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16. Abstract

This report summarizes the effects of various mixing temperatures and stockpile moisture contents on asphalt mixtures produced by conventional and drum mix plants.

Asphalt mixtures were produced and placed on the road with water contents ranging from zero to saturated and at temperatures ranging from 175°F to 325°F at three different sites with different absorptive aggregates. Laboratory specimens as well as field specimens were made in order to evaluate various engineering properties.

While some variation in tensile strength, tensile strength ratio, and boiling test results was observed, no significant difference was identified between mixtures produced in the batch plant and the drum plant for all conditions of stockpile moisture and mixing temperature.

Both types of asphalt plants were able to remove most or all of the moisture from the stockpile aggregate though they were penalized with higher fuel costs and lower production.

Several uncontrolled variables encountered during the experiments (moisture content of asphalt mixture, voids in the mineral aggregate, air voids, asphalt content and asphalt penetration) caused some variability in the results; however, they did not mask the effects of the controlled variables completely.

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THE EFFECT OF MIXING TEMPERATURE AND STOCKPILE MOISTURE ON ASPHALT MIXTURES

by

Thomas W. Kennedy
Gerald A. Huber

Research Report Number 358-1

The Effect of Mix Temperature on Asphalt Mixtures as Related to Drum Mixers

Research Project 3-9-83-358

conducted for

Texas
State Department of Highways and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH

BUREAU OF ENGINEERING RESEARCH

THE UNIVERSITY OF TEXAS AT AUSTIN

August 1984

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. This report does not constitute a standard, specification, or regulation.

PREFACE

This is the first report in a series of reports for Project 3-9-83-358, "The Effect of Mixing Temperature and Stockpile Moisture on Asphalt Mixtures." This report summarizes the findings at the three test site locations.

Special appreciation is due to the assistance of the Texas State Department of Highways and Public Transportation, especially personnel from Districts 14 and 16 where the tests were conducted.

Appreciation is also due to the contractors involved in this work, Heldenfeld Brothers of Corpus Christi, Texas, and Capital Aggregates of Austin, Texas. Without their cooperation and enthusiasm it would have been impossible to complete the various tasks.

Thanks are expressed to members of the Center for Transportation Research staff. In particular, the guidance and aid of Mr. James N. Anagnos is especially appreciated. Special thanks are directed to Mr. Pat Hardeman and Mr. Eugene Betts for the volumes of test data which were done as part of this project.

The support of the Federal Highway Administration, Department of Transportation, is gratefully acknowledged.

Thomas W. Kennedy
Gerald A. Huber

LIST OF REPORTS

Report No. 358-1, "The Effect of Mixing Temperature and Stockpile Moisture on Asphalt Mixtures," by Thomas W. Kennedy and Gerald A. Huber summarizes the results of a study concerned with various mixing temperatures and aggregate moisture contents for asphalt mixtures at three test sites.

ABSTRACT

This report summarizes the effects of various mixing temperatures and stockpile moisture contents on asphalt mixtures produced by conventional and drum mix plants.

Asphalt mixtures were produced and placed on the road with water contents ranging from zero to saturated and at temperatures ranging from 175°F to 325°F at three different sites with different absorptive aggregates. Laboratory specimens as well as field specimens were made in order to evaluate various engineering properties.

While some variation in tensile strength, tensile strength ratio, and boiling test results was observed, no significant difference was identified between mixtures produced in the batch plant and the drum plant for all conditions of stockpile moisture and mixing temperature.

Both types of asphalt plants were able to remove most or all of the moisture from the stockpile aggregate though they were penalized with higher fuel costs and lower production.

Several uncontrolled variables encountered during the experiments (moisture content of asphalt mixture, voids in the mineral aggregate, air voids, asphalt content and asphalt penetration) caused some variability in the results; however, they did not mask the effects of the controlled variables completely.

KEY WORDS: asphalt mixtures, indirect tensile test, elastic properties, resilient modulus, tensile strength, aggregate moisture, stockpile moisture, mix temperature, drum mix plant, conventional plant

SUMMARY

Studies have indicated that mixtures produced in drum plants have workability and short-term performances equal to mixtures produced in conventional plants and that long-term performance will be equivalent. This work, however, has led to questions related to the effect of lower mixing temperatures and higher aggregate moisture contents. In addition, there is a need for information related to effects of stockpile and asphalt-mixture moisture contents for conventional and drum plants in order to develop cost-effective specifications.

To determine these effects, the Center for Transportation Research at The University of Texas at Austin and the Texas State Department of Highways and Public Transportation initiated a series of field experiments involving an evaluation of the engineering properties of asphalt mixtures produced with a range of stockpile moisture contents, a range of mixing temperatures, and both drum and conventional batch plants.

This paper covers the first phase of the study and involved a variety of aggregate types and different plants in Texas. Mixing temperatures ranged from 175°F to 325°F and stockpile moisture contents varied from dry to saturated. The engineering properties evaluated were Hveem stability, tensile strength, resilient modulus of elasticity, and moisture damage susceptibility for batch and drum mix plants. If the specifications could be changed without detrimental effects to the mixture properties, significant savings could be realized.

To determine these effects the Center for Transportation Research (CTR) and the Texas State Department of Highways and Public Transportation (Texas SDHPT) through their cooperative research program initiated a series of experiments which were performed on asphalt plants under regular field conditions. These experiments were conducted on both drum mix plants and conventional batch plants with a variety of aggregate types.

This paper covers the first phase of the study. It discusses the experimental work performed, problems encountered, results obtained, and conclusions reached.

IMPLEMENTATION STATEMENT

Several studies have indicated that the mixture produced in drum mix plants has workability and short-term performance qualities equal to those of a mixture produced in conventional plants. There is also an indication that long-term performance of both will be equivalent. However, these studies evaluated material produced only under existing specifications and an effort has not been made to establish the performance qualities of mixtures produced outside of existing specifications.

The work done to assess and compare the properties of drum mixed to conventionally mixed asphalt mixtures led to the question as to whether the drum mix plant could produce acceptable mixtures at lower temperatures and higher moisture contents than existing specifications allow. In addition, there is a need for information related to the effects of stockpile or mixture moisture contents for both conventional plants and drum plants. If the specifications could be changed without detrimental effects to the mixture properties, significant savings could be realized.

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CHAPTER 1. INTRODUCTION

In the past decade the use of drum mix asphalt plants has increased significantly and the trend is expected to continue since new plant sales are predominantly of this type. The simplicity, lower initial cost, and lower operating cost of the drum mix plant are the reasons for the sales dominance. A conventional plant heats the aggregate in a rotating drum drier, separates the particles by sieve size into hot storage bins, weighs out appropriate quantities of each, and mixes the aggregate with asphalt in a pugmill. By contrast a drum mix plant heats the aggregate in a drum and mixes it by injecting the asphalt in the lower third of the drum length. As a result the aggregate drier, hot aggregate bins, weighing scales, and pugmill of a conventional asphalt plant are replaced by a drum mixer which is approximately the same size as the aggregate drier alone. In addition, the drum mix plant relies on a foaming action, produced when the hot asphalt and moist aggregate are mixed, to coat the particles and in turn allows lower operating temperatures. These simplifications account for the advantages of the drum mix asphalt plant.

Several studies have indicated that the mixture produced in drum mix plants has workability and short-term performance qualities equal to those of a mixture produced in conventional plants. There is also an indication that long-term performance of both will be equivalent (Ref 1). However, these studies evaluated material produced only under existing specifications and an effort has not been made to establish the performance qualities of mixtures produced outside of existing specifications.

The work done to assess and compare the properties of drum mixed to conventionally mixed asphalt mixtures led to the question as to whether the drum mix plant could produce acceptable mixtures at lower temperatures and higher moisture contents than existing specifications allow. In addition, there is a need for information related to the effects of stockpile or mixture moisture contents for both conventional plants and drum plants. If the specifications could be changed without detrimental effects to the mixture properties, significant savings could be realized. Unfortunately, research on the combined effects of mixing temperature and moisture content of asphalt mixtures was not available for either conventional asphalt plants or drum mix plants. To determine these effects the Center for Transportation Research (CTR) and the Texas Department of Highways and Public Transportation (DHT) through their cooperative research program initiated a series of experiments which were performed on asphalt plants under regular field conditions. These experiments were conducted on both drum mix plants and conventional batch plants with a variety of aggregate types.

Details of the experimental program and analysis of the results are contained in this report. Chapter 2 contains a description of the experimental program and the locations of the asphalt plants involved. The test results are presented in Chapter 3 and the conclusions are summarized in Chapter 4. Appendices A, B and C discuss the experiments done on Aggregates A, B and C, respectively.

CHAPTER 2. EXPERIMENTAL PROGRAM

The primary objective of this study was to determine the effects of mixing temperature and moisture content on the properties of asphalt mixtures. The properties evaluated included the indirect tensile strength, the resilient modulus of elasticity, the Hveem stability, and moisture damage susceptibility. To achieve this objective, an experiment was designed and performed on several asphalt mixing plants in the state of Texas. This chapter describes the asphalt plants, the aggregates, the sampling program, the testing program, and the test methods employed in the study.

STUDY DESIGN

The study involved an experiment in which combinations of various mixing temperatures and stockpile moisture contents were used to produce asphalt mixtures with different aggregates (Table 1). This basic experiment was repeated at several different asphalt plants in the state.

Experiment Mixing Temperatures and Stockpile Moisture Contents

The mixing temperature was varied from normal operating temperature (325°F) to temperatures well below present normal operations (175°F) and the stockpile moisture contents were varied from virtually dry to nearly saturated. The three levels of moisture content used were referred to as dry, wet, and saturated. Dry stockpiles were obtained by predrying the aggregate before mixing. Wet stockpiles were defined as the natural stockpile moisture and saturated aggregates were obtained by applying water to small stockpiles of individual aggregates. Mixing temperature measured at the discharge of the mixture was varied by changing the burner flame control. The temperature of the asphalt cement prior to mixing was held constant throughout the experiments at an estimated 275°F to 300°F.

Asphalt Plants Used for Experimentation

Selection of asphalt mixture plants and construction projects was coordinated with the Texas Department of Highways and Public Transportation,

TABLE 1. MOISTURE-TEMPERATURE EXPERIMENT DESIGN

Asphalt Mixture Mixing Temp.* °F	Cold Feed Aggregate Moisture Content		
	Dry	Wet	Saturated
175	x	x	x
225	x	x	x
250	x	x	x
275	x	x	x
325	x	x	x

* The mixing temperatures in one of the experiments were changed to 200, 250 and 325°F.

the Texas Hot Mix Pavement Association, and individual hot mix contractors. The Texas Hot Mix Pavement Association provided a list of contractors who were interested in the objectives of this study and were willing to participate. After identifying suitable highway projects the proposed experimentation was discussed with the Highway Department district staff and the contractor. On State Highway projects the Highway Department and the Federal Highway Administration permitted the experimentation to be done as part of the contract.

The plant locations used for experimentation are shown in Figure 1. At Alice and Mathis the asphalt plants were producing asphalt concrete for specific contracts on two sections of Interstate Highway 37. The third plant site at Austin produced material for a variety of miscellaneous Highway Department projects and a City of Austin project.

Materials

Three asphalt mix designs were used. The major component for the two designs from the Corpus Christi Highway District (Alice and Mathis) was sandstone, and for the third, from Austin, was hard limestone. The individual aggregates in each of the mix designs and the gradations of the mixtures are shown in Table 2 and Figure 2, respectively. The asphalt cement used for all projects was an AC-10. Both of the Corpus Christi mixtures were susceptible to moisture damage and as part of the contract work a 1 percent hydrated lime slurry was sprayed on the coldfeed belt.

Sampling Program

Samples of both asphalt mixture and uncoated aggregate were gathered during each experimental run. The asphalt mixture was shovelled from a truck after the material had been mixed at the desired temperature. Approximately 200 pounds was gathered and carried to the field laboratory for specimen preparation.

Uncoated aggregate samples were gathered to determine aggregate moisture contents at key points in the plant processing (Fig 3). Samples of individual aggregates were taken from the feedbelts on the coldfeed bins and a sample of the combined mixture was taken from the coldfeed conveyor belt.

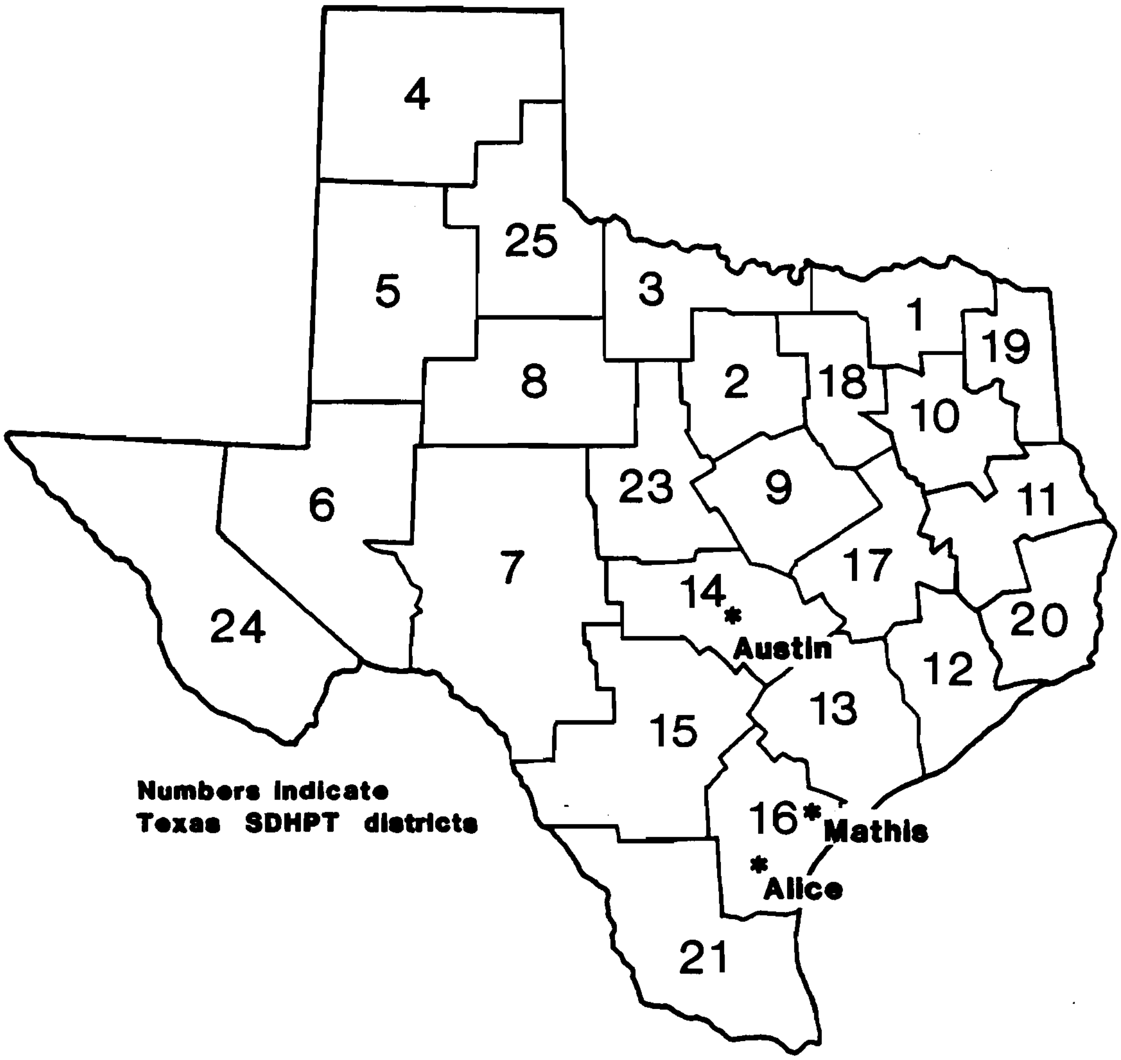


Fig 1. Location of asphalt plants used for experimentation.

TABLE 2. LOCATION AND DESCRIPTION OF AGGREGATE MIXTURES

Aggregate	Asphalt Plant				Aggregate		
(District*)	Owner	Location	Type	Design	Type	Producer	Source
Aggregate A (14, Austin)	Capital Aggregates	Austin	Drum/ Batch	Type D**	Crushed sandstone	Delta Rock	Marble Falls
					Crushed limestone	Zachary Aggregates	Georgetown
					Limestone screenings	Zachary Aggregates	Georgetown
					Field sand	Capital Aggregates	Austin
Aggregate B (16, Corpus Christi)	South Texas Construction	Mathis	Batch	Type D**	Crushed sandstone	South Texas Const.	Tuleta
					Limestone screenings	McDonough Brothers	New Braunfels
					Field sand	South Texas Const.	Mathis
Aggregate C (16, Corpus Christi)	Heldenfel Brothers	Alice	Drum	Type D**	Crushed sandstone	Heldenfel Brothers	Whitley Property
					Sandstone screenings	Heldenfel Brothers	Whitley Property
					Field sand	Heldenfel Brothers	Freeborn Property

* Texas State Department of Highways and Transportation (SDHPT) Districts

** Designation of Texas SDHPT, 1/2" maximum size aggregate

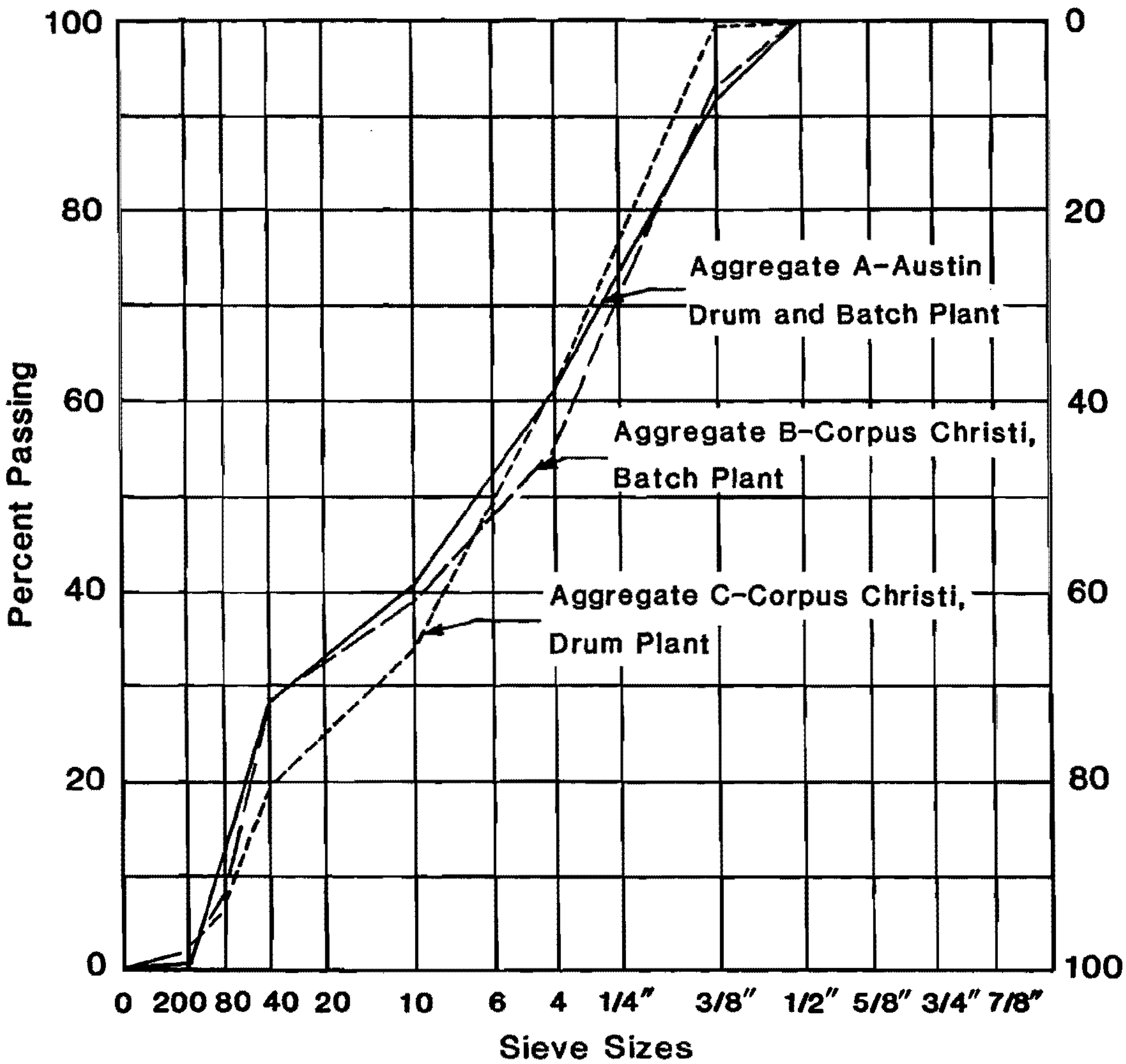


Fig 2. Design gradation of asphalt mixtures.

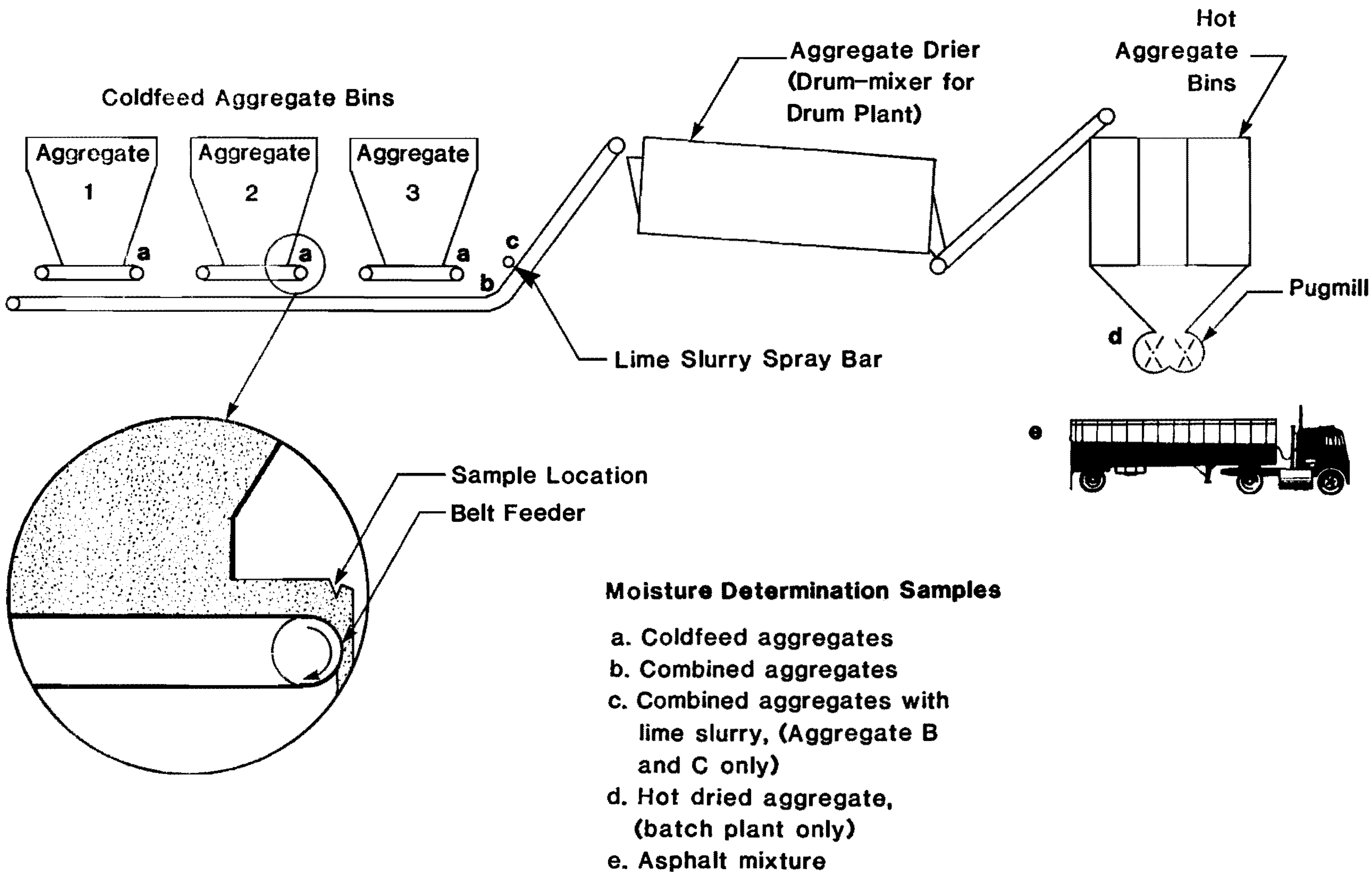


Fig 3. Locations of moisture content sampling.

Specimen Preparation and Conditioning

Specimens, 2-inch high by 4-inch diameter briquets, were molded using a Texas Gyratory Shear compactor. Three compaction procedures were used and are referred to as standard, modified-standard, and modified. The standard compaction specimens were prepared using the standard procedures of the Texas Department of Highways and Public Transportation in which the mixture was compacted at 250°F (Ref 2). The modified-standard compaction specimens were prepared using the same method with the exception of the compaction temperature which was not changed from the plant mixing temperature. The modified compaction specimens were prepared at the plant mixing temperature to a target density of 7 percent air voids.

Two conditioning methods were applied to each of the specimens. Dry-conditioned specimens were stored at room temperature for several days and wet-conditioned specimens were vacuum saturated under 26-inch mercury vacuum, placed through a freeze-thaw cycle, then tested at room temperature.

Testing Program

The testing program used for each of the experiments is shown in Table 3.

TEST METHODS

The three basic test methods used were the Hveem stability test, the static and repeated-load indirect tensile tests, and the Texas Boiling Test.

Hveem Stability Test

Hveem stabilities were determined using the Hveem stabilometer (Fig 4) as described in Tex-208-F (Ref 2). Compacted asphalt mixture specimens 2 inches high by 4 inches diameter are loaded at 140°F at a constant strain rate of 0.05 inches per minute to a maximum vertical load of 5,000 pounds. The horizontal force is measured as a pressure on the stabilometer wall and is used to calculate the Hveem stability.

TABLE 3. TESTING PROGRAM FOR MOISTURE-TEMPERATURE EXPERIMENTS

Standard Compaction Specimens*

Dry Conditioned	Freeze-Thaw Conditioned
Indirect Tensile Test	Indirect Tensile Test
Hveem Stability	

Modified-Standard Compaction Specimens**

Dry Conditioned	Freeze-Thaw Conditioned
Indirect Tensile Test	Indirect Tensile Test
Hveem Stability	

Modified Compaction Specimens***

Dry Conditioned	Freeze-Thaw Conditioned
Indirect Tensile Test	Indirect Tensile Test
Hveem Stability	

Bulk Specimens (including asphalt mixture and aggregates)

- Moisture content determination
- Texas Boiling Test
- Asphalt Extraction
- Aggregate Gradation
- Penetration of extracted asphalt
- Viscosity of extracted asphalt
- Theoretical specific gravity of mixture

* Standard - Standard DHT test method at 250°F

** Modified-Standard - Standard DHT test method at plant temperature

*** Modified (7% air) - Modified DHT test method at plant temperature

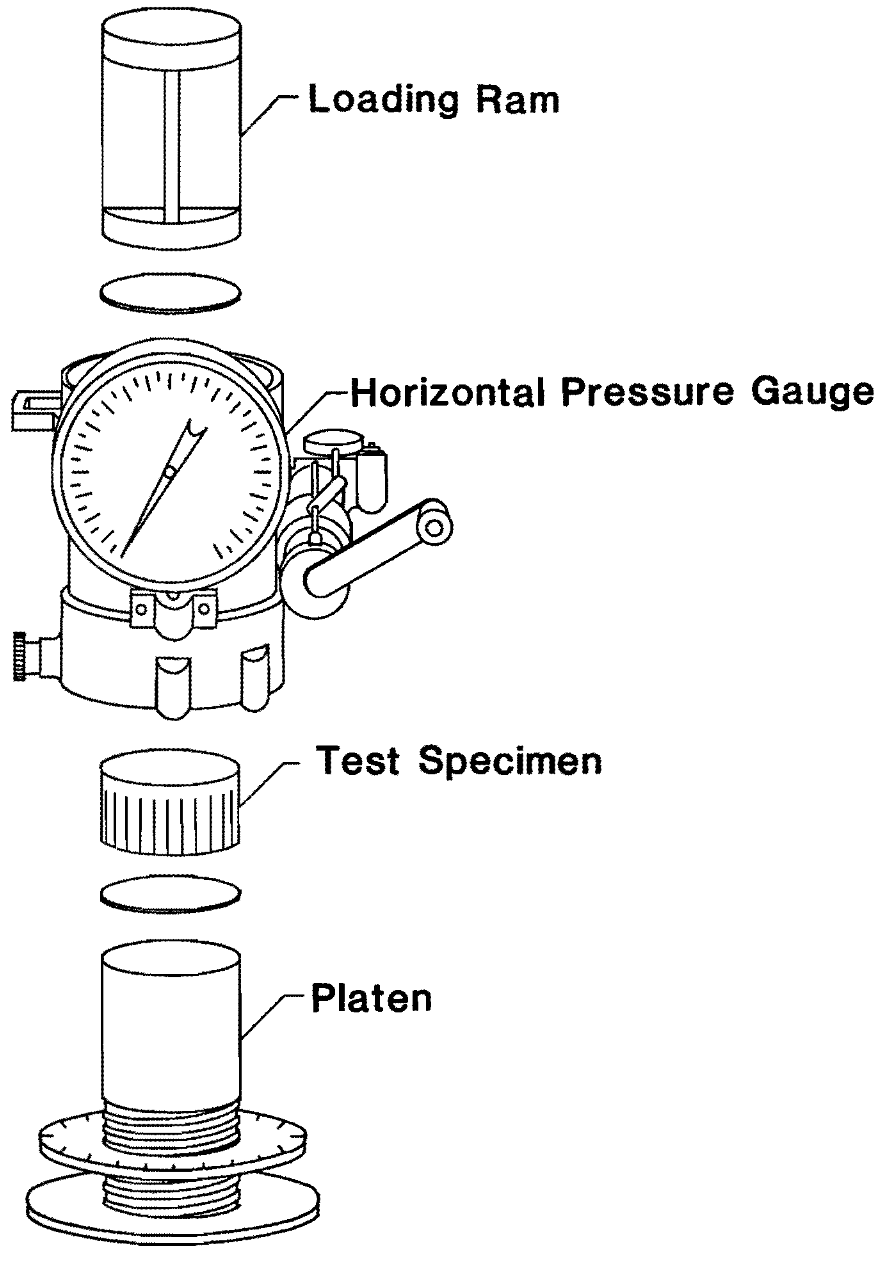


Fig 4. Exploded view of Hveem stabilometer.

Static Indirect Tensile Test

The indirect tensile test, which estimates the tensile strength of the asphalt mixtures, used the following equipment and procedures.

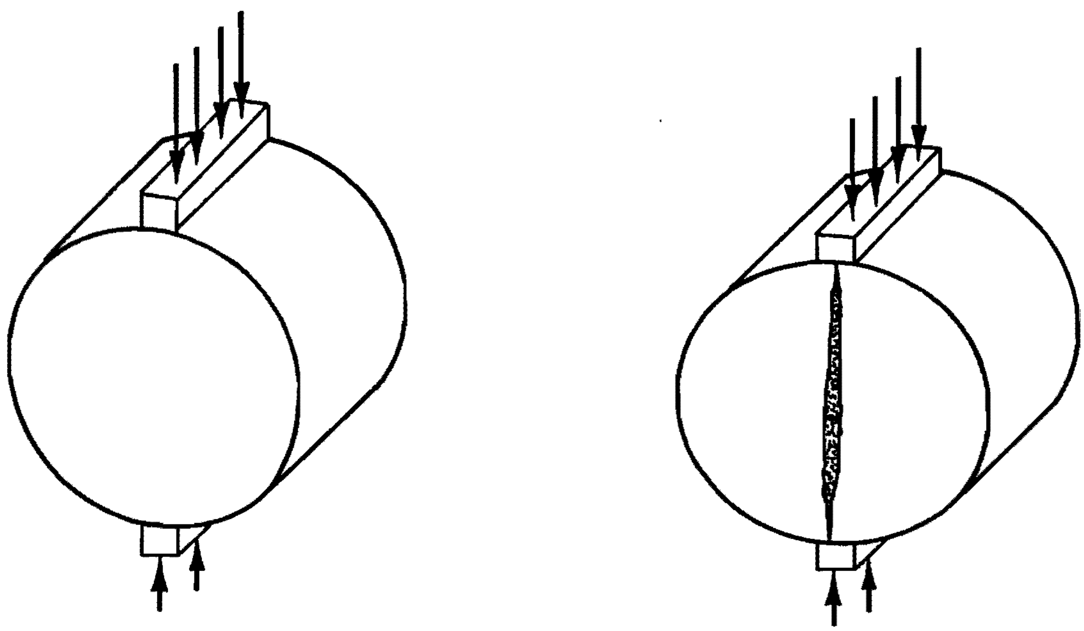
A cylindrical specimen was loaded with a compressive load acting parallel to and along the vertical diametrical plane (Fig 5a). The load, which was distributed through 0.5-inch wide steel loading strips curved to fit the specimen, produced a fairly uniform tensile stress perpendicular to the plane of the applied load. The specimen ultimately failed by splitting along the vertical diameter (Fig 5b). An estimate of the tensile strength was calculated from the applied load at failure and the specimen dimensions.

The test equipment included a loading frame, loading head, and an MTS closed-loop electrohydraulic system to apply load and control the deformation rate. The loading head was a modified commercially available die set with the lower platen fixed and the upper platen constrained so that both platens remained parallel. The curved stainless steel loading strips were attached to both the upper and lower platens (Ref 3).

Repeated-Load Indirect Tensile Test

To determine the resilient modulus of elasticity, the repeated-load indirect tensile test was used in which approximately 20 percent of the static failure load was applied repeatedly to the specimen using the static indirect tensile test equipment (Ref 4). A small preload was applied to the specimens to prevent impact loading and to minimize the effect of seating the loading strip; then the repeated load was added.

The load-vertical deformation and load-horizontal deformation relationships were recorded by a pair of X-Y plotters while the load was applied at a frequency of one cycle per second (1 Hz) with a 0.2-second load duration and a 0.8-second rest period. A typical load pulse and the resulting deformation relationships are shown in Figures 6 and 7. All tests were conducted at 75°F.



(a) Compressive load being applied. (b) Specimen failing in tension.

Fig 5. Indirect tensile test loading and failure.

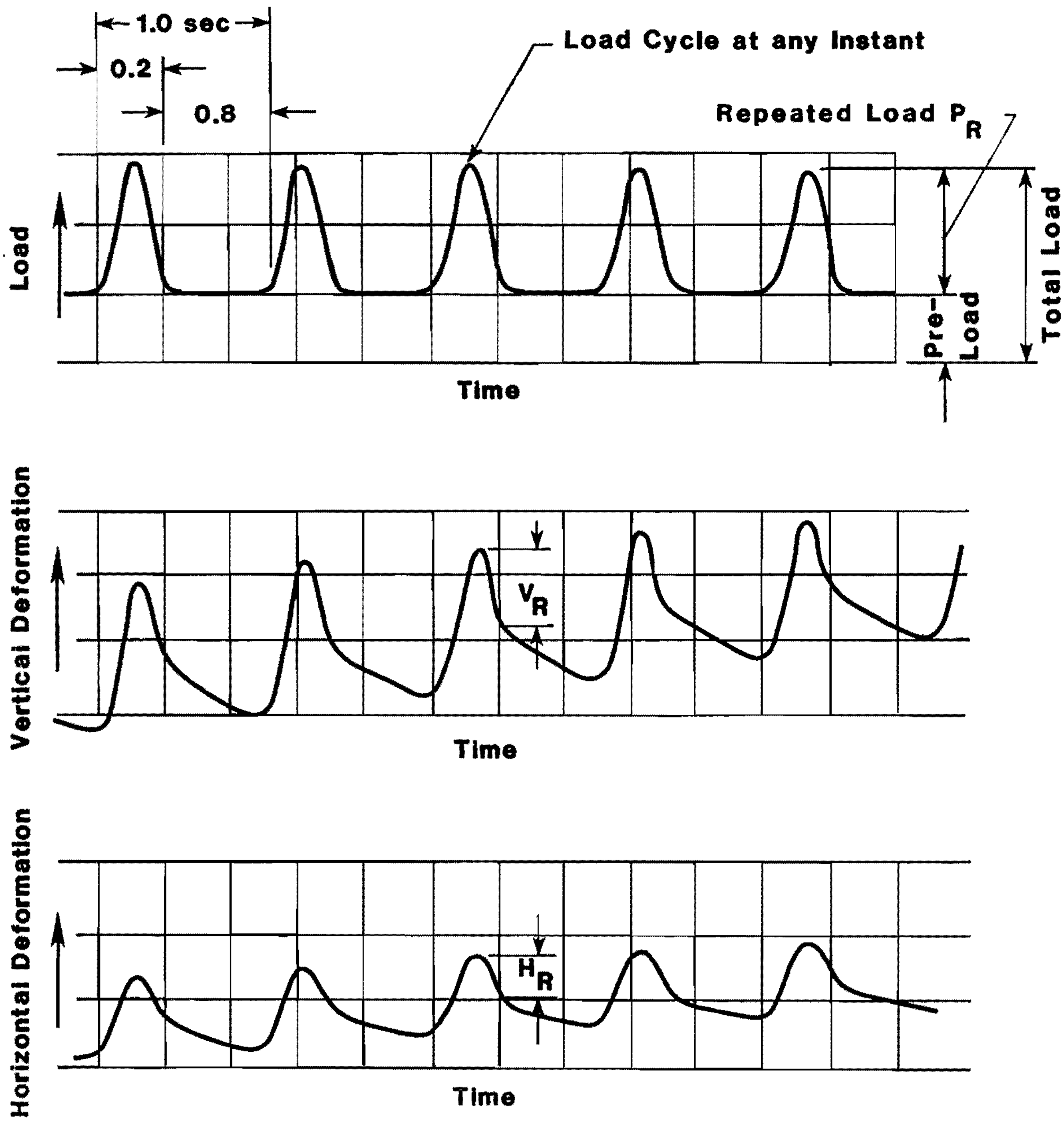


Fig 6. Typical load pulse and deformation-time relationships for the repeated-load indirect tensile test.

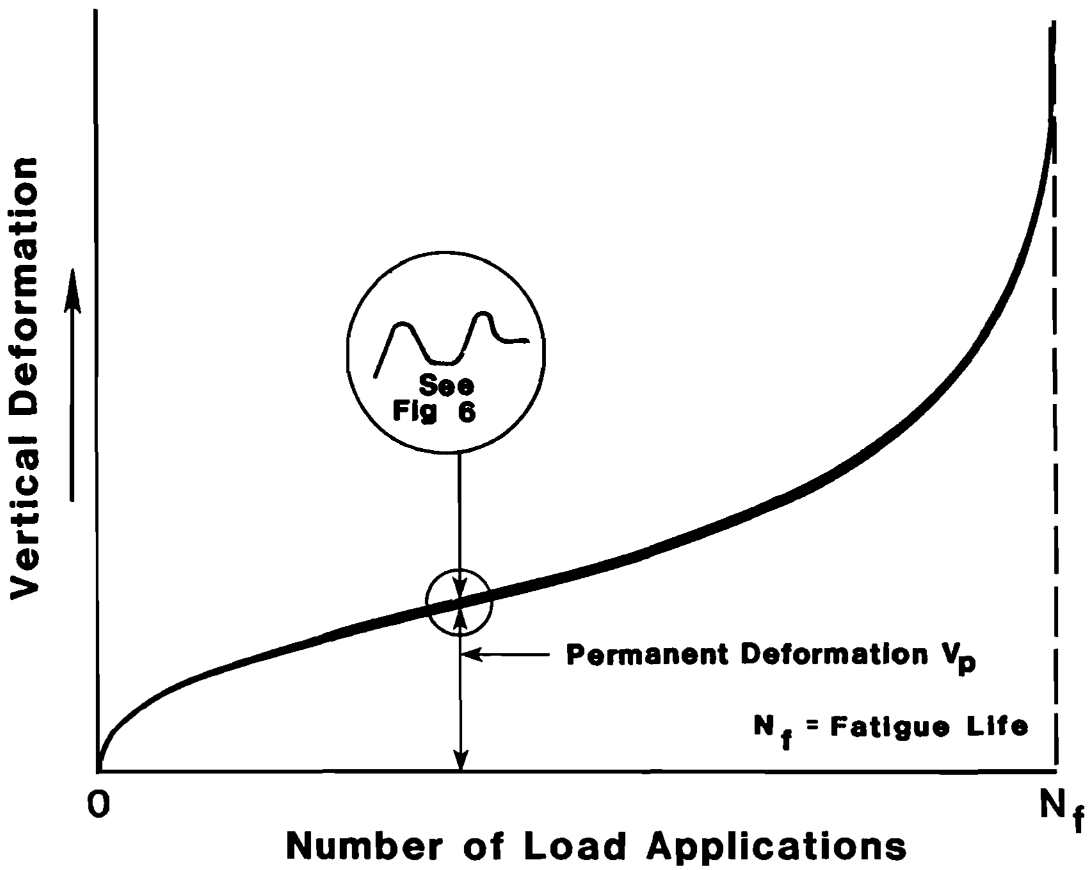


Fig 7. Typical permanent deformation curve for repeated-load indirect tensile test.

Texas Boiling Test

The Texas Boiling Test* is a rapid method to evaluate the moisture susceptibility or stripping potential of aggregate-asphalt mixtures (Ref 5). In this test a visual observation was made of the extent of stripping of the asphalt from aggregate surfaces after the mixture has been subjected to the action of boiling water for a specified time.

A 1,000 ml beaker was half filled with distilled water, was heated to boiling, and an approximate 200-gram sample of the aggregate-asphalt mixture was added to the boiling water, then boiled for 10 minutes. The mixture was allowed to cool to room temperature while still in the beaker. After cooling, the water was drained from the beaker and the wet mixture was emptied onto a paper towel and allowed to dry. The amount of stripping was determined by a visual rating, expressed in terms of the percent of asphalt retained (scale 0 to 100 percent retained).

Other Tests

Other tests used on asphalt mixtures which were conducted according to standard methods of the Texas State Department of Highways and Public Transportation (Ref 2) and ASTM (Ref 6) included:

- Asphalt extraction, Tex-210-F, to determine percent asphalt binder.
- Asphalt recovery by the Abscon process, Tex-211-F, to recover extracted asphalt.
- Asphalt penetration and viscosity, Tex-502-C and Tex-528-C, of the extracted asphalt.
- Sieve analysis, Tex-200-F, of the aggregate recovered from the asphalt extraction.
- Theoretical maximum specific gravity, ASTM 2041, the specific gravity of the asphalt-coated aggregate.
- Bulk specific gravity of compacted specimens, Tex-207-F.
- Compacting test specimens of asphaltic mixtures, Tex-206-F.

Moisture content determinations of the coated and uncoated aggregate were performed by drying to constant weight at 250°F.

*Procedure differed from the procedure currently specified by SDHPT.

ENGINEERING PROPERTIES ANALYZED

The testing program was designed to achieve two objectives: measure the controlled variables and outputs of the experiment and monitor other variables which could not be controlled. The properties analyzed were Hveem stability, tensile strength, resilient modulus of elasticity, tensile strength ratio, and Boiling test values.

Hveem Stability

The equation for calculating the Hveem stability was

$$S = \frac{22.2}{\frac{P_h D_2}{P_v - P_h} + 0.222}$$

where

S = Hveem stability, %,

P_v = vertical pressure, psi,

P_h = horizontal pressure, psi, and

D_2 = displacement of specimen, tenths of an inch.

Tensile Strength

Tensile strength is the maximum tensile stress which the specimen can withstand. Using the load-deformation information obtained from the static indirect tensile test, the following relationship can be used to calculate tensile strength for 4-inch diameter specimens:

$$S_T = \frac{0.156P}{t}$$

where

S_T = tensile strength, psi,

P = the maximum load carried by the specimen, lb, and

t = thickness or height of the specimen, in.

Tensile Strength Ratio

To evaluate the moisture susceptibility of the experimental mixtures an additional parameter, the tensile strength ratio, was used. The tensile strength ratio, TSR, is defined as follows:

$$TSR = \frac{S_{T_{wet}}}{S_{T_{dry}}}$$

where

$S_{T_{wet}}$ = tensile strength of the wet-conditioned specimen, psi,

and

$S_{T_{dry}}$ = tensile strength of the dry-conditioned specimen, psi.

Resilient Modulus of Elasticity

The resilient modulus of elasticity was calculated using the resilient, or instantaneously recoverable, horizontal and vertical deformations after 300 applied load cycles. The equation used to calculate the resilient modulus was

$$E_R = \frac{P_R}{t\ H_R}(0.27 + \nu_R)$$

where

E_R = resilient modulus of elasticity, psi,

P_R = the applied repeated load, lb (Fig 6),

t = specimen thickness,

H_R = horizontal resilient deformation, and

ν_R = resilient Poisson's ratio.

The value of ν_R was calculated using the following equation:

$$\nu_R = 3.59\frac{H_R}{V_R} - 0.27$$

where

V_R = vertical resilient deformation, and

H_R = horizontal resilient deformation.

CHAPTER 3. PRESENTATION OF EXPERIMENTAL RESULTS

The primary objective of this study was to determine the effects of mixing temperature and stockpile moisture content on various engineering properties of asphalt mixtures including Hveem stability, tensile strength, resilient modulus of elasticity, tensile strength ratio, and asphalt retained after the Texas boiling test. In the experiment design only mixing temperature and stockpile moisture content were to be varied; however, other mixture parameters were found to change during field production of the experimental mixtures and analysis of the results was complex. An initial attempt was made to analyze the data using various statistical methods. These methods, however, did not yield useful results and a decision was made to abandon the use of regression and analysis of variance with consideration of covariates as analytical tools. Instead, the uncontrolled variables were examined individually to determine if each was likely to cause a significant effect on the experiment results.

UNCONTROLLED VARIABLES

The uncontrolled variables which varied during the experiment were moisture in the asphalt mixture, voids in the mineral aggregate, air voids, asphalt content, and asphalt penetration.

Stockpile Moisture Content

Although the stockpile moisture contents were controlled qualitatively as dry, wet, and saturated, the actual moisture contents were dependent on the type of aggregate, the atmospheric conditions, the length of time the experiment was conducted, and the technique used to introduce moisture.

The stockpile moisture content for each experimental run (Fig 8) is the moisture content of the combined aggregates entering the drier or the drum mixer. The values for Aggregate C include a lime slurry sprayed on the cold-feed belt. Aggregate B also was treated with a lime slurry; however, since field measurement was not possible, the moisture added by the slurry was estimated and included in the results.

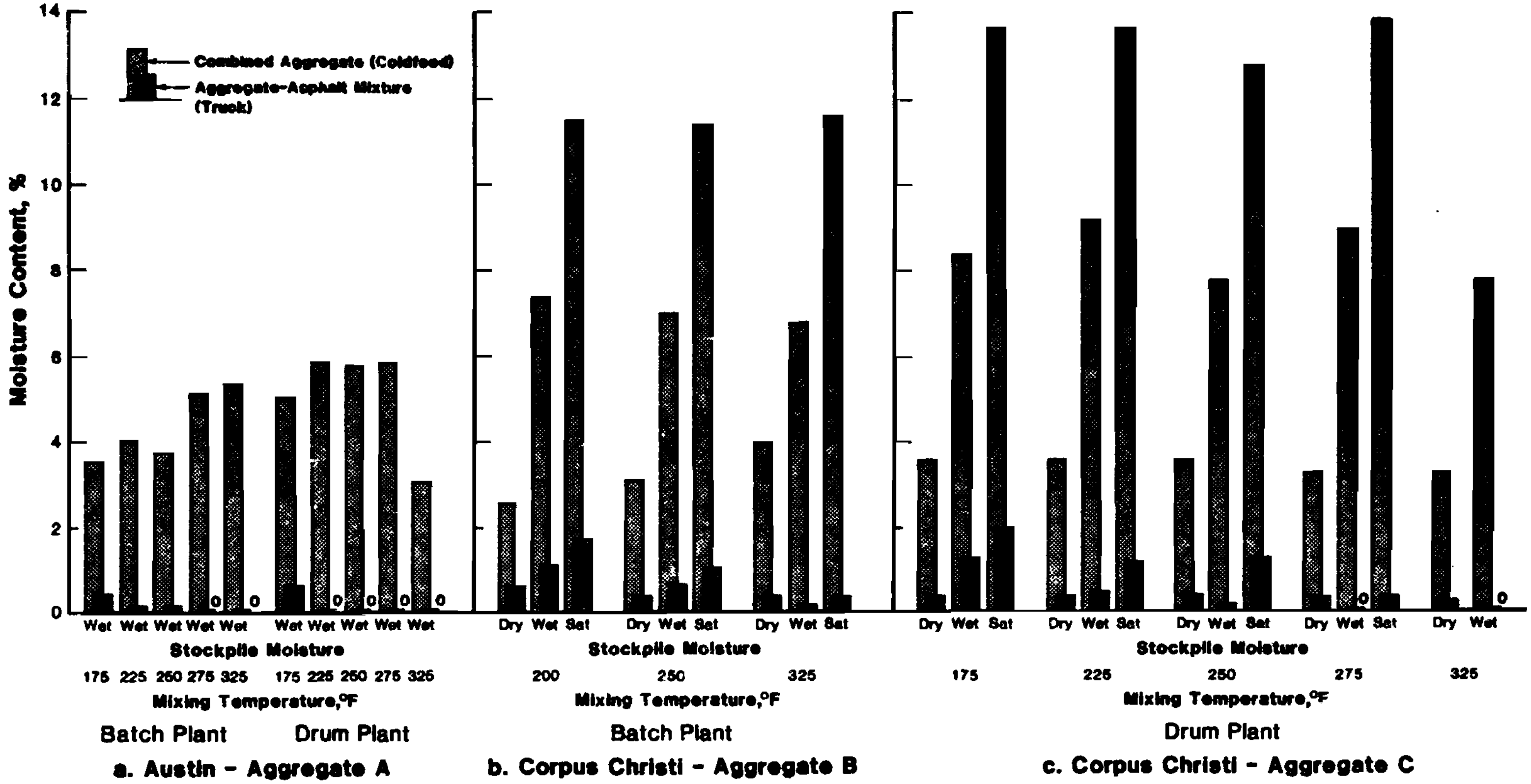


Fig 8. Relationship between mixing temperatures and asphalt mixture moisture contents.

Within each aggregate type the moisture contents for the three stockpile moisture conditions were relatively uniform except for Aggregate A. This aggregate was used at the stockpile moisture content and the variation of these contents is attributable to the long (9 month) interval during which the runs were done.

Aggregates B and C are sandstone mixtures from the same geologic source. Within each aggregate mixture the moisture contents are relatively uniform for each stockpile moisture condition; however, Aggregate C tends to have somewhat higher contents. This difference is attributed to the method of wetting the aggregates. Aggregate B was saturated by spraying with water delivered from the spray bar of a water truck while Aggregate C was wetted by soaking with a garden hose for approximately eight hours.

The saturated moisture contents, determined by soaking a nominal 1000-gram sample under water for 24 hours and allowing it to drain for 30 minutes, of each stockpiled component and of the total mixture are shown in Table 4. The relative saturation or the moisture content expressed as a percentage of the saturated moisture contents is shown in Figure 9. The higher moisture content of Aggregate C plus its lower saturated moisture content combine to produce the higher levels of relative saturation than for Aggregate B.

Moisture in the Asphalt Mixture

Generally the moisture content of the asphalt mixtures was less than about 0.5 percent, especially for the nonporous Aggregate A. Nevertheless, the moisture content of the asphalt mixture was influenced by the stockpile moisture content, the mixing temperature, and the aggregate porosity (Fig 8).

As expected, the moisture content increased with increased stockpile moisture, decreased as mixing temperature increased, and was higher for Aggregates B and C which were more porous than Aggregate A. During the experimental runs the stockpile moisture content and the mixing temperature were controlled and no attempt was made to produce a given asphalt mixture moisture. Thus, all tests were conducted on prepared specimens in which the moisture content had achieved equilibrium. The amount of moisture which escaped from the specimens was not known; however, some moisture was believed to have remained trapped in the specimen at the time of testing.

TABLE 4. SATURATED AGGREGATE MOISTURE CONTENTS

Aggregate	Saturated Moisture Content* %
Aggregate A	
Sandstone	5.4
Limestone	6.8
Limestone screenings	20.0
Field sand	25.5
Aggregate mixture	11.8
Aggregate B	
Sandstone	12.5
Limestone	16.1
Sandstone screenings	26.5
Field sand	22.7
Aggregate mixture	16.7
Aggregate C	
Sandstone	4.7
Sandstone screenings	19.1
Field sand	19.6
Aggregate mixture	10.0**

* Moisture content after soaking for 24 hours and draining 30 minutes.

** Estimated from saturated moisture contents of individual aggregates.

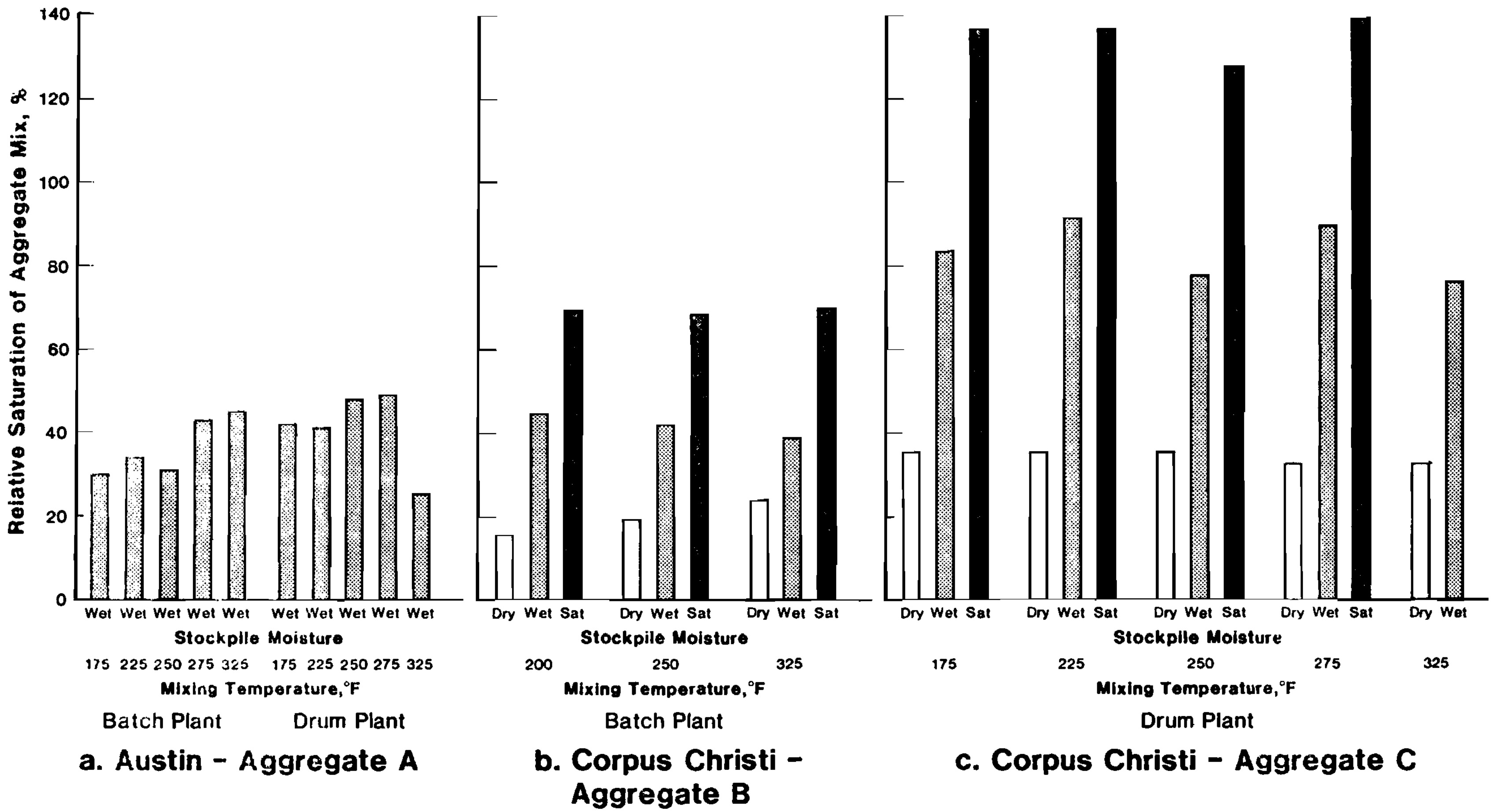


Fig 9. Relative saturation of the aggregate mixture for experimental runs.

Specimen Density

Voids in the Mineral Aggregate (VMA). Density was evaluated in terms of voids in the mineral aggregate since the specific gravities of the various aggregates differed and the asphalt contents for the mixtures also differed. The average VMA's of the specimens for each experimental condition are shown in Figures 10, 11, and 12 for standard, modified-standard, and modified compacted specimens, respectively. The variation in VMA was relatively small for a given compaction procedure and thus it is felt that density probably did not have a significant effect on the test results. Differences did occur, however, for the various compaction procedures.

Air Voids. The air voids in each of the molded specimens were affected by the combination of VMA and asphalt content in the compacted mixture. If the asphalt content among separate specimens is the same, the air voids will vary only with the VMA and as such will be a measure of density.

The air voids for individual compacted samples were calculated using the bulk specific gravity of the specimen and the theoretical specific gravity of the aggregate asphalt combination as determined by the Rice method (ASTM 2041). The average for each of the compaction types is presented in Figures 13, 14, and 15 for standard, modified-standard, and modified compaction specimens, respectively. The variation in air void content observed for the various experimental runs is representative of the variation in density. Within each group of compacted specimens this change did not have a significant effect on the test results.

Asphalt Content

An attempt was made to maintain the asphalt content at the design percentage for each experimental run. Aggregate moisture contents were measured and adjustments were made to the amount of asphalt added to compensate for the amount of water in the coldfeed aggregate; however, the extracted asphalt contents were found to vary considerably (Fig 16). The asphalt contents for Aggregate C were generally much higher than for Aggregates A and B. Later work indicated that the samples which were being used for extraction contained some moisture, producing erroneously high asphalt contents. Corrections to the testing procedure were made for the

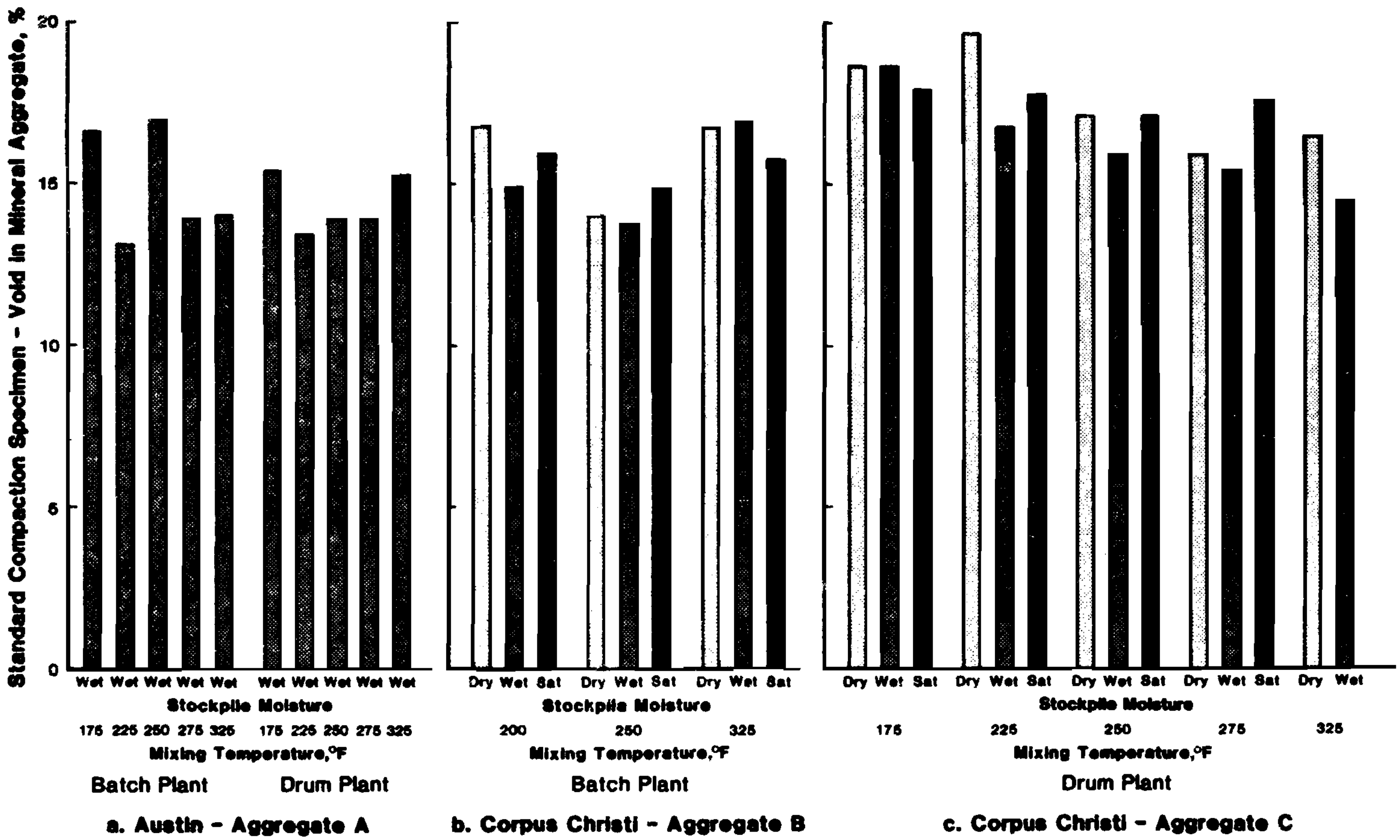
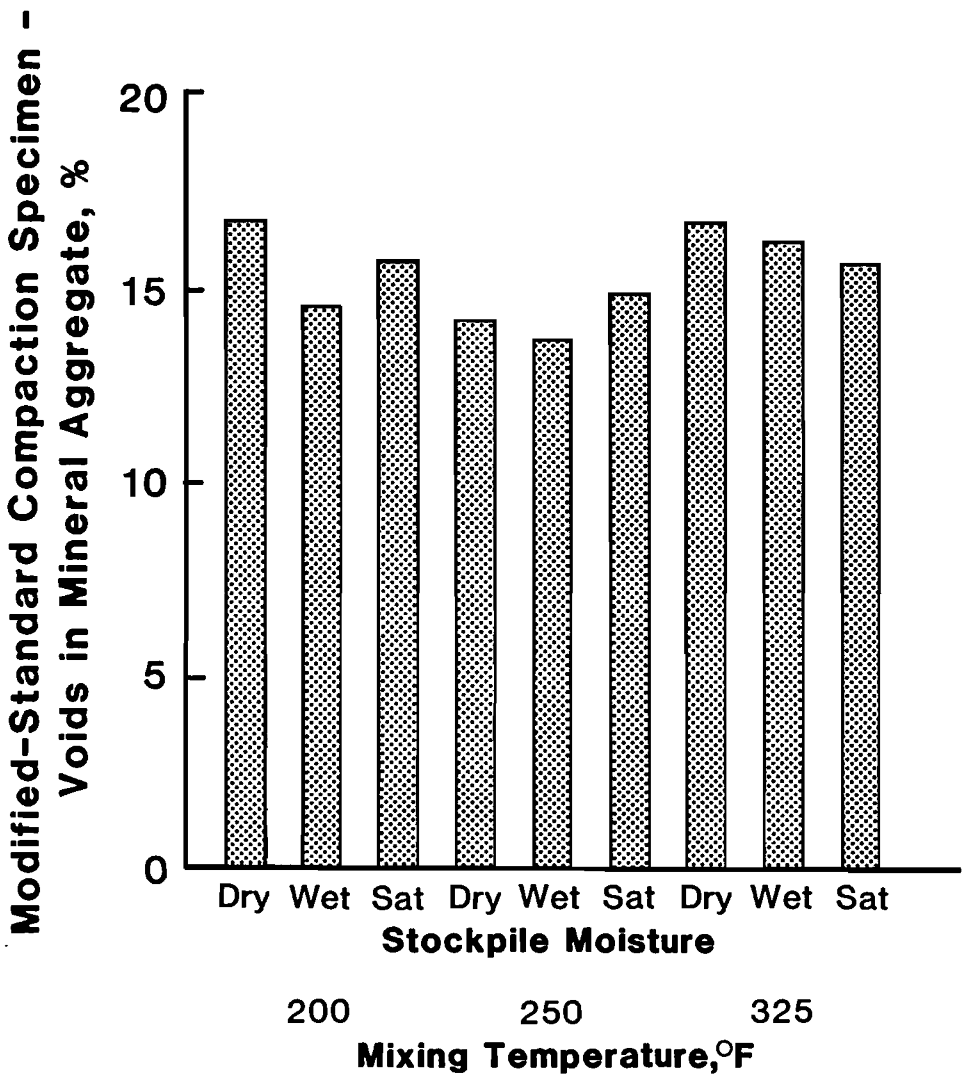


Fig 10. Standard compaction specimens, voids in the mineral aggregate.



b. Corpus Christi - Aggregate B

Fig 11. Modified-standard compaction specimens, voids in the mineral aggregate.

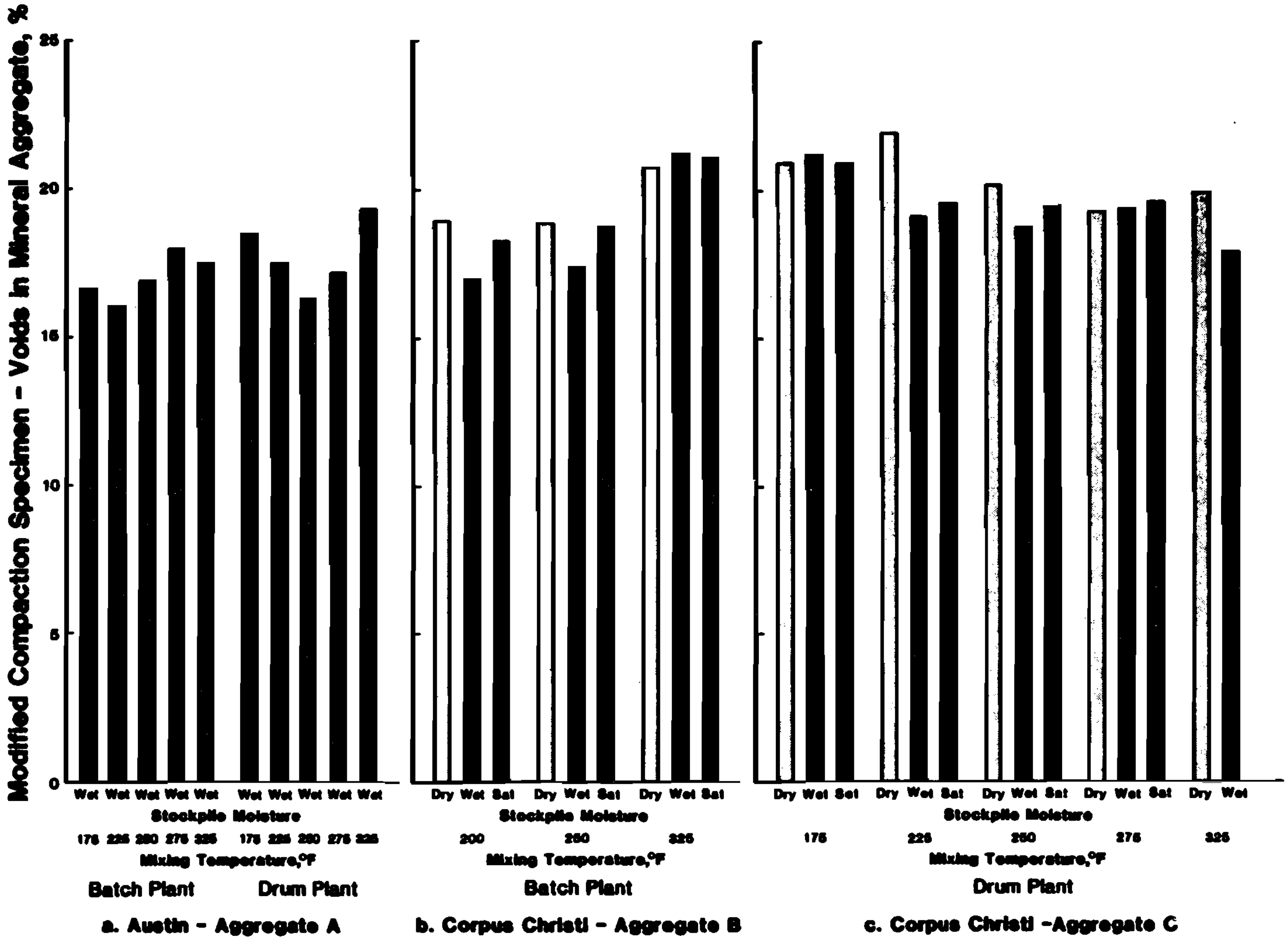


Fig 12. Modified compaction specimens, voids in the mineral aggregate.

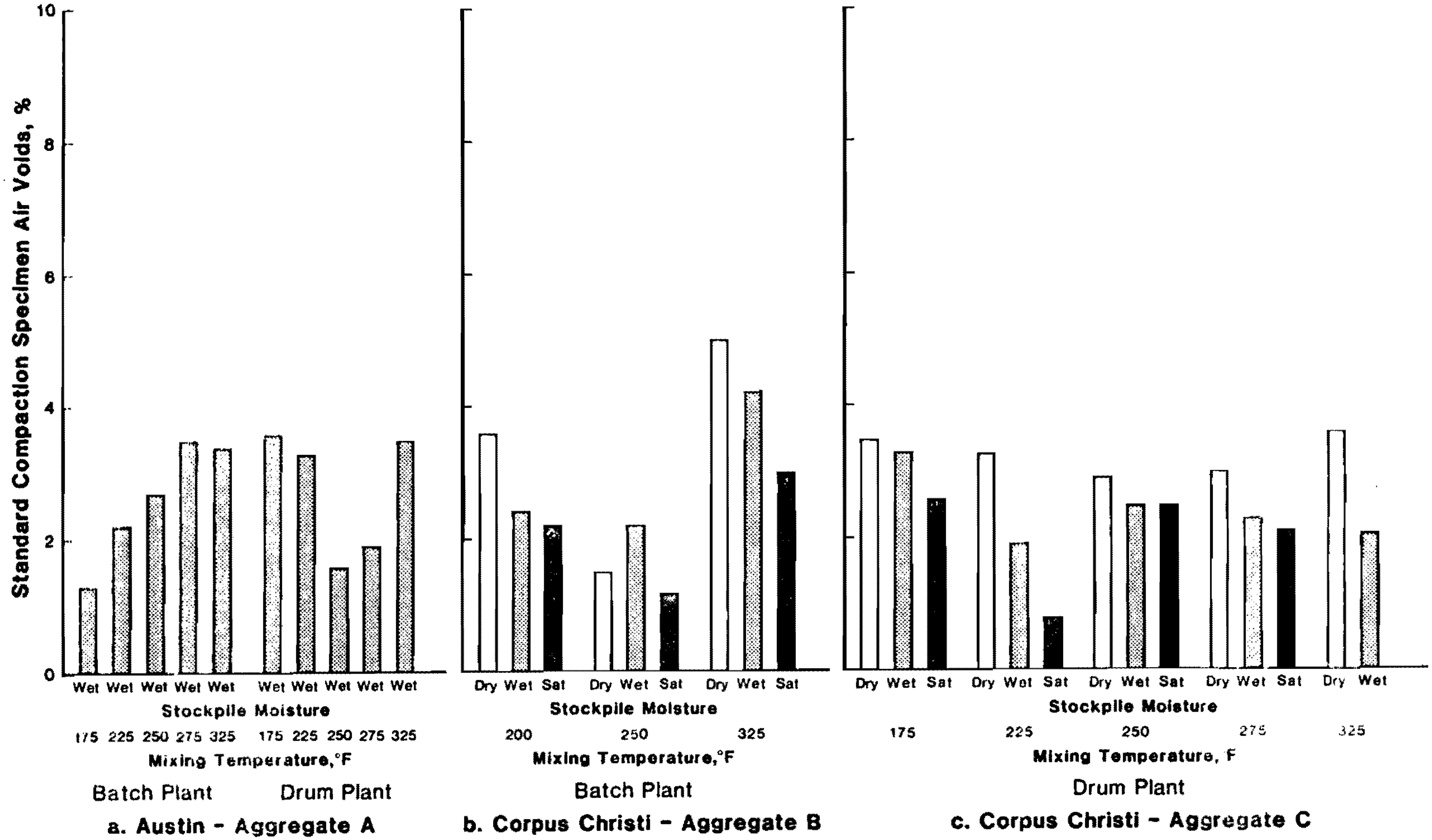


Fig 13. Standard compaction specimens, air voids.

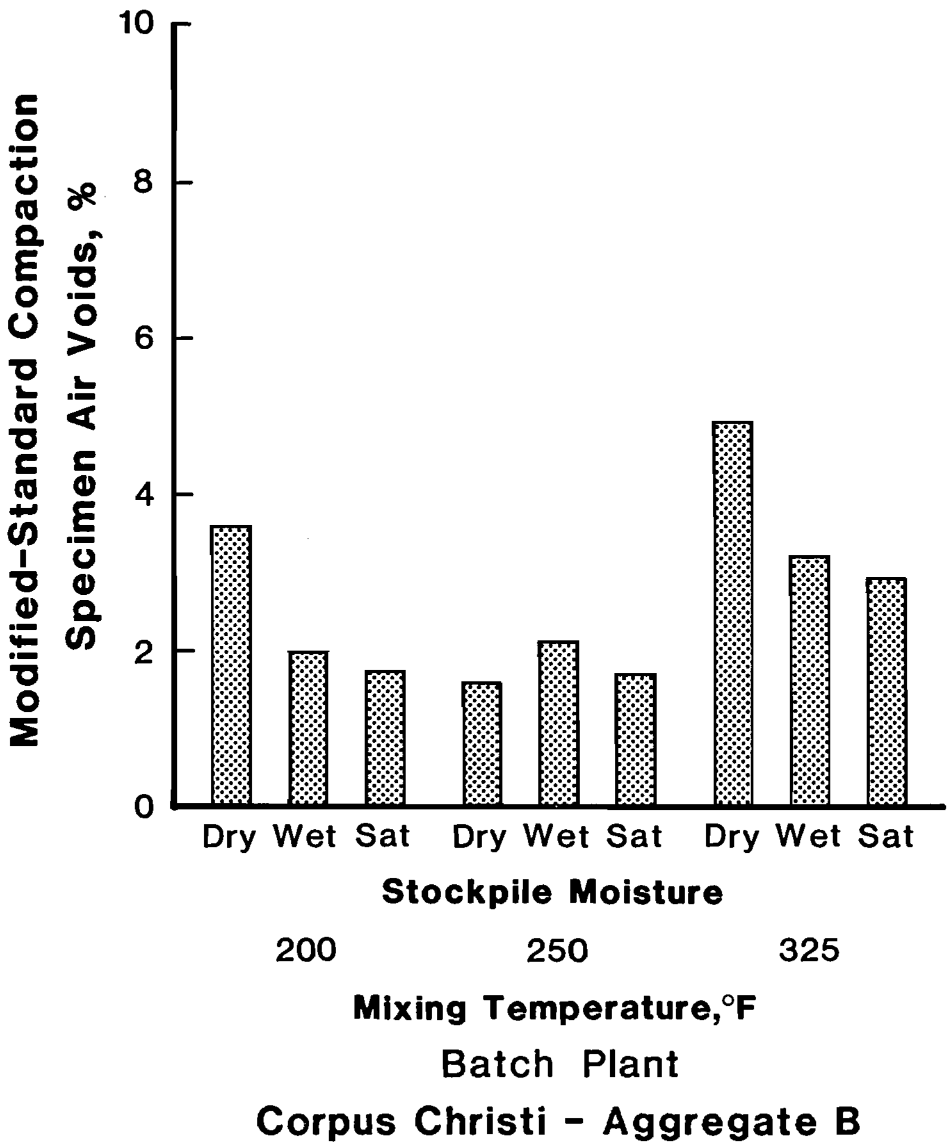


Fig 14. Modified-standard compaction specimens, air voids.

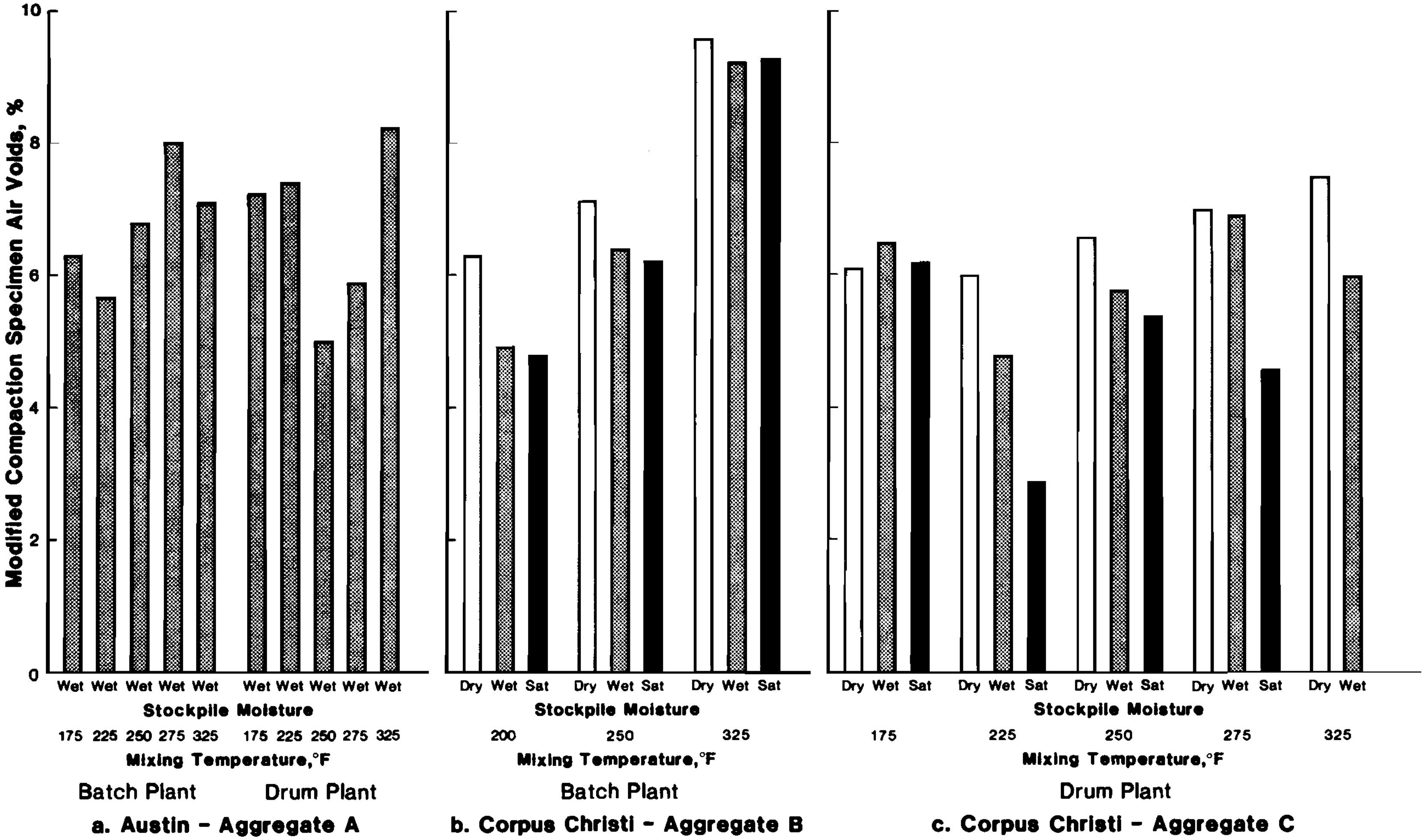


Fig 15. Modified compaction specimens, air voids.

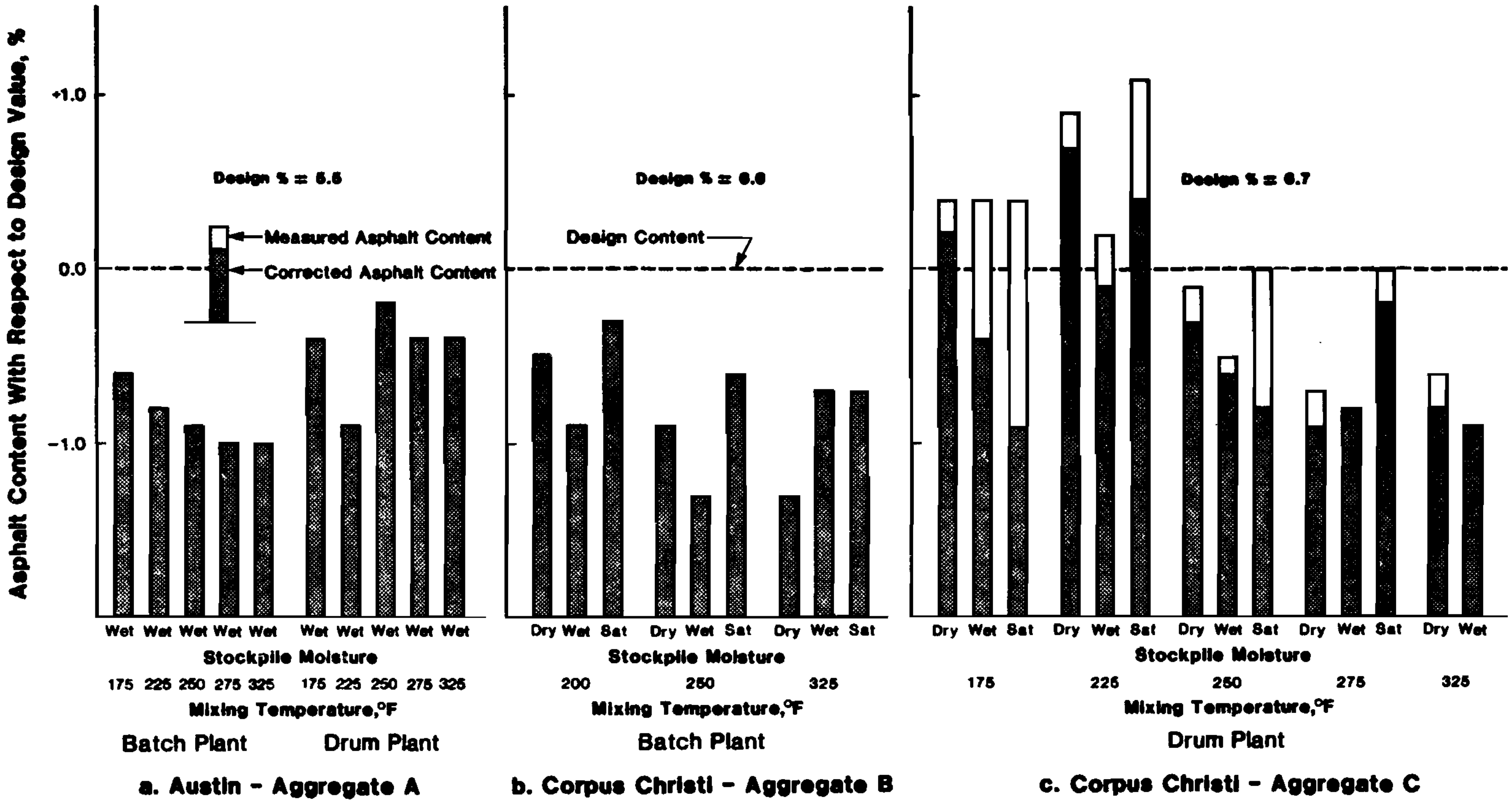


Fig 16. Asphalt content variations in experimental runs.

experimental runs in Aggregate B, the last experiment done, hence the error is not present. Also, the asphalt contents for Aggregate A are believed to be accurate despite the testing procedure because of the relative imperviousness of the aggregate. Therefore Aggregate C appears to be the only experiment affected by the non-dry samples.

The daily plant testing done by Texas SDHPT on non-experimental mixtures indicated that the asphalt contents varied ± 0.1 percent from the design. Thus, there is no evidence to indicate that the plant calibration was not accurately supplying the proper asphalt volume. If the actual experimental asphalt contents were varying as indicated then the most probable occurrence would have been non-uniformity of moisture contents in the stockpiles, yet the results determined for the wet stockpile conditions varied even though the stockpiles had not changed. Unfortunately, state personnel did not test any of the experimental mixtures and a direct comparison of extraction results cannot be made.

Thus, a correction was made for moisture in the extraction sample which was assumed to be equal to 75 percent of the asphalt mixture moisture content. The resulting corrected asphalt contents for Aggregate C are at least closer to the actual values (Fig 16).

Based on the consideration given to asphalt contents as discussed above, it is felt that an experimental error of undeterminable origin has entered the indicated asphalt contents of the experimental mixtures and that the actual contents were approximately equal to the design value. Therefore, asphalt content will be treated as a constant throughout the analysis of experiment results which will follow.

Extracted Asphalt Penetration

The penetration of the extracted asphalt was measured to determine the amount of hardening which had occurred under the experimental conditions. Results indicate that the amount of asphalt hardening was not significantly affected within the range of mixing temperatures studied (Fig 17). However, the higher mixing temperatures did cause somewhat more hardening. This trend, evident in the Aggregate A batch plant mixtures, is suggested for the Aggregate B mixtures. The high penetration of the asphalt extracted from the two low mixing temperatures of Aggregate A are not caused by the mixing

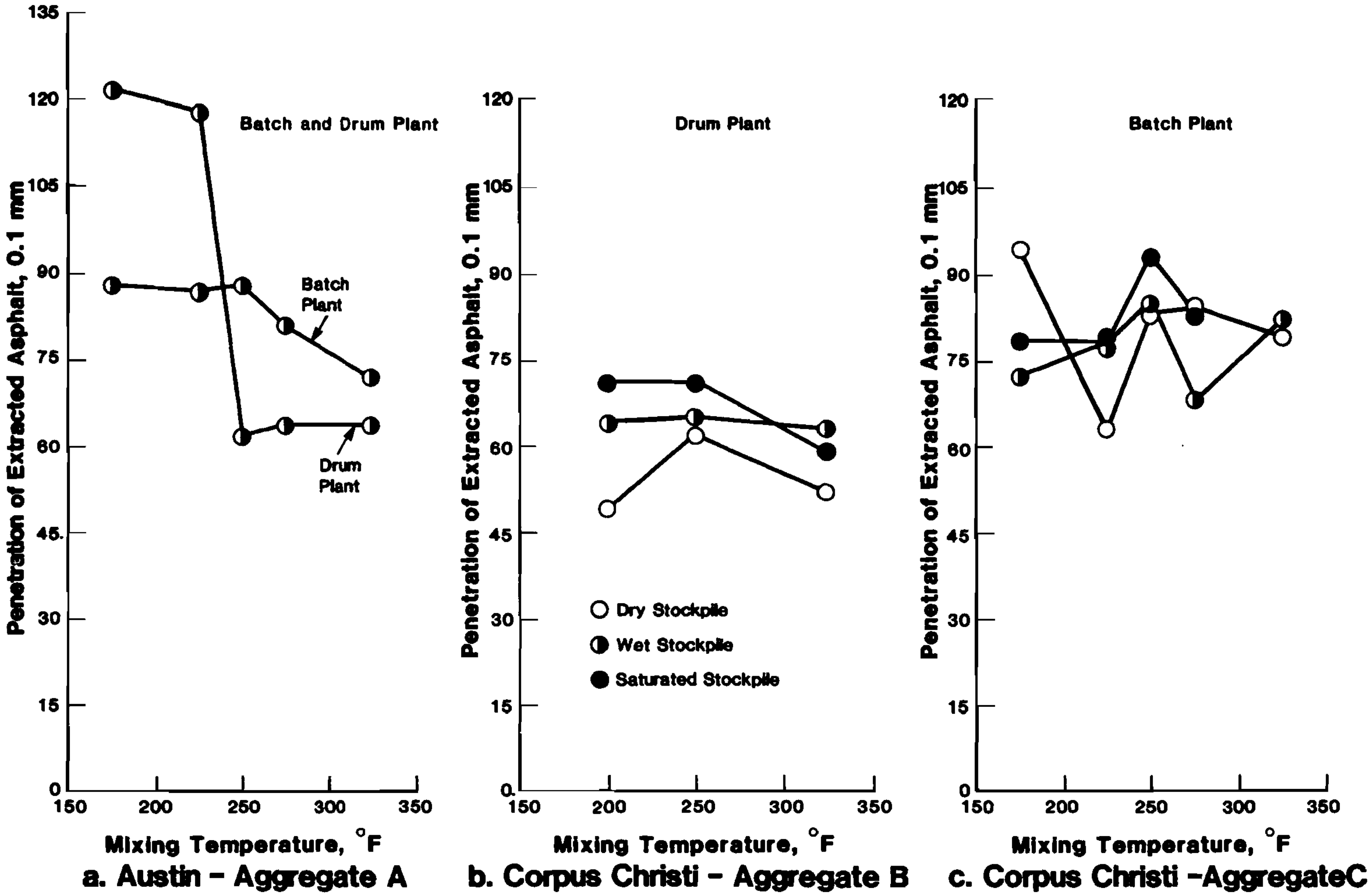


Fig 17. Effect of mixing temperature on asphalt hardening.

temperature but are believed to be the result of an incorrect asphalt grade being used.

Hardening of the asphalt was found to be affected by the stockpile moisture content (Fig 18). The high stockpile moisture contents decreased the amount of hardening which the asphalt experienced during mixing and thus retained a higher penetration. Both Aggregate A and Aggregate C demonstrated this behavior, which is likely caused by the presence of increased humidity in the pugmill or the drum mixer with increasing stockpile moisture. The presence of this humidity is thought to retard the evaporation of the lighter fractions of the asphalt.

SUMMARY OF TEST RESULTS

Tests were conducted on each of the experimental mixtures to determine the Hveem stability, tensile strength, resilient modulus of elasticity, tensile strength ratio, and asphalt retained after the boiling test. The results, tabulated in Tables 5, 6, 7, 8, and 9, respectively, are the average result of duplicate or triplicate specimens for each experiment condition. Results of the individual specimens are tabulated in Appendices A, B, and C for Aggregates A, B, and C, respectively.

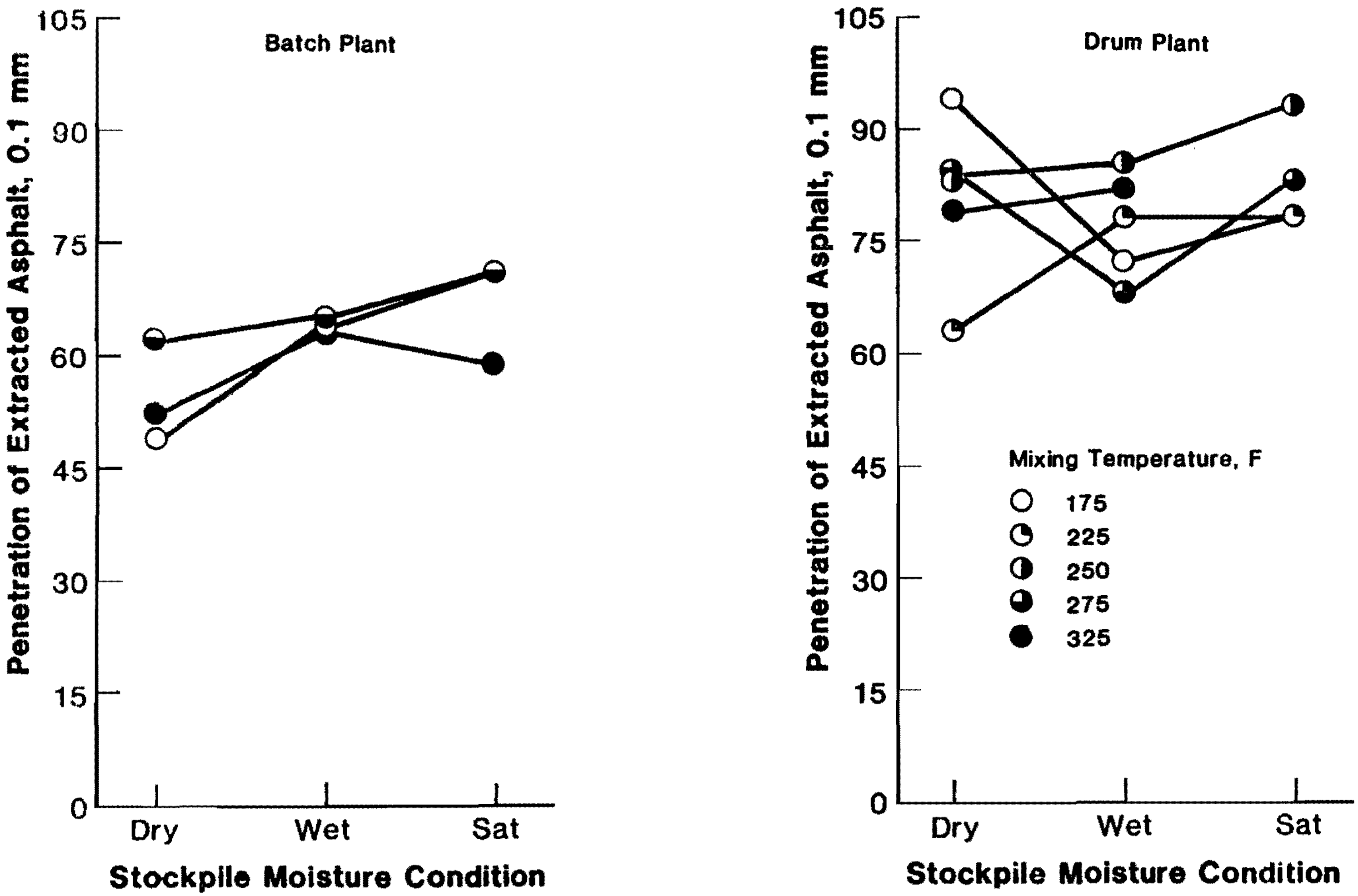
EFFECT OF MIXING TEMPERATURE

The effect of mixing temperature on each of the measured engineering properties is shown in Figures 19 through 23 and is discussed for each of the engineering properties.

Hveem Stability

As shown in Figure 19, mixing temperature produced a slight increase in Hveem stability for the standard and modified-standard specimens; however, the increase was of no practical significance and the effects were inconsistent. The modified compaction specimens did not exhibit any significant change in stability with different mixing temperatures.

Compaction procedure was observed to produce a major effect on Hveem stability. As shown in Figure 19, the modified compaction specimens which had significantly lower densities and higher air voids, had significantly lower stabilities.



a. Corpus Christi – Aggregate B

b. Corpus Christi – Aggregate C

Fig 18. Effect of stockpile moisture on asphalt hardening.

TABLE 5. SUMMARY OF HVEEM STABILITIES

Nominal Mix Temp °F	Hveem Stability, %								
	Compaction, Standard			Compaction, Modified-Standard			Compaction, Modified		
	Stockpile Condition								
	Dry	Wet	Sat.	Dry	Wet	Sat.	Dry	Wet	Sat.
Austin - District 14									
Batch Plant (Aggregate A)									
175	-	(31)	-	-	-	-	-	(30)	-
	-	40	-	-	-	-	-	31	-
225	-	(36)	-	-	-	-	-	(33)	-
	-	45	-	-	-	-	-	37	-
250	-	(34)	-	-	-	-	-	(34)	-
	-	44	-	-	-	-	-	37	-
275	-	(38)	-	-	-	-	-	(34)	-
	-	42	-	-	-	-	-	33	-
325	-	(40)	-	-	-	-	-	(32)	-
	-	47	-	-	-	-	-	34	-
Drum Plant (Aggregate A)									
175	-	-	-	-	-	-	-	-	
	-	45	-	-	-	-	-	36	-
225	-	-	-	-	-	-	-	-	-
	-	49	-	-	-	-	-	39	-
250	-	(35)	-	-	-	-	-	(35)	-
	-	40	-	-	-	-	-	38	-
275	-	(36)	-	-	-	-	-	(33)	-
	-	42	-	-	-	-	-	36	-
325	-	(42)	-	-	-	-	-	(39)	-
	-	40	-	-	-	-	-	36	-
Corpus Christi - District 16									
Batch Plant (Aggregate B)									
200	34	34	27	33	30	19	27	32	29
250	33	35	29	33	38	29	30	30	30
325	36	39	38	37	39	40	27	28	30
Drum Plant (Aggregate C)									
175	39	36	42	-	-	-	28	30	28
225	39	40	12	-	-	-	33	34	25
250	40	42	37	-	-	-	35	35	33
275	42	44	16	-	-	-	34	35	29
325	42	43	-	-	-	-	31	34	-

All values are averages of duplicate specimens

Numbers in parentheses are for specimens subjected to freeze-thaw

Aggregate A - 30% coarse sandstone, 52% intermediate limestone, 18% field sand
Aggregate B - 50% coarse sandstone, 20% intermediate limestone, 10% intermediate sandstone, 20% field sand
Aggregate C - 64% coarse sandstone, 16% intermediate sandstone, 20% field sand.

TABLE 6. SUMMARY OF TENSILE STRENGTHS

Nominal Mix Temp °F	Compaction, Standard			Compaction, Modified-Standard			Compaction, Modified		
	Dry	Wet	Sat.	Dry	Wet	Sat.	Dry	Wet	Sat.
Austin - District 14									
Batch Plant (Aggregate A)									
175	-	(56)	-	-	-	-	-	(13)	-
	-	89	-	-	-	-	-	43	-
225	-	(58)	-	-	-	-	-	(20)	-
	-	82	-	-	-	-	-	49	-
250	-	(44)	-	-	-	-	-	(17)	-
	-	93	-	-	-	-	-	50	-
275	-	(55)	-	-	-	-	-	(26)	-
	-	95	-	-	-	-	-	56	-
325	-	(66)	-	-	-	-	-	(40)	-
	-	118	-	-	-	-	-	70	-
Drum Plant (Aggregate A)									
175	-	(40)	-	-	-	-	-	(16)	-
	-	71	-	-	-	-	-	41	-
225	-	(56)	-	-	-	-	-	(26)	-
	-	92	-	-	-	-	-	52	-
250	-	(94)	-	-	-	-	-	(37)	-
	-	109	-	-	-	-	-	84	-
275	-	(87)	-	-	-	-	-	(33)	-
	-	112	-	-	-	-	-	83	-
325	-	(86)	-	-	-	-	-	(44)	-
	-	115	-	-	-	-	-	53	-
Corpus Christi - District 16									
Batch Plant (Aggregate B)									
200	(91)	(131)	(120)	(54)	(89)	(86)	(27)	(49)	(58)
	100	132	116	77	92	80	43	66	67
250	(111)	(109)	(131)	(95)	(80)	(84)	(40)	(31)	(48)
	158	116	158	100	97	95	55	58	56
325	(76)	(111)	(114)	(74)	(85)	(102)	(34)	(42)	(44)
	100	146	123	92	99	113	46	58	57
Drum Plant (Aggregate C)									
175	(92)	(103)	(122)	-	-	-	(24)	(17)	(33)
	109	105	120	-	-	-	51	60	65
225	(95)	(97)	(107)	-	-	-	(28)	(23)	(59)
	105	85	102	-	-	-	60	62	67
250	(110)	(102)	(95)	-	-	-	(23)	(24)	(33)
	122	106	109	-	-	-	63	65	69
275	(102)	(110)	(101)	-	-	-	(31)	(22)	(65)
	108	115	94	-	-	-	56	55	63
325	(83)	(114)	-	-	-	-	(31)	(30)	-
	106	124	-	-	-	-	58	70	-

Indirect Tensile Strength, psi; columns by Stockpile Condition.

All values are averages of duplicate specimens

Numbers in parentheses are for specimens subjected to freeze-thaw

Aggregate A - 30% coarse sandstone, 52% intermediate limestone, 18% field sand
Aggregate B - 50% coarse sandstone, 20% intermediate limestone, 10% intermediate sandstone, 20% field sand
Aggregate C - 64% coarse sandstone, 16% intermediate sandstone, 20% field sand.

TABLE 7. SUMMARY OF RESILIENT MODULUS OF ELASTICITY

Nominal Mix Temp °F	Compaction, Standard			Compaction, Modified-Standard			Compaction, Modified		
	Dry	Wet	Sat.	Dry	Wet	Sat.	Dry	Wet	Sat.
Austin - District 14									
Batch Plant (Aggregate A)									
175	-	(889)	-	-	-	-	-	(581)	-
	-	1134	-	-	-	-	-	799	-
225	-	(679)	-	-	-	-	-	(529)	-
	-	804	-	-	-	-	-	608	-
250	-	(795)	-	-	-	-	-	(600)	-
	-	1079	-	-	-	-	-	803	-
275	-	(701)	-	-	-	-	-	(703)	-
	-	1091	-	-	-	-	-	760	-
325	-	(778)	-	-	-	-	-	(661)	-
	-	754	-	-	-	-	-	770	-
Drum Plant (Aggregate A)									
175	-	(511)	-	-	-	-	-	-	-
	-	637	-	-	-	-	-	-	-
225	-	(712)	-	-	-	-	-	-	-
	-	715	-	-	-	-	-	-	-
250	-	(923)	-	-	-	-	-	(923)	-
	-	1003	-	-	-	-	-	715	-
275	-	(889)	-	-	-	-	-	(1031)	-
	-	1492	-	-	-	-	-	863	-
325	-	(908)	-	-	-	-	-	(819)	-
	-	920	-	-	-	-	-	768	-
Corpus Christi - District 16									
Batch Plant (Aggregate B)									
220	(532)	(887)	(826)	-	-	-	-	-	-
	575	805	681	-	-	-	-	-	-
250	(820)	(483)	(957)	-	-	-	-	-	-
	1163	467	1320	-	-	-	-	-	-
325	(359)	(612)	(575)	-	-	-	-	-	-
	517	628	569	-	-	-	-	-	-
Drum Plant (Aggregate C)***									
175	(743)	(893)	(806)	-	-	-	-	-	-
	671	874	876	-	-	-	-	-	-
225	(778)	(858)	(827)	-	-	-	-	-	-
	791	825	753	-	-	-	-	-	-
250	(701)	(854)	(776)	-	-	-	-	-	-
	857	833	925	-	-	-	-	-	-
275	(729)	(784)	(779)	-	-	-	-	-	-
	792	705	699	-	-	-	-	-	-
325	(697)	(705)	-	-	-	-	-	-	-
	788	853	-	-	-	-	-	-	-

Resilient Modulus of Elasticity, ksi; columns grouped by Stockpile Condition**

All values are averages of duplicate specimens

Numbers in parentheses are for specimens subjected to freeze-thaw

Aggregate A - 30% coarse sandstone, 52% intermediate limestone, 18% field sand
Aggregate B - 50% coarse sandstone, 20% intermediate limestone, 10% intermediate sandstone, 20% field sand
Aggregate C - 64% coarse sandstone, 16% intermediate sandstone, 20% field sand.

TABLE 8. SUMMARY OF TENSILE STRENGTH RATIOS

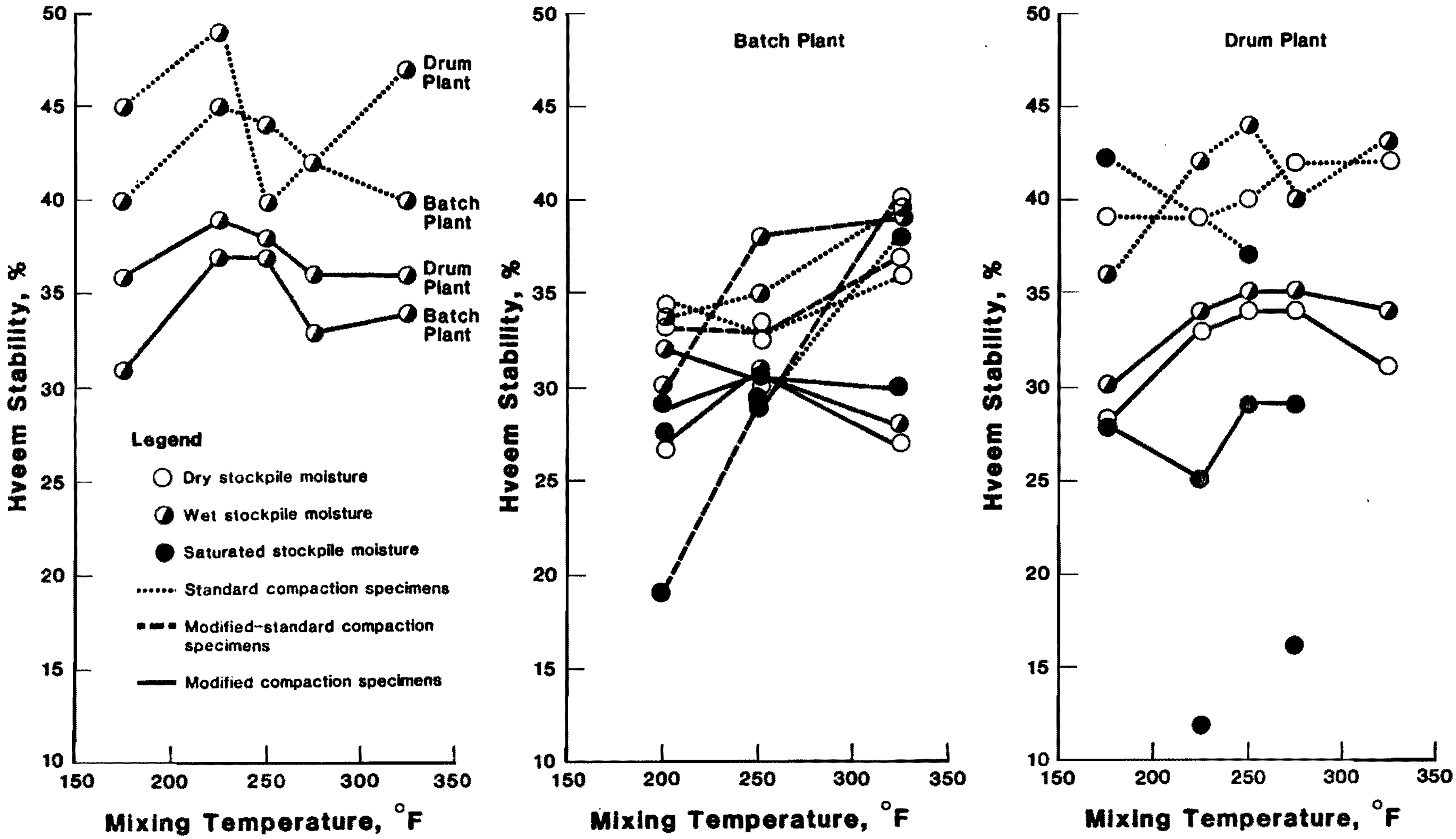
Nominal Mix Temp °F	Tensile Strength Ratio: Compaction, Standard			Compaction, Modified-Standard			Compaction, Modified		
	Stockpile Condition**								
	Dry	Wet	Sat.	Dry	Wet	Sat.	Dry	Wet	Sat.
Austin - District 14									
Batch Plant (Aggregate A)									
175	-	0.63	-	-	-	-	-	0.30	-
225	-	0.71	-	-	-	-	-	0.41	-
250	-	0.47	-	-	-	-	-	0.34	-
275	-	0.58	-	-	-	-	-	0.46	-
325	-	0.50	-	-	-	-	-	0.57	-
Drum Plant (Aggregate A)									
175	-	0.56	-	-	-	-	-	0.39	-
225	-	0.61	-	-	-	-	-	0.50	-
250	-	0.86	-	-	-	-	-	0.44	-
275	-	0.78	-	-	-	-	-	0.40	-
325	-	0.75	-	-	-	-	-	0.83	-
Corpus Christi - District 16									
Batch Plant (Aggregate B)									
200	0.90	1.00	1.03	0.70	0.97	1.07	0.63	0.75	0.87
250	0.70	0.93	0.83	0.95	0.82	0.89	0.74	0.54	0.87
325	0.76	0.76	0.92	0.80	0.86	0.90	0.74	0.73	0.77
Drum Plant (Aggregate C)									
175	0.84	0.96	1.02	-	-	-	0.47	0.28	0.51
225	0.90	1.14	1.05	-	-	-	0.47	0.37	0.88
250	0.92	0.90	0.87	-	-	-	0.37	0.37	0.49
275	0.94	0.96	1.07	-	-	-	0.55	0.40	1.03
325	0.76	0.91	-	-	-	-	0.53	0.43	-

All values are individual ratios of the average wet and average dry tensile strengths (Table 6).

TABLE 9. SUMMARY OF BOILING TEST RESULTS

	Nominal Mix Temp °F	Retained Asphalt, % Stockpile Condition		
		Dry	Wet	Sat.
Austin - District 14				
Batch Plant (Aggregate A)				
	175	-	25	-
	225	-	60	-
	250	-	60	-
	275	-	75	-
	325	-	85	-
Drum Plant (Aggregate A)				
	175	-	60	-
	225	-	-	-
	250	-	-	-
	275	-	-	-
	325	-	95	-
Corpus Christi - District 16				
Batch Plant (Aggregate B)				
	200	50	60	75
	250	40	40	65
	325	85	70	85
Drum Plant (Aggregate C)				
	175	15	-	45
	225	25	50	70
	250	40	-	45
	275	70	-	75
	325	85	-	-

All values are individual results



a. Austin - Aggregate A

b. Corpus Christi - Aggregate B

c. Corpus Christi - Aggregate C

Fig 19. Relationship between mixing temperature and Hveem stability.

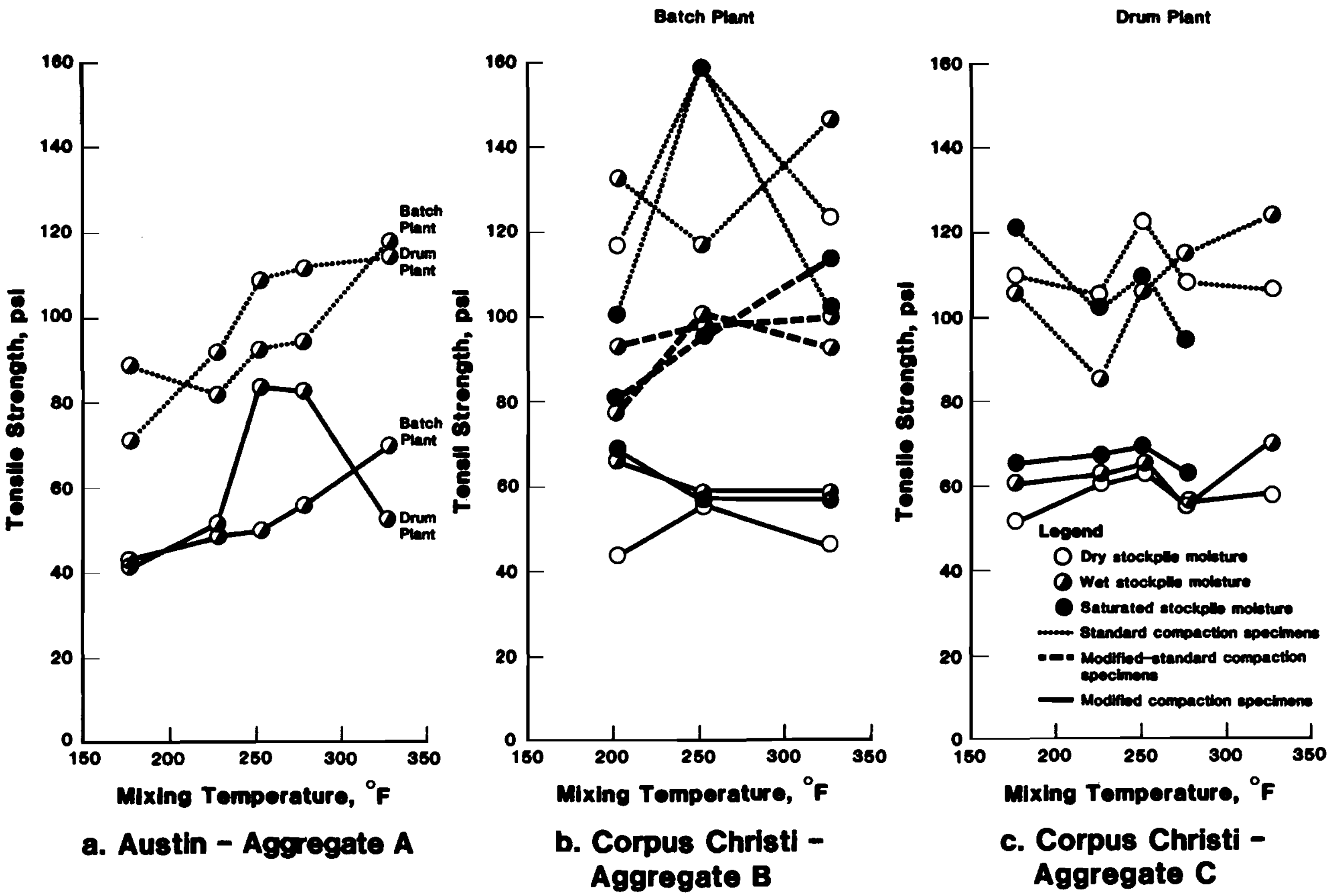


Fig 20. Relationship between mixing temperature and tensile strength.

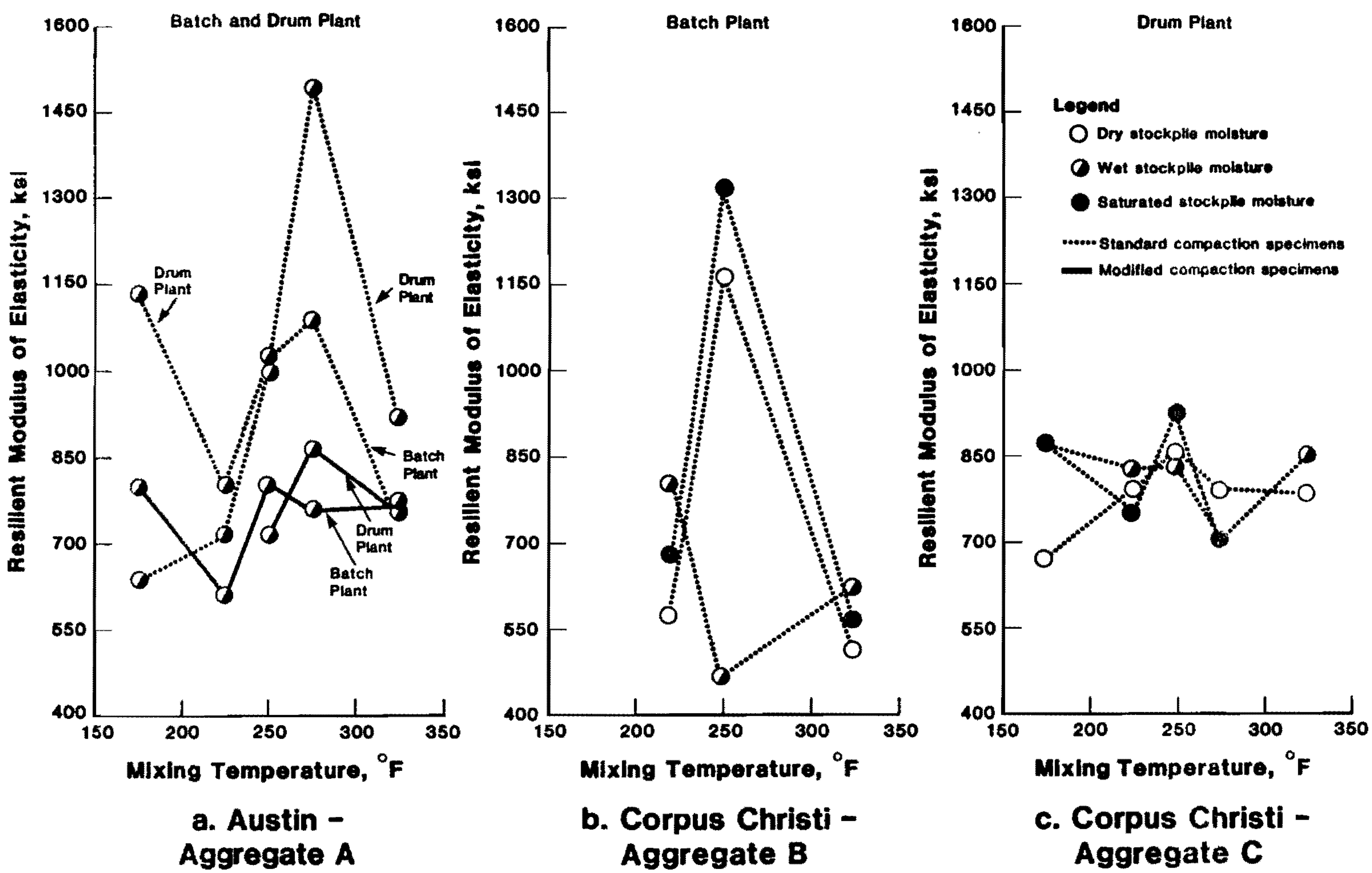


Fig 21. Relationship between mixing temperature and resilient modulus of elasticity.

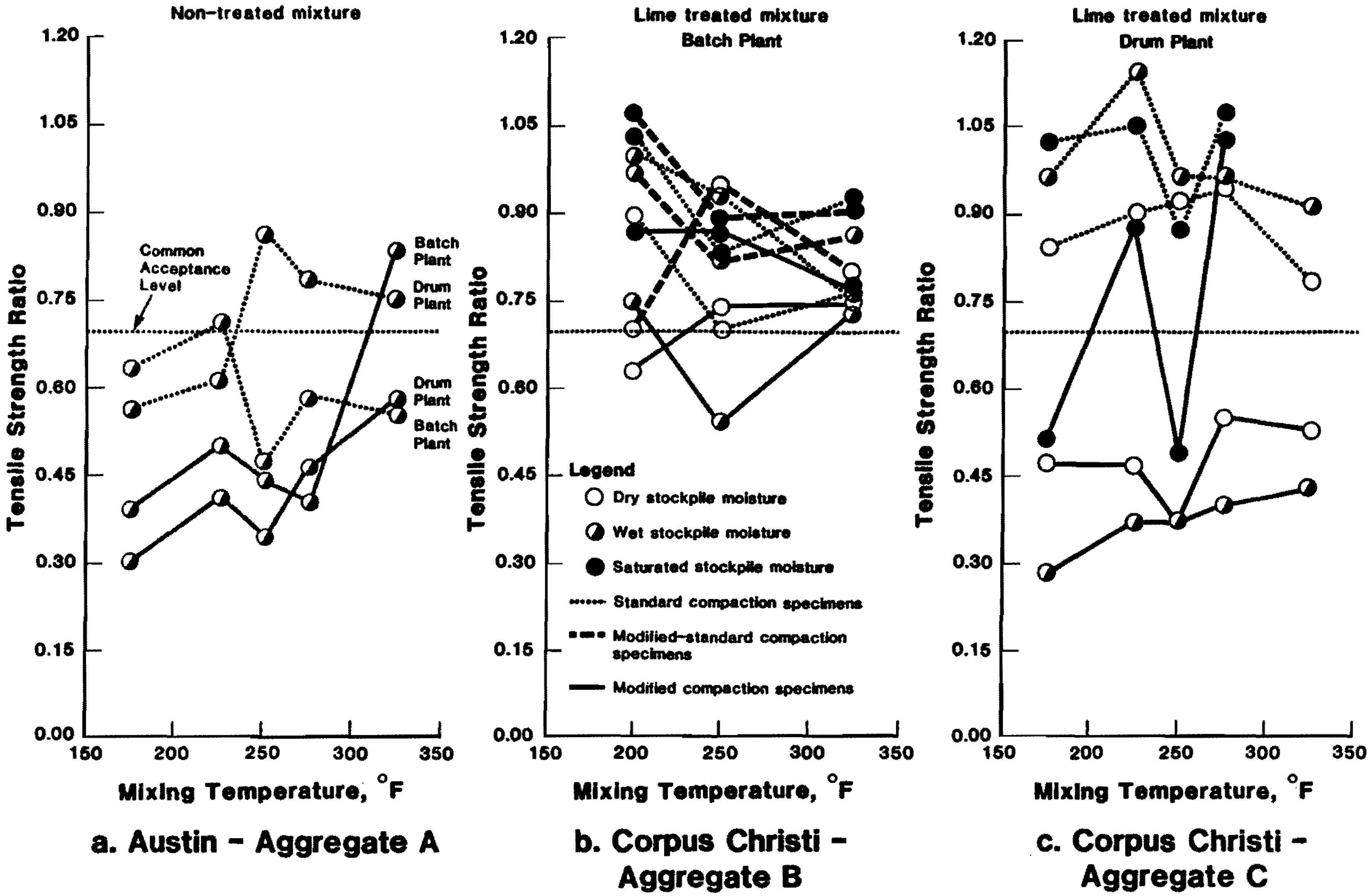


Fig 22. Relationship between mixing temperature and tensile strength ratio.

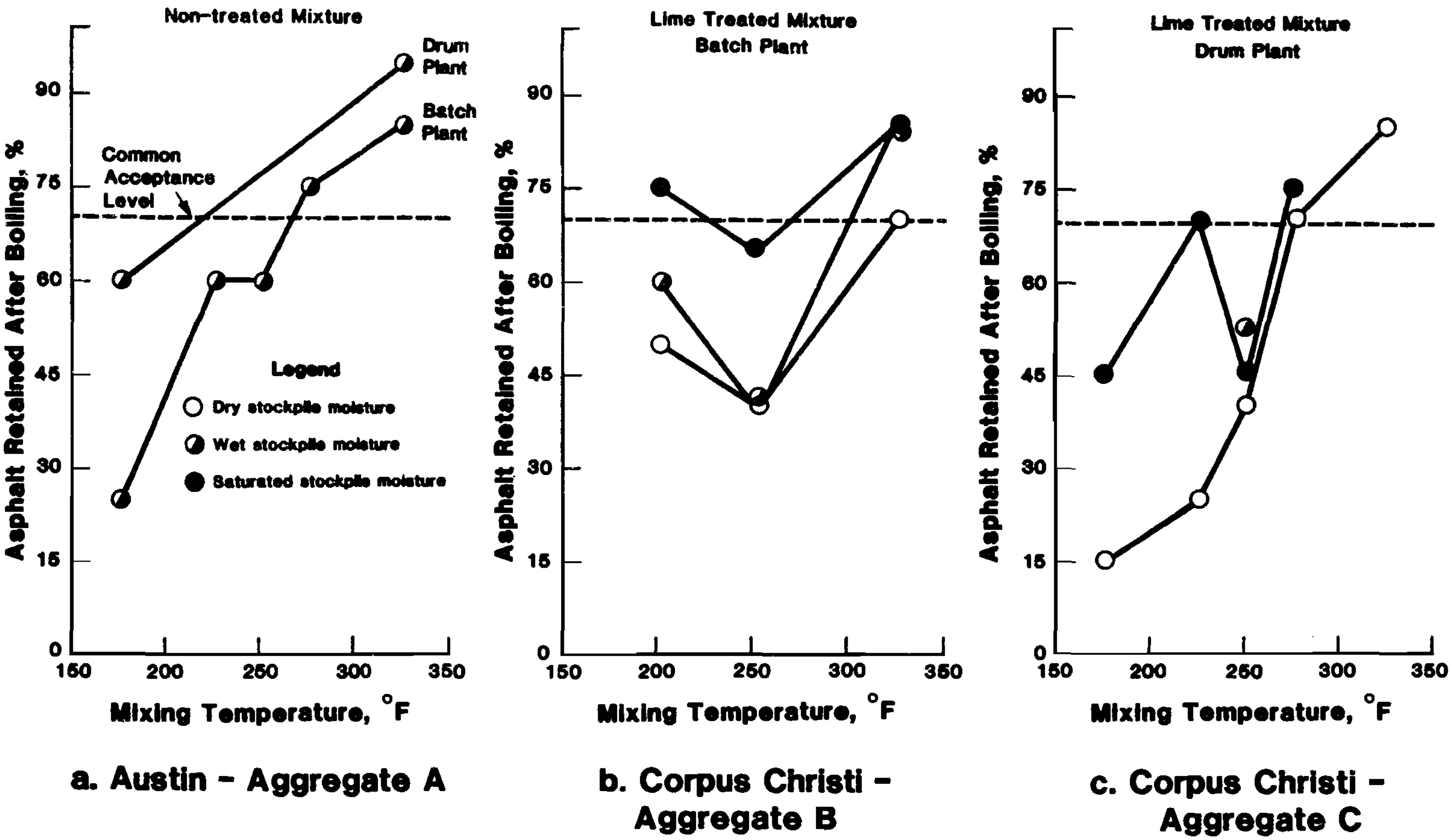


Fig 23. Relationship between mixing temperature and asphalt retained after boiling test.

Tensile Strength

The tensile strengths of the standard specimens show a trend to increase with increased mixing temperature but the degree and consistency of this trend is variable (Fig 20).

For Aggregate A, the standard compaction specimens and to some degree the modified compaction specimens exhibited an increase in tensile strength with increasing mixing temperatures. This trend is also apparent for the modified-standard compaction specimens of Aggregate B. No relationship with mixing temperature existed for the other mixture conditions.

The compaction procedure used to prepare the specimens had the greatest effect on the tensile strength values. The modified, modified-standard, and standard specimens have tensile strengths which lie within distinct separate bands.

Resilient Modulus of Elasticity

A discernible relationship between mixing temperature and resilient modulus of elasticity does not appear to exist in the observed experimental results (Fig 21). The measured values for Aggregate C suggest that the resilient modulus of elasticity is fairly uniform regardless of mixing temperature; however, Aggregates A and B do not exhibit the same uniformity. For Aggregates A and B the observed values vary over a wide range and the variation does not appear to be related to the mixing temperature.

Moisture-Damage Resistance

Two evaluation techniques utilized to determine the moisture-damage resistance of the experimental mixtures were the indirect tensile strength ratio and the Texas Boiling Test. The Texas Freeze-Thaw Pedestal Test, which also measures moisture-damage resistance, could not be conducted because it requires uniform sized material.

Tensile Strength Ratio. To determine the tensile strength ratio a paired grouping of specimens was formed. One group was subjected to a moisture saturation, freeze-thaw conditioning and the other was not. The tensile strength ratio was expressed as the ratio of the average freeze-thaw conditioned tensile strength to the dry conditioned tensile strength.

The proposed acceptance level of the tensile strength ratio, 0.70, which is used to identify a non-moisture susceptible aggregate mixture does not appear to be an appropriate threshold value for all compaction methods. The measured tensile strength ratio was found to be significantly affected by the applied compaction effort (Fig 22). The modified compaction specimens had a lower density and were more susceptible to water entry during vacuum saturation. As a result they lost a larger proportion of the dry tensile strength than did the standard specimens which were more resistant to water entry. Therefore the modified compaction specimens are considered to be better indicators of moisture damage susceptibility than the denser standard and modified standard ones. Further discussion considers only the modified compaction specimens.

The effect of mixing temperature on the measured tensile strength ratios of the modified compaction specimens was not consistent for all the aggregates tested. Aggregate A results suggest that increased mixing temperature caused an increase in the tensile strength ratio; however, for the other aggregates, with the exception of the wet stockpile moisture specimens of Aggregate C, no consistent effect was observed.

Boiling Test. The resistance to moisture damage as measured by the percent retained asphalt after the boiling test increased with increased mixing temperature (Fig 23). This trend is relatively consistent throughout the three aggregates and shows substantial changes in retained asphalt across the range of temperatures tested.

Aggregates B and C were known to be moisture susceptible aggregates, and as part of the non-experimental work both were treated with a hydrated lime slurry before mixing to improve their resistance to moisture damage. Aggregate A, a non-moisture-susceptible aggregate, was not treated. The relationship between mixing temperature and retained asphalt is similar for all three aggregates. Both treated and non-treated aggregates show substantial losses in retained asphalt at lower mixing temperatures. At higher mixing temperatures the effect of the lime slurry treatment is evidenced by the acceptable level of percent retained asphalt.

The percentage of asphalt retained after the boiling test is known to increase for asphalts which have lower penetrations. The penetration of the extracted asphalt which was discussed earlier (Figs 15 and 16) does decrease somewhat with increasing mixing temperature; however, the percent retained asphalt is not sufficiently sensitive to account for the significant changes which were observed.

EFFECT OF STOCKPILE MOISTURE

The effect of stockpile moisture on each of the engineering properties is shown in Figures 24 through 28. In the discussion which follows, Aggregate A is not considered since only one stockpile moisture condition was studied.

Hveem Stability

The experiment results do not indicate that stockpile moisture had a major effect on Hveem stability (Fig 24). The results indicate that the saturated stockpile conditions caused a decrease but the change is neither consistent nor large. The major influence on the Hveem stability results is density. The values for each of the compaction methods generally lie in distinct groups.

Tensile Strength

The measured values of tensile strength are relatively uniform and generally do not vary with stockpile moisture condition (Fig 25). The most significant variable which does affect the tensile strength is compaction type (density), as shown by the separate groups in which the results fall.

Resilient Modulus of Elasticity

The results indicate that the resilient modulus of elasticity is not affected by the stockpile moisture condition (Fig 26). The values for Aggregate C do not show any change for varying stockpile moisture contents and the results measured for Aggregate B, though varied, do not show a trend.

Moisture-Damage Resistance

The two measures of moisture-damage resistance, the tensile strength ratio and the Texas Boiling Test, are discussed separately.

Tensile Strength Ratio. A discernible trend is exhibited between the stockpile moisture condition and the measured tensile strength ratio

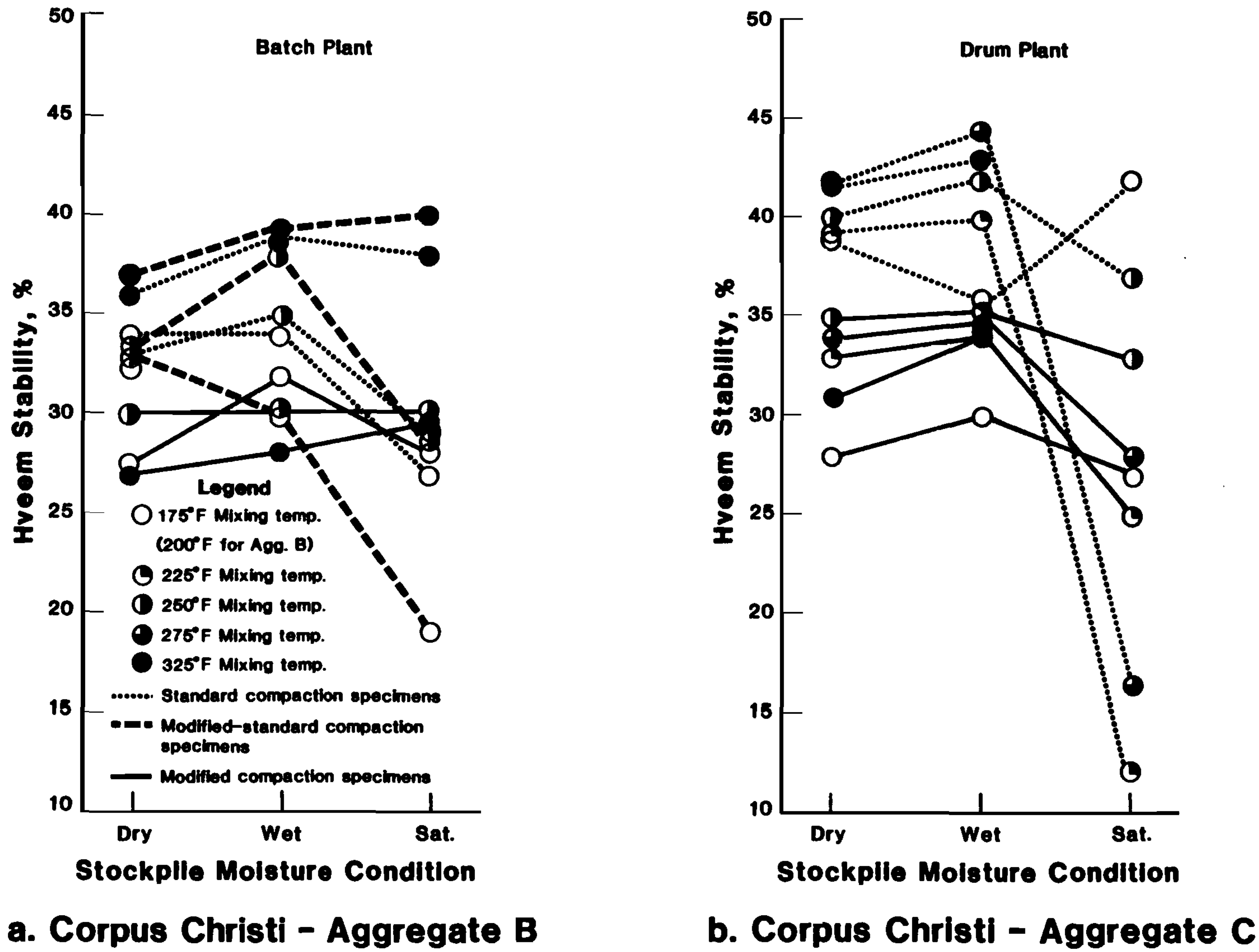
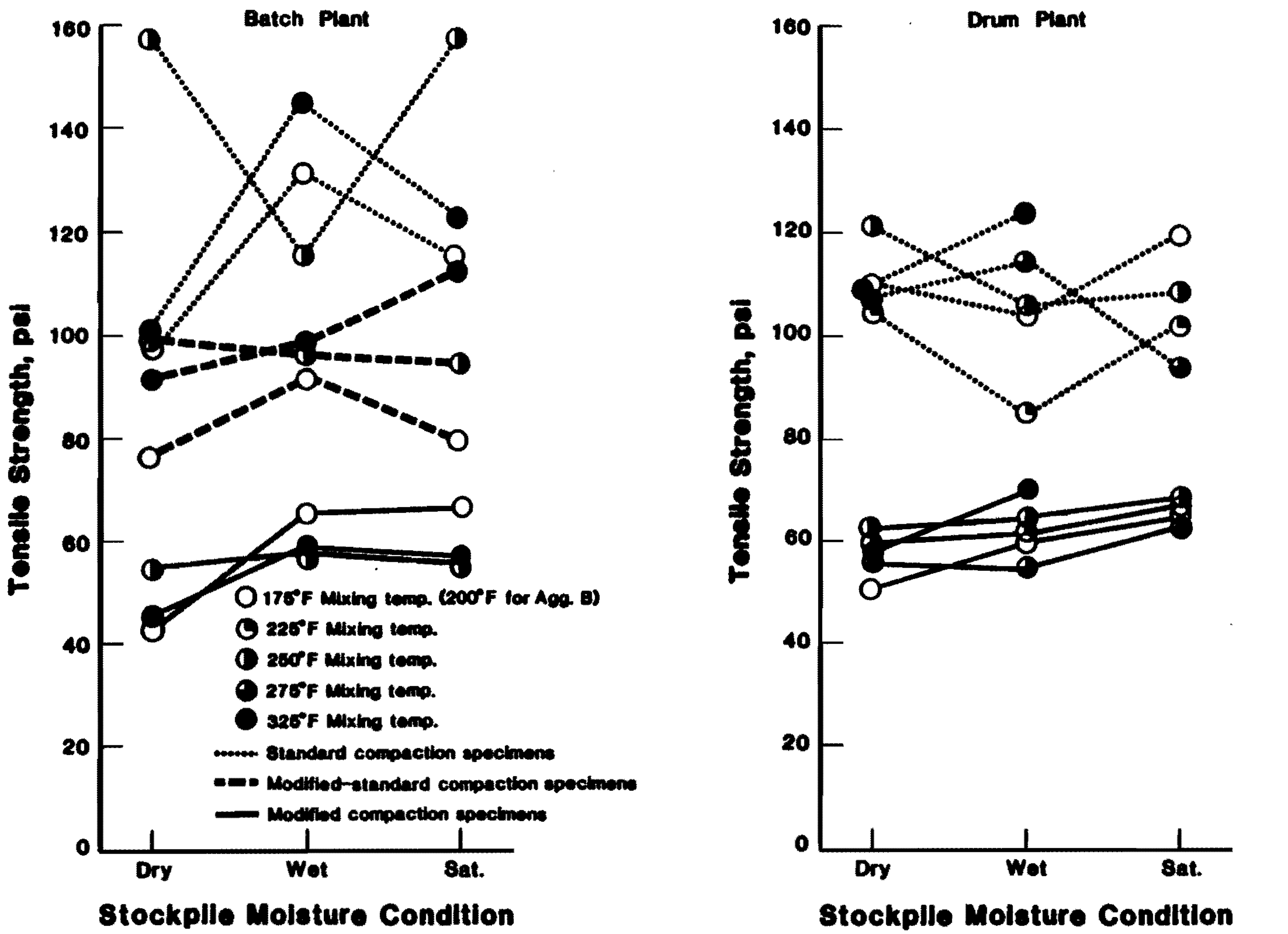
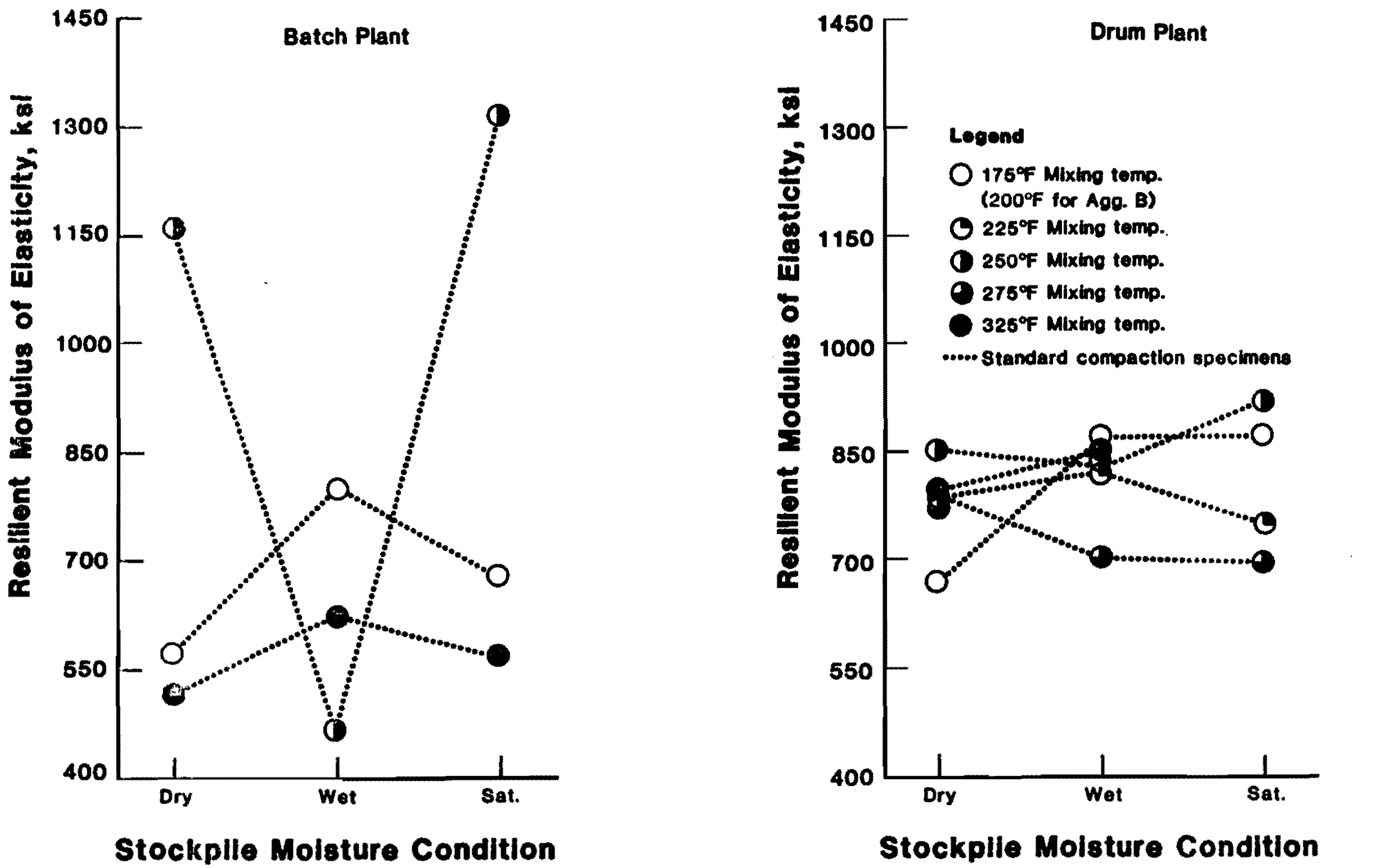


Fig 24. Relationship between stockpile moisture condition and Hveem stability.



a. Corpus Christi - Aggregate B **b. Corpus Christi - Aggregate C**

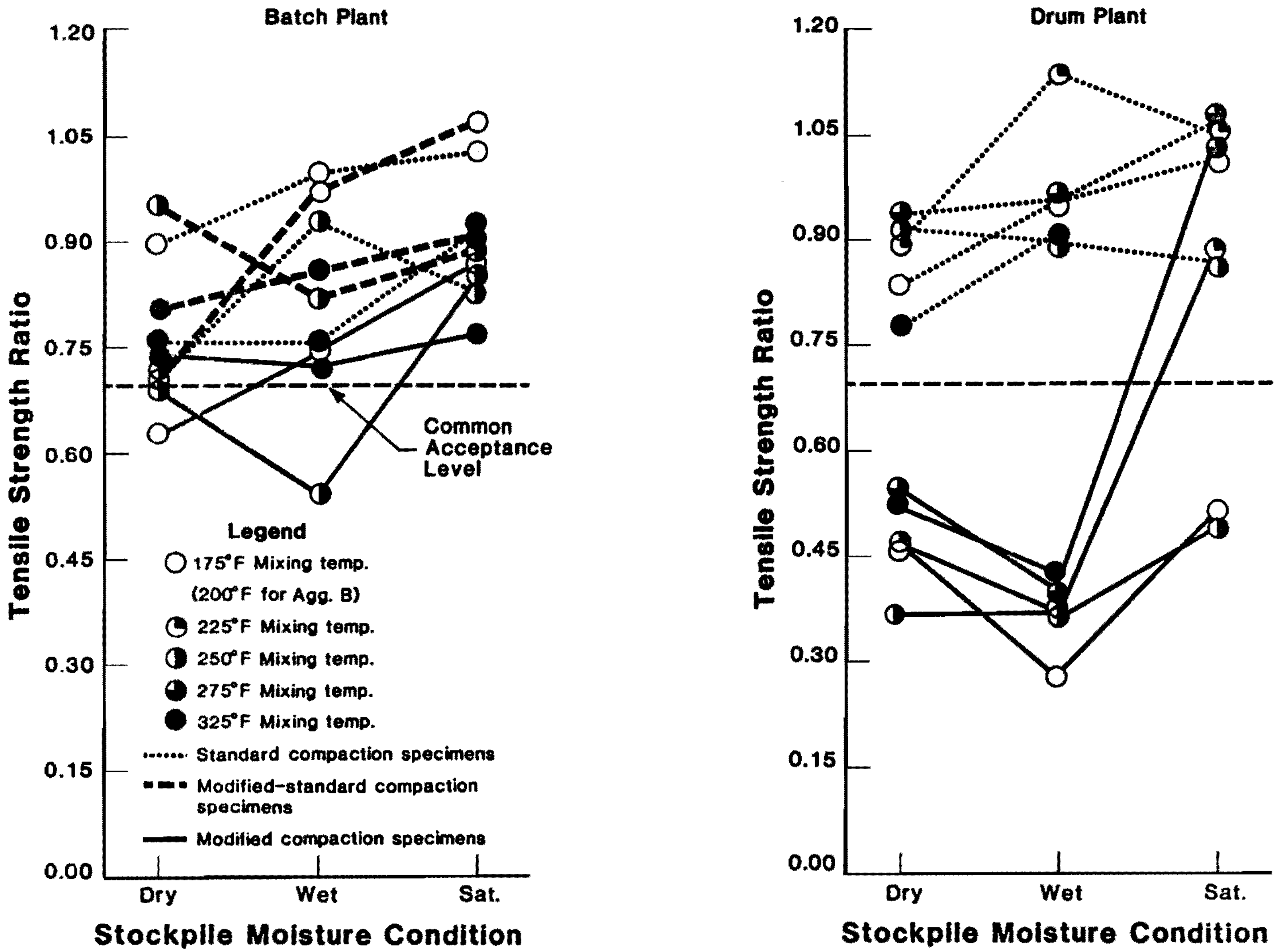
Fig 25. Relationship between stockpile moisture condition and tensile strength.



a. Corpus Christi - Aggregate B

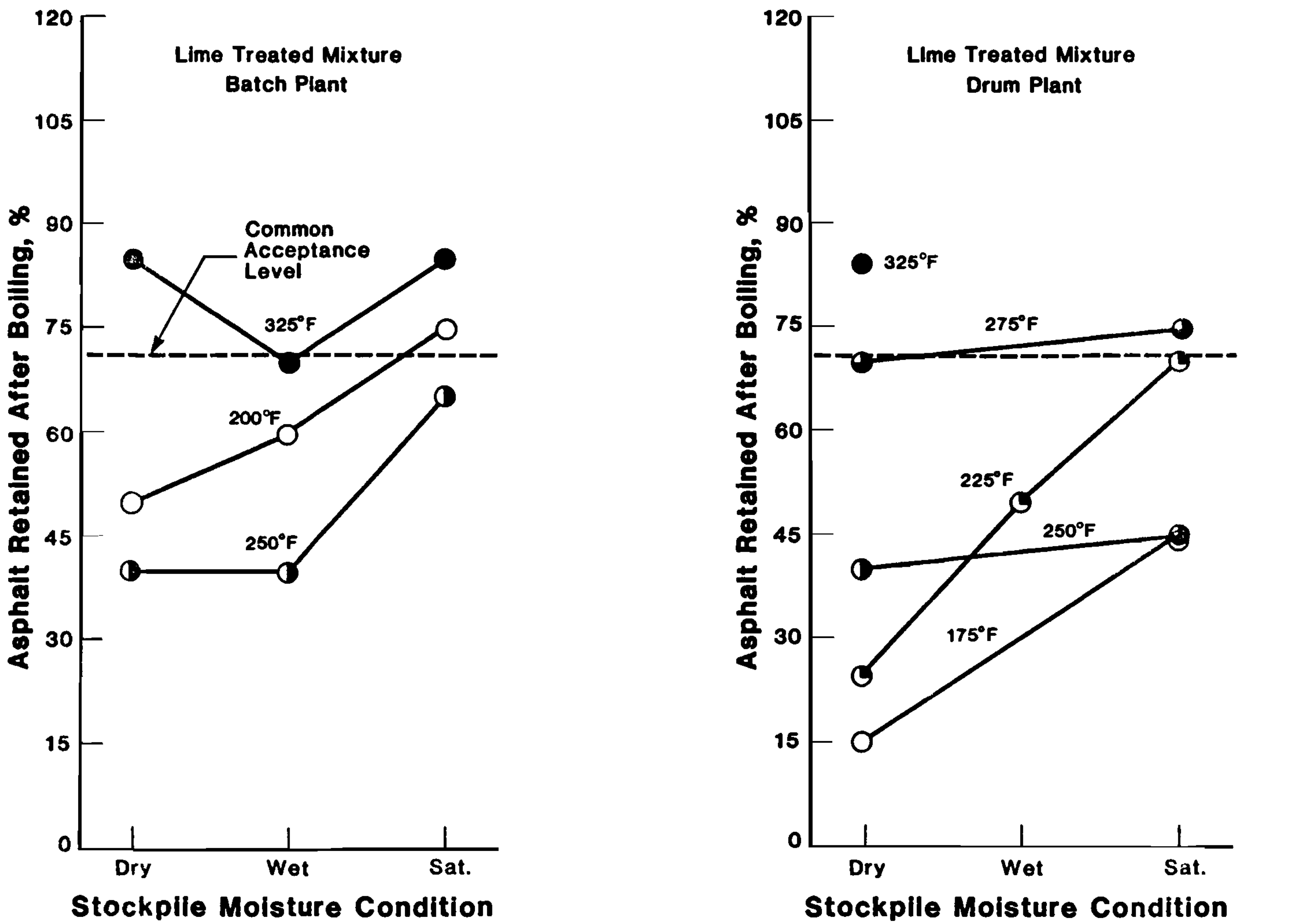
b. Corpus Christi - Aggregate C

Fig 26. Relationship between stockpile moisture condition and resilient modulus of elasticity.



a. Corpus Christi - Aggregate B **b. Corpus Christi - Aggregate C**

Fig 27. The relationship between stockpile moisture condition and tensile strength ratio.



a. Corpus Christi - Aggregate B **b. Corpus Christi - Aggregate C**

Fig 28. The relationship between stockpile moisture condition and asphalt retained after the boiling test.

(Fig 27). The ratio and hence the resistance to moisture damage tends to increase with increasing stockpile moisture contents although the amount of the increase is generally not large.

Texas Boiling Test. A clear trend is indicated between the asphalt retained after the Texas Boiling Test and the stockpile moisture content (Fig 28). The retained asphalt showed significant increases as the stockpile moisture content increased, indicating a higher resistance to moisture damage. The increase measured over the range of stockpile moistures used shows the greatest increase in resistance occurs at the lower mixing temperatures. Generally the increase of retained asphalt becomes less as the mixing temperature increases.

The penetration of the extracted asphalt which is known to affect the results of the boiling test did vary among experimental runs (Fig 17). Typically, as the asphalt penetration decreases the retained asphalt will increase. In the experimental results for one mixing temperature, the penetration of the extracted asphalt increased with increasing stockpile moisture yet despite the tendency of this effect to reduce the retained asphalt, the results show that it increased. Therefore any effects caused by the penetration are greatly outweighed by the increase in moisture-damage resistance for mixtures which had high stockpile moisture contents.

EXPERIMENT REPEATABILITY

Duplicate runs of the same experimental conditions were done to determine if the uncontrolled variations inherent in the field study caused large variations in the experiment results. A detailed study of the repeatability of the experiment was not done as part of the project; however, a repeat of one set of experimental conditions was expected to indicate the size of random variations in the measured results.

During the Aggregate B experiment the run with saturated stockpile moisture and low mixing temperature was repeated and the resulting measured properties were compared (Table 10). As shown, the experimental conditions and most of the measured properties indicate similar results in both cases. Exceptions are the resilient modulus of elasticity and the Hveem stability.

The variation of the resilient modulus of elasticity for the two runs agrees with resilient modulus data for the Aggregate B experiment which shows

TABLE 10. COMPARISON OF REPEAT EXPERIMENTAL RUNS*

Experimental Conditions		Engineering Properties					Other Measured Properties				
Stockpile Moisture %	Mixing Temp. °F	Hveem Stability %	Tensile Strength psi	Resilient Modulus ksi	Tensile Strength Ratio	Boiling Test %	Asphalt Mixture Moisture %	Asphalt Content %	Extracted Asphalt Penetration 0.1 mm	Air Voids %	Voids in Mineral Aggregate %
Uncompacted Asphalt Mixture											
8.0	200	-	-	-	-	75	1.7	6.3	69	-	-
9.6	210	-	-	-	-	80	1.7	6.3	72	-	-
Standard Compaction											
8.0	200	20	118	787	1.02	-	-	-	-	2.4	16.2
9.6	210	33	116	575	1.04	-	-	-	-	1.8	15.5
Modified Standard Compaction											
8.0	200	11	77	-	1.07	-	-	-	-	1.5	15.3
9.6	210	28	84	-	1.06	-	-	-	-	1.5	15.3
Modified Compaction											
8.0	200	28	69	-	0.77	-	-	-	-	4.4	18.0
9.6	210	30	64	-	0.96	-	-	-	-	5.1	18.4

* Respective date of experimental runs: 7:00 am September 29, 1983
11:30 am October 3, 1983

considerable variation (Fig 26). An apparent reason for the variation is not evident. The Hveem stability measured in the comparison runs show some variation for the standard compaction specimens. The variation is not explained by the asphalt contents which are equal or the gradation (Table B9, Appendix B).

The results of the duplicate experimental runs suggest that despite some variation of measured results the repeatability is acceptable for runs performed within a relatively short time span. Therefore the resulting measurements between different runs indicate an actual change in the material properties.

ASPHALT PLANT FUEL CONSUMPTION

The fuel consumption of the asphalt plant is directly related to both mixing temperature and stockpile moisture content. During the Aggregate C experiment an attempt was made to determine the fuel consumption of the drum-mixer for each of the temperature-moisture combinations. The intent was to determine the amount of fuel per ton consumed by the burner. Although direct measurement of the fuel was not possible, two methods were used to provide estimates.

The first method used the position of the fuel control valve to estimate fuel consumption during the experimental runs (Table 11). The control located on the operating console was marked from 0 to 100 percent in increments of 10 percent. A plot of the individual settings (Fig 29) with the corresponding stockpile moisture contents and mixing temperatures allows contours of equal burner control settings to be drawn. Unfortunately the fuel flow for each of the control settings is not known; hence Figure 29 is applicable only to the asphalt plant used in the experiment.

The second method to determine the fuel consumption for Aggregate C used average energy values required to remove moisture and raise the temperature of the aggregate-asphalt mixture. The values were 28,000 Btu/ton for 1 percent moisture removed and 620 Btu/ton for each °F the mixture temperature was raised (Ref 7). The moisture losses, temperature gains, and energy requirements are listed in Table 11. The resulting values were plotted (Fig 30) and contours were drawn.

TABLE 11. AGGREGATE C FUEL CONSUMPTION DATA

Stockpile Moisture %	Mixing Temp °F	Burner Control %	Moisture Loss* %	Temp Gain** °F	Energy Required (1000's)*** Moisture Loss BTU/ton	Temp Gain BTU/ton	Total BTU/ton
3.5	190	0	3.2	130	89.6	80.6	170
3.5	215	5	3.2	155	89.6	96.1	186
3.5	240	15	3.2	180	89.6	111.6	201
3.2	285	20	2.9	225	81.2	139.5	221
3.2	320	30	3.0	260	84.0	161.2	245
8.3	175	25	7.1	115	198.8	71.3	270
9.1	230	40	8.7	170	243.6	105.4	349
7.7	260	45	7.6	200	212.8	124.0	337
8.9	270	50	8.9	210	249.2	130.2	379
7.5	335	65	7.5	275	210.0	170.5	381
13.6	185	50	11.7	125	327.6	77.5	405
13.6	215	60	12.5	155	350.0	96.1	446
12.7	245	90	11.5	185	322.0	114.7	437
13.8	270	110	13.5	210	378.0	130.2	508

* Difference between stockpile moisture content and moisture content of asphalt mixture.

** Stockpile temperature estimated to be 60°F.

*** Energy requirements per ton are 28,000 BTU per percent moisture removed and 620 BTU per °F temperature increase (Ref 7).

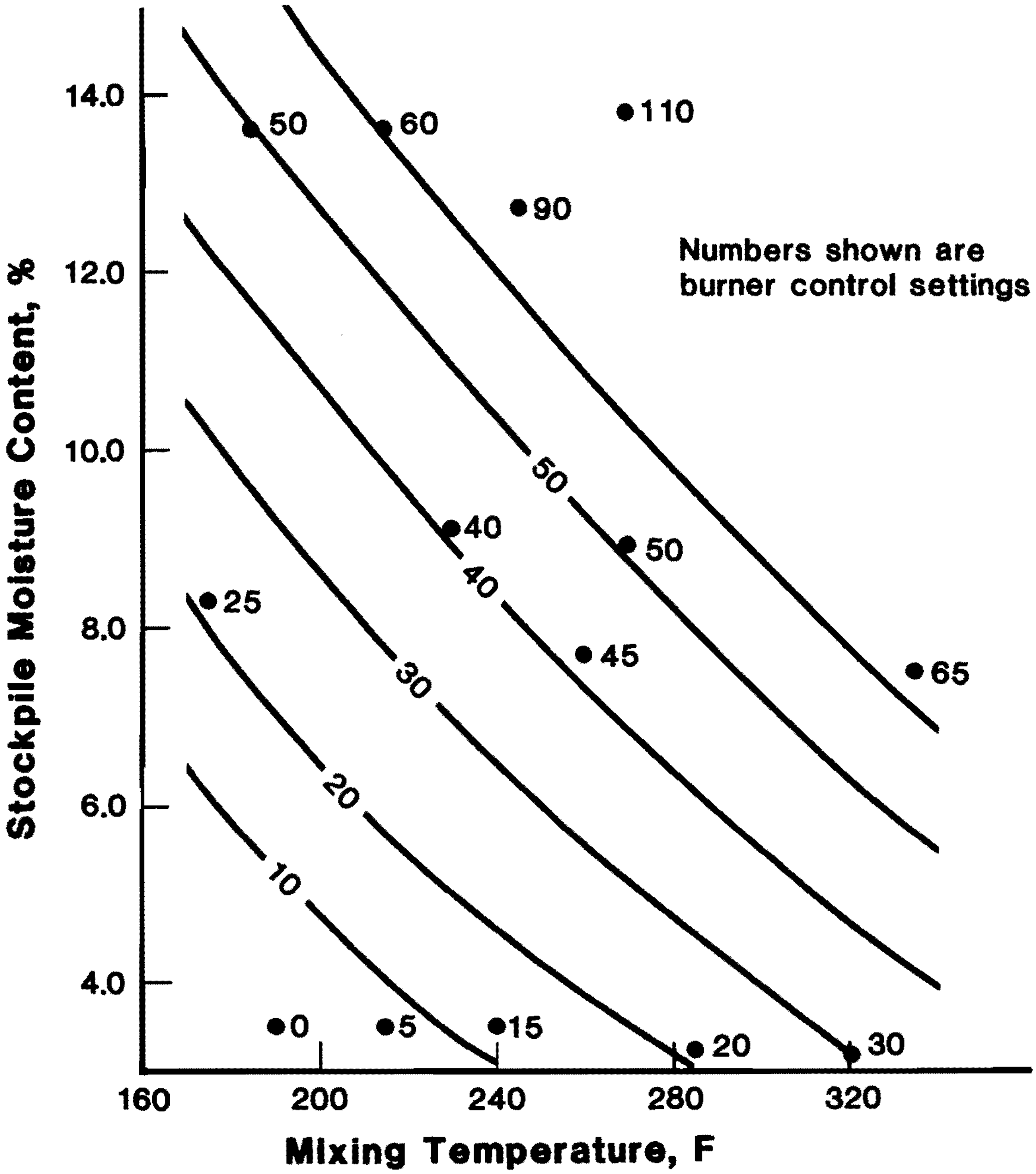


Fig 29. Experiment fuel consumption, Aggregate C.

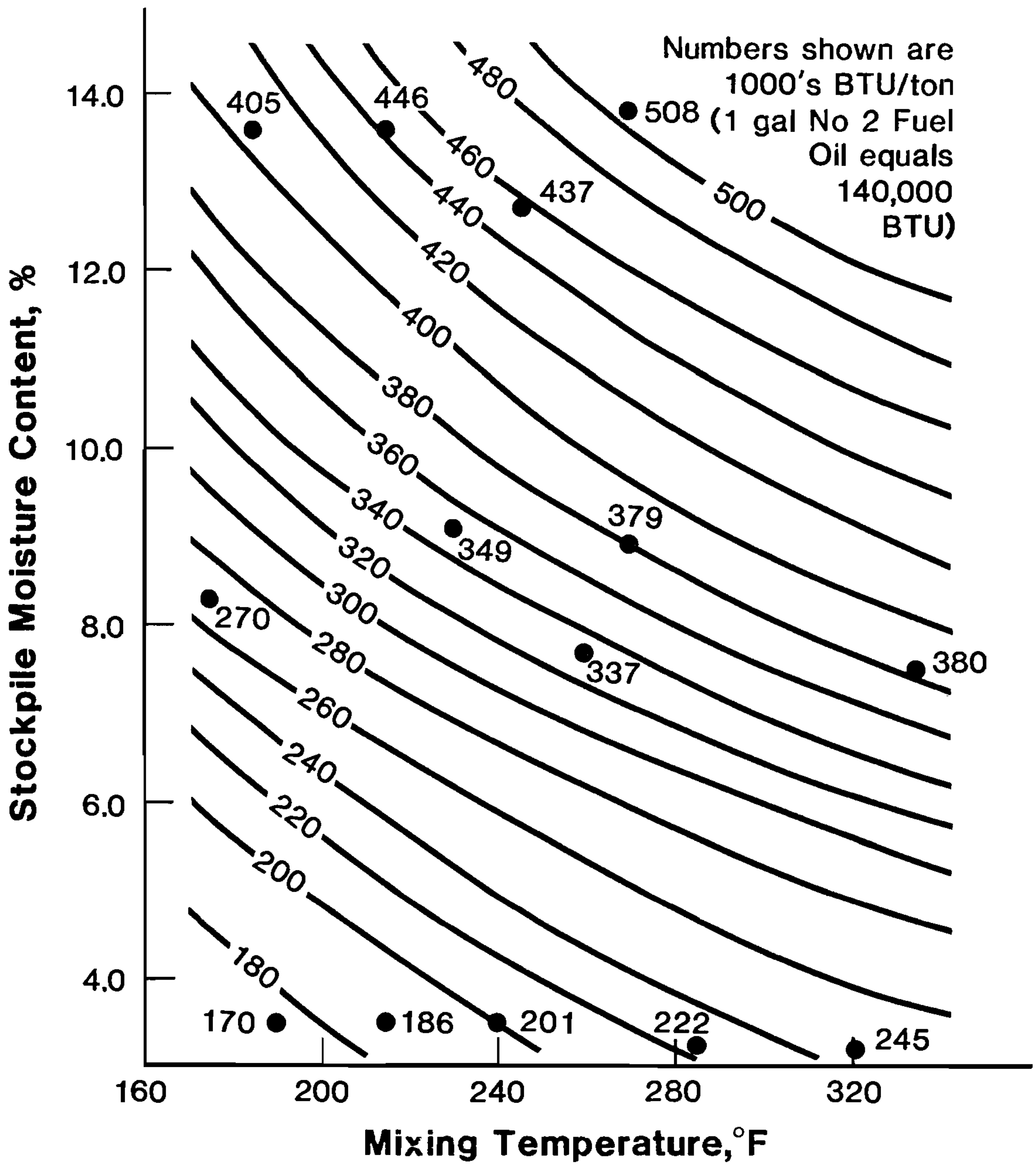


Fig 30. Heating energy requirements for Aggregate C.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this study was to determine the effects of mixing temperature and stockpile moisture on selected engineering properties of asphalt mixtures produced in conventional batch asphalt plants and drum mix plants. Based on the findings of this study several conclusions were reached and some proposed recommendations can be made.

General Conclusions

1. Several uncontrolled variables encountered during the experiments (moisture content of asphalt mixture, voids in the mineral aggregate, air voids, asphalt content and asphalt penetration) caused some variability in the results; however, they did not mask the effects of the controlled variables completely.
2. While some variation in tensile strength, tensile strength ratio, and boiling test results was observed, no significant difference was identified between mixtures produced in the batch plant and the drum plant for all conditions of stockpile moisture and mixing temperature.
3. Both types of asphalt plants were able to remove most or all of the moisture from the stockpile aggregate though they were penalized with higher fuel costs and lower production. The higher fuel costs were measured and documented for a drum mix plant and the effect is believed to be similar for a batch plant.
4. Density was the major factor which affected the properties of the experimental mixtures.
5. Asphalt mixtures with moisture contents above 1.5% were difficult to produce and then only at very low mixing temperatures.

Effects of Mixing Temperature

1. Mixing temperature was observed to have a slight effect on Hveem stability; however, the effects were small and inconsistent.

2. The effect of mixing temperature on tensile strength was found to be dependent on aggregate type. Tensile strength increased with increasing mixing temperature for the hard limestone aggregate (Aggregate A) in both the drum and batch plant. The sandstone aggregates (Aggregates B and C) did not show a similar effect.
3. Resilient modulus of elasticity did not appear related to mixing temperature. Significant variations were measured for different experimental conditions; however, these changes were quite random.
4. There was a good indication that moisture damage susceptibility as measured by the boiling test improved with increasing mixing temperature. A slight indication of improved tensile strength ratios with increased mixing temperature was also observed.
5. Increased mixing temperature did not significantly increase the amount of asphalt hardening which occurred during mixing for the temperature range of the experiment.
6. Asphalt mixtures with mixing temperatures below 200°F could not be produced with a uniform coating of asphalt.

Effects of Stockpile Moisture Content

1. Changes in stockpile moisture content did not affect measured Hveem stabilities.
2. Tensile strength measurements were uniform for the range of moisture contents measured.
3. Stockpile moisture content did not affect the resilient modulus of elasticity.
4. A slight indication of increased moisture damage resistance as measured by the tensile strength ratio was observed.
5. An indication of reduced asphalt hardening during mixing was observed for increased stockpile moisture contents.

Recommendations

1. The experimental study did not identify any clear relationships among mixing temperature, stockpile moisture content, and the properties of asphalt mixtures produced in either batch or drum mix plants for the aggregates studied. Therefore, further testing of

other aggregates should be done to determine if the observations of this study are generally valid or if the results are dependent on aggregate type. As a minimum, one or two aggregates should be studied in the next construction season.

2. The results of the experimental study indicate that the measured engineering properties are predominantly affected by the compaction density of the mixture. If mixing temperature and stockpile moisture are believed to have a negligent effect on the engineering properties the critical step in determining the properties of the mixture may be the density which can be obtained on the road. The location of the experimental mixtures for Aggregate B and Aggregate C is known and a coring program should be taken to determine the in-place densities. Although the compaction process used on the road was not well documented, the results of the cores will demonstrate the densities and engineering properties which were achieved without alteration of the regular compaction procedures.

   On future experiments involving mixing temperature and stockpile moisture, the study should include a documentation of compaction procedures and variations in compactive effort to determine at what temperature adequate density can be achieved.

APPENDIX A

AGGREGATE A

HARD LIMESTONE AGGREGATE

APPENDIX A. HARD LIMESTONE AGGREGATE

Aggregate Characteristics and Asphalt Plant Details

The hard limestone aggregate used in this experiment was processed by Capitol Aggregates at a plant site in Austin (Fig A1). The site, located on the banks of the Colorado River, consists of a permanently installed batch plant and drum plant, stockpiles of aggregate, and other related equipment.

The aggregates used in the asphalt mixture were produced in the Austin area (Fig A2, Table A1). With the exception of the sandstone, all other aggregates at the plant site were formed into stockpiles which butted directly one against the other. The material was trucked to the site and stockpiled using a crawler tractor. Two sets of aggregate feeders were located under the stockpiles in a service tunnel, one for the batch plant, the other for the drum mixer. The sandstone aggregate was handled separately using two coldfeed bins.

No modifications were required on the asphalt plants to perform the experiment. Mixing temperature of the asphalt mixture was controlled exclusively by altering the burner fuel control. The angle of the drier on the batch plant and the drum on the drum plant was not altered.

TABLE A1. AGGREGATE A MATERIAL SOURCES

Material	Material Source
Sandstone	Delta Materials, Marble Falls, Texas
Limestone	Zachary Materials, Georgetown, Texas
Limestone Screenings	Zachary Materials, Georgetown, Texas
Field Sand	Colorado River, Austin, Texas
AC 10 Asphalt Cement	Texas Fuel and Asphalt, Austin, Texas

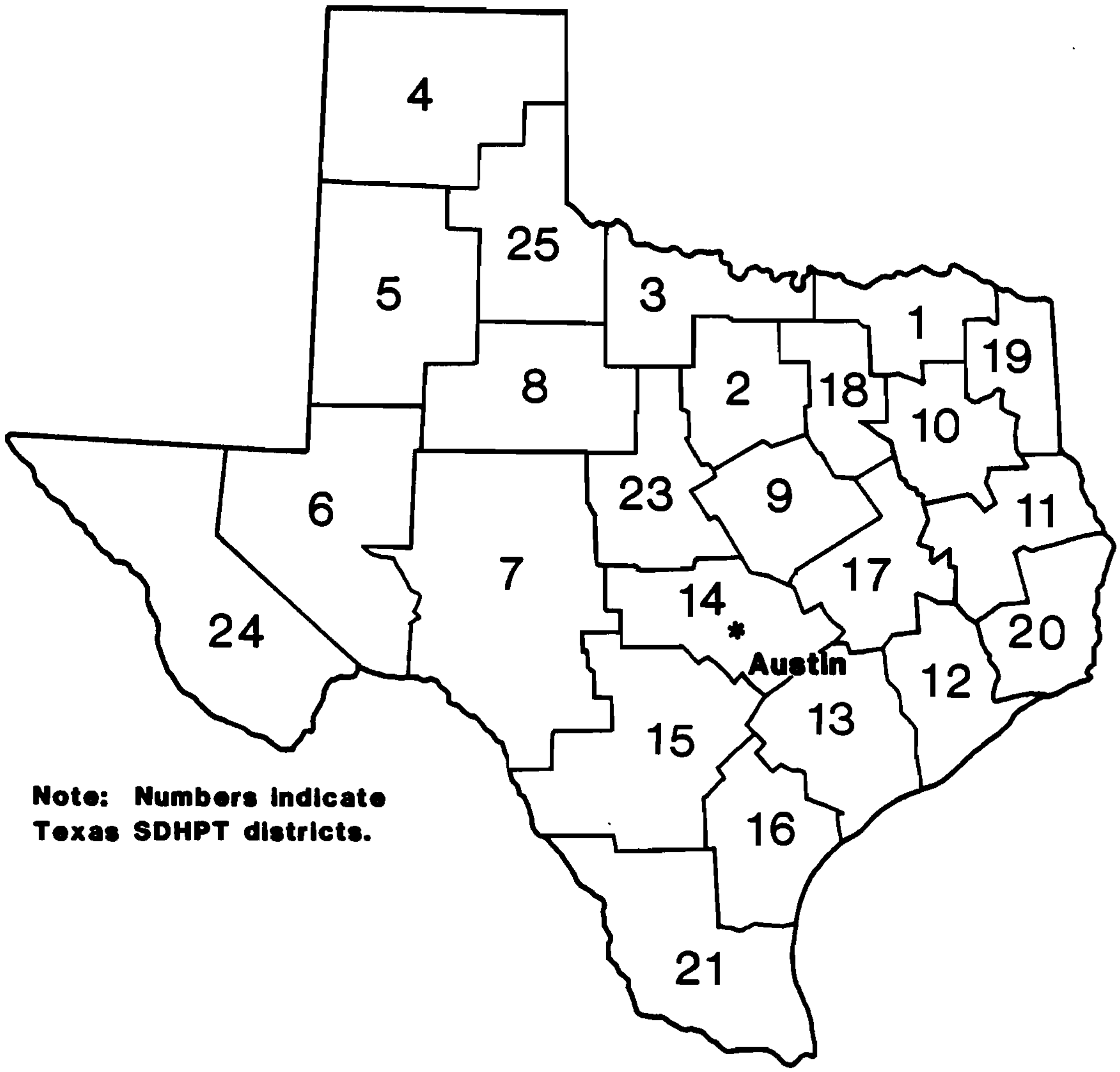


Fig A1. Location of hard limestone experiment.

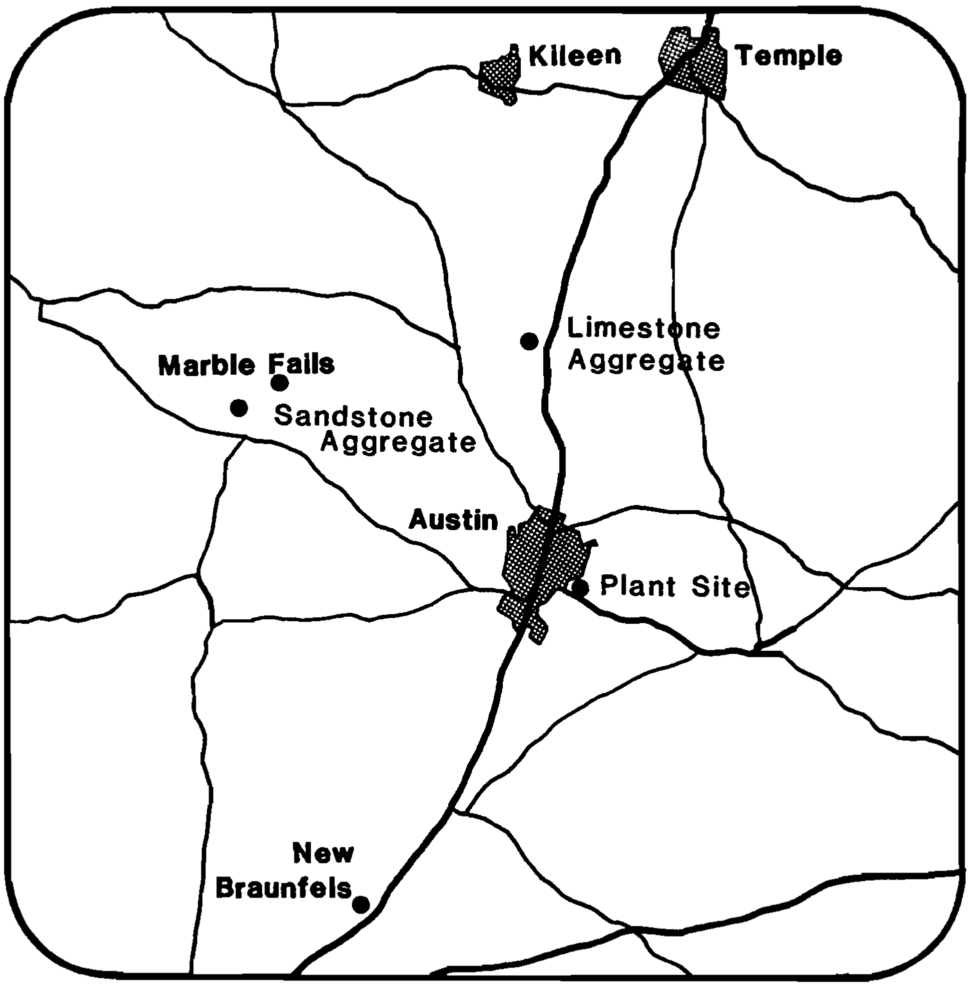


Fig A2. Vicinity of hard limestone experiment.

Asphalt Mix Design

The asphalt mix design was done by the Texas State Department of Highways and Public Transportation using the Hveem method of design and was not altered for this experiment. The design includes the gradations of both the individual and the combined aggregates (Table A2), the theoretical specific gravities of the individual aggregates, the combined aggregates and the aggregate-asphalt combinations (Table A3), and the results of the density and stability tests for the various asphalt contents (Table A4). These results, which are plotted in Figure A3, determine the design asphalt content.

Compaction Effort Study

Before the experiment was started, a laboratory study was done at each experiment temperature to determine the compactive effort required to produce molded specimens with 7% air voids. These procedures were then used in the field to compact modified compaction specimens.

The study was done as follows. Oven-dried samples of the individual aggregates were sieved, then recombined to form the gradations shown in Table A2. Asphalt was added to produce the design mix and the material was compacted at 175°F, 225°F, 250°F, 275°F, and 325°F. By trial and error, the compactive effort which would leave the desired 7% air voids in the specimen was determined. The results are shown in Table A5.

Sample Preparation and Testing

On the batch plant the following method was used to obtain samples:

(1) The hot aggregate bins were emptied.

(2) The aggregate drier was restarted and adjusted to desired temperature.

(3) A batch of asphalt concrete was mixed and dumped directly into a truck. The temperature was measured and corrections were made until the desired mixing temperature was obtained.

(4) A sample of approximately 200 pounds was shovelled into a large covered metal container and transported to the University of Texas asphalt laboratory. Travel time to the University was approximately 20 minutes.

(5) Moisture determination samples were taken from the hot aggregate bins and the asphalt mix. Initial weighings were done in the field laboratory after which samples were transported to The University of Texas.

TABLE A2. AGGREGATE A DESIGN GRADATION

Sieve Size	Aggregate Type, %				
	Sandstone	Limestone	Limestone Screenings	Field Sand	Aggregate Mixture*
1/2" - 3/8"	5.6	0.0	0.0	0.0	1.7
3/8" - #4	80.9	40.9	1.2	0.0	36.9
#4 - #10	7.5	58.1	38.4	0.7	28.1
+#10	94.0	99.0	40.6	0.7	66.7
#10 - #40	2.2	0.7	43.5	16.4	13.5
#40 - #80	0.3	0.2	9.7	63.0	13.6
#80 - #200	0.7	0.0	4.0	18.5	4.4
-#200	2.8	0.1	3.2	1.4	1.8

* Combined aggregates composed of 30% sandstone, 30% limestone, 22% limestone screenings, and 18% field sand.

TABLE A3. AGGREGATE A DESIGN THEORETICAL SPECIFIC GRAVITIES

Material	Specific Gravity*
Sandstone	2.474
Limestone	2.564
Limestone screenings	2.602
Field sand	2.626
Aggregate mixture	2.555
Aggregate mixture with 4.0% asphalt	2.410
Aggregate mixture with 5.0% asphalt	2.376
Aggregate mixture with 6.0% asphalt	2.343
Aggregate mixture with 7.0% asphalt	2.311
Aggregate mixture with 8.0% asphalt	2.280

* The specific gravities of the aggregates are measured bulk specific gravities and the specific gravities of the mixtures are calculated.

TABLE A4. AGGREGATE A DESIGN SPECIMEN RELATIVE DENSITIES AND HVEEM STABILITIES

Asphalt Content, %	Relative Density,* %	Hveem Stability, %
4.0	92.9	55
5.0	95.6	51
6.0	98.4	53
7.0	100.0	48
8.0	100.8	32

* Percent theoretical specific gravity of the asphalt mixture.

TABLE A5. COMPACTIVE EFFORT FOR AGGREGATE A, MODIFIED SPECIMENS

Compaction Temperature, °F	Number of Cycles*	Level-Up Load, lb**
175	6	500
225	5	1000
250	5	1000
275	4	800
325	4	1000

* One cycle is three revolutions on the Texas Gyratory Shear Compactor

** Final static load in pounds applied to the 4-inch-diameter specimen

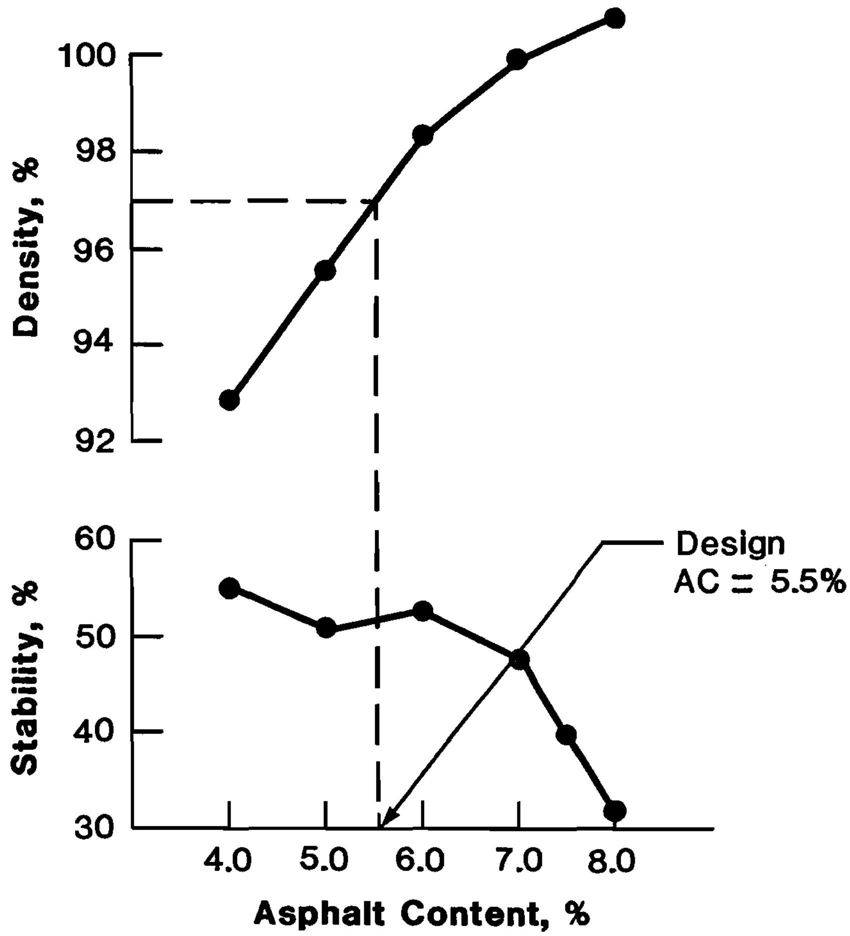


Fig A3. Aggregate A density-stability design curve.

(6) Moisture determination samples for the aggregates were gathered. Individual aggregates were sampled from the feeders and the combined aggregates were sampled by cross-sectioning the coldfeed belt.

For experimentation on the drum mixer the samples were gathered as follows:

(1) One of the mixture storage silos was emptied while the other was in use.

(2) The temperature control for the drum mixer was set at the desired temperature and the production was switched to the empty silo.

(3) The material was dumped into a truck, its temperature was measured, and the drum temperature was adjusted until the desired mixing temperature was obtained.

(4) A sample of approximately 200 pounds was shovelled into a covered metal container.

(5) A moisture determination sample for the asphalt mix was taken and transported with the large bulk sample to The University of Texas laboratory.

(6) Moisture determination samples for the aggregates were taken. Individual aggregates were sampled at the feeders and the combined aggregate was sampled by cross-sectioning the coldfeed belt.

For both batch and drum plant mixtures the large bulk sample was used to prepare specimens to be tested later. Modified compaction specimens were made with material taken directly from the bulk sample. The temperature loss of this material during transport was 5 to 10°F. Standard compaction specimens were compacted using material which had been tempered to 250°F in an oven. In addition to the compacted specimens, a 30-lb bulk sample was retained for an asphalt extraction, theoretical specific gravity, and other miscellaneous tests.

Test Results

The results of all tests performed during this experiment are tabulated in Tables A6 to A10. The results are listed for each of the individual duplicate or triplicate test specimens. Tensile strength, resilient modulus of elasticity, and Hveem stability are listed in Table A6 for the standard compaction specimens and in Table A7 for the modified compaction specimens. Table A8 lists the moisture damage susceptibility parameters and Table A9 contains gradation and extracted asphalt data. The gradations are shown in Figure A4. Moisture contents of the asphalt mixture and the coldfeed aggregates are listed in Table A10 and shown in Figure A5.

TABLE A6. AGGREGATE A RESULTS OF INDIVIDUAL STANDARD COMPACTION SPECIMEN TESTS

		Dry Conditioning			Freeze-Thaw Conditioning		
Stockpile Moisture %	Mixing Temp., °F	Tensile Strength, psi	Resilient Modulus, ksi	Hveem Stability, %	Tensile Strength, psi	Resilient Modulus, ksi	Hveem Stability, %
Batch Plant							
Wet	180	85	1000	40	51	1067	32
		88	1086	40	57	856	27
		93	1315	41	60	875	34
	230	75	857	46	59	1154	35
		82	778	44	60	748	35
		87	776	46	56	1054	38
	250	96	1084	45	50	1192	30
		92	1051	44	42	898	34
		90	1103	44	40	876	37
	275	95	1172	41	53	911	37
		98	1203	41	56	904	39
		92	898	44	57	1142	37
	325	119	758	48	68	1185	41
		111	700	47	66	1188	40
		122	803	45	63	1658	39
Drum Plant							
Wet	175	74	678	44	40	511	--
		68	595	46	40	511	--
	230	92	641	49	53	709	--
		92	790	48	59	714	--
	250	110	915	38	100	811	35
		104	798	40	94	944	31
		114	1297	43	87	996	38
	275	109	1695	44	86	867	37
		111	1185	41	80	845	34
		115	1597	42	96	955	38
	330	117	1092	10	98	930	40
		125	839	40	82	898	41
		103	831	40	79	895	44

TABLE A7. AGGREGATE A RESULTS OF INDIVIDUAL MODIFIED COMPACTION SPECIMEN TESTS

Stockpile Moisture %	Mixing Temp., °F	Dry Conditioning: Tensile Strength, psi	Dry Conditioning: Resilient Modulus, ksi	Dry Conditioning: Hveem Stability, %	Freeze-Thaw Conditioning: Tensile Strength, psi	Freeze-Thaw Conditioning: Resilient Modulus, ksi	Freeze-Thaw Conditioning: Hveem Stability, %
Batch Plant							
Wet	180	44	743	33	12	1948	30
		41	847	30	13	1314	30
		43	808	31	13	786	29
	230	48	557	36	20	597	31
		50	578	40	20	666	33
		49	691	36	19	397	33
	250	53	762	37	17	493	34
		52	849	36	17	614	34
		51	801	37	17	819	35
	275	54	723	33	26	814	33
		59	715	35	24	1125	34
		54	772	32	26	811	35
	325	68	703	39	37	1052	36
		71	758	32	41	1033	29
		71	847	32	43	949	31
Drum Plant							
Wet	175	42	--	36	16	--	--
		40	--	36	16	--	--
	230	51	--	39	26	--	--
		53	--	39	26	--	--
	250	81	755	37	33	1005	34
		82	681	39	39	867	35
		89	707	37	39	895	35
	275	80	836	35	34	1013	34
		73	815	35	33	1223	32
		94	938	37	33	856	33
	325	56	--	37	47	858	39
		53	769	36	42	880	42
		52	766	36	44	718	35

TABLE A8. AGGREGATE A MOISTURE DAMAGE SUSCEPTIBILITY PARAMETERS

Stockpile Moisture %	Mixing Temp., °F	Standard Compaction Tensile Strength Ratio*	Modified Compaction Tensile Strength Ratio*	Boiling Test Retained Asphalt, %
Batch Plant				
Wet	180	0.63	0.30	25
	230	0.71	0.41	60
	250	0.47	0.34	60
	275	0.58	0.46	75
	325	0.56	0.57	85
Drum Plant				
Wet	175	0.56	0.39	60
	230	0.61	0.50	--
	250	0.86	0.44	--
	275	0.78	0.40	--
	330	0.75	0.83	95

* Tensile strength ratio computed from the average tensile strength of the freeze-thaw conditioned specimens divided by the average tensile strength of the dry conditioned specimens.

TABLE A9. AGGREGATE A EXPERIMENTAL RUN GRADATION AND ASPHALT DATA

Stockpile Moisture	Mixing Temp., °F	Gradation, % Passing 1/2"	3/8"	#4	#10	#40	#80	#200	Extracted Asphalt Content, %	Penetration, mm	Viscosity,	Theoretical Specific Gravity*
Batch Plant												
Wet	180	100	97	69	38	22	10	4	4.9	88	1879	2.385
	230	100	99	71	41	24	12	5	4.7	87	1447	2.397
	250	100	97	68	37	22	10	4	4.6	88	1589	2.406
	275	100	97	68	38	23	11	5	4.5	81	2154	2.419
	325	100	97	66	38	23	11	5	4.5	72	2194	2.418
Drum Plant												
Wet	175	100	91	55	33	22	8	4	5.1	122	1134	2.409
	230	100	92	62	36	21	9	5	4.6	118	1112	2.407
	250	100	98	63	41	25	10	5	5.3	62	3137	2.378
	275	100	98	61	40	25	10	5	5.1	64	2873	2.394
	325	100	98	66	42	25	7	4	5.1	64	2969	2.406

* Rice theoretical specific gravity of asphalt aggregate combination.

TABLE A10. AGGREGATE A EXPERIMENTAL RUN MOISTURE CONTENTS

Stockpile Moisture	Mixing Temp., °F	Moisture Content, %					
		Sandstone	Limestone	Limestone Screenings	Field Sand	Aggregate Mixture	Asphalt Mixture
Batch Plant							
Wet	180	1.2	4.2	5.3	5.0	3.5	0.4
	230	2.4	5.2	6.1	4.8	4.0	0.1
	250	1.4	4.4	5.5	4.4	3.7	0.1
	275	2.2	5.7	6.3	5.3	5.1	0.0
	325	3.0	6.7	6.8	5.0	5.3	0.0
Drum Plant							
Wet	175	2.5	4.3	9.1	5.6	5.0	0.6
	230	2.7	4.1	7.2	6.2	4.8	--
	250	2.9	8.0	7.8	5.0	5.7	0.0
	275	4.3	5.3	7.9	7.9	5.8	0.0
	325	2.7	3.2	4.2	3.8	3.0	0.0

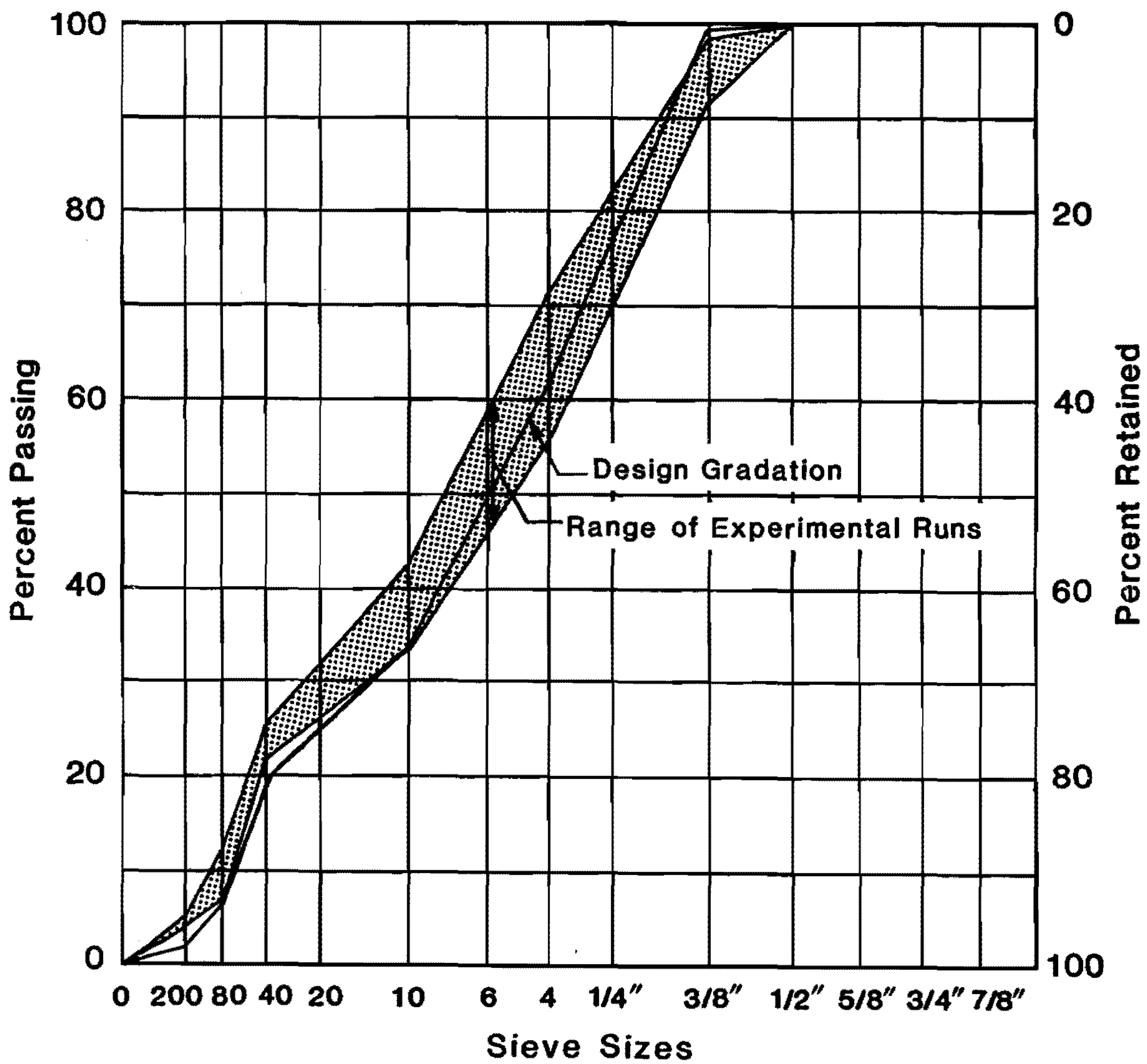


Fig A4. Aggregate A gradation limits of experimental runs.

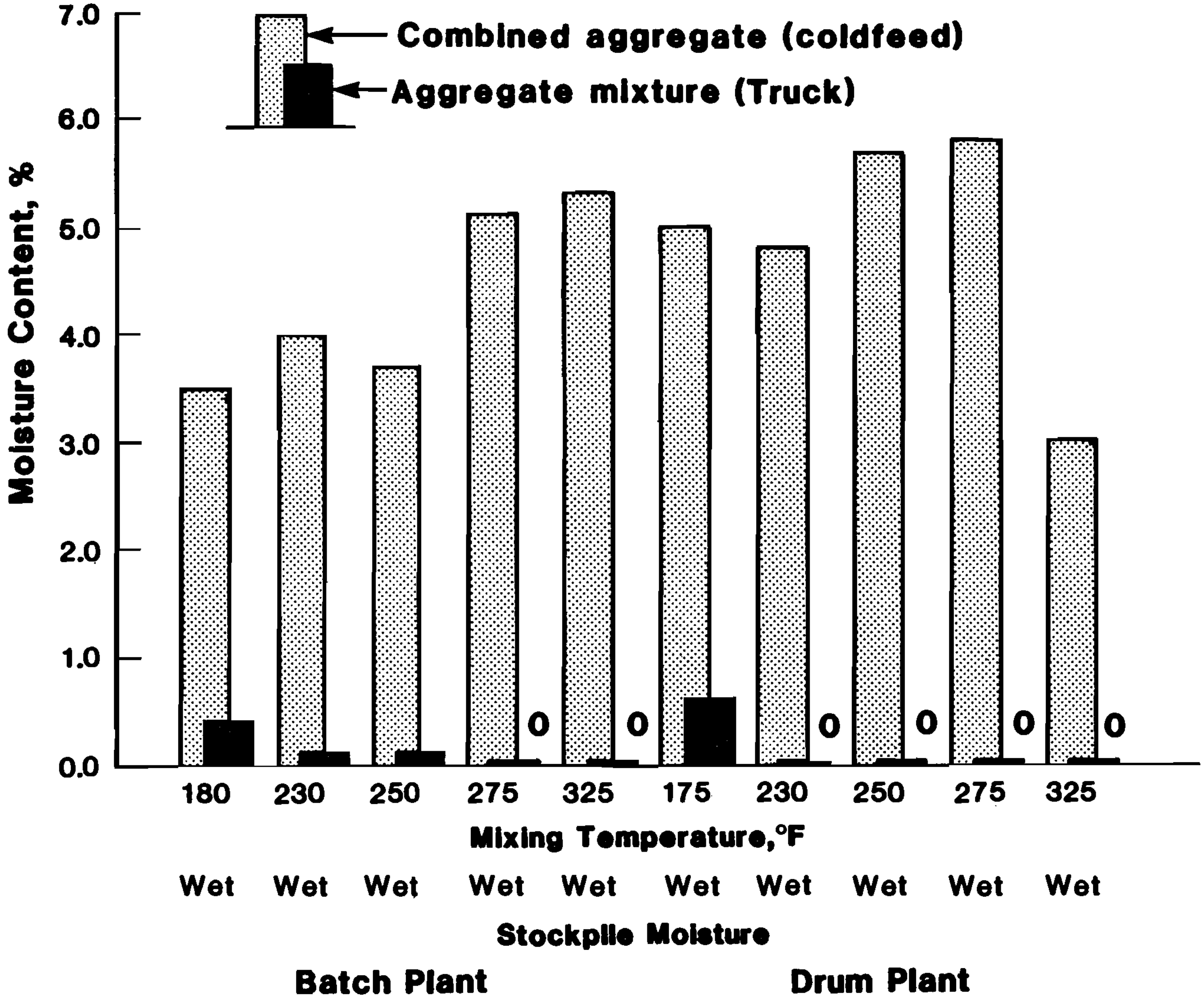


Fig A5. Aggregate A moisture contents of experimental runs.

APPENDIX B

AGGREGATE B

SANDSTONE AGGREGATE USING A

BATCH PLANT

APPENDIX B. SANDSTONE AGGREGATE USING A BATCH ASPHALT PLANT

Aggregate Characteristics and Asphalt Plant Details

The sandstone aggregate used to produce the asphalt mixtures in this experiment was mixed by South Texas Construction Company. The plant, located 5 miles north of Mathis, Texas (Fig B1), consists of a mobile batch asphalt plant, stockpiles of aggregate, asphalt and lime storage tanks, and other related equipment. Cold feed bins were used to feed the aggregates, which were trucked on site and pushed up into stockpiles with a crawler tractor, then loaded into the coldfeed bins with a rubber-tired loader. The source of the aggregates is shown in Figure B2 and listed in Table B1.

TABLE B1. AGGREGATE B MATERIAL SOURCES

Material	Material Source
Sandstone (coarse)	Raybe Property, Tuleta, Texas
Sandstone (fine)	Ehler Property
Limestone Screenings	McDonough Brothers, New Braunfels, Texas
Field Sand	Timmon Property, Mathis, Texas
AC 10 Asphalt Cement	Texas Fuel and Asphalt, Corpus Christi, Texas

No modifications were required on the batch plant to perform the experiment. The mixing temperature of the asphalt mixture was controlled by altering fuel flow to the burner of the aggregate drier. The angle of the drier was not changed so the retention time remained constant.

Asphalt Mix Design

The mix design for the sandstone aggregate was done using the Hveem method of asphalt mix design by the Texas State Department of Highways and Public Transportation (SDHPT). A summary of the design includes the gradations of the individual and the combined aggregates (Table B2), the

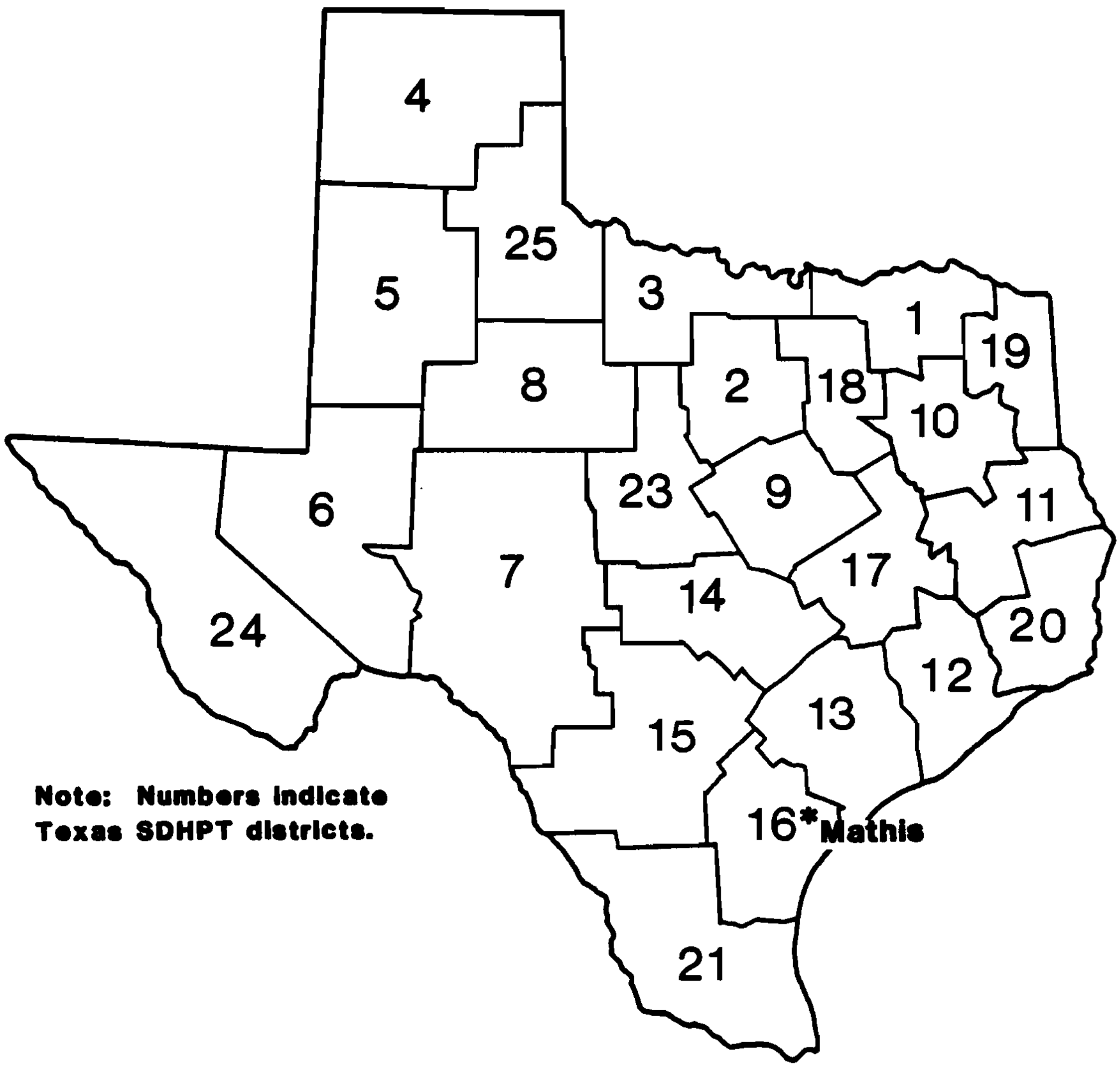


Fig B1. Location of sandstone experiment, batch plant.

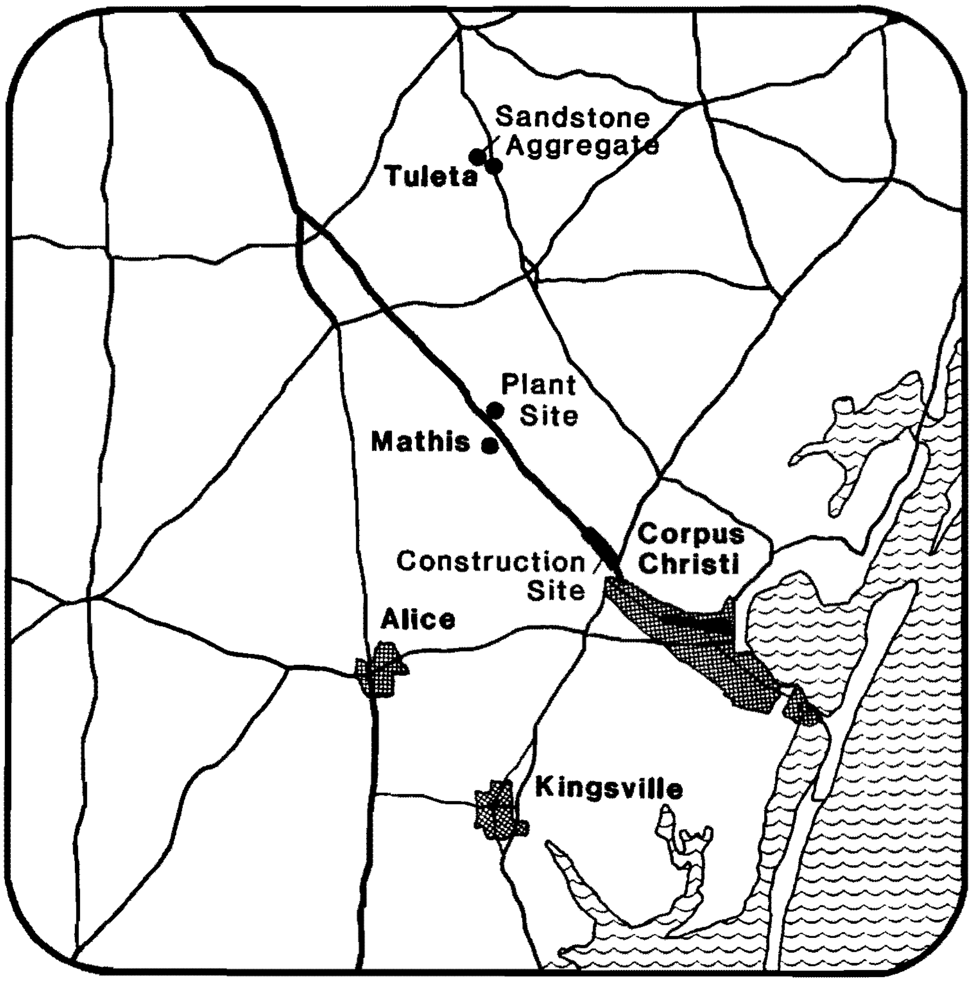


Fig B2. Vicinity of sandstone batch plant experiment.

TABLE B2. AGGREGATE B DESIGN GRADATION

Sieve Size	Aggregate Type, %				
	Coarse Sandstone	Fine Sandstone	Limestone Screenings	Field Sand	Aggregate Mixture*
1/2" - 3/8"	17.8	0.0	0.0	0.0	8.9
3/8" - #4	56.1	16.9	0.0	0.0	29.8
#4 - #10	22.3	70.9	11.2	0.0	20.4
+#10	96.2	87.8	11.2	0.0	59.1
#10 - #40	1.9	5.4	46.6	6.0	11.9
#40 - #80	0.4	3.2	13.8	63.0	15.9
#80 - #200	0.6	2.7	14.2	28.5	9.2
-#200	0.9	0.9	14.2	2.5	3.9

* Combined aggregates composed of 50% coarse sandstone, 10% fine sandstone, 20% limestone screenings, and 20% field sand.

theoretical specific gravities of the individual aggregates, the combined aggregates, and the asphalt aggregate combinations (Table B3), and the results of the density and stability tests for the various asphalt contents (Table B4). These results, which are plotted in Figure B3, determine the design asphalt content.

Compaction Effort Study

Before the experiment was started a laboratory study was done to determine the compactive effort required to produce specimens with 7% air voids at each of the experiment temperatures. These procedures were then used in the field to produce modified compaction specimens.

The study was done as follows. Oven-dried samples of the individual aggregates were sieved to individual sizes, then recombined to form the gradation in Table B2. Asphalt was added to produce the design mix of 6.6% and the material was compacted at temperatures of 200°F, 250°F, and 325°F. By trial and error, the compactive effort which would leave 7% air voids in the specimen was determined. The results are listed in Table B5.

Sample Preparation and Testing

The following procedure was used to obtain samples for each of the experimental runs.

(1) Moisture determination samples for the aggregates were gathered. Individual aggregates were sampled from the feeders on the coldfeed bins and the combined aggregates were sampled by cross-sectioning the coldfeed belt.

(2) The hot aggregate bins were emptied.

(3) The aggregate drier was restarted and adjusted to the desired temperature.

(4) Moisture determination samples for the heated aggregate were gathered from the hot aggregate bins.

(5) A batch of asphalt concrete was mixed and dumped directly into a truck. The temperature was measured and corrections were made until the desired mixing temperature was obtained.

(6) An approximate 200-pound sample was shovelled into a large covered metal container and taken to the field laboratory on site.

(7) A moisture determination sample for the asphalt mixture was taken and dried in the field lab.

(8) Modified compaction specimens, then modified-standard compaction specimens, were prepared using material taken directly from the

TABLE B3. AGGREGATE B DESIGN THEORETICAL SPECIFIC GRAVITIES

Material	Specific Gravity*
Coarse sandstone	2.351
Fine sandstone	2.161
Limestone screenings	2.721
Field sand	2.635
Aggregate Mixture	2.449
Aggregate Mixture with 5.5% asphalt	2.271
Aggregate Mixture with 6.0% asphalt	2.256
Aggregate Mixture with 6.5% asphalt	2.241
Aggregate Mixture with 7.0% asphalt	2.227
Aggregate Mixture with 7.5% asphalt	2.213

* Aggregate specific gravities are measured bulk specific gravities. Specific gravities of mixtures are calculated.

TABLE B4. AGGREGATE B DESIGN SPECIMEN RELATIVE DENSITIES AND HVEEM STABILITIES

Asphalt Content %	Relative Density* %	Hveem Stability %
5.5	96.6	45
6.5	97.6	41
7.5	99.1	30

* Percent theoretical specific gravity of the asphalt mixture

TABLE B5. COMPACTIVE EFFORT FOR AGGREGATE B MODIFIED SPECIMENS

Compaction Temperature, °F	Number of Cycles*	Level-Up Load, lb**
200	4	1000
250	3	1000
325	2	1000

* One cycle is three revolutions on the Texas Gyratory Shear Compactor

** Final static load applied to the 4-inch-diameter specimen

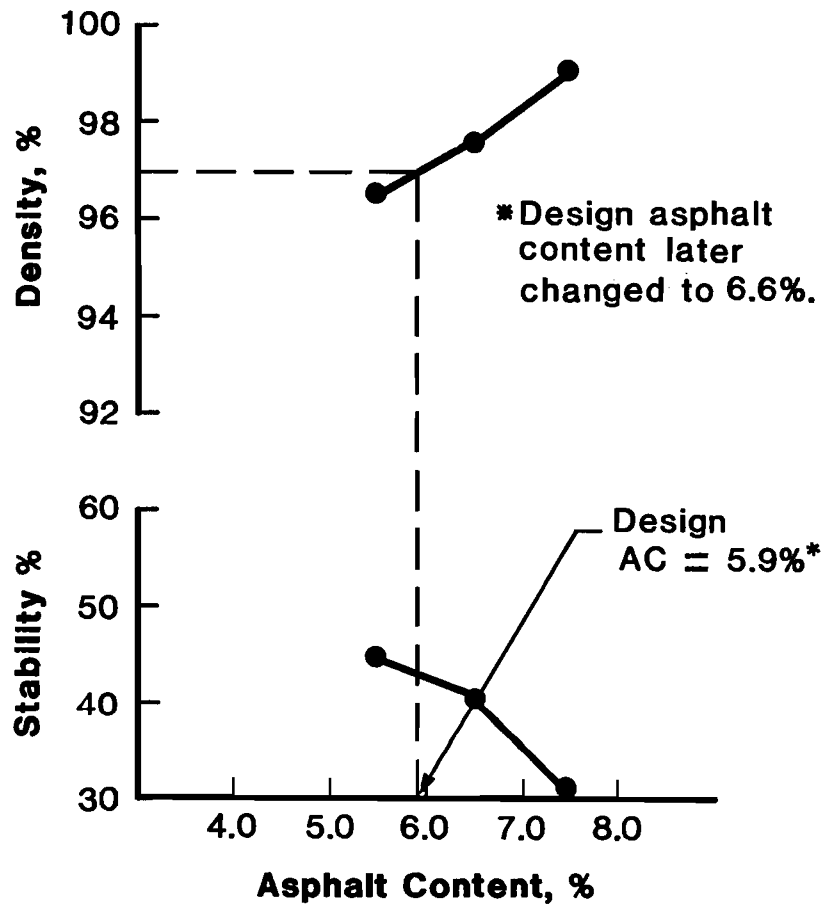


Fig B3. Aggregate B density-stability design curve.

metal container. The temperature drop of the mixture in the container during this time ranged from 10°F to 30°F.

(9) The material for standard compaction specimens was weighed into pans and its temperature was tempered to 250°F, ±10°F, in an electric oven.

(10) A small bulk sample, approximately 30 pounds, was retained for an asphalt extraction, a theoretical specific gravity test, and other miscellaneous tests.

Test Results

The results of all tests performed during this experiment are tabulated in Tables B6 through B10. The values listed are for the individual test specimens. Tensile strength, resilient modulus of elasticity, and Hveem stability are listed in Table B6 for the standard compaction specimens and in Table B7 for the modified compaction specimens. Table B8 lists the moisture damage susceptibility parameters and Table B9 contains aggregate gradation and extracted asphalt data. The gradations are plotted in Figure B4. Moisture contents of the asphalt mixture and coldfeed aggregates are listed in Table B10 and shown in Figure B5.

The experimental mixtures were placed and compacted as part of the highway contract using routine constructure procedures. The location of the experimental mixtures and the inplace compacted densities as measured by the Texas SDHPT are shown in Table B11.

TABLE B6. AGGREGATE B RESULTS OF INDIVIDUAL STANDARD SPECIMEN TESTS

		Dry Conditioning			Freeze-Thaw Conditioning	
Stockpile Moisture	Mixing Temp., °F	Tensile Strength, psi	Resilient Modulus, ksi	Hveem Stability, %	Tensile Strength, psi	Resilient Modulus, ksi
Dry	210	100	531	33	75	441
		101	618	35	94	624
		-	-	-	104	-
	255	145	874	33	114	849
		166	1452	32	108	792
		163	-	-	-	-
	340	97	533	36	77	397
		104	501	35	75	321
		-	-	36	-	-
Wet	220	122	895	34	132	926
		143	716	35	131	868
		-	-	-	132	-
	275	120	493	34	109	582
		117	442	37	108	384
		111	-	-	-	-
	325	128	679	39	118	650
		165	577	41	103	586
		-	-	37	-	-
Saturated	200	115	948	20	123	1117
		120	627	16	117	1068
		-	-	24	-	-
	210	101	559	35	121	463
		131	591	33	121	666
		-	-	32	-	-
	245	169	1392	28	118	818
		147	1249	30	138	1097
		-	-	-	137	-
	325	129	671	37	116	497
		117	467	37	112	654
		-	-	40	-	-

TABLE B7. AGGREGATE B RESULTS OF INDIVIDUAL MODIFIED COMPACTION SPECIMENS

		Modified Standard Specimens*			Modified Specimens**		
		Dry Conditioning		F/T Cond.	Dry Conditioning		F/T Cond.
Stockpile Moisture	Mixing Temp., °F	Tensile Strength, psi	Hveem Stability, %	Tensile Strength, psi	Tensile Strength, psi	Hveem Stability, %	Tensile Strength, psi
Dry	210	76	35	51	49	28	28
		79	31	57	37	26	26
	255	100	31	96	52	31	38
		-	35	95	57	30	43
	340	90	34	79	44	26	32
		95	40	69	48	28	36
Wet	220	91	30	91	67	32	51
		93	30	87	65	32	48
	275	97	39	83	58	30	34
		98	37	77	59	31	29
	325	112	39	82	55	27	43
		91	39	88	61	28	43
		95	37	-	57	30	42
Saturated	200	77	10	83	68	29	48
		77	11	81	70	26	59
	210	85	29	93	63	30	54
		84	28	85	66	31	70
	245	95	28	87	61	30	51
		95	29	82	50	30	46
	325	126	40	103	52	31	45
		101	39	102	62	30	43

* Compacted to standard compaction procedure endpoint at mixing temperature
** Compacted to 7% air voids at mixing temperature

TABLE B8. AGGREGATE B MOISTURE DAMAGE SUSCEPTIBILITY PARAMETERS

Stockpile Moisture	Mixing Temp., °F	Standard Comp. Tensile Strength Ratio*	Modified-Std. Compaction Tensile Strength Ratio*	Modified Comp. Tensile Strength Ratio*	Boiling Test Retained Asphalt %
Dry	210	0.90	0.70	0.63	50
	255	0.70	0.95	0.74	40
	340	0.76	0.80	0.74	85
Wet	220	1.00	0.97	0.75	60
	275	0.93	0.82	0.54	40
	325	0.76	0.86	0.73	70
Saturated	200	1.02	1.07	0.77	75
	210	1.04	1.06	0.96	80
	245	0.83	0.89	0.87	65
	325	0.92	0.90	0.77	85

* Tensile strength ratio computed from the average tensile strength of the freeze-thaw conditioned specimens divided by the average tensile strength of the dry conditioned specimens.

TABLE B9. AGGREGATE B EXPERIMENTAL RUN GRADATION AND ASPHALT DATA

Stockpile Moisture	Mixing Temp., °F	Gradation, % Passing							Extracted Asphalt		Theoretical Specific Gravity*
		1/2"	3/8"	#4	#10	#40	#80	#200	Content, %	Penetration, mm	
Dry	210	100	95	67	44	36	16	4	6.1	49	2.221
	255	100	96	70	46	41	17	1	5.7	62	2.239
	340	100	95	67	44	37	16	1	5.3	52	2.222
Wet	220	100	95	68	44	36	17	4	5.7	64	2.258
	275	100	95	70	44	37	17	3	5.3	65	2.243
	325	100	95	68	44	36	17	4	5.9	63	2.273
Saturated	200	100	97	69	45	35	18	6	6.3	69	2.270
	210	100	97	73	45	37	19	5	6.3	72	2.246
	245	100	95	67	43	36	17	4	6.0	71	2.245
	325	100	94	62	39	31	15	4	5.9	59	2.239

* Rice theoretical specific gravity of asphalt-aggregate combination

TABLE B10. AGGREGATE B EXPERIMENTAL RUN MOISTURE CONTENTS

Stockpile Moisture	Mixing Temp., °F	Moisture Content, %								
		Coarse Sandstone	Fine Sandstone	Limestone Screenings	Field Sand	Cold Feed Aggregate Mixture*	Coarse Hot Bin	Inter-mediate Hot Bin	Fine Hot Bin	Asphaltic Mixture
Dry	210	0.9	1.1	0.2	0.2	--	0.4	0.9	0.2	0.6
	255	1.1	3.1	0.3	0.0	--	0.4	0.5	0.0	0.3
	340	2.2	5.1	0.2	0.0	--	0.3	0.5	0.0	0.3
Wet	220	5.8	11.0	2.9	5.4	5.5	2.2	1.2	0.2	1.1
	275	--	--	--	--	5.1	1.5	0.9	0.3	0.6
	325	7.7	11.8	3.6	4.9	4.5	0.8	0.3	0.1	0.1
Saturated	200	7.1	13.0	7.7	16.4	8.0	1.6	0.1	0.0	1.7
	210	10.2	14.9	5.3	7.3	9.6	3.2	2.4	0.2	1.7
	245	10.2	14.9	5.3	7.3	9.5	1.5	0.6	0.0	1.0
	325	10.2	14.9	5.3	7.3	9.7	0.8	1.9	0.0	0.3

* Measured without addition of lime slurry

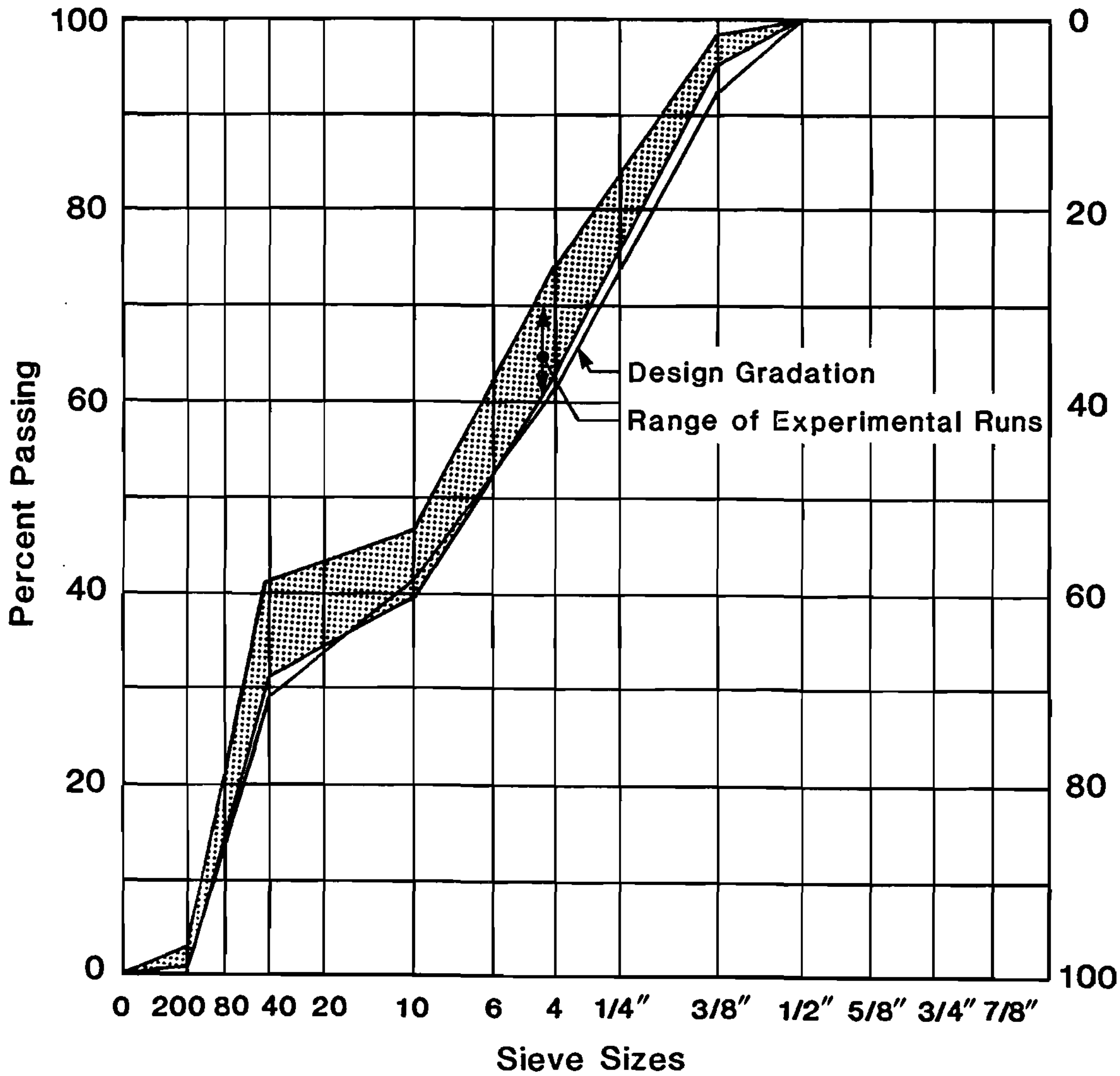


Fig B4. Aggregate B gradation limits of experimental runs.

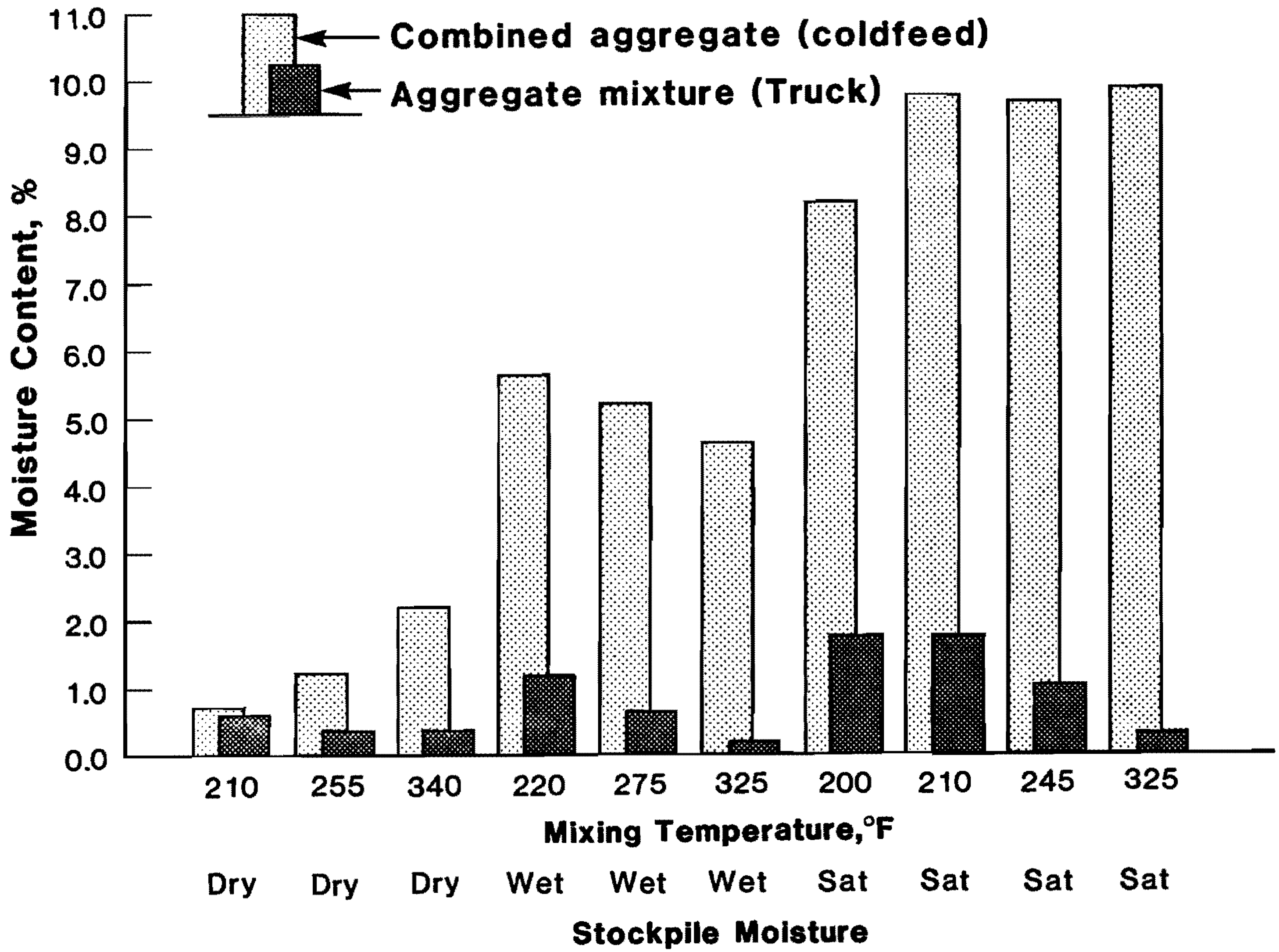


Fig B5. Aggregate B moisture contents of experimental runs.

TABLE B11. AGGREGATE B FIELD LOCATION OF EXPERIMENTAL MIXTURES

Stockpile Moisture	Mixing Temp., °F	Location*	Station	Field Density**
Dry	210	Left main lane	1191+00 to 1191+90	92.5
	255	Right shoulder	1055+70 to 1058+00	94.9
	340	Left main lane	1128+70 to 1130+40	92.0
Wet	220	Right main lane	966+50 to 969+00	92.5
	275	Right shoulder	1053+50 to 1055+40	98.8
	325	Left main lane	989+10 to 991+10	98.0
Saturated	200	Right shoulder	944+20 to 950+25	99.6
	210	Left main lane	1145+10 to 1147+20	96.1
	245	Right main lane	1074+50 to 1076+90	96.1
	325	Right main lane	1122+40 to 1124+50	95.0

* All experimental asphalt mixture placed on northbound lanes of Interstate Highway 37.

** Density expressed as percent theoretical specific gravity, as measured by Texas SDHPT.

APPENDIX C

AGGREGATE C

SANDSTONE AGGREGATE USING A

DRUM MIX ASPHALT PLANT

APPENDIX C. SANDSTONE AGGREGATE USING A DRUM MIX ASPHALT PLANT

Aggregate Characteristics and Asphalt Plant Details

The sandstone aggregate used to produce asphalt mix in this experiment was mixed by the Heldenfel Brothers of Corpus Christi at a plant site 20 miles north of Alice, Texas (Fig C1). It consists of a mobile drum mix asphalt plant in a semi-permanent installation, stockpiles of aggregate, asphalt and lime storage tanks, and other related equipment. Coldfeed bins were used to feed the aggregates which were trucked on site, pushed into stockpiles with a crawler tractor, and loaded into the coldfeed bins with a rubber tired loader. The source of the aggregates is shown in Figure C2 and listed in Table C1.

TABLE C1. AGGREGATE C MATERIAL SOURCES

Material	Material Source
Sandstone	Whitley Property
Sandstone Screenings	Whitley Property
Field Sand	Freeborn Property (Plant Site)
AC 10 Asphalt Cement	Gulf Oil, Corpus Christi, Texas

No modification was required on the asphalt plant to perform the experiment. The mixing temperature of the asphalt mixture was controlled exclusively by altering the burner fuel control. The angle of the drum was not changed throughout the experiment hence retention time in the drum and also mixing time remained constant.

Asphalt Mix Design

The mix design for the sandstone aggregate was done using the Hveem method of asphalt mix design by the Texas State Department of Highways and

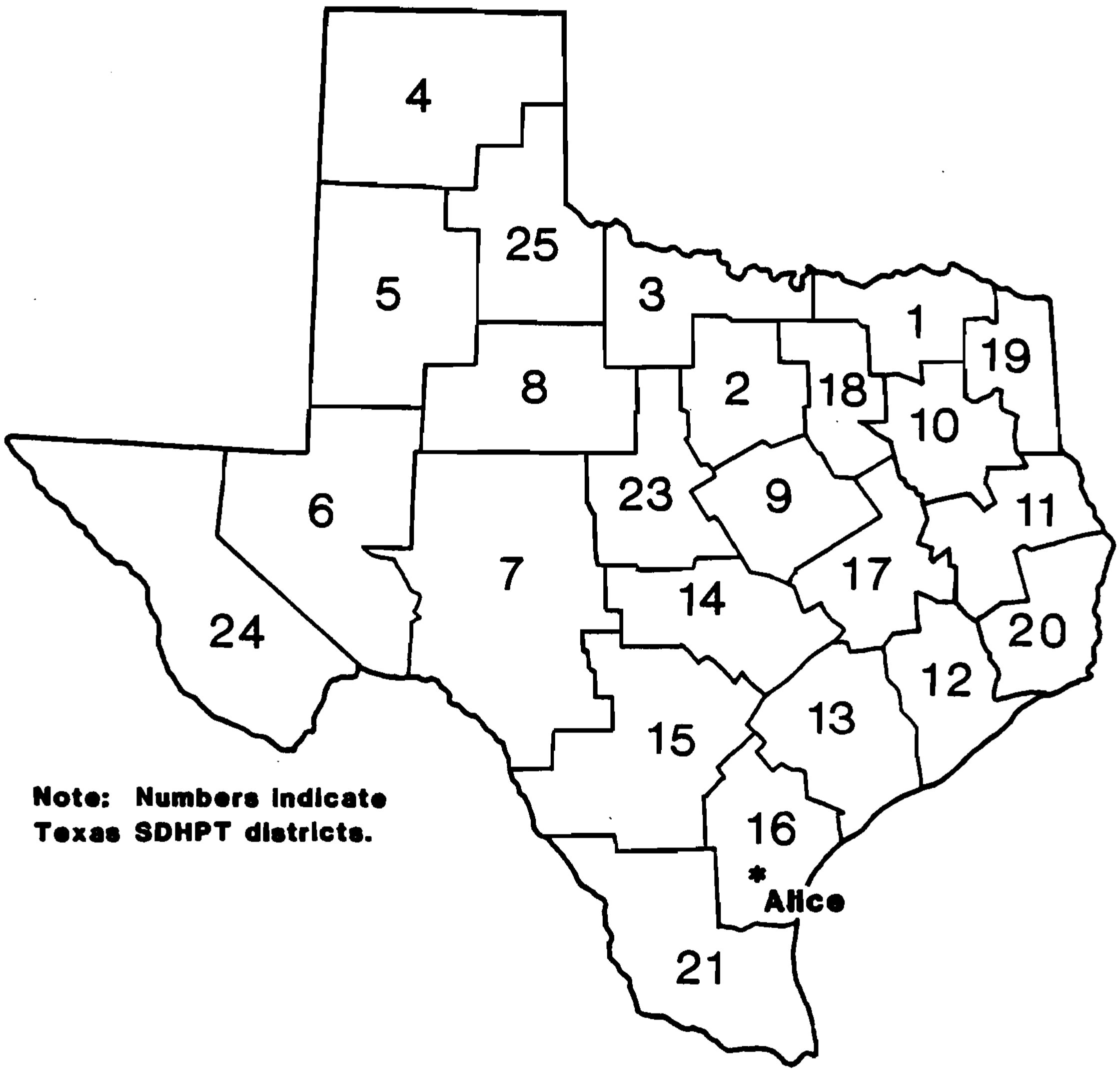


Fig Cl. Location of sandstone drum plant experiment.

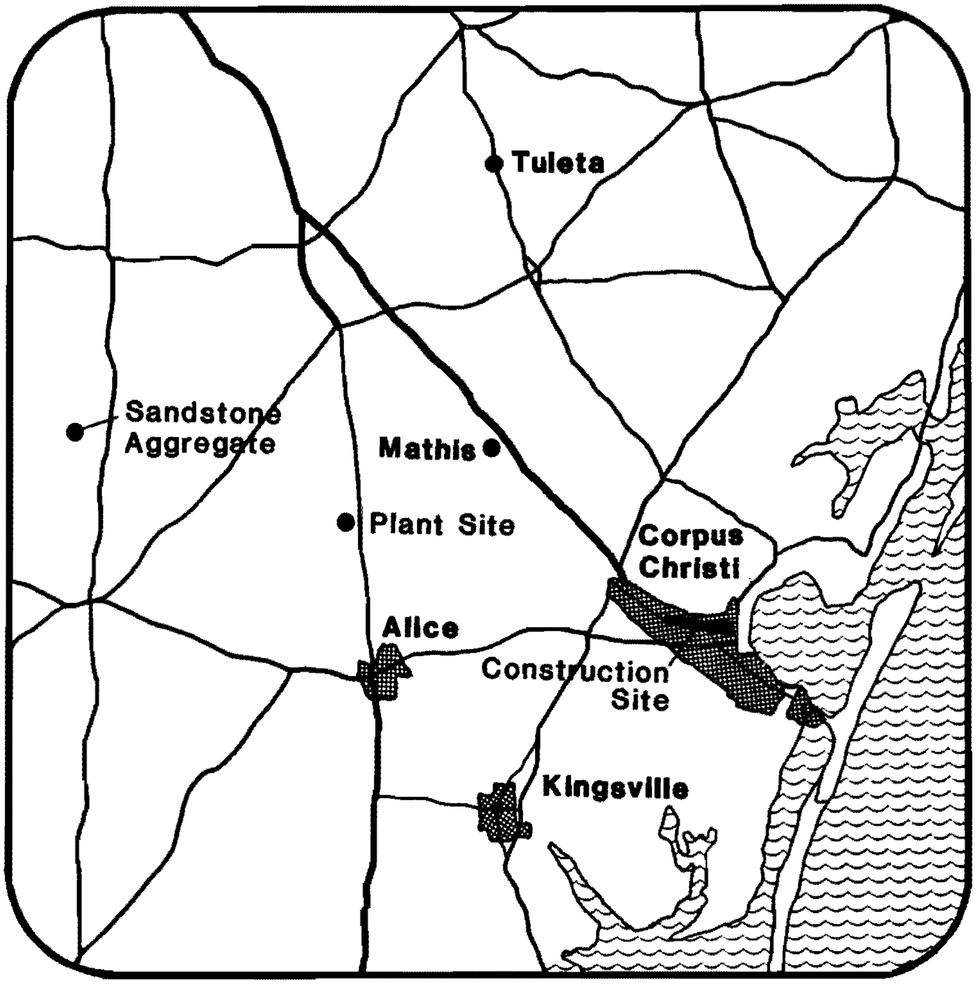


Fig C2. Vicinity of sandstone drum plant experiment.

Public Transportation. Prior to the start of the experiment, a field change increased the design asphalt content from 6.1% to 6.7%.

Each of the aggregate gradations and the combined mix gradation are shown in Table C2. Table C3 contains theoretical specific gravities for each aggregate and the theoretical specific gravity of the mixture when combined with various percentages of asphalt. Listed in Table C4 are the relative densities and Hveem stabilities determined in the design and the same information, from which the design asphalt content was determined, is plotted in Figure C3.

Compaction Effort Study

Before the experiment was started a laboratory study was done to determine the compactive effort required to produce specimens with 7% air voids at each of the experiment temperatures. These procedures were later used in the field to produce modified compaction specimens.

The study was done as follows. Oven-dried samples of the individual aggregates were sieved to individual sizes, then recombined to form the gradation in Table C2. Asphalt was added to produce the design mix and the material was compacted at temperatures of 175°F, 225°F, 250°F, 275°F, and 325°F. By trial and error, the compactive effort which would leave 7% air voids in the specimen was determined. The results are shown in Table C5.

Field Sample Preparation and Testing

The experimental runs were usually done in the mid-morning after the first group of trucks had departed. The following method was used.

(1) The asphalt mixture storage silo was emptied.

(2) The asphalt plant was restarted and the burner control set for the desired temperature. The production rate of the plant was not altered except for two of the experimental runs in which the high stockpile moisture content required a slowing of the production rate to achieve the desired temperature.

(3) The material was dumped into a truck and the temperature was measured. Corrections were made until the desired temperature was obtained.

(4) A sample of approximately 200 pounds was shovelled into a covered metal container and taken to a field laboratory on site.

(5) A moisture determination sample for the asphalt mix was taken by one of the field staff. Meanwhile the other member gathered moisture determination samples for the aggregates.

TABLE C2. AGGREGATE C DESIGN GRADATION

Sieve Size	Aggregate Type, %			
	Sandstone	Sandstone Screenings	Field Sand	Aggregate Mixture*
1/2" - 3/8"	11.8	0.0	0.0	7.5
3/8" - #4	58.3	0.0	0.0	37.3
#4 - #10	22.7	6.6	0.0	15.5
+ #10	92.8	6.6	0.0	60.3
#10 - #40	4.6	43.6	5.4	11.1
#40 - #80	1.6	38.4	69.6	20.8
#80 - #200	0.7	11.3	22.4	6.7
- #200	0.3	2.7	2.6	1.1

* Combined aggregates composed of 64% sandstone, 16% sandstone screenings and 20% field sand

TABLE C3. AGGREGATE C DESIGN THEORETICAL SPECIFIC GRAVITIES

Material	Specific Gravity*
Sandstone	2.364
Sandstone screenings	2.405
Field sand	2.622
Aggregate mixture	2.418
Aggregate mixture with 5.5% asphalt	2.246
Aggregate mixture with 6.0% asphalt	2.231
Aggregate mixture with 6.5% asphalt	2.217
Aggregate mixture with 7.0% asphalt	2.203
Aggregate mixture with 7.5% asphalt	2.189

* Aggregate specific gravities are measured bulk specific gravities. Specific gravity of asphalt mixtures is calculated.

TABLE C4. AGGREGATE C DESIGN SPECIMEN RELATIVE DENSITIES AND HVEEM STABILITIES

Asphalt Content, %	Relative Density,* %	Hveem Stability, %
5.5	95.3	48
6.0	96.8	47
6.5	98.0	43
7.0	98.3	42
7.5	98.6	36

* Percent theoretical specific gravity of the asphalt mixture.

TABLE C5. COMPACTIVE EFFORT FOR AGGREGATE C MODIFIED SPECIMENS

Compaction Temperature, °F	Number of Cycles*	Level-Up Load, lb**
175	5	400
225	4	800
250	4	1000
275	3	800
325	2	1000

* One cycle is three revolutions on the Texas Gyratory Shear Compactor at 50 pounds pressure

** Final static load applied to the 4-inch-diameter specimen

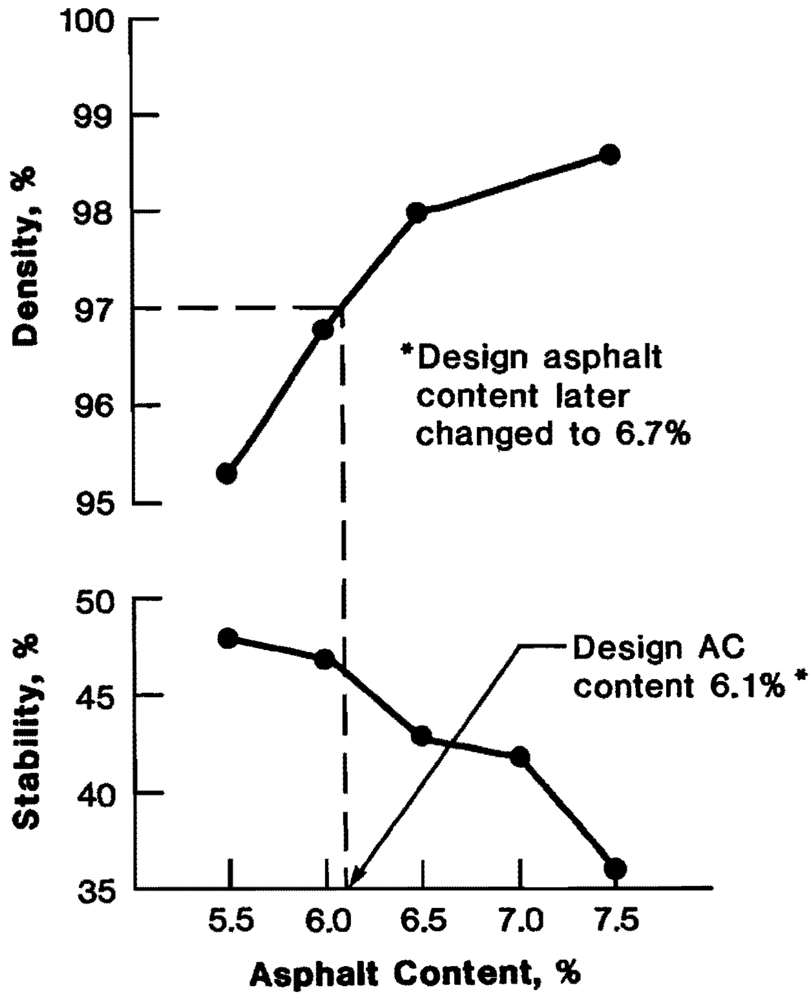


Fig C3. Aggregate C density-stability design curve.

(6) The individual aggregates were sampled from the belt feeders on the bottom of the coldfeed bins. Combined aggregates were sampled before and after the lime slurry spray bar by stopping the feed conveyor belt and removing a cross-section of material. All the aggregate moisture samples gathered were sealed in polyethylene bags and returned to The University of Texas for testing.

(7) In the field laboratory modified compaction specimens were made with material taken directly from the bulk sample. The temperature change of the material in the container during this time was about 10°F.

(8) The material used to make standard compacted specimens was weighed into pans and placed in a small electric oven to change the temperature to 250°F. Control on this oven was ±10°F.

(9) After all compacted specimens were completed, a small bulk sample, approximately 30 pounds, was kept for an asphalt extraction, theoretical specific gravity determination, and other miscellaneous tests.

(10) The small bulk sample, the compacted specimens, and the aggregate moisture content samples were transported to The University of Texas asphalt laboratories for testing.

Test Results

The results of all tests performed during this experiment are tabulated in Tables C6 to C10. The values listed are for the individual test specimens. Tensile strength, resilient modulus of elasticity, and Hveem stability are listed in Table C6 for the standard compaction specimens and in Table C7 for the modified compaction specimens. Table C8 lists the moisture damage susceptibility parameters and Table C9 contains aggregate gradation and extracted asphalt data. These gradations are plotted in Figure C4. Moisture contents of the asphalt mixtures and coldfeed aggregates are listed in Table C10 and shown in Figure C5.

The burner control setting for each of the experimental runs was plotted using the mixing temperature and stockpile moisture content for each experimental run. These points and suggested lines of equal burner control settings are shown in Figure C6.

The experimental mixtures were placed and compacted as part of the highway contract using routine construction procedures. The location of the experimental mixtures and the inplace compacted densities as measured by the Texas SDHPT are shown in Table C11.

TABLE C6. AGGREGATE C RESULTS OF INDIVIDUAL STANDARD COMPACTION SPECIMEN TESTS

		Dry Conditioning			Freeze-Thaw Conditioning	
Stockpile Moisture, %	Mixing Temp., °F	Tensile Strength, psi	Resilient Modulus, ksi	Hveem Stability, %	Tensile Strength, psi	Resilient Modulus, ksi
Dry	190	98	688	37	93	826
		119	654	41	91	660
	215	112	754	40	90	782
		97	828	38	99	774
	240	122	838	40	106	718
		166*	876	40	114	684
	285	111	794	42	105	814
		105	792	41	99	745
	320	108	752	41	79	681
		103	823	42	87	714
Wet	175	103	990	34	103	857
		108	863	35	95	934
		105	768	38	112	888
	230	84	882	43	104	1046
		86	794	41	95	847
		106*	795	36	91	869
	260	108	742	42	101	790
		109	914	44	105	860
		100	844	40	100	914
	270	119	671	46	79	675
		116	660	42	109	868
		111	784	43	112	808
	335	123	909	44	110	775
		123	764	43	118	684
		125	867	41		654
Saturated	185	122	875	40	118	681
		118	878	44	127	931
	215	107	724	15	111	827
		97	781	8	103	940
	245	111	1039	38	107	894
		109	934	40	95	742
		105	801	34	85	692
	270	92	685	17	99	681
		95	713	15	103	800

* Data point not used for average.

TABLE C7. AGGREGATE C RESULTS OF INDIVIDUAL MODIFIED COMPACTION SPECIMEN TESTS

		Dry Conditioning		Freeze-Thaw Conditioning
Stockpile Moisture*, %	Mixing Temp., °F	Tensile Strength, psi	Hveem Stability, %	Tensile Strength, psi
Dry	190	51	28	23
		-	28	24
	215	59	33	29
		61	33	27
	240	59	35	23
		67	36	22
	285	54	33	32
		58	35	31
	320	59	31	33
		58	31	30
Wet	175	65	31	18
		59	30	17
		61	30	16
	230	60	35	20
		61	33	23
		64	35	26
	260	67	36	25
		63	37	24
		66	33	24
	270	57	37	22
		56	34	22
		51	33	22
	335	65	37	33
		71	32	29
		73	34	29
Saturated	185	63	27	34
		67	28	33
	215	66	25	59
		68	25	-
	245	71	33	30
		73	33	34
		63	34	35
	270	62	29	66
		64	28	65

TABLE C8. AGGREGATE C MOISTURE DAMAGE SUSCEPTIBILITY PARAMETERS

Stockpile Moisture, %	Mixing Temp., °F	Standard Compaction Tensile Strength Ratio*	Modified Compaction Tensile Strength Ratio*	Boiling Test Retained Asphalt, %
Dry	190	0.84	0.47	15
	215	0.90	0.47	25
	240	0.92	0.37	40
	285	0.94	0.55	70
	320	0.78	0.53	85
Wet	175	0.96	0.28	-
	230	1.14	0.37	50
	260	0.96	0.37	-
	270	0.96	0.40	-
	335	0.91	0.43	-
Saturated	185	1.02	0.51	45
	215	1.05	0.88	70
	245	0.87	0.49	45
	270	1.07	1.03	75

* Tensile strength ratio computed from the average tensile strength of the freeze-thaw conditioned specimens divided by the average tensile strength of the dry conditioned specimens.

TABLE C9. AGGREGATE C EXPERIMENTAL RUN GRADATION AND ASPHALT DATA

Stockpile Moisture	Mixing Temp., °F	Gradation, % Passing							Extracted Asphalt			Theoretical Specific Gravity*
		1/2"	3/8"	#4	#10	#40	#80	#200	Content, %	Penetration, mm	Viscosity,	
Dry	190	100	96	64	45	35	15	3	7.1	94	1422	2.240
	215	100	95	64	46	35	16	4	7.6	63	2155	2.249
	240	100	95	65	46	34	16	4	6.6	83	1259	2.240
	285	100	93	54	39	31	14	3	6.0	84	1588	2.239
	320	100	96	66	50	39	17	3	6.1	79	1578	2.228
Wet	175	100	94	55	39	31	14	4	7.1	72	1484	2.256
	230	100	93	59	42	34	15	5	6.9	78	1464	2.218
	260	100	93	61	45	36	19	5	6.2	85	1660	2.231
	270	100	91	55	40	22	16	5	6.1	68	1635	2.223
	335	100	93	58	42	34	16	4	5.8	82	1664	2.219
Saturated	185	100	95	61	46	36	16	5	7.1	78	1272	2.242
	215	100	93	57	39	31	14	5	7.8	78	1514	2.216
	245	100	94	60	43	35	15	5	6.7	93	1486	2.248
	270	100	95	62	45	35	17	5	7.1	33	1559	2.242

* Rice theoretical specific gravity of asphalt-aggregate combination.

TABLE C10. AGGREGATE C EXPERIMENTAL RUN MOISTURE CONTENTS

Stockpile Moisture	Mixing Temp., °F	Moisture Content, %					
		Sandstone	Sandstone Screenings	Field Sand	Aggregate Mixture	Mixture with Lime	Asphaltic Mixture
Dry	190	-*	-	-	1.5	3.5	-
	215	-	-	-	1.5	3.5	-
	240	-	-	-	1.5	3.5	-
	285	-	-	-	0.9	3.2	0.3
	320	-	-	-	0.9	3.2	0.2
Wet	175	5.1	5.7	6.6	6.0	8.3	1.2
	230	6.7	6.6	7.4	6.9	9.1	0.4
	260	4.9	6.0	6.5	4.9	7.7	0.1
	270	6.6	6.6	6.9	6.7	8.9	0.0
	335	4.9	5.9	7.1	5.7	7.5	0.0
Saturated	185	9.7	21.8	5.9	11.9	13.6	1.9
	215	9.7	21.8	5.9	11.9	13.6	1.1
	245	8.6	22.5	6.2	11.2	12.7	1.2
	270	8.8	22.2	5.9	12.0	13.8	0.3

* Individual aggregate moisture contents not used. For dry stockpile condition aggregates were combined then predried.

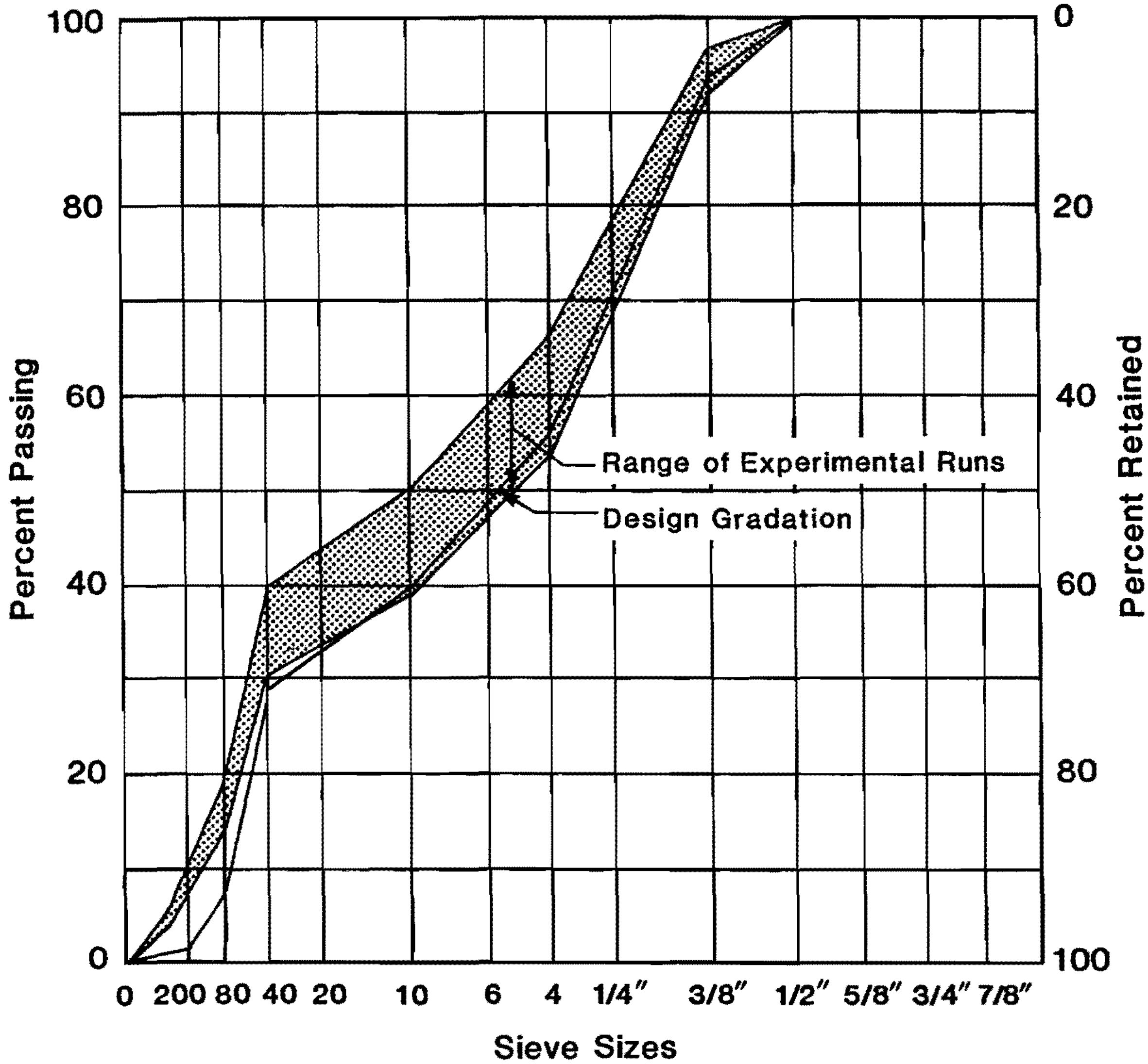


Fig C4. Aggregate C gradation limits of experimental runs.

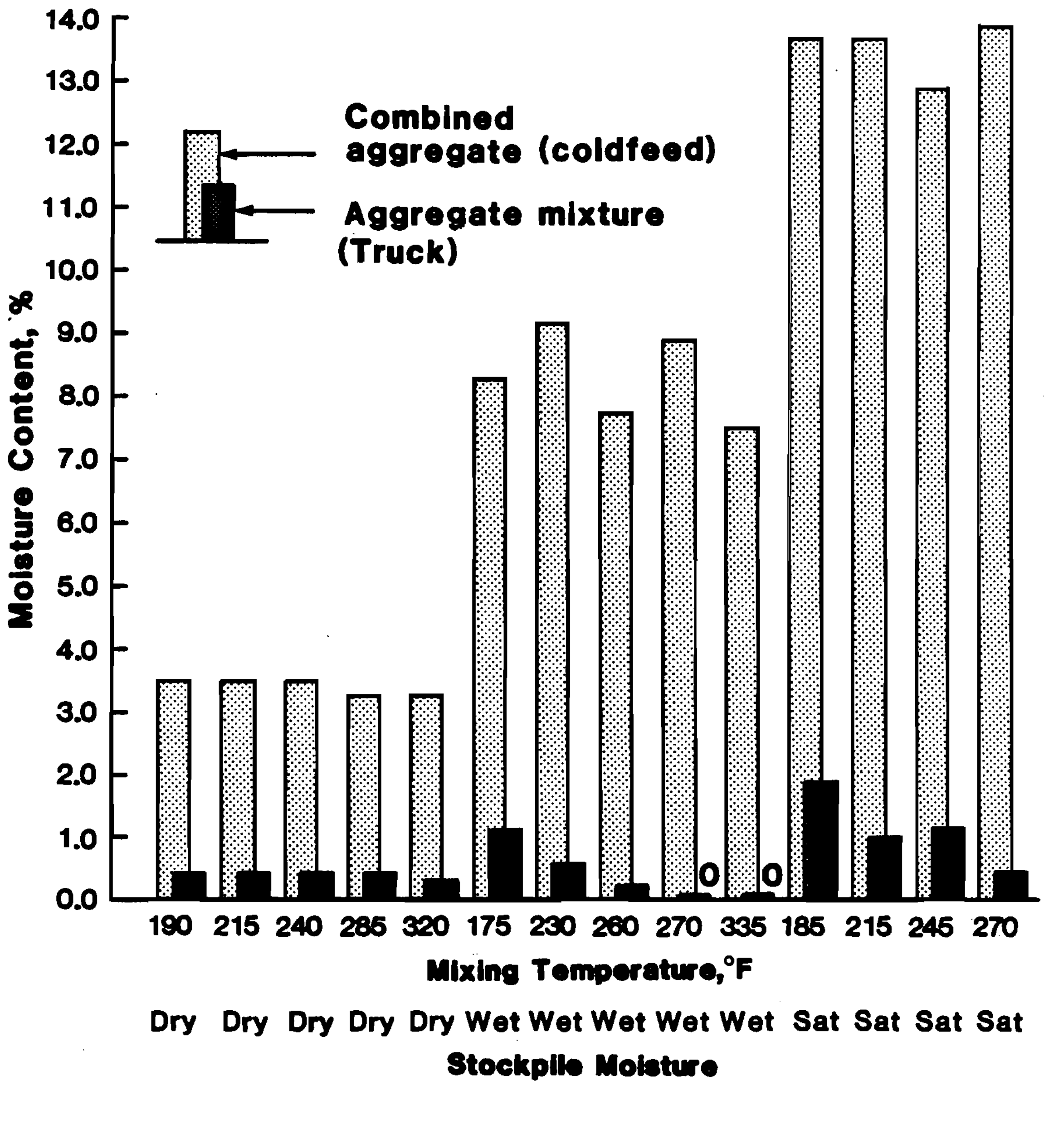


Fig C5. Aggregate C moisture contents of experimental runs.

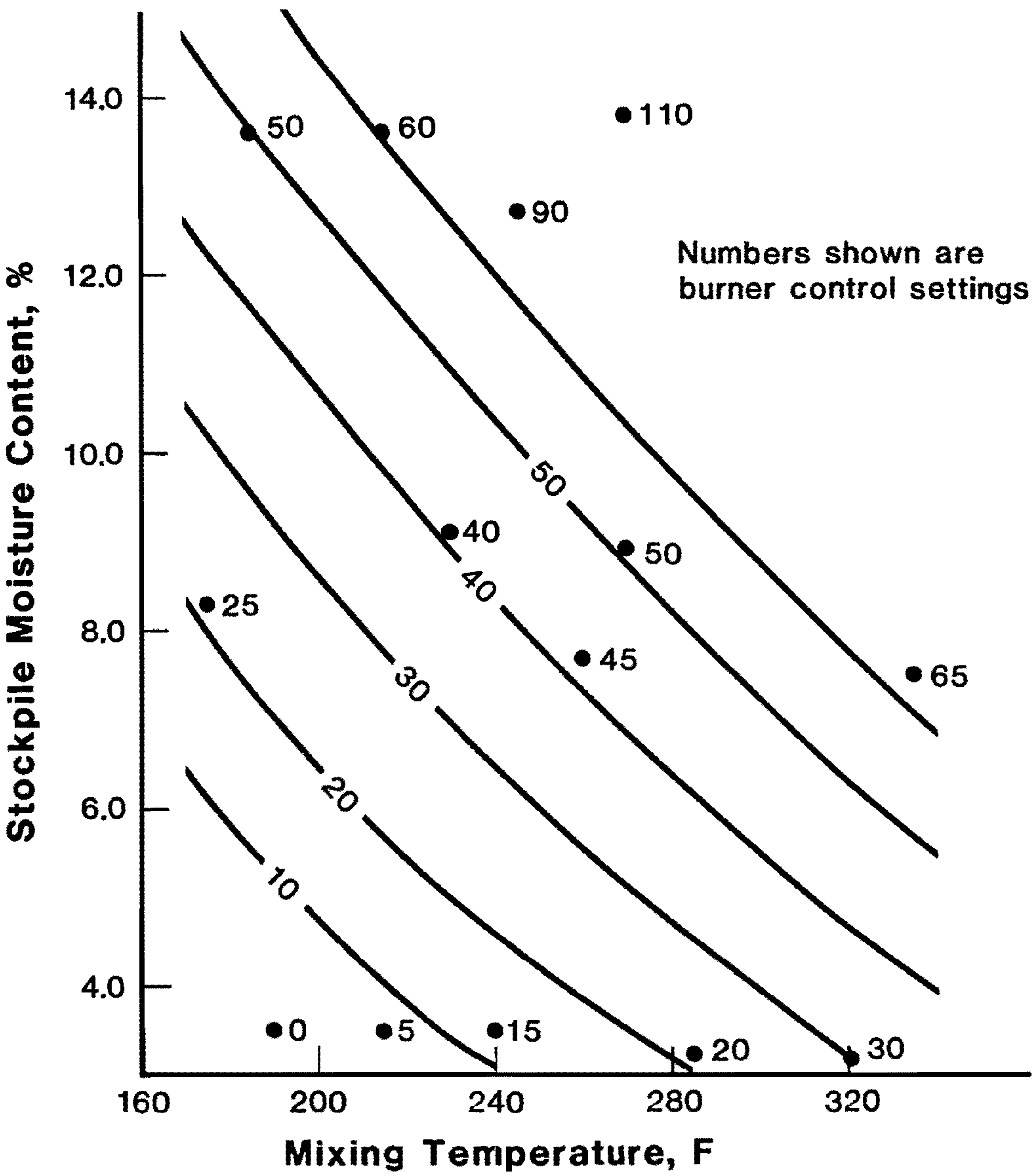


Figure C6. Experiment fuel consumption, Aggregate C.

TABLE C11. AGGREGATE C FIELD LOCATION OF EXPERIMENTAL MIXTURES

Stockpile Moisture	Temp., °F	Location*	Station	Field Density,** %
Dry	190	-	-	-
	215	-	-	-
	240	-	-	-
	285	W.B. Lt main lane	247+50 to 249+10	98.9
	320	W.B. Lt main lane	246+00 to 247+50	98.2
Wet	175	E.B. Rt shoulder	87+00 to 90+00	98.8
	230	E.B. Lt main lane	4+25 to 6+75	92.2
	260	E.B. Rt shoulder	65+15 to 66+80	97.1
	270	E.B. center lane	26+00 to 28+50	95.2
	335	E.B. Gore and exit	110+00	92.2
Saturated	185	W.B. Lt main lane	26+00 to 28+70	96.2
	215	E.B. Rt main lane	8+70 to 11+20	96.6
	245	E.B. Rt main lane	39+00 to 41+00	95.1
	270	W.B. Lt main lane	28+70 to 30+50	97.8

* All locations on Interstate Highway 37 near Corpus Christi.

** Densities expressed as percent theoretical specific gravity as measured by Texas SDHPT.

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