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16. Abstract

The economic pressure from higher fuel, asphalt, and aggregate costs, along with the growing use of milling equipment for pavement removal, have resulted in an abundance of salvaged roadway materials for recycling. Material availability has led to the consideration of using these salvaged roadway materials on low-volume roads. The laboratory study reported in this report evaluated the feasibility of using foamed asphalt to recycle asphalt pavements.

The study involved an initial evaluation of the foamed process using two field sands. Upon determining that satisfactory mixtures could be prepared, two additional series of tests were conducted using salvaged pavement materials mixed with a foamed AC-5, an MC-800 cutback, and two emulsions (EA-11M and AES-300). Specimens were prepared, cured, and then tested under both dry and wet conditions.

The wet strengths were less than approximately one half the dry strengths but in almost all cases the foamed AC-5 produced strength values equal to or greater than those produced using a cutback or emulsion. In addition, the asphalt content for the foamed asphalt specimens was lower than for the cutback or emulsions. Overall, the foamed asphalt materials appear to offer a possible option for use in cold recycled asphalt mixtures for bases and paved shoulders.

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USE OF FOAMED ASPHALT IN COLD, RECYCLED MIXTURES

by

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Research Report Number 252-3

Design and Characterization of Recycled Pavement Mixtures

Research Project 3-9-79-252

conducted for

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State Department of Highways and Public Transportation

in cooperation with the
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Federal Highway Administration

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The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration and the Texas Department of Highways and Public Transportation. This report does not constitute a standard, specification, or regulation.

PREFACE

This is the third in a series of reports dealing with the design and characterization of recycled pavement materials. A laboratory study was conducted to evaluate the feasibility of using foamed asphalt to recycle asphalt mixtures and to compare the properties of foamed mixtures with those of conventional cold mixtures. Tests were conducted on salvaged pavement materials mixed with a foamed asphalt cement, two emulsions, and a cutback. Specimens were prepared, cured, and then tested under both dry and wet conditions. Properties considered were Hveem stability, tensile strength, static modulus of elasticity, and density.

This report was completed with the assistance of many people. Special appreciation is due to Messrs. James Anagnos, Pat Hardeman, Eugene Betts, and Dr. Freddy L. Roberts for the field and laboratory evaluations that provided the background for this report. Appreciation is expressed to Billy R. Neeley and to District personnel of the Texas State Department of Highways and Public Transportation for their assistance both in the field and in securing specimens and material samples. Appreciation is extended to the Center for Transportation Research staff for their assistance in the preparation of manuscript materials. The support of the Federal Highway Administration, Department of Transportation, is acknowledged.

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September 1985

LIST OF REPORTS

Report No. 252-1, "Mixture Design Procedure for Recycled Asphalt Pavements," by Thomas W. Kennedy, Freddy L. Roberts, and James N. Anagnos, provides an evaluation and mixture design procedure that includes the use of salvaged materials from a road that is to be recycled.

Report No. 252-2, "Guidelines for Design and Construction of Recycled Asphalt Mixtures," by Thomas W. Kennedy, Maghsoud Tahmoressi, and James N. Anagnos, provides detailed design and quality assurance procedures for recycled asphalt mixtures. September 1985.

Report No. 252-3, "Use of Foamed Asphalt in Cold, Recycled Mixtures," by Maghsoud Tahmoressi, Johann C. Engelbrecht, and Thomas W. Kennedy, provides a preliminary evaluation of the foamed process by comparing test results from laboratory specimens prepared with foamed recycled materials with those from conventional cold mixed materials using two emulsions and a cutback asphalt. September 1985.

ABSTRACT

The economic pressure from higher fuel, asphalt, and aggregate costs, along with the growing use of milling equipment for pavement removal, have resulted in an abundance of salvaged roadway materials for recycling. Material availability has led to the consideration of using these salvaged roadway materials on low-volume roads. The laboratory study reported in this report evaluated the feasibility of using foamed asphalt to recycle asphalt pavements.

The study involved an initial evaluation of the foamed process using two field sands. Upon determining that satisfactory mixtures could be prepared, two additional series of tests were conducted using salvaged pavement materials mixed with a foamed AC-5, an MC-800 cutback, and two emulsions (EA-11M and AES-300). Specimens were prepared, cured, and then tested under both dry and wet conditions.

The wet strengths were less than approximately one half the dry strengths but in almost all cases the foamed AC-5 produced strength values equal to or greater than those produced using a cutback or emulsion. In addition, the asphalt content for the foamed asphalt specimens was lower than for the cutback or emulsions. Overall, the foamed asphalt materials appear to offer a possible option for use in cold recycled asphalt mixtures for bases and paved shoulders.

Key Words: Recycling, foamed asphalt, emulsion, cutback, tensile strength, Hveem stability, modulus of elasticity

SUMMARY

The existing technical literature has conflicting reports on the performance of foamed asphalt mixtures. The purpose of this study was to evaluate the performance of foamed asphalt used in recycling asphalt mixtures. A laboratory study was conducted which involved salvaged pavement materials as well as a mixture of field sands which were mixed with a foamed AC-5, two emulsions, and a cutback.

Based on the results of this study it was concluded that generally the strength characteristics of foamed asphalt mixtures were comparable to the mixtures produced using conventional cold-mixing techniques. A problem exhibited by all cold-mixed mixtures was a strength loss of at least 50 percent of the dry strength when tested after wet curing. This moisture susceptibility must be considered before extensive use of these materials is warranted. However, salvaged roadway materials probably can be effectively used for bases and shoulders.

IMPLEMENTATION STATEMENT

Foamed asphalt appears to be feasible for use in cold recycled mixtures if the mixture is to be used as a base, or a paved shoulder. Because of the very large strength losses after wet curing, it is recommended that other uses of this mixture be restricted until field experience reveals its performance characteristics.

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CHAPTER 1. INTRODUCTION

Because of the continued price escalation of both energy and asphalt cement, there is a continuing interest in producing asphalt mixtures using cold mixing techniques, especially for lower volume roads. In addition, substantial volumes of surface material from the growing use of cold milling as well as the use of salvage materials from existing roadways represent high quality materials that can be recycled with the proper technology. Since there have been conflicting reports on the performance of foamed asphalt mixtures, a laboratory evaluation was conducted to determine the properties of foamed asphalt mixtures and to compare these properties with those of cutback and emulsion mixtures. Properties evaluated were indirect tensile strengths and static modulus of elasticity and Hveem stabilities.

CHAPTER 2. FOAMED ASPHALT--A REVIEW

In 1957, Professor L. H. Csanyi of the Iowa State University (Ref 1) demonstrated the effectiveness of preparing low-cost mixes by stabilizing ungraded local aggregates such as gravel, sand, and loess with foamed asphalt. Controlled foam was produced by introducing saturated steam into heated asphalt through a specially designed nozzle. The reduced viscosity and increased volume of approximately 2000 percent allowed intimate coating when mixed with cold, wet aggregates. Foamed asphalt allowed materials normally considered unsuitable for hot plant-mixed applications to be used in stabilized bases and surface mixtures for low-volume roads.

In 1968 the patent rights for the Csanyi process were acquired by Mobil of Australia (Ref 1). Mobil modified the steam production process by blending 1 to 2 percent cold water with the hot asphalt before mixing with cold, mineral aggregate.

MATERIALS SUITABLE FOR USE

Aggregates

Bowering and Martin (Ref 3) tested foamed asphalt mixtures comprised of materials ranging from a sandy clay to a well-graded gravel. Test results indicate that the low plasticity materials with a relatively large percentage of fines (-200 sieve) were best, since the asphalt tends to coat the fines and partially coat the larger particles (Ref 4). Acott (Ref 5) suggested adding fines to increase low stabilities of foamed asphalt mixtures made with both clean and dirty sands. Fine material must be present to enhance the ability of the foam to produce uniform, thin coatings on a large surface area. Soils that benefit the most from the addition of foamed asphalt also exhibited significant strength loss when tested wet.

In addition to using virgin aggregates, foamed asphalt mixtures have been prepared with salvaged asphalt materials. Lee (Ref 2) prepared foamed asphalt mixtures using two recycled materials. The reclaimed materials were blended with virgin aggregates of the type and amount normally specified in Iowa for hot recycled mixtures.

Brennan, et al (Ref 6) produced a foamed recycled asphalt mixture using salvaged material from a state road near Wabash, Indiana, that had an asphalt content of 5.4 percent and a penetration of 20. The material was crushed, graded, separated into four sizes, and recombined to produce a 100 percent recycled mixture.

These studies (Refs 2 and 6) demonstrate the feasibility of using salvaged material to produce a foamed, recycled mixture with or without virgin material. Generally, the mixture properties were reported to have improved when fines were added to the salvaged material.

Asphalt

The percent asphalt included in a foamed asphalt mixture is a function of the soil type, moisture content, and desired mixture properties. Generally, foamed asphalt mixtures can be prepared at lower asphalt contents than conventional cold mixtures and still produce essentially equal properties (Refs 1 and 4). Typical asphalt contents for foamed mixtures range from 3 to 6 percent. When the films are too thick, the asphalt simply lubricates the aggregate particles. When the films are too thin there may not be enough asphalt for coating with a resulting decrease in mixture stability and high strength loss when tested wet.

Brennan (Ref 6) reported excellent Marshall stabilities by adding 0.5 and 1.0 percent asphalt by total weight to salvaged material with stabilities peaking at 1 percent asphalt. The amount of water absorption and the effect of water on stability decreased with increasing asphalt content.

Most asphalt cement (Ref 7) can be foamed, but Abel (Ref 4) reported that the lower viscosity asphalts foamed better than higher viscosity asphalts, but the higher viscosity asphalts produce better aggregate coating.

Shackel, et al (Ref 8) reported that mixtures made from higher penetration asphalts experienced lower strains under repeated loading but also had lower resilient moduli.

CONSTRUCTION CONSIDERATIONS

Prewetting Aggregate

Brennan (Ref 6) reported that it is necessary to add a small amount of water to the aggregate prior to mixing so that the foamed asphalt can thoroughly coat and adhere to the particles. Best mixing occurred at the fluff point, i.e., the point at which the loose material occupies the maximum volume.

The amount of moisture was reported to be fairly critical since the proper amount of water aids in the distribution of the asphalt while insufficient water results in a mixture that cannot be laid (Ref 10). Too much water increases curing times and reduces both density and strength of the compacted mixtures.

Anderson, et al (Ref 7) reported different optimum water contents for strength, density, minimum moisture absorption, and minimum expansion. Anderson, et al, concluded that since mixing generally controls the construction process, the selected optimum moisture content should be controlled by that value. Lee (Ref 2) recommended that 65 to 85 percent of the AASHTO optimum moisture content be used for mixing and stressed that the moisture content prior to mixing was the most important design factor that affected the construction of foamed asphalt mixtures.

Construction and Curing

Most foamed asphalt mixtures have been mixed in a conventional pugmill, fitted with a special spraybar for mixing the water and asphalt to produce foam (Ref 10). After mixing, the material can be placed and compacted with conventional equipment and traffic may be allowed on the pavement shortly after compaction. Curing of foamed asphalt mixtures occurs as the water evaporates (Refs 4 and 7), and is considerably longer than that for emulsion mixtures. Brennan (Ref 6) indicated that most of the mixing water had to evaporate before best compaction could be achieved. During the curing period the mixture can be reworked and relaid with no apparent detrimental effects (Ref 10). Laboratory test results indicate that the method of curing and length of the curing period significantly affect the properties of the foamed mixture. Bowering (Ref 9) stressed the importance of curing and reported that laboratory specimens developed ultimate strength only after a large percentage of the mixing water was lost.

TABLE 1. ASPHALT USED IN LABORATORY STUDY

Tests on Residual Asphalt	
Recycle Project	
Penetration (77°F)	37
Ductility (cm)	141
Viscosity @ 140°F (Stokes)	5570
Tests on New Asphalt	
Cutback MC-800 (#399)	
Producer: Cosden Oil & Chemical Co.	
Penetration (77°F)	208
Kinematic Viscosity (140°F)	1266
AES-300 (#395)	
Producer: Texas Emulsions, Inc.	
Furol Viscosity (77°F)	180
Penetration (77°F)	300
EA-11M (#398)	
Producer: Texas Emulsions, Inc.	
Furol Viscosity seconds at (77°F)	74
Penetration (77°F)	134
AC-5 (#274)	
Producer: Dorchester	
Penetration (77°F)	208

CHAPTER 3. LABORATORY STUDIES

A preliminary laboratory study was conducted first to evaluate the effects on tensile strength and Hveem stability produced by curing methods, moisture content, and asphalt content. Subsequently, the main laboratory study to evaluate the characteristics of foamed recycled mixtures was conducted.

Specimens were prepared with both the field sands and the salvaged asphalt material using a cutback and two emulsions in order to compare properties of foamed specimens with those prepared using traditional cold-mixed procedures. The asphalts used in the laboratory study are shown in Table 1, along with the properties of the recycled asphalt.

All mixtures were tested to obtain indirect tensile strengths, static modulus of elasticity, and Hveem stabilities.

PRELIMINARY LABORATORY STUDY

The sand consisted of a fine white sand and a coarser sand that were blended in equal parts to produce a gradation with 100 percent passing the No. 10 sieve, 73 percent passing the No. 40 sieve, 31 percent passing the No. 80 sieve, and 10 percent passing the No. 200 sieve.

The curing cycle consisted of oven curing for 4 days at 140°F followed by either the "wet" or "dry" 3-day cure at 75°F. The "wet" cure consisted of 2 hours of 26-inch vacuum-saturation followed by 3 days of soaking at 75°F. Bowering (Ref 9) previously concluded that the moisture content of the specimen reaches equilibrium after 3 days of curing at 140°F.

Preliminary Test Result Summary

Specimens prepared at different asphalt and initial water contents and tested in the Hveem stabilometer at 140°F and indirect tensile test at 75°F (11) showed that:

(1) There was a significant increase in tensile strengths as curing temperatures increased from 75°F to 140°F (Fig 1).

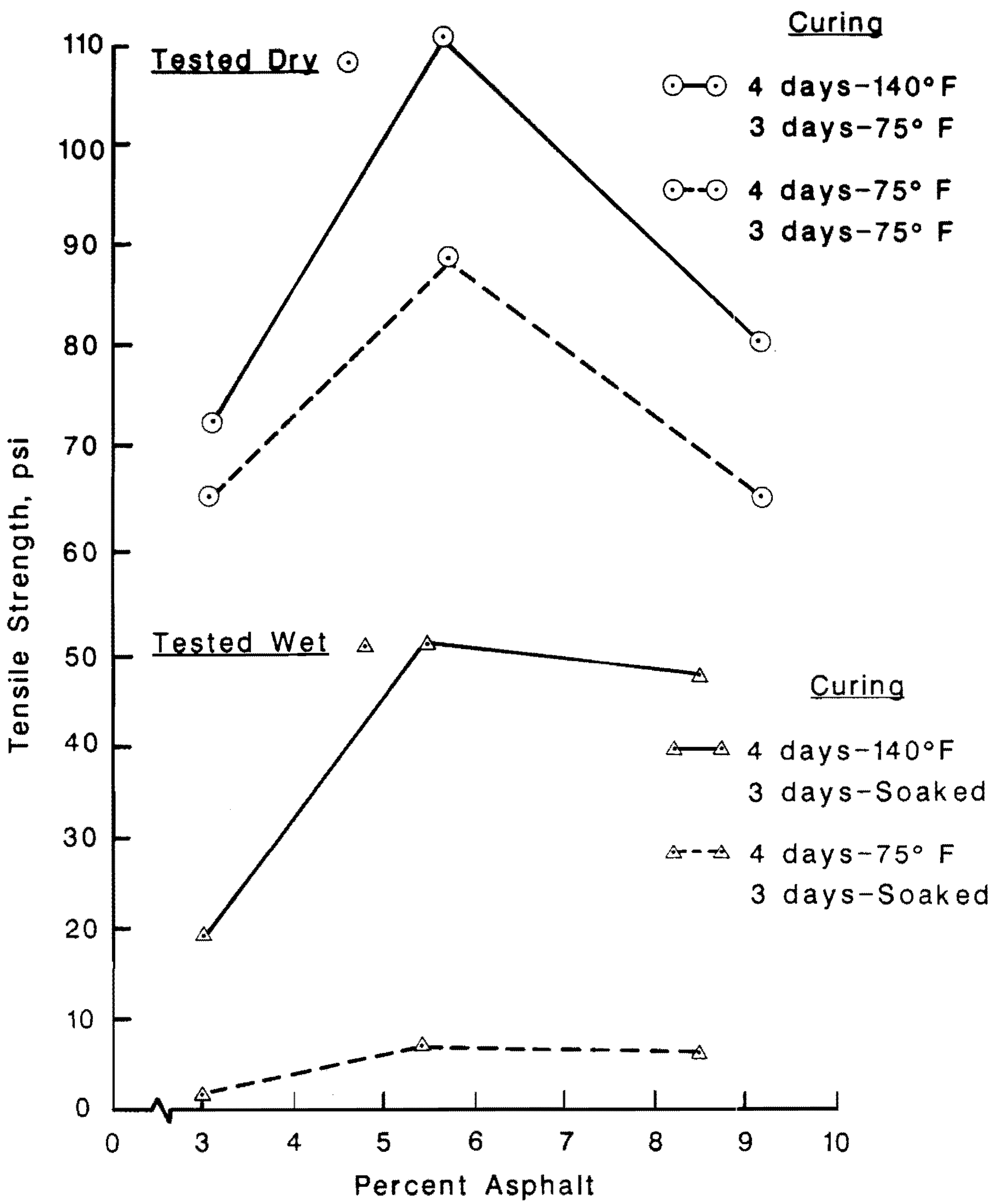

Fig 1. Effects of curing on tensile strength of foamed sand specimens.

(2) Specimens tested after wet curing had less than 50 percent of the strength of those tested after dry curing (Fig 1).

(3) Stabilities of all specimens were low, which is typical of sand-asphalt mixtures, and the stability decreased with increased asphalt content (Fig 2).

(4) Stabilities of foamed asphalt-sand specimens were higher than that for sand mixtures mixed with MC-800 cutback and AES-300 and EA-11M emulsions (Fig 3).

(5) Tensile strengths for the foamed sand asphalt were substantially higher than those for either the cutback or the emulsions (Fig 4).

(6) Tensile strengths decreased as the initial moisture content increased (Fig 5).

LABORATORY STUDY OF SALVAGED PAVEMENT MATERIAL

A laboratory study was conducted to evaluate the characteristics of salvaged materials recycled using foamed asphalt. The purposes of the study were to evaluate the properties of foamed recycled materials and to compare those properties to the properties of more traditional cold mixtures prepared with the same salvaged material using the two emulsions and a cutback.

Specimen Preparation

The salvaged material was sieved into two sizes and recombined with 40 percent of material passing the No. 4 sieve; material larger than 3/4 inches was discarded. The resulting gradation is shown in Figure 6. Mixing and compaction occurred at room temperature. Specimens were compacted with a gyratory compactor.

Experimental Program

The first series of tests was performed on specimens prepared from salvaged materials that had no water added before mixing. These specimens were cured for 7 days including 4 days at 140°F with 3 additional days at 75°F either dry or submerged in water (wet).

A second series of tests was conducted to evaluate the effect of mixing water content and curing temperature on the strengths of the foamed, recycled asphalt mixtures. The water content before mixing varied from zero to two

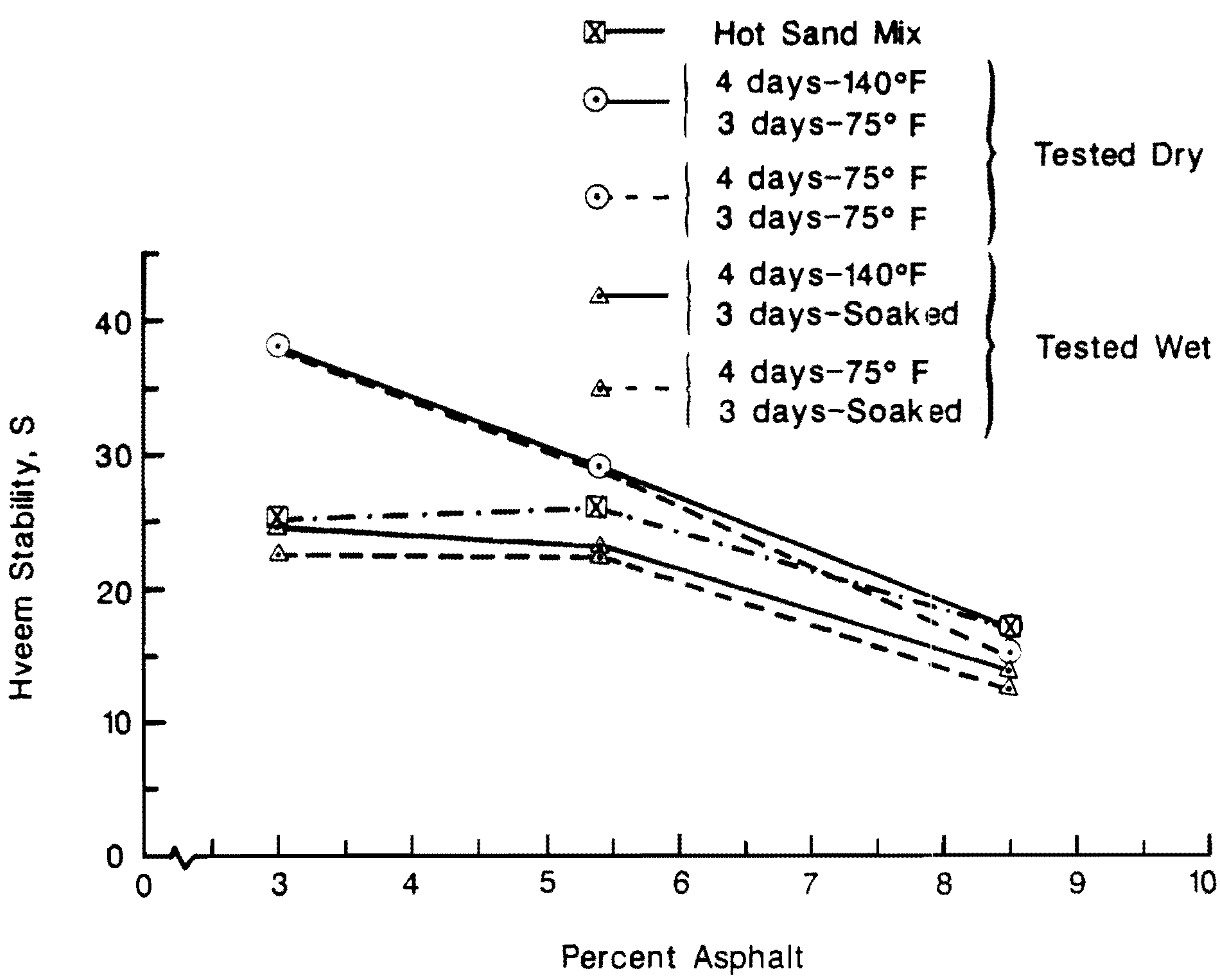

Fig 2. Effects of curing on Hveem stability of foamed sand specimens.

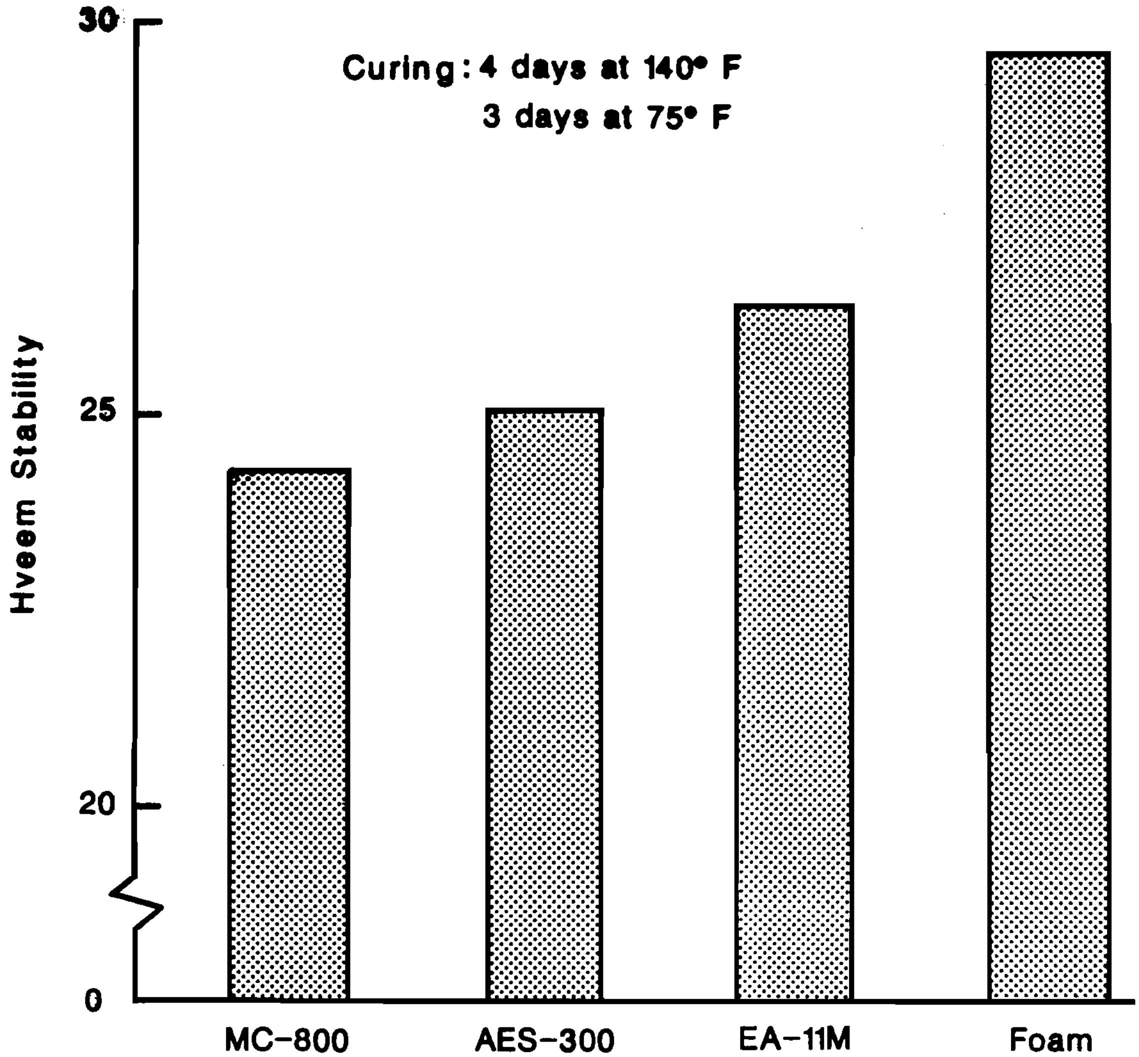

Fig 3. Hveem stability for sand mixtures at 5.4 percent residual asphalt content.

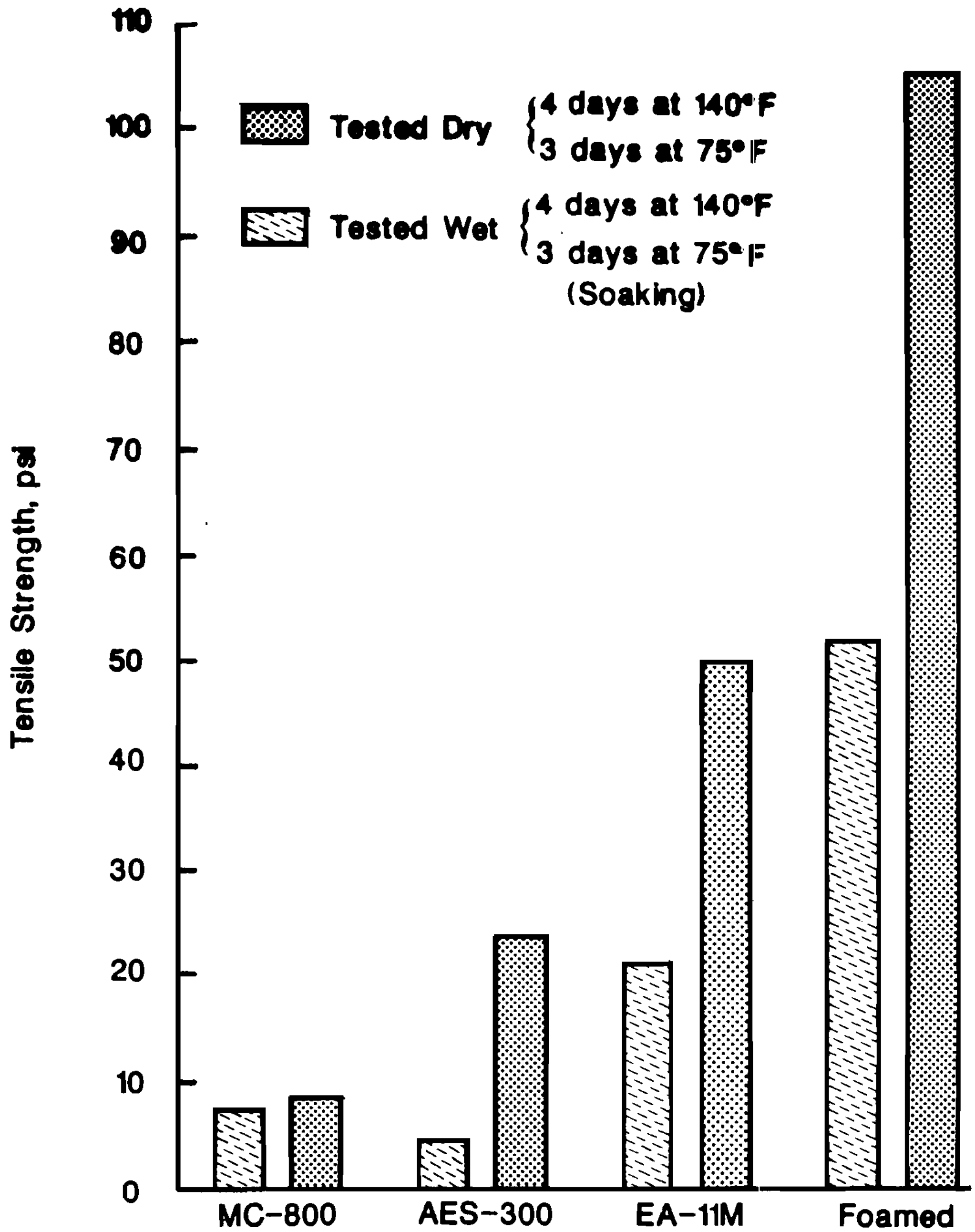

Fig 4. Tensile strength for sand mixtures at 5.4 percent residual asphalt content.

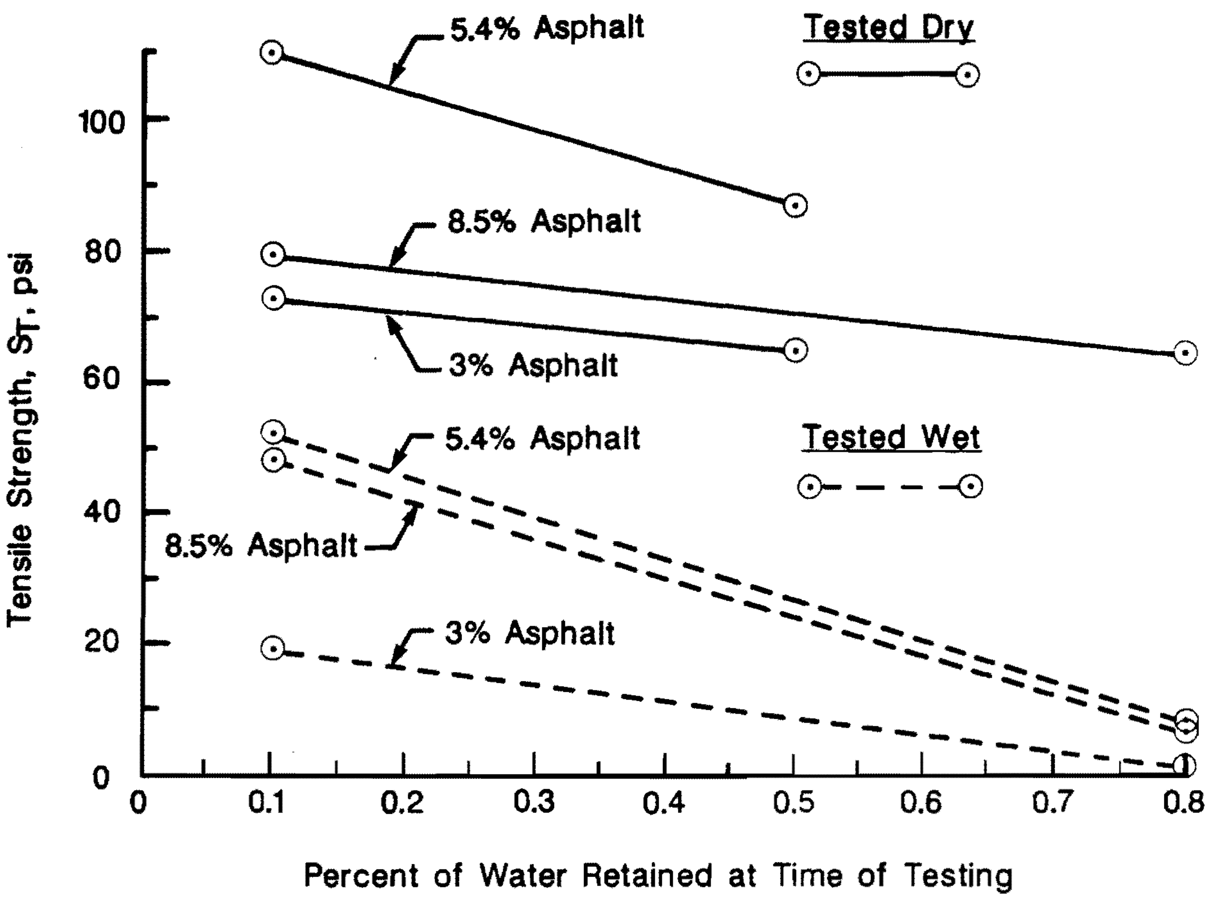

Fig 5. Effects of water content at time of testing on tensile strength of foamed sand asphalt specimens.

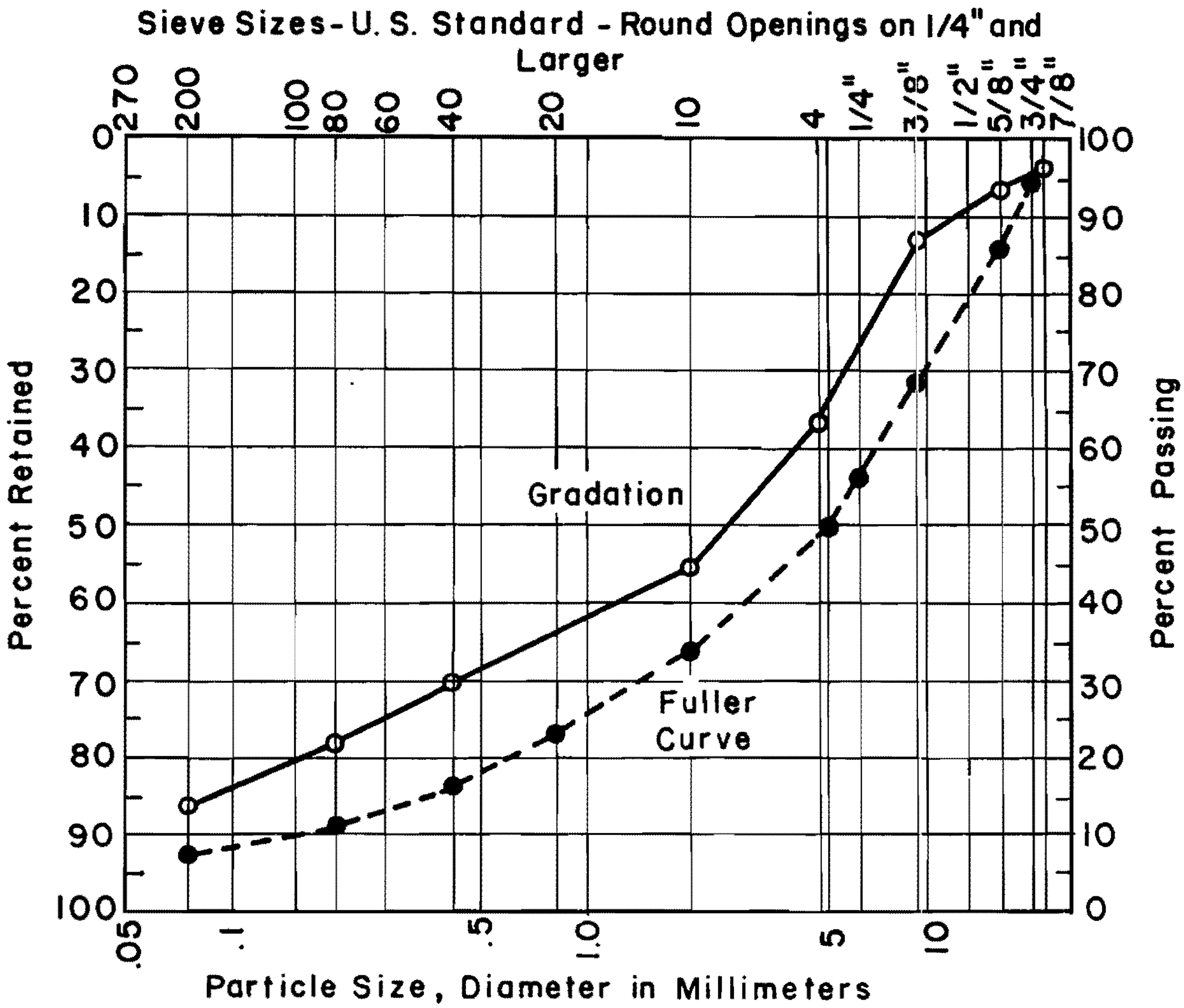

Fig 6. Gradation of salvaged pavement materials from SDHPT District 13.

percent. The curing temperatures ranged from 75°F to 140°F for the initial 4-day cure and the final 3 days of curing was at 75°F, either dry or submerged in water (wet).

A third series of tests involved using the salvaged material to prepare specimens with two emulsified asphalts and one cutback asphalt. Test results from these specimens were used to compare the properties of foamed, recycled specimens to those of specimens prepared using traditional cold mixed processes. Curing conditions for all specimens were the same as the first test series.

Specimens were tested using the indirect tensile and Hveem stability tests. In addition to engineering properties, various other standard tests were conducted on specimens to determine density, air void content, asphalt content, and gradations in order to evaluate the characteristics of foamed, recycled asphalt specimens and to compare those results to specimens prepared using other techniques or materials.

Series 1. Test Results - No Mixing Water

Specimens were prepared at asphalt contents varying from zero to 2 percent and tested at 75°F after the dry and wet curing periods. Due to the foaming process the amount of water in the mix varied from about 0.5 percent to 1.0 percent, averaging about 0.8 percent at the time of compaction.

Figure 7 contains tensile strength results for dry and wet cured specimens. The dry cured specimens show a very definite optimum at 0.5 percent foamed asphalt while the wet cured specimens achieved a maximum tensile strength at about 1 percent. In general, the strengths of the wet cured specimens were less than 50 percent of the strengths of the dry cured specimens. Strength losses of this magnitude are fairly typical for specimens of foamed asphalt mixtures tested wet (Refs 6 and 9).

Hveem stabilities for dry cured specimens are contained in Figure 8 along with the stabilities for specimens of salvaged material heated and compacted at 320°F without the addition of new asphalt.

These data show that only specimens with around 0.5 percent foamed asphalt would meet the Texas SDHPT stability requirement of 35. However, it should be noted that the stabilities of the foamed specimens compare favorably with those of the salvaged material that was only heated and compacted. Since stability tests are performed immediately after curing and

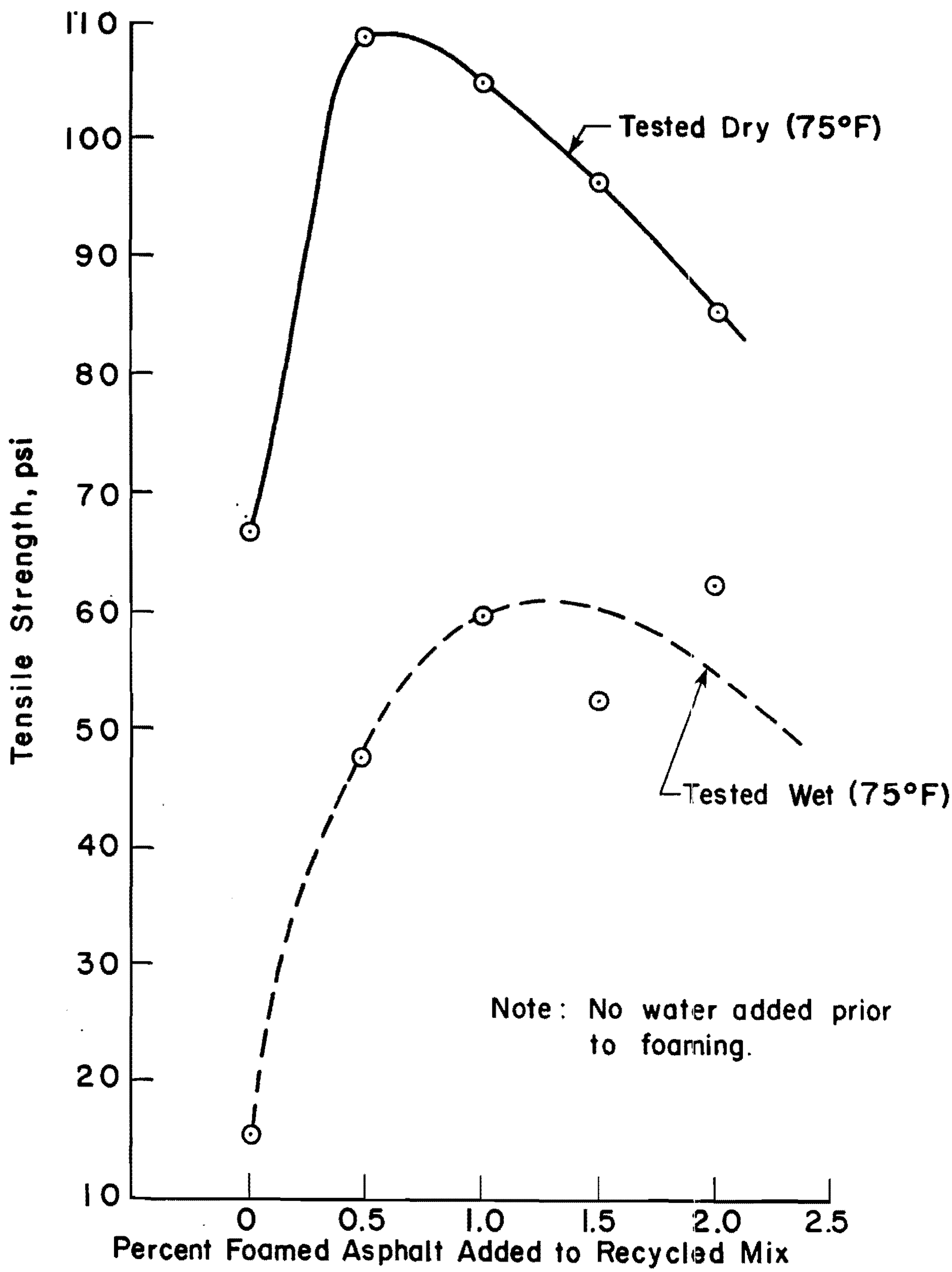

Fig 7. Effects of percentage of residual A.C. in foamed asphalt on tensile strength (no water added prior to foaming).

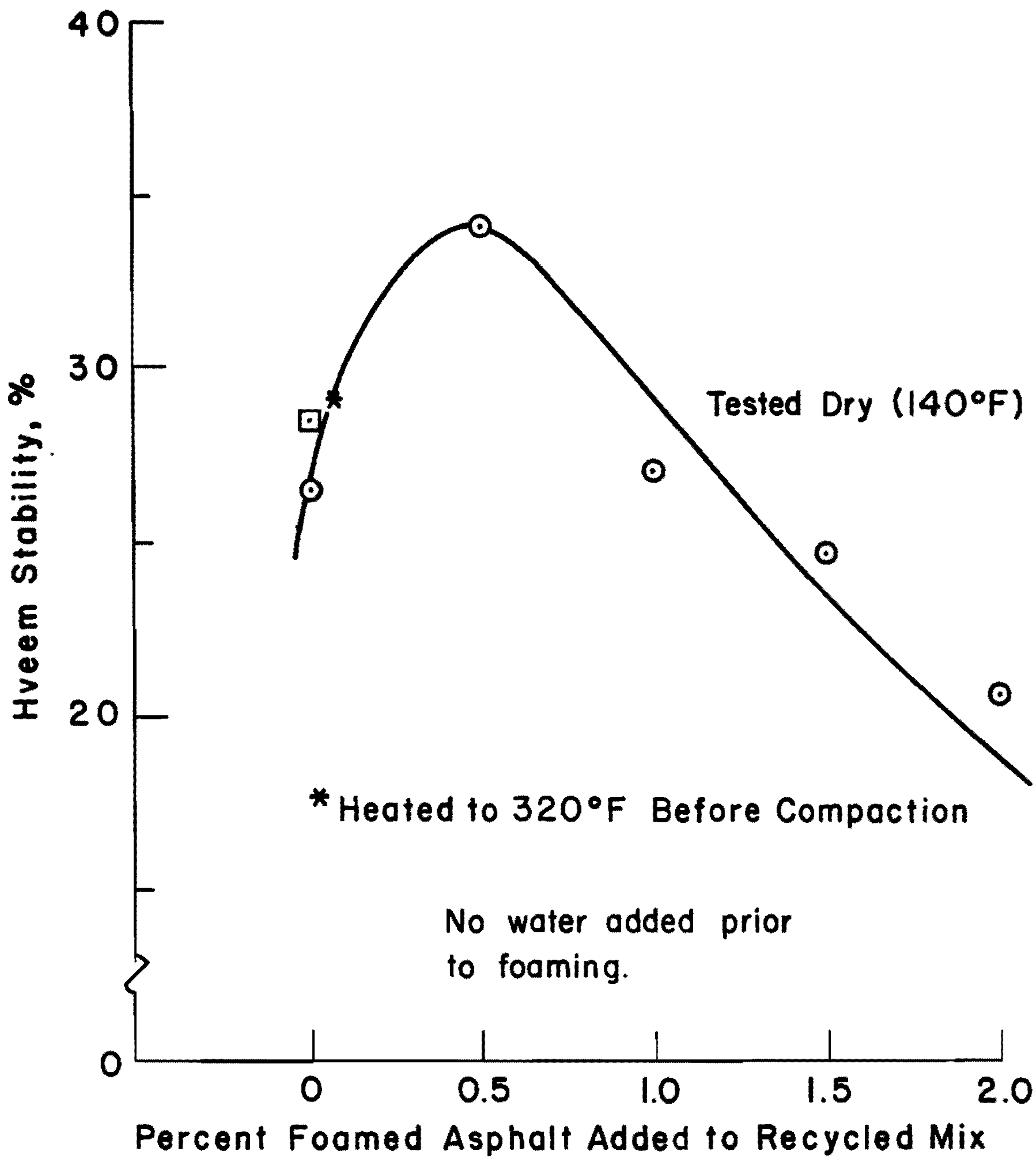

Fig 8. Effects of percentage of residual A.C. in foamed asphalt on tensile strength (no water added prior to foaming).

since no soaking is prescribed in the procedure, stability tests were performed only on the dry cured foamed asphalt specimens.

The static modulus of elasticity of both dry and wet cured foamed recycled asphalt specimens and of recycled mixtures which were heated to 320°F before compaction and testing is shown in Figure 9. The static modulus was fairly constant for both dry and wet cured foamed asphalt specimens for asphalt contents between 0.5 and 1.5 percent. Above and below this range the static modulus decreased significantly. In the asphalt content range between 0.5 and 1.5 percent the static modulus for the dry cured specimens was at least three times the moduli for the wet cured specimens, indicating again the significant effect of moisture on the engineering properties of foamed asphalt mixtures. The static modulus for the recycled mixtures which were only heated before compaction and testing was higher than those for the foamed asphalt specimens and the strength loss was much less for the wet specimens.

Figure 10 shows the relationship between foamed asphalt content and density for both the wet and dry cured specimens. The optimum asphalt content for both sets of data indicate that about the same density was achieved between 0.5 and 1.5 percent asphalt. The percents of theoretical maximum density achieved for the dry cured specimens ranged from about 93 to 95 percent for added asphalt contents ranging from 0.5 to 1.5 percent. The density for the recycled mixtures which were only heated before compaction and testing was significantly higher than that for the foamed, dry cured specimens.

Series 2. Test Results - Effect of Mixing Water on Properties

Specimens were prepared at 0.5 and 1.0 percent asphalt with the water content at compaction varying from 0 to slightly greater than 2 percent. Both the foaming process and the premixing water contributed to the total water in the material at compaction; therefore, water contents were determined from the weights of specimens immediately after compaction and after curing 4 days at ± 40°F.

The effect of mixing water content and asphalt content on tensile strength are shown in Figure 11. For both those specimens tested wet and those tested dry the total liquids at optimum were about the same, i.e., the percent water in the specimens with 1.0 percent asphalt was about 0.5 percent

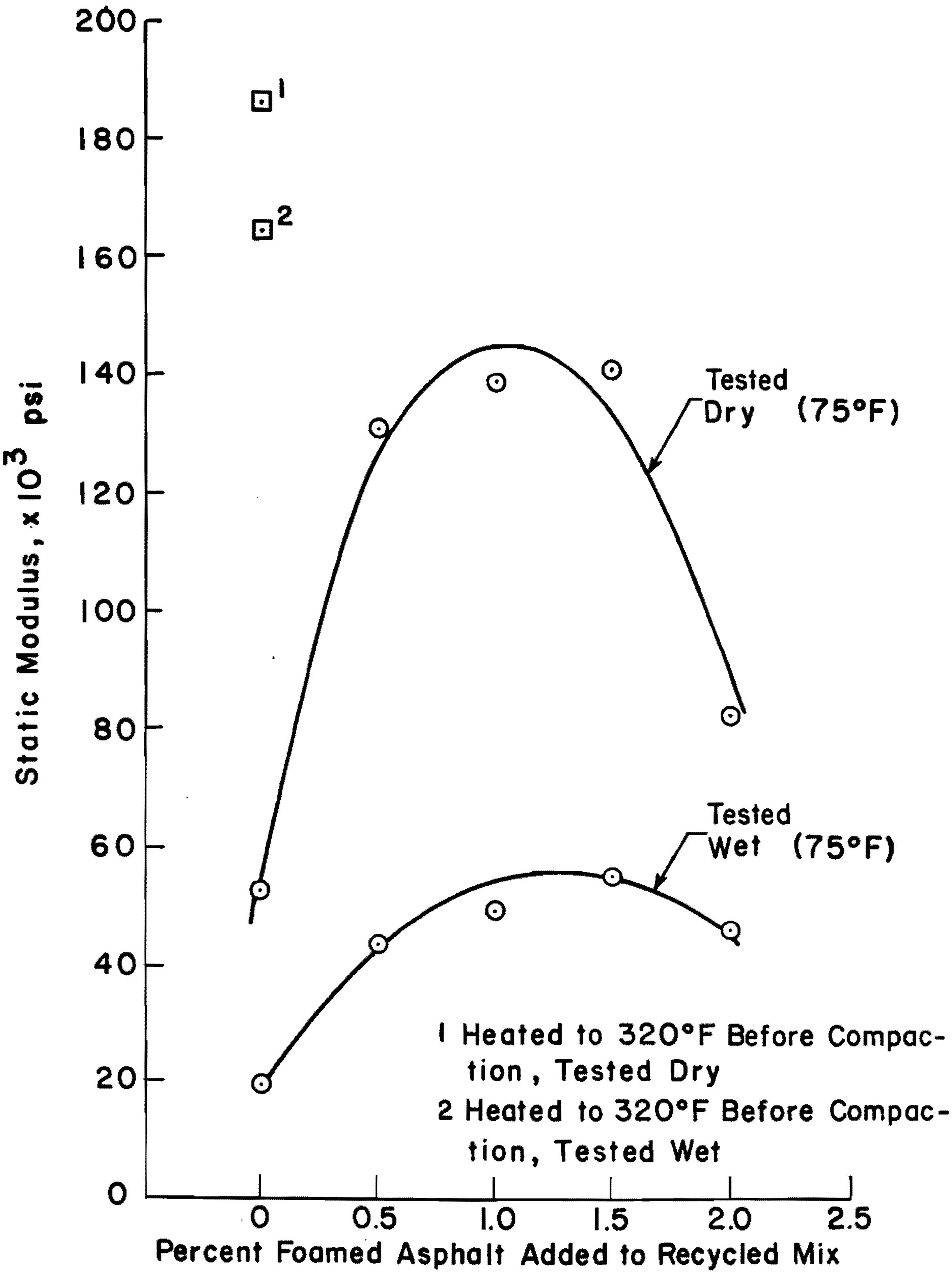

Fig 9. Effects of percentage of residual A.C. in foamed asphalt on static modulus of elasticity (no water added prior to foaming).

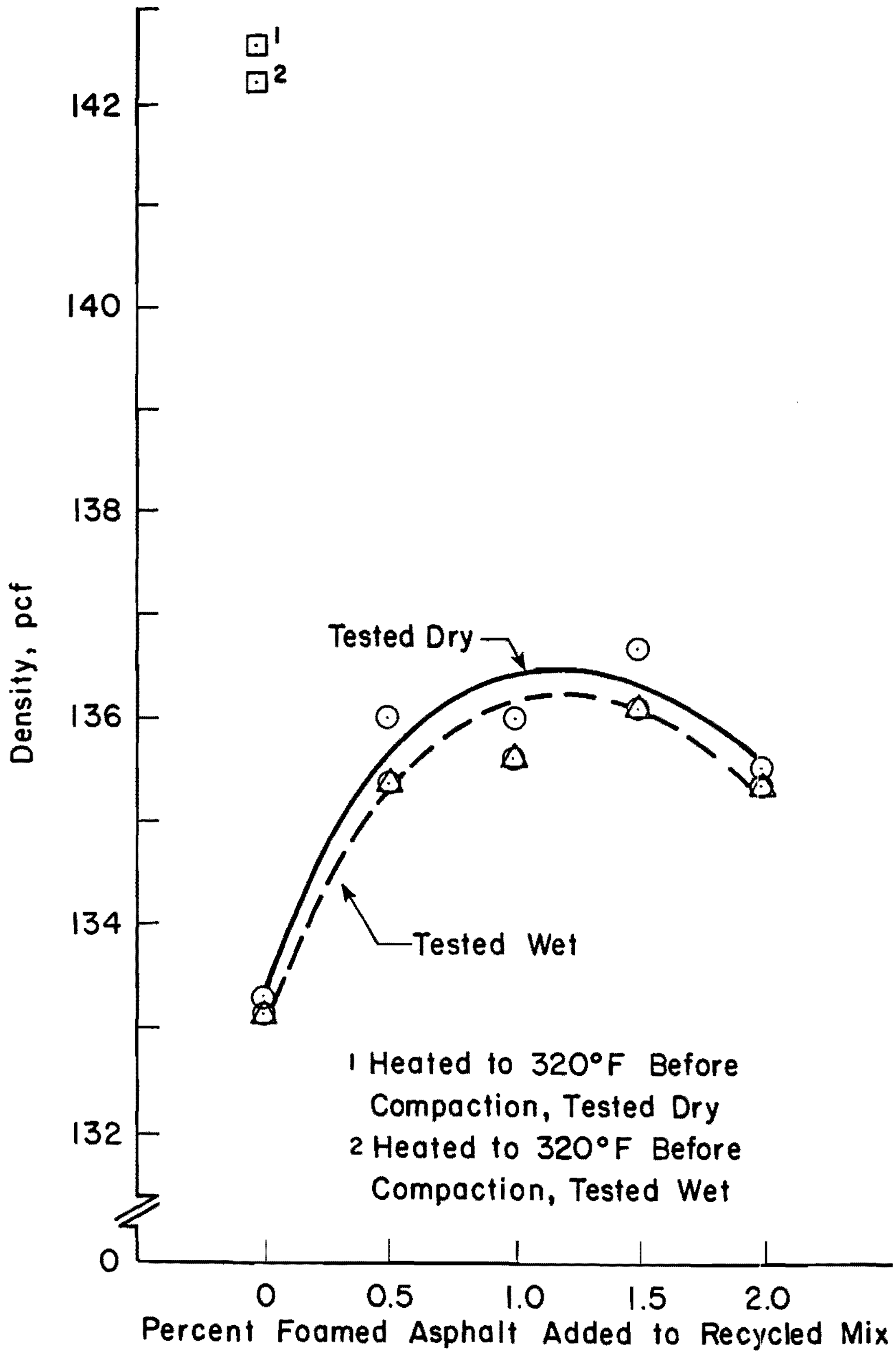

Fig 10. Relationship between density and percentage of residual A.C. in foamed asphalt (no water added prior to curing).

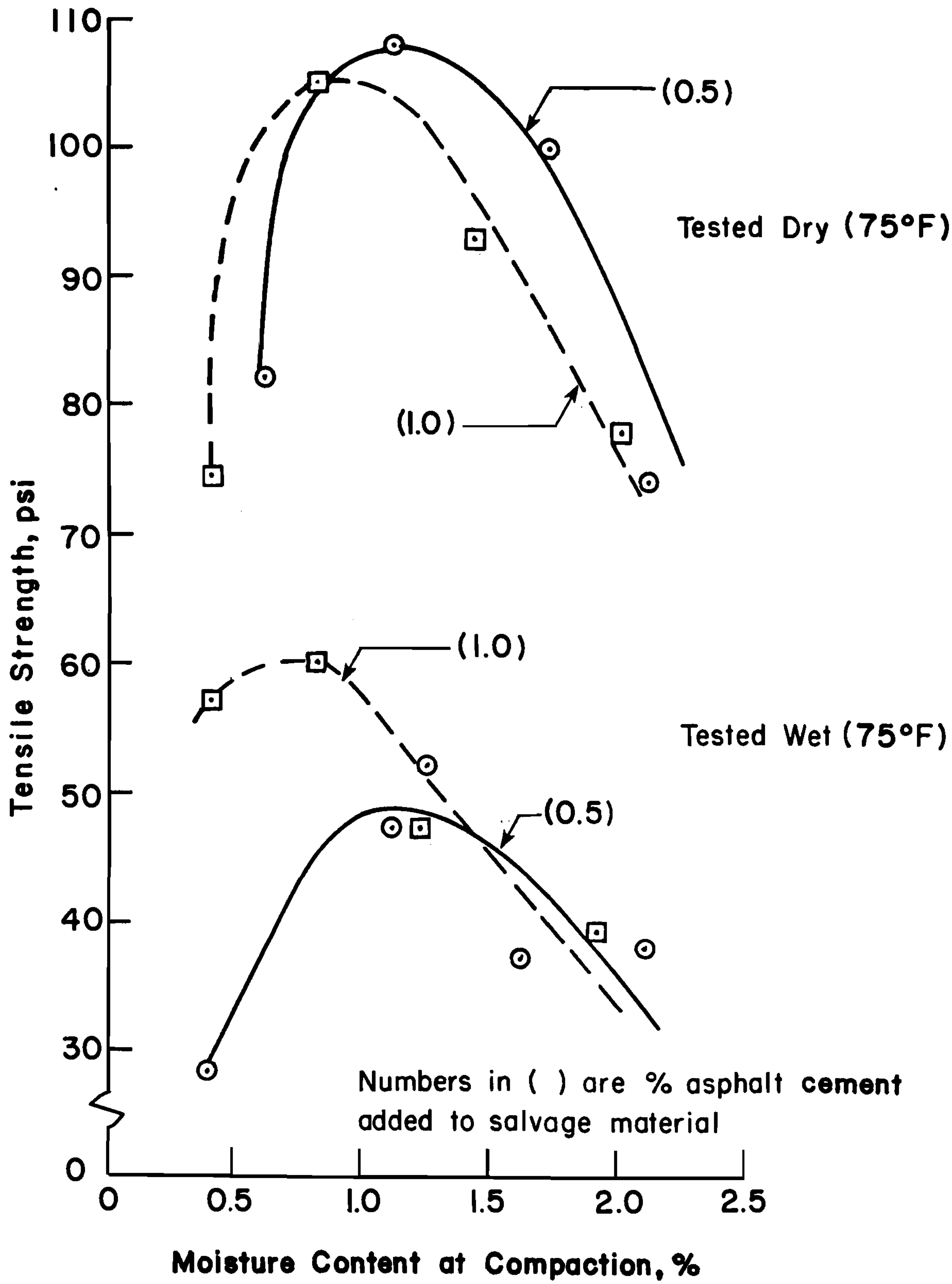

Fig 11. Effects of moisture and asphalt contents on tensile strength of foamed asphalt specimens.

less than for the specimens with 0.5 percent asphalt. In addition, the loss of tensile strength between the dry and wet specimens was consistent with that previously shown in Figure 7 and in the preliminary testing.

There was no significant difference in density for the wet specimens at either 1.0 or 0.5 percent asphalt. The increased wet tensile strength at 1.0 percent asphalt was probably due to the protection provided by the extra asphalt.

Figure 12 shows the effect of both asphalt content and moisture content at compaction on Hveem stability. As expected, the stabilities were lower for specimens prepared with 1.0 percent foamed asphalt since at the same water content the total volume of liquids is larger than for 0.5 percent asphalt, producing additional lubrication and hence lower stability. The optimum moisture content appears to be slightly lower for the 1.0 percent asphalt curve than for the 0.5 percent asphalt, although the latter is not well defined. The optimum stability for both curves may well occur at about the same total liquids content.

The effect of temperature during the initial 4-day curing period on the tensile strength of specimens tested dry and wet is shown in Figure 13. These specimens were compacted from a different mixture. Due to variations in AC content of the salvaged material, the results are different from those obtained in Series 1 (Fig 7). The foamed asphalt content varied from 0 to 1.0 percent. For the specimens tested dry, the optimum foamed asphalt content was 0.5 percent. However, for the specimens tested wet, the tensile strength continued to increase as the asphalt content increased. For the specimens tested wet, however, the effect of curing temperature was much more significant than the effect of asphalt content, indicating the tremendous impact of curing conditions on the properties of this type of pavement material. The higher the initial curing temperature the less the effect of moisture for the wet tests and the lower the strength loss due to wetting. For the specimens tested dry, the effect of asphalt content was much less than for those tested wet; however, a well-defined optimum asphalt content occurred at 0.5 percent.

The effects of temperature and length of the curing period on tensile strengths were also investigated and the results from specimens tested wet after curing are shown in Figure 14. These specimens were prepared from a different mixture. Due to variability of AC content of salvaged material,

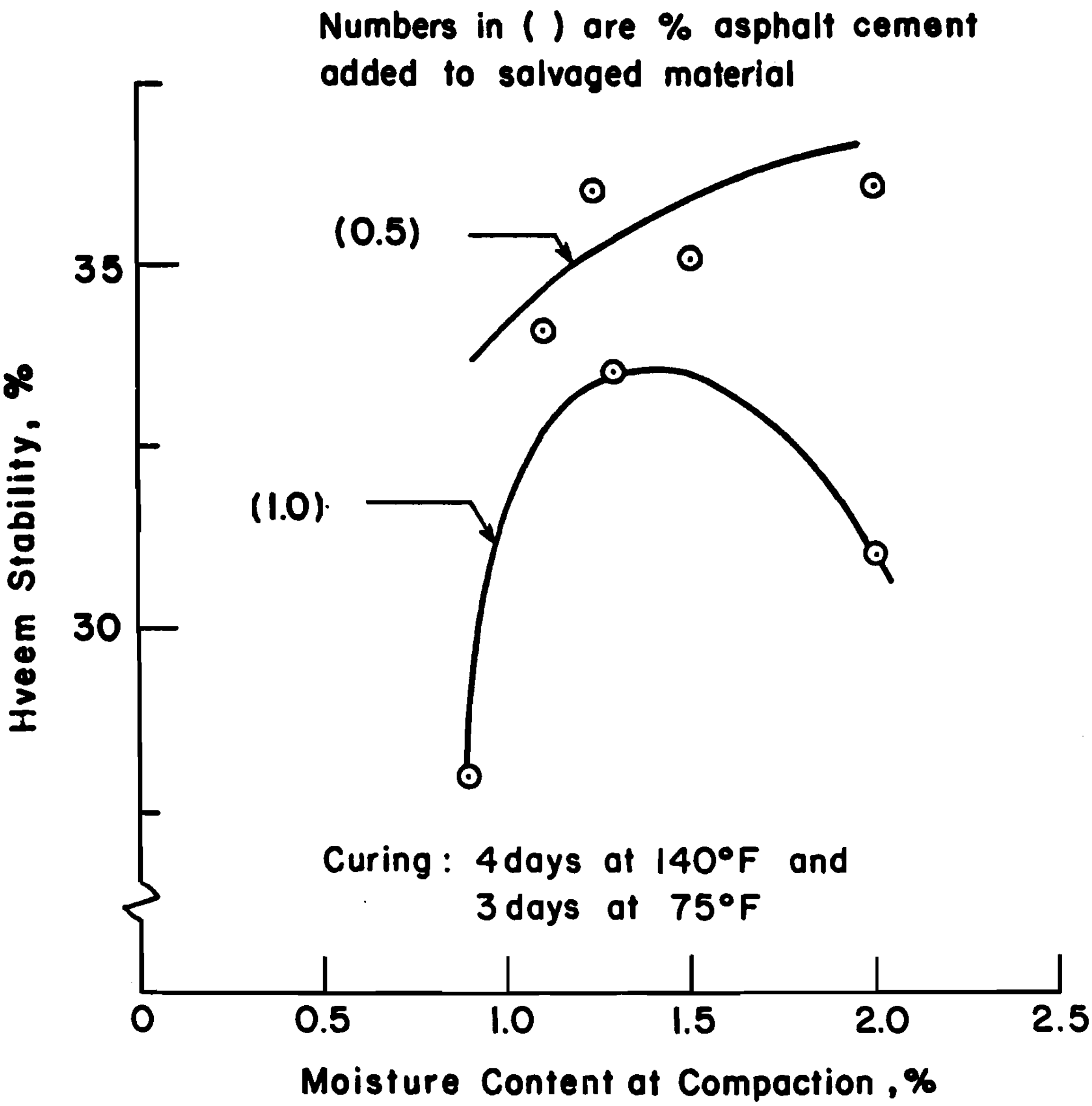

Fig 12. Effects of moisture content at compaction on Hveem stability of foamed asphalt specimens.

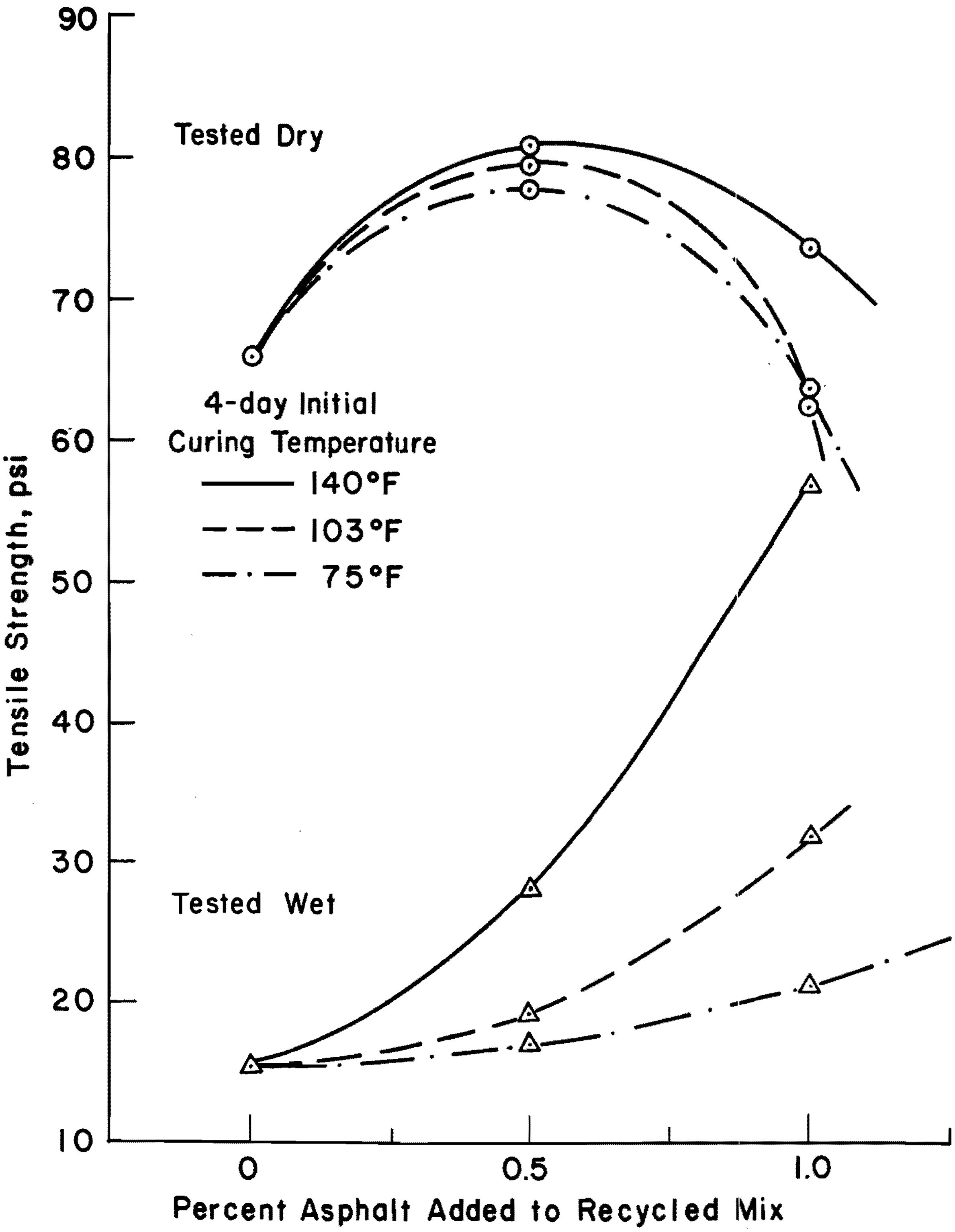

Fig 13. Effects of curing temperature on tensile strength of foamed asphalt specimens.

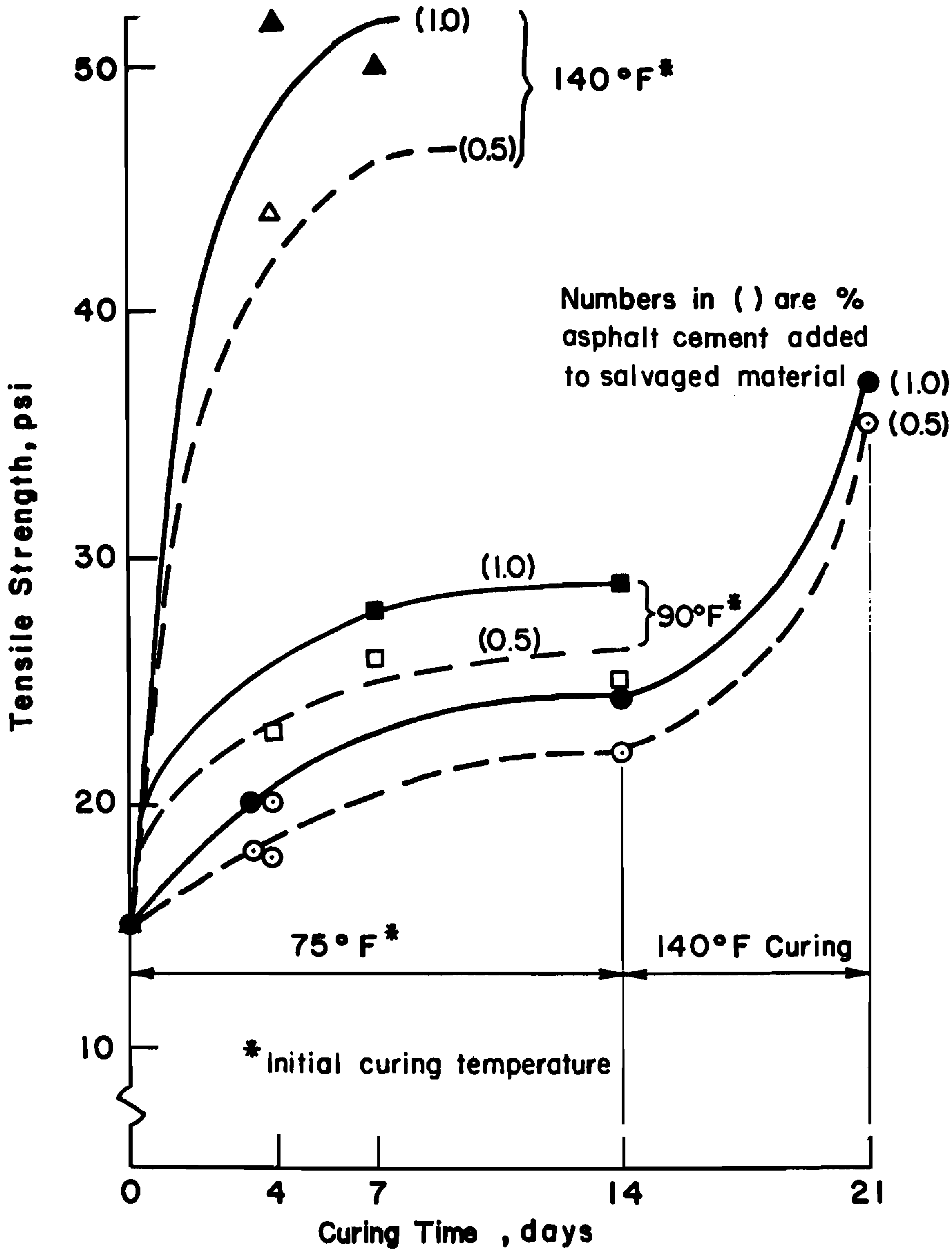

Fig 14. Effects of curing temperature and length of curing period on tensile strength of specimens tested after soaking.

results are somewhat different from those of Figure 13. These results show that the higher the temperature during curing the higher the tensile strength, but that about 75 percent of the strength was developed after 4 days of curing for all curing temperatures. After curing begins, if the curing temperature is increased to 140°F, the tensile strength also increased, but at a lower rate than for specimens that began curing at 140°F.

Series 3. Test Results - Comparison with Emulsions and Cutbacks

To evaluate the engineering properties of foamed asphalt specimens a series of tests was conducted on cold mixed specimens prepared using selected emulsions and a cutback asphalt. The foaming process caused a moisture content of ± 1 percent at compaction. Pre-mixing water of 1 percent was added to the emulsion mixes for consistency. Specimens were prepared and cured in the same manner as for the foamed asphalt specimens: one set at 140°F for 4 days followed by 3 days of either wet or dry curing at 75°F, and a second set at 75°F for 4 days and then either wet or dry cured for 3 days at 75°F. The specimens were then tested immediately after curing at 75°F; those which were tested after dry curing were designated as "tested dry" while those tested after wet curing were designated as "tested wet."

Test results for the specimens prepared with EA-11M and AES-300 emulsions are shown in Figures 15 and 16 while the results for specimens prepared with the MC-800 cutback are shown in Figure 17. The same basic trends as for the foamed, recycled asphalt are evident in these relationships. The tensile strength of the dry specimens cured at 140°F for 4 days exhibited a fairly well defined optimum asphalt content of 0.5 percent for both the dry tested specimens and the wet tested specimens cured at 140°F. Generally, the strengths of the specimens prepared with emulsions and cutbacks compared favorably with those of similar specimens prepared with foamed asphalt (Fig 18).

Hveem stabilities from specimens prepared with foamed AC-5, EA-11M, AES-300, and MC-800 and then dry cured are shown in Figure 19. Specimens prepared using the foamed AC-5 and EA-11M asphalts showed higher stabilities than those prepared using AES-300 and MC800. The optimum asphalt content for stability occurred at 0.5 percent for foamed AC-5 and at 0.71 percent for both emulsions. Stabilities were low at both 0.0 and 1.0 percent added asphalt. When no new asphalt was added the air void content was around 7

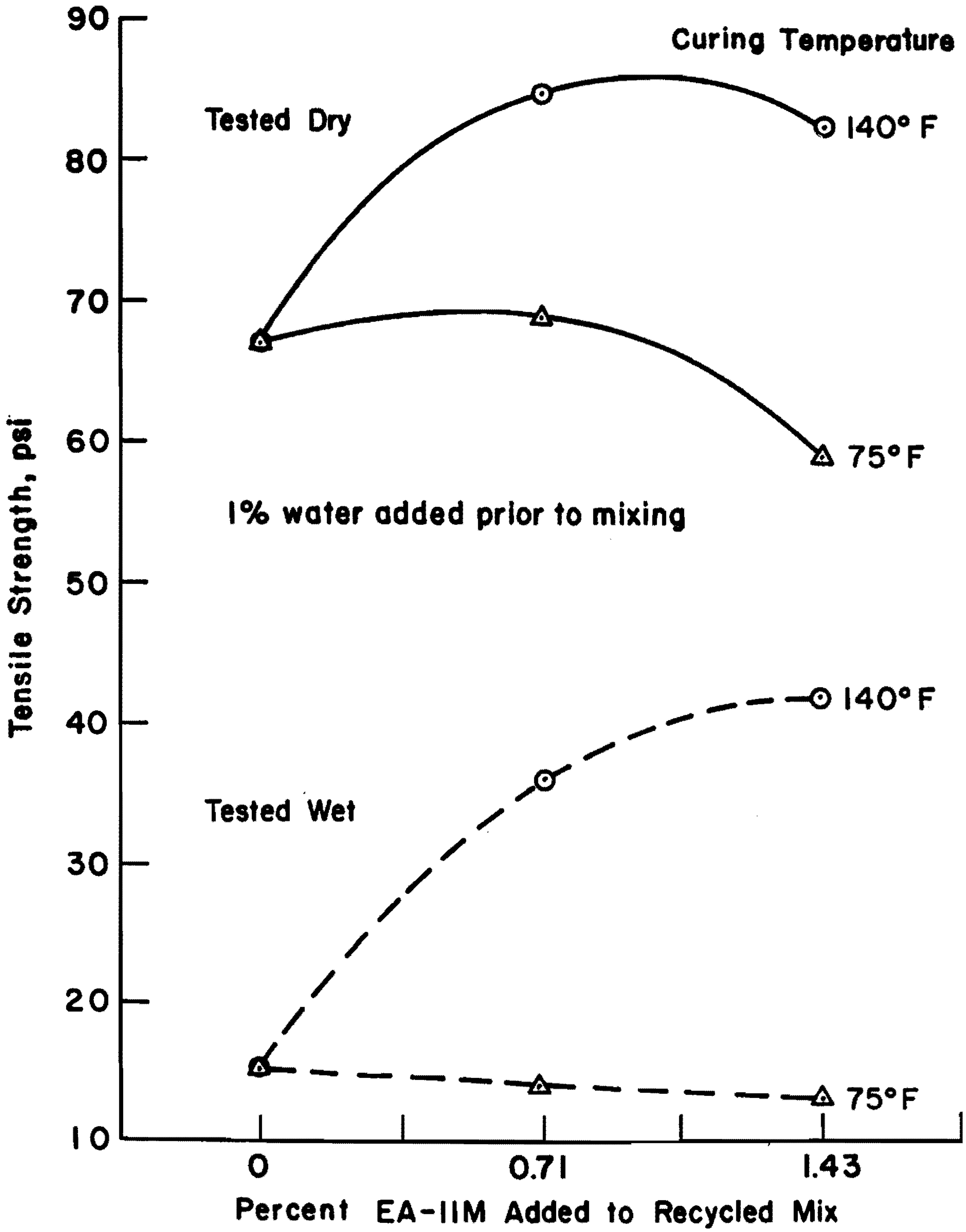

Fig 15. Effects of percentage of residual A.C. content in EA-11M (70/30) emulsion on tensile strength.

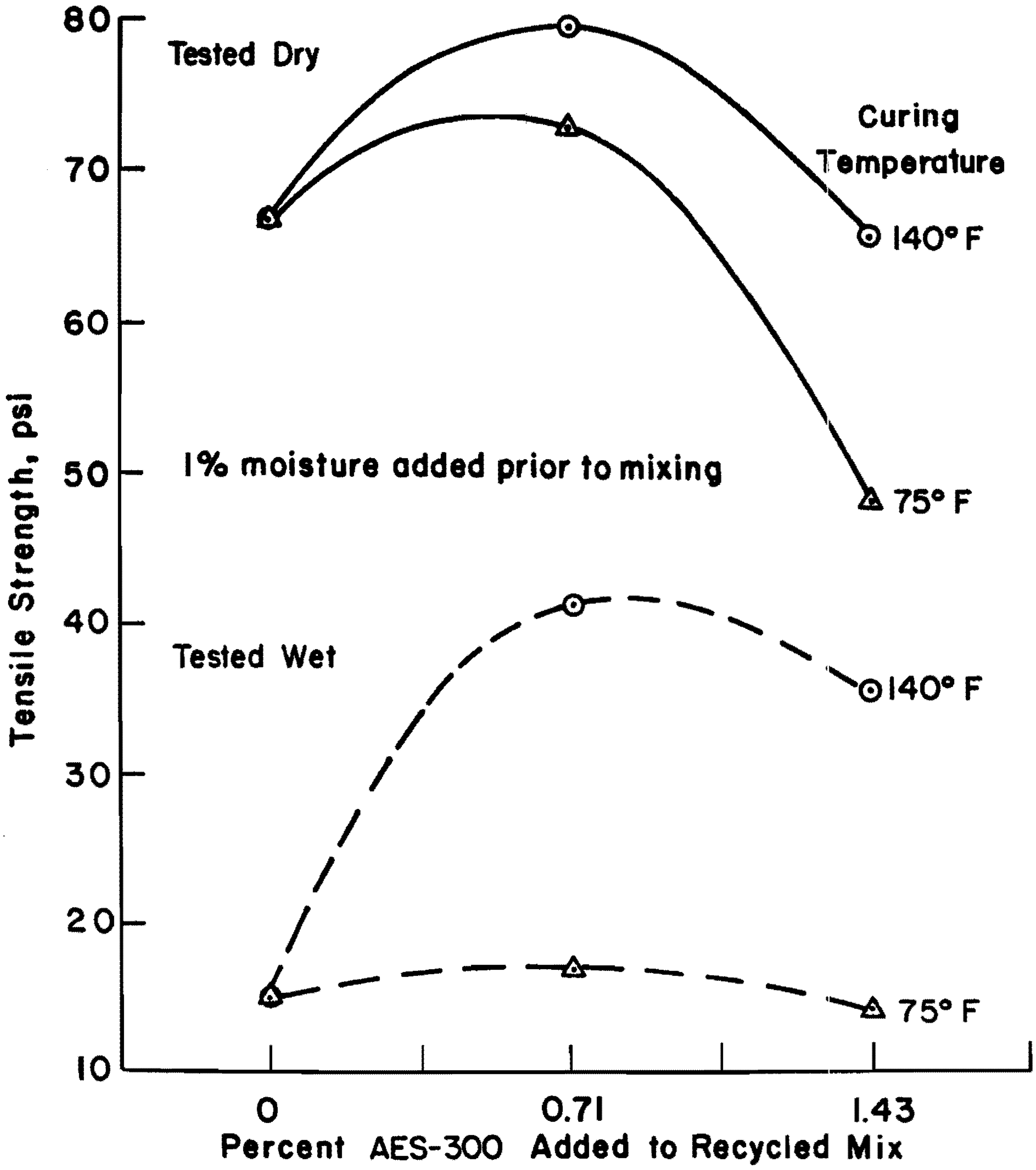

Fig 16. Effects of percentage of residual A.C. content in AES-300 (70/30) emulsion on tensile strength.

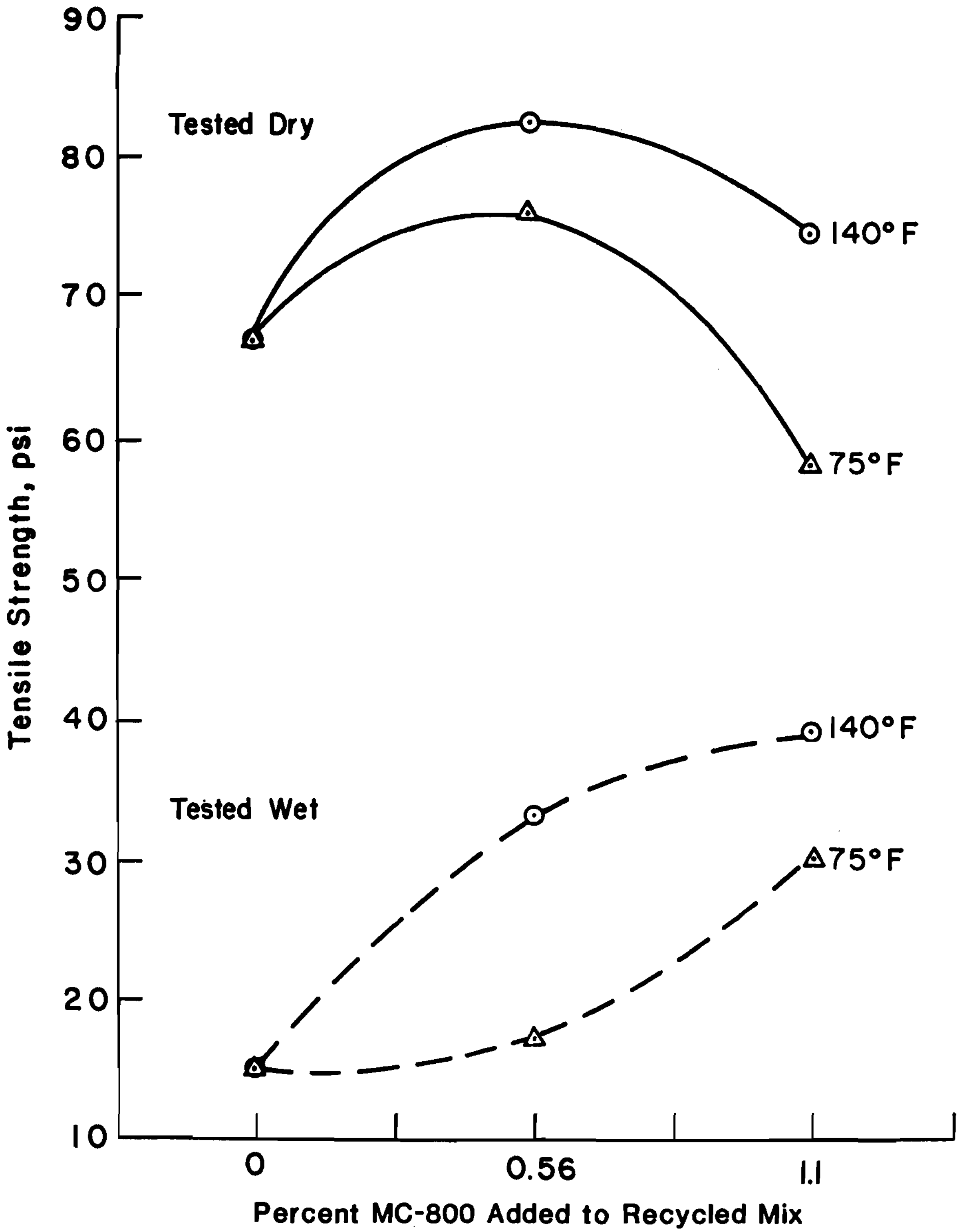

Fig 17. Effects of percentage of residual A.C. content in MC-800 cutback on tensile strength.

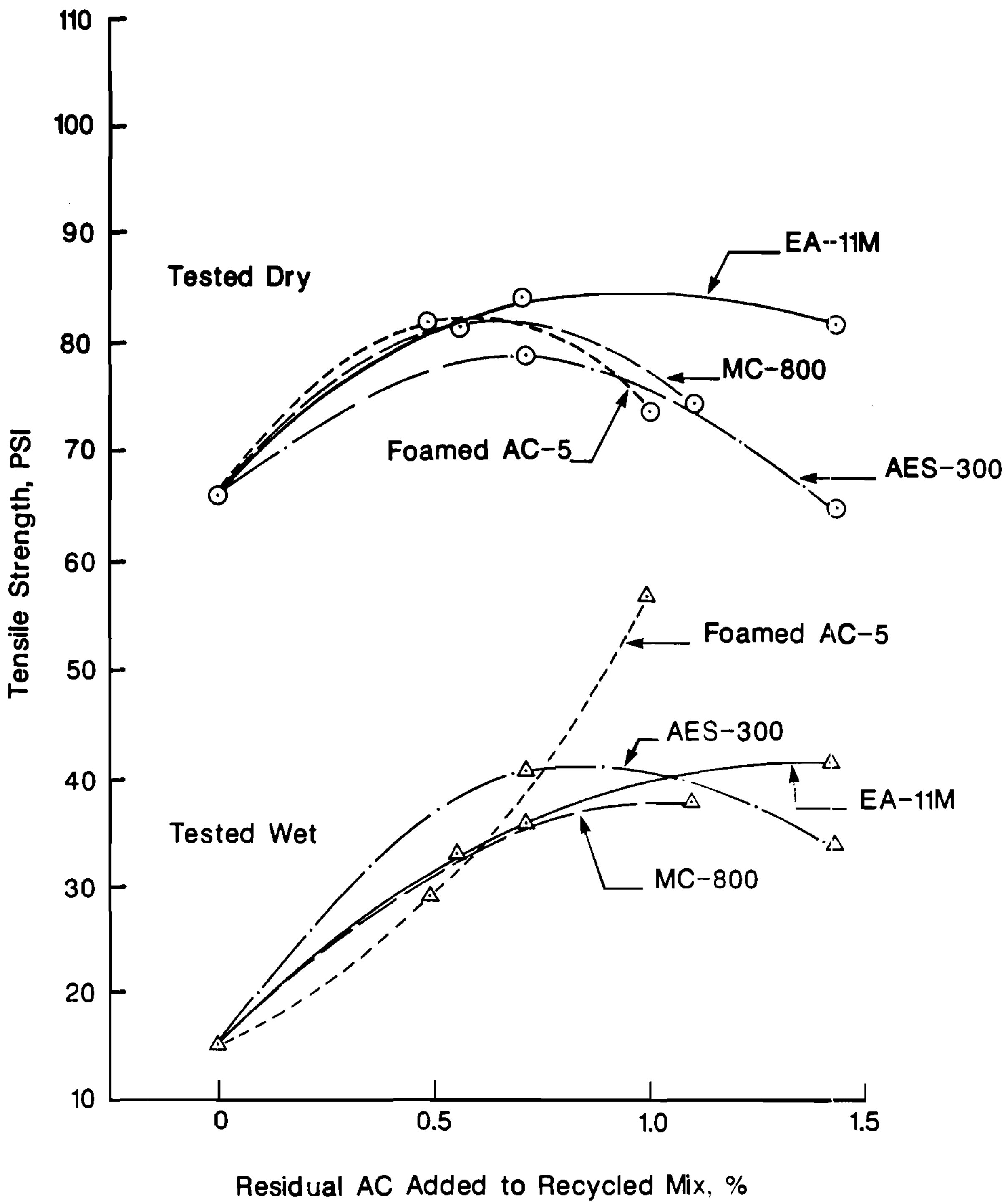

Fig 18. Comparison of tensile strength for foamed, emulsions, and cutback specimens (at 140°F curing temperature).

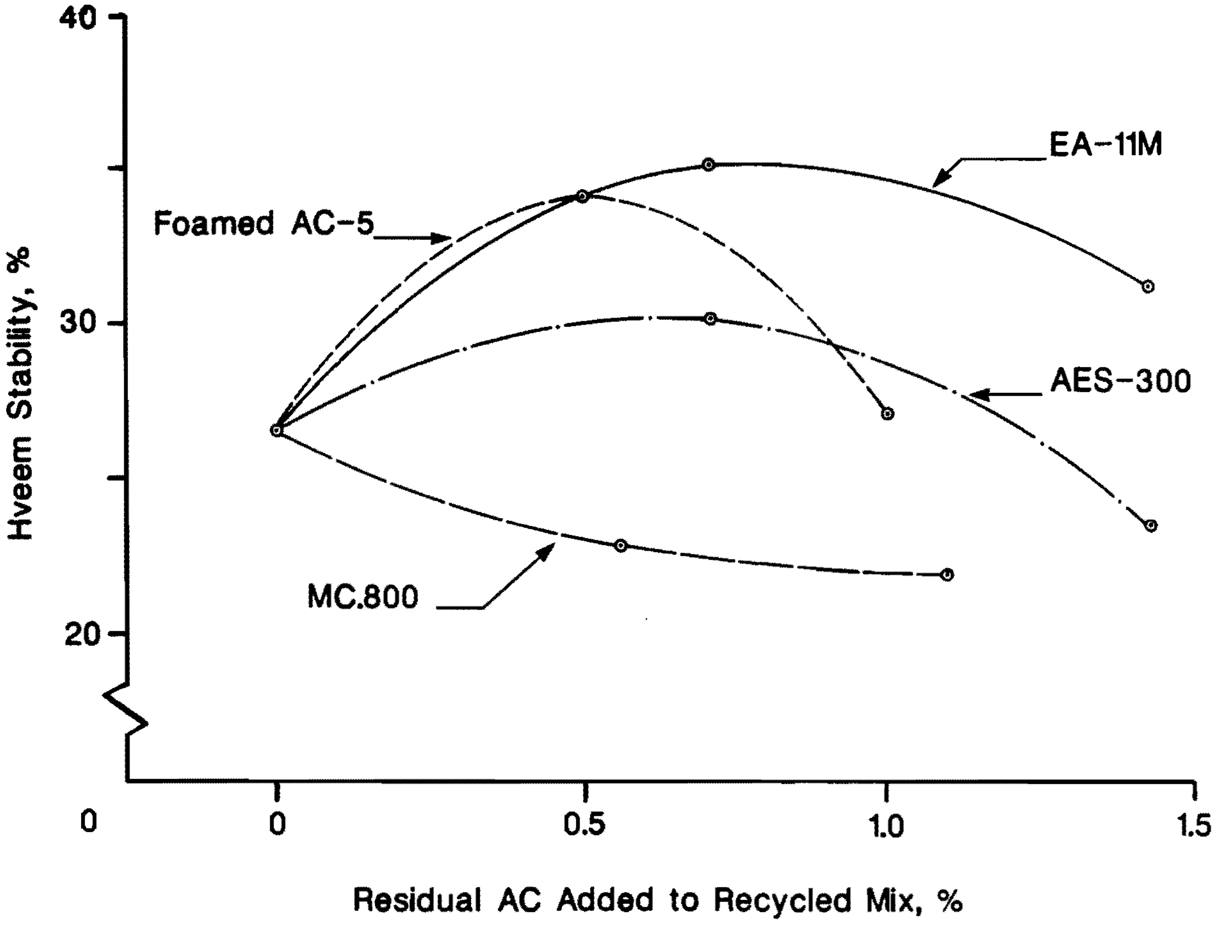

Fig 19. Comparison of Hveem stability for foamed, emulsion, and cutback specimens (at 140°F curing temperature).

percent; at an asphalt content of 1.0 percent the voids ranged from about 4.3 to 6.8 percent as shown in Figure 20. It is obvious that the foamed asphalt specimens were compacted to a higher density than were specimens prepared with either the emulsions or the cutback. This ease of compaction could have resulted from better distribution of the asphalt because of the thinner films produced by the foaming process and from the lubricating effects of extra water introduced into the foamed materials from the cold water that produced the foaming of the asphalt.

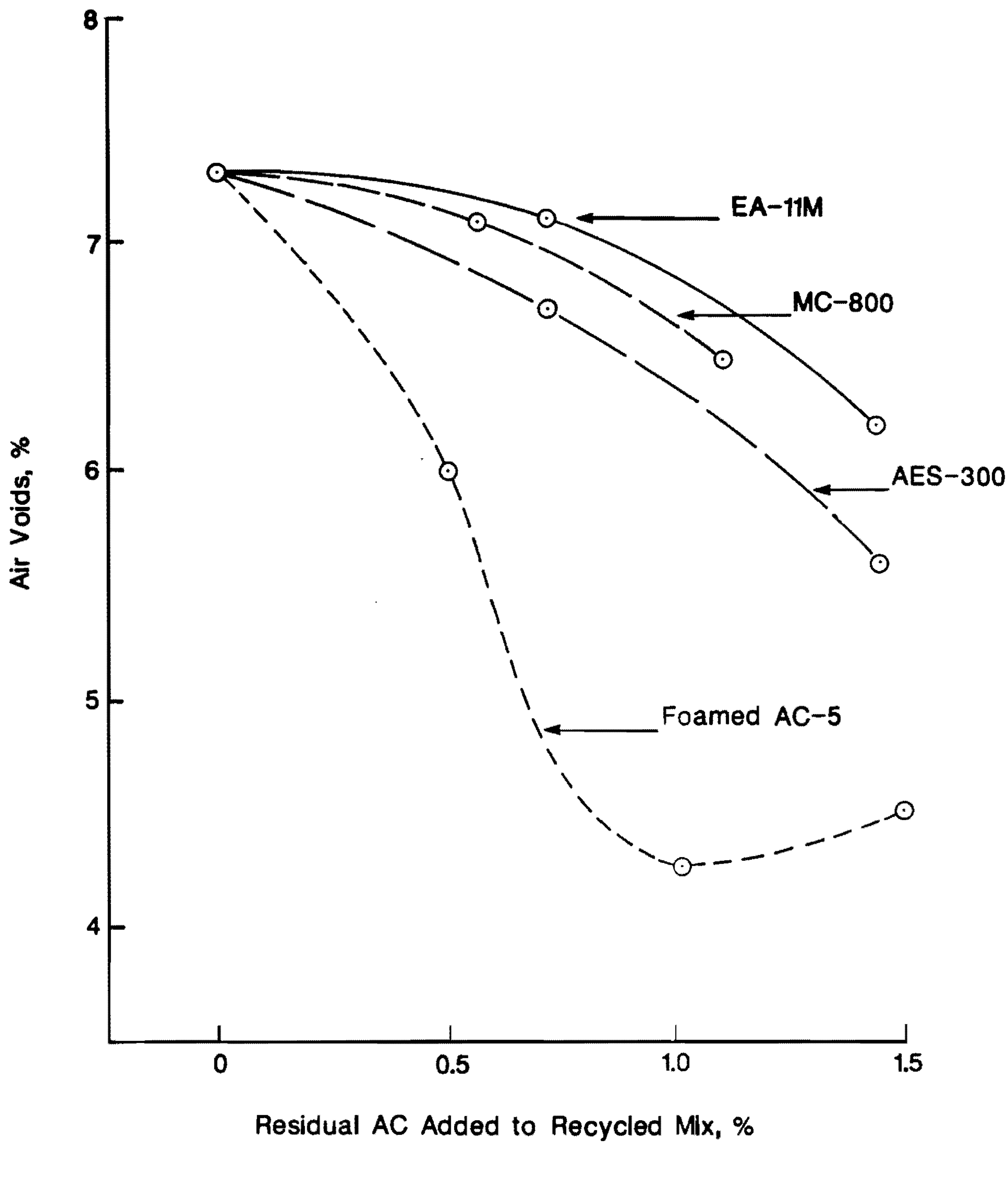

Fig 20. Air void content for mixtures prepared using different asphalts.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

Based on the data collected in this limited laboratory study using one salvaged pavement material, one blend of field sands, an AC-5 asphalt cement, two emulsions, and one cutback, the following tentative conclusions and recommendations were prepared.

CONCLUSIONS

1. Curing temperature, length, and moisture conditions dramatically affected the strength of foamed asphalt mixtures prepared using both the sand and the salvaged pavement materials.
2. The Hveem stabilities of dry cured foamed asphalt and sand mixtures were equivalent to that of a hot sand-asphalt prepared using the same sand and asphalt cement. However, when the foamed asphalt-sand mixtures were tested wet the strengths were reduced to less than 50 percent; however, all specimens lost at least 50 percent of their strength when tested wet as compared to the strengths when tested dry.
3. The foamed asphalt specimens prepared from both the salvaged pavement materials and the sand exhibited equivalent engineering properties to specimens prepared using either the emulsions or the cutback.
4. The static modulus and density of the foamed salvaged asphalt specimens were substantially less than the properties of mixtures prepared by heating the salvaged materials before compaction.
5. Hveem stabilities were significantly affected by the total volume of liquids added to the salvaged materials with these changes being more pronounced at higher asphalt contents.

RECOMMENDATIONS

1. In those situations where cold-mixed materials are being considered for use in bases or subbases, foamed asphalt may be a feasible

alternative especially if acceptable materials include silty sands and gravels that are otherwise considered marginal.

2. The foamed asphalt process probably can be used with salvaged pavement materials to produce base courses and paved shoulder surfaces. However, at this time, the use of these materials as a permanent surface on any roads is not recommended.
3. Field experience should be well documented since, to date, reports on the performance of foamed asphalt mixtures have been conflicting.

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APPENDIX A

TEST RESULTS

TABLE A1. Effects of Curing on Tensile Strength of Foamed Sand Specimens

Asphalt Content, %	Tensile Strength, psi			
	Tested Dry		Tested Wet	
	Curing Condition		Curing Condition	
	4 Days-140°F 3 Days-75°F	4 Days-75°F 3 Days-75°F	4 Days-140°F 3 Days-Soaked	4 Days-75°F 3 Days-Soaked
3	72	66	19	1.7
5.4	111	87	51	7
8.5	79.7	63.5	48.2	6.3

TABLE A2. Effects of Curing on Hveem Stability of Foamed Sand Specimens

Asphalt Content, %	Hveem Stability, %			
	Tested Dry		Tested Wet	
	Curing Condition		Curing Condition	
	4 Days-140°F 3 Days-75°F	4 Days-75°F 3 Days-75°F	4 Days-140°F 3 Days-Soaked	4 Days-75°F 3 Days-Soaked
3	37	37	25	22
5.4	29	29	23	22
8.5	17	15	14	13

TABLE A3. Hveem Stabilities for Sand Mixtures at 5.4 Percent Residual Asphalt Content

Asphalt Type	Hveem Stability, %
MC-800	24.2
AES-300	25.0
EA-11M	26.2
Foamed	29.5

TABLE A4. Tensile Strength for Sand Mixtures at 5.4 Percent Residual Asphalt

Asphalt Type	Tensile Strength, psi	
	Dry	Wet
MC-800	8.75	7.5
AES-300	23.75	5.0
EA-11M	50.0	21.5
Foamed	105.0	52.5

TABLE A5. Effects of Water Content at Time of Testing on Tensile Strength of Foamed Sand Asphalt Specimens

Water Content, %	Tensile Strength, psi					
	3		5.4		8.5	
	Dry	Wet	Dry	Wet	Dry	Wet
0.1	71	19.8	110	51.2	79.8	44
0.5	65	-	89	-	-	-
0.8	-	0.8	-	5.8	65	5.0

TABLE A6. Gradation of Salvaged Pavement Materials

Sieve Size	Percent Passing
7/8"	97
5/8"	94
3/8"	87
No. 4	64
No. 10	45
No. 40	30
No. 80	22.5
No. 200	14

TABLE A7. Effects of Percentage of Foamed Asphalt on Tensile Strength

Asphalt Content, %	Tensile Strength, psi	
	Tested Dry	Tested Wet
0	66	15
0.5	108	48
1.0	104	60
1.5	97	52
2.0	85	62

TABLE A8. Effects of Percentage of Foamed Asphalt on Hveem Stability

Asphalt Content, %	Hveem Stability, %
0	26.5
0.5	34.0
1.0	27.0
1.5	24.0
2.0	21.0

TABLE A9. Effects of Percentage of Foamed Asphalt on Static Modulus

Asphalt Content, %	Static Modulus, 10^3 psi	
	Tested Dry	Tested Wet
0	52	20
0.5	130	43
1.0	138	50
1.5	140	53
2.0	82	46

TABLE A10. Relationship Between Density and Percentage of Foamed Asphalt

Asphalt Content, %	Density, pcf	
	Tested Dry	Tested Wet
0	133.2	133.1
0.5	136.0	135.3
1.0	136.0	135.7
1.5	136.7	136.1
2.0	135.5	135.4

TABLE A11. Effects of Mixing Water and Asphalt Contents on Tensile Strength of Foamed Asphalt Specimens

Water Content, %	Tensile Strength, psi			
	Added Asphalt Content, %			
	1.0		0.5	
	Dry	Wet	Dry	Wet
0.45	75	57	0	28
0.60	-	-	82	-
0.87	105	60	-	-
1.15	-	-	108	48
1.30	-	52	-	48
1.40	93	-	-	-
1.65	-	-	-	-
1.80	-	-	100	-
1.90	-	-	-	39
2.0	77	-	-	-
2.10	74	-	-	38

TABLE A12. Effects of Moisture Content at Compaction on Hveem Stability of Foamed Asphalt Specimens

Water Content, %	Hveem Stability, %	
	Added Asphalt Content, %	
	1.0	0.5
0.8	23	-
1.15	-	34
1.20	-	36
1.30	33.5	-
1.5	-	35
2.0	31	36

TABLE A13. Effects of Curing Temperature on Tensile Strength of Foamed Sand Asphalt Specimens

Added Asphalt Content, %	Tensile Strength, psi					
	4-day Curing Temperature, °F					
	140		103		75	
	Dry	Wet	Dry	Wet	Dry	Wet
0.1	66	15	66	15	66	15
0.5	81.5	29	79.5	19.5	78	17.3
1.0	74	57	62	32	64	21

TABLE A14. Effects of Curing Temperature and Length of Curing Period on Tensile Strength of Specimens Tested After Soaking

Curing Time, Days	Tensile Strength, psi					
	Curing Temperature, °F					
	75		90		140	
	Added Asphalt Content, %					
	0.5	1.0	0.5	1.0	0.5	1.0
3.5	18	20	-	-	-	-
4	17.5	20	23	0	44	52
7	-	-	25.5	27.5	-	50
14	22	24	24.5	28.5	-	-
21	-	-	-	-	35.5*	36.8*

* Specimens were initially cured for 14 days at 75°F and then cured at 140°F for an additional 7 days.

TABLE A15. Comparison of Tensile Strengths at Various Percentages of Two Emulsions, a Cutback, and Foamed AC-5

Added Asphalt Content, %	Tensile Strength, psi			
	Curing Temperature, °F			
	75		140	
	Dry	Wet	Dry	Wet
EA-11M Emulsion				
0	66	15	66	15
0.71	69	14	84	36
1.43	59.5	13	86	41.5
AES-300 Emulsion				
0	66	15	66	15
0.71	73	17	79	41
1.43	48	14	65	35.5
MC-800 Cutback				
0	66	15	66	15
0.56	75.5	17	82	33
1.1	58	29.5	74	38
AC-5 Foamed				
0	66	15	66	15
0.5	78	17.3	81.5	29
1.0	64	21	74	57

TABLE A16. Comparison of Hveem Stabilities at Various Percentages of Two Emulsions, a Cutback, and Foamed AC-5

Added Asphalt Content, %	Hveem Stability, %
<u>EA-11M Emulsion</u>	
0	26.5
0.71	35
1.43	31
<u>AES-300 Emulsion</u>	
0	26.5
0.71	30
1.43	23.5
<u>MC-800 Cutback</u>	
0	26.5
0.56	23
1.1	22
<u>AC-5 Foamed</u>	
0	26.5
0.5	34
1.0	27

TABLE A17. Air Void Contents for Mixtures Prepared Using Different Asphalts

Added Asphalt Content, %	Air Voids, %
EA-11M Emulsion	
0	7.3
0.71	7.1
1.43	6.2
AES-300 Emulsion	
0	7.3
0.71	6.7
1.43	5.6
MC-800 Cutback	
0	7.3
0.56	7.1
1.1	6.5
AC-5 Foamed	
0	7.3
0.5	6.0
1.0	4.3
1.5	4.5