, the maximum strain at failure, and the unit weight were increased by increasing the asphalt content. The V.M.A. was decreased by increasing the percent of asphalt added. The asphalt functioned the same way as it did for group A. Figure 22 shows the relationship between V.M.A. was linear for the range of asphalt contents used. This supports the previous assumption that the asphalt has functioned as a filler. Further evidence of this fact is indicated by the degree of saturation as shown in Figure 26.

In this group, the maximum stress increased noticeably when the asphalt content was increased from 4% to 5%. The reason for this increase can be related to the absence of filler in this group. The same statement made concerning the desirable percentage of asphalt added to the group A could be made about group B. That is if the V.M.A. were kept low, and within desirable limits, the 4 percent asphalt content appears to be the optimum value.

3. Group C:

For this group, the unit weight and V.M.A. acted the same as in both group A and C. However, the maximum stress and maximum strain at failure increased with asphalt contents up to 4% then it decreased thereafter as shown in Table 4 and Figure 29. Even though the asphalt acted as a filler for a portion of voids, the comparatively low viscosity of asphalt used in this group made it easier for the particles of sand to slide on each other when the asphalt content was increased beyond the optimum value.

For this group the optimum percentage of asphalt is in the order of 4% as shown in both Figures 20 and 29.

CONCLUSIONS

On the basis of the data accumulated during the experiments and the analysis thereof, certain trends for the behavior of sand-asphalt mixtures have been mentioned which lead to the following tentative conclusions.

1. Filler has a definite beneficial effect on the physical properties of sand-asphalt mixes. The use of 5% filler in the mixtures increased the unit weight, maximum stress, and decreased the VMA.

2. A continuous increase in the maximum compressive stress resulted from an increase in the percentage of 85-100 penetration asphalt used in a mix. In the case of 120-150 penetration asphalt the increase in the compressive stress continued with increasing the percentage of asphalt to 4% decreased thereafter.

3. The unit weight of the mixture in each of the three groups was increased with an increase in the percent asphalt added.

4. At asphalt contents above 5%, a portion of the asphalt acted as a filler for part of the total void volume.

5. There appears to be no direct relation between unconfined compressive stress and the Youngs Modulus of the mixes of group A.

6. In general for the groups B and C, the maximum compressive stress increased and decreased successively by the increase or decrease in the Youngs Modulus of the materials of that group.

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VITA

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