Effect of Mixing Temperature and Stockpile Moisture on Asphalt Mixtures

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ABSTRACT

Studies have indicated that mixtures produced in drum plants have workability and short-term performances equal to those of mixtures produced in conventional plants and that long-term performance will be equivalent. This work, however, has led to questions about the effect of lower mixing temperatures and higher aggregate moisture contents. In addition, there is a need for information on the effects of stockpile and asphalt-mixture moisture contents for conventional batch and drum plants for use in developing 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 to evaluate 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. The first phase of the study, discussed here, 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, and moisture susceptibility characteristics. Essentially, for the studies conducted, there were no significant effects produced by stockpile moisture and mixing temperatures for either batch or drum plants. Both plants were able to remove most of the moisture although this probably increased fuel costs and lowered possible production rates. Density was the major factor that affected the engineering properties and was indirectly related to mixing temperature.

In the past decade the use of drum mix asphalt plants has increased significantly and the trend is expected to continue; new plant sales are predominantly of this type because of their simplicity, lower initial cost, and lower operating cost.

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 (1). However, these studies evaluated material produced only under existing specifications and no effort was 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 and conventionally mixed asphalt mixtures led to the question of whether the drum mix plant could produce acceptable mixtures at lower temperatures and higher moisture contents than are normal with a batch plant. In addition, there is a need for information about the effects of stockpile or mixture moisture contents for both conventional plants and drum plants. If the specifications could be changed without detrimental effects on 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 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 is a report on the first phase of the study and contains a summary of the experimental program, problems encountered, results, and conclusions.

EXPERIMENTAL PROGRAM

Study Design

The study involved an experiment in which asphalt mixtures containing different aggregates were produced at various combinations of mixing temperatures and stockpile moisture contents (Table 1). This basic experiment was repeated at several different asphalt plants in Texas.

TABLE 1 Moisture-Temperature Experiment Design

Asphalt Mixture Mixing Temperature (°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

Experimental Mixing Temperatures and Stockpile Moisture Contents

The mixing temperature was varied from 325°F to 175°F, which is well below current operating temperatures, 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 drying 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 before mixing was held constant throughout the experiments at an estimated 275°F to 300°F.

Asphalt Plants Used for Experimentation

The three asphalt plant sites used in the study were located at Austin (drum and batch plants), Mathis (batch plant), and Alice (drum plant). Mathis and Alice are near Corpus Christie. Two different contractor-producers were involved.

Materials

Three asphalt mix designs were used (Table 2). The major components were hard limestone for the Austin aggregate and sandstone for both the Mathis and Alice aggregates. The asphalt cement used for all projects was an AC-10. The Alice and Mathis aggregates were susceptible to moisture damage and as part of the regular contract work a 1 percent hydrated lime slurry was sprayed on the cold feed belt.

TABLE 2 Location and Description of Aggregate Mixtures

Asphalt Plant		
Location	Type	Aggregate Type[a]
Austin	Drum/Batch	Crushed sandstone Crushed limestone Limestone screenings Field sand
Mathis	Batch	Crushed sandstone Crushed limestone Sandstone screenings Field sand
Alice	Drum	Crushed sandstone Sandstone screenings Field sand

[a]All mixture designs were 1/2-in. maximum size aggregate.

Sampling Program

Samples of both asphalt mixture and raw aggregate were gathered during each experimental run. The asphalt mixture was taken from a truck after the material had been mixed at the desired temperature and test specimens were prepared in the field laboratory.

Raw aggregate samples were gathered to determine aggregate moisture contents at key points in plant processing.

Specimen Preparation and Conditioning

Specimens, 2 in. high by 4 in. in 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:

- Standard compaction. Specimens were prepared using the standard procedures of the Texas SDHPT in which the mixture was compacted at 250°F (2).
- Modified-standard compaction. Specimens were prepared using the same method except that the compaction temperature was the same as the plant mixing temperature.
- 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.
- Wet conditioned. Specimens were vacuum saturated under 26-in. mercury vacuum, put through a freeze-thaw cycle, then tested at room temperature.

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 according to Texas SDHPT standard procedures (2). Compacted asphalt mixture specimens 2 in. high by 4 in. in diameter are loaded at a constant strain to a maximum vertical load of 5,000 lb. The horizontal force generated by the vertical load is measured as a pressure on the stabilometer wall and is used to calculate the Hveem stability.

Static Indirect Tensile Test

The indirect tensile test (3) was conducted to estimate the tensile strength of the asphalt mixtures. A cylindrical specimen was loaded with a compressive load distributed through steel loading strips curved to fit the specimen. The specimen ultimately failed by splitting along the vertical diameter. The tensile strength was calculated from the applied load at failure and the specimen dimensions. Tests were conducted at 75°F.

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 (4 and ASTM D 4123-82) at a testing temperature of 75°F. The load-vertical deformation and the load-horizontal deformation relationships were recorded and the resilient modulus was calculated.

Texas Boiling Test

The Texas boiling test is a rapid method of evaluating the moisture susceptibility or stripping potential of aggregate-asphalt mixtures (5). In this test a visual observation is 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. The amount of stripping is determined by a visual rating, expressed in terms of the percentage of asphalt retained on a scale of 0 to 100 percent.

Other Tests

Other tests used on asphalt mixtures were conducted according to standard methods of the Texas State Department of Highways and Public Transportation (2) and ASTM D 2041-78 and included asphalt extraction and recovery (Abscon process), asphalt penetration and viscosity of the extracted asphalt, sieve analysis of the asphalt mixture, Rice theoretical maximum specific gravity (ASTM 2041), bulk specific gravity of compacted specimens, and moisture content determinations of the coated and uncoated aggregate (250°F).

EXPERIMENTAL RESULTS

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, which complicated the evaluation. 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 any was likely to cause a significant effect on the experiment results.

A complete listing and analyses of the test results are given elsewhere (6).

Uncontrolled Variables

The uncontrolled variables in 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 aggregate type, atmospheric conditions, length of time the experiment was conducted, and technique used to introduce moisture (Figures 1 and 2).

Within each aggregate type the moisture contents for each of the three stockpile moisture conditions were relatively uniform except for the Austin aggregate. This aggregate was used at the stockpile moisture content and the variation of this content is attributable to the 9-month period during which the experiment was conducted.

Moisture in the Asphalt Mixture

Most asphalt mixtures had moisture contents of less than about 0.5 percent, especially for the relatively nonporous Austin aggregate. Nevertheless, for high stockpile moisture contents and low mixing temperatures, moisture contents did exceed 0.5 percent and approached 1 or 2 percent (Figure 1). Thus the moisture content of the asphalt mixture was influenced by the stockpile moisture content, the mixing temperature, and the aggregate porosity.

As expected, moisture content increased with increased stockpile moisture, decreased as mixing temperature increased, and was higher for the Mathis and Alice aggregates that were more porous than the

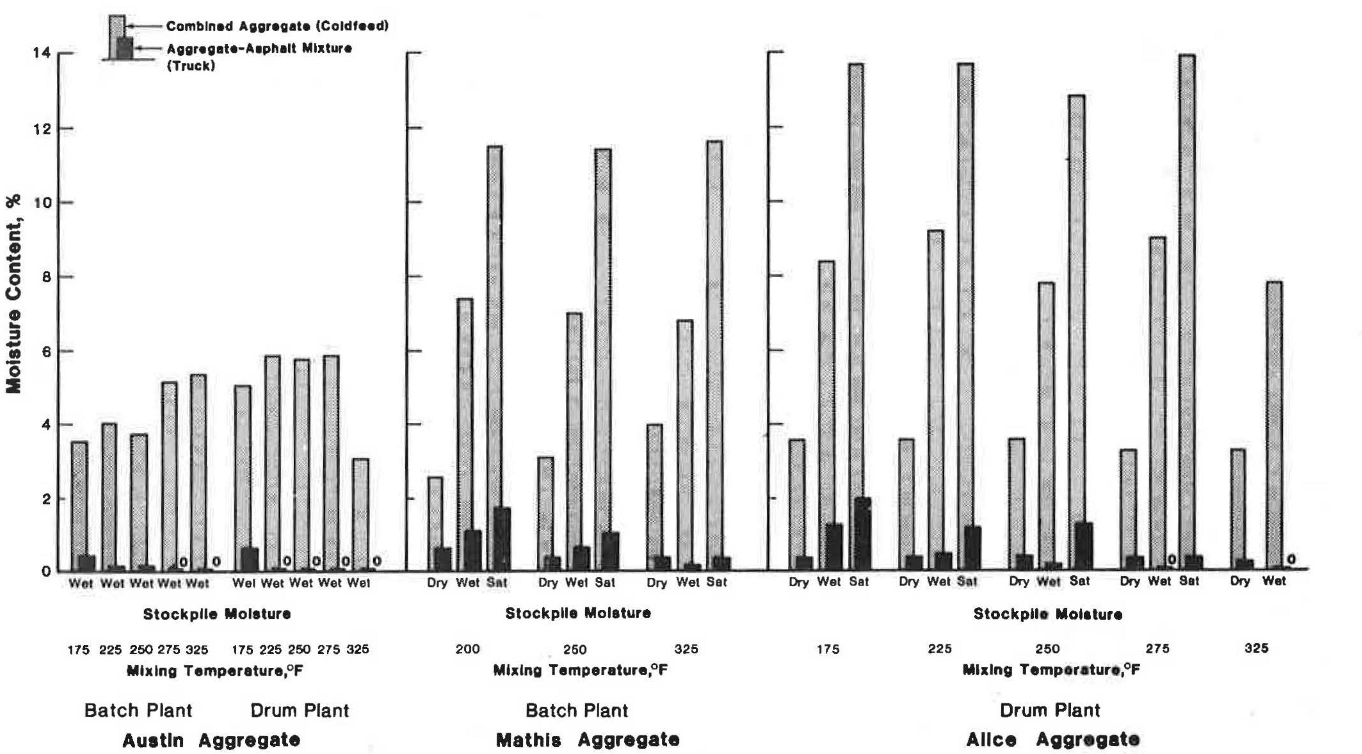

FIGURE 1 Relationship between mixing temperatures and moisture content of the asphalt mixtures.

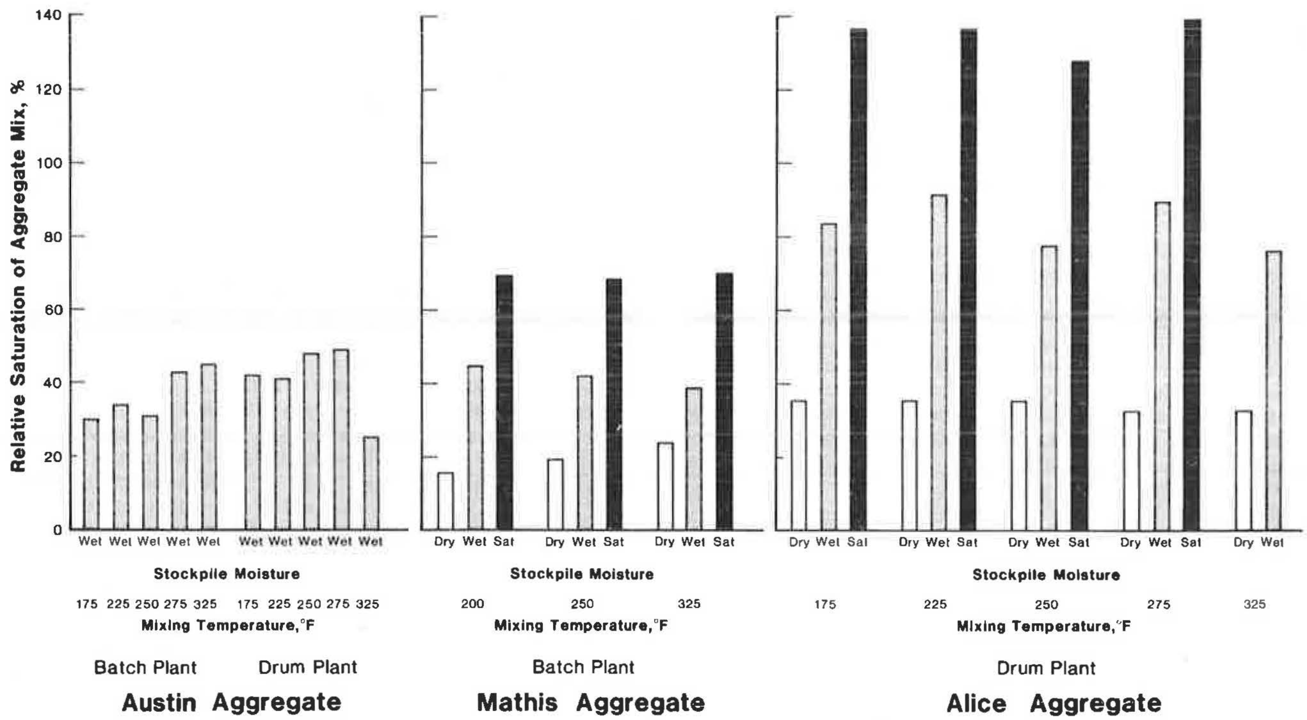

FIGURE 2 Degree of saturation of aggregate.

Austin aggregate. 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.

Specimen Density

Density was estimated in terms of voids in the mineral aggregate (VMA) and air voids because the specific gravities of the various aggregates differed and the asphalt contents of the mixtures also differed. Variation in VMA and air void content is given elsewhere (6). The variation in both VMA and air voids was relatively small for any given compaction procedure and thus it is believed that density variations probably did not have a significant effect on the laboratory test results.

Asphalt Content

An attempt was made to maintain the asphalt content at the design percentage for each experimental run. However, the extracted asphalt contents were found to vary considerably.

The daily plant testing done by Texas SDHPT on nonexperimental 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. Unfortunately, state personnel did not test any of the experimental mixtures and a direct comparison of extraction results cannot be made.

It is believed that an experimental error of undeterminable origin has affected the indicated asphalt contents of the experimental mixtures but that the actual contents were approximately equal to the design value. Therefore asphalt content was treated as a constant throughout the analysis of experiment results.

Extracted Asphalt Penetration

The penetration of the extracted asphalt was measured to determine the amount of hardening that 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; however, the higher mixing temperatures did cause a penetration reduction of 5 to 10.

Hardening of the asphalt was found to be affected by the stockpile moisture content. High stockpile moisture contents decreased the amount of hardening that the asphalt experienced during mixing. The difference in penetration over the range of moisture contents is approximately 10. This behavior may have been caused by the presence of increased humidity in the pugmill or the drum mixer with increasing stockpile moisture, which in turn may have retarded the evaporation of the lighter fractions of the asphalt and also reduced oxidation.

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 are the average result of duplicate or triplicate specimens for each experiment condition.

Effect of Mixing Temperature

The effect of mixing temperature on each of the measured engineering properties is shown in figures and is discussed for each of the engineering properties. It should be noted that it was difficult to achieve uniform coating of the aggregates with mixing temperatures below about 200°F.

Hveem Stability

As shown in Figure 3, 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. The modified compaction specimens that had significantly lower densities and higher air voids also had significantly lower stabilities.

Tensile Strength

The tensile strengths of the standard specimens show a tendency to increase with increased mixing temperature, but the degree and consistency of this trend is variable (Figure 4).

For Austin aggregate, 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 the Mathis aggregate. 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 that 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 (Figure 5). The measured values for the Alice aggregate suggest that the resilient modulus of elasticity is fairly uniform regardless of mixing temperature; however, Austin and Mathis aggregates do not exhibit the same uniformity. The observed values vary over a wide range and the variation did not appear to be related to the mixing temperature.

Moisture-Damage Resistance

Two evaluation techniques used to determine the moisture-damage resistance of the experimental mixtures were the indirect tensile strength ratio and the Texas boiling test.

Tensile Strength Ratio

To determine the tensile strength ratio two sets of specimens were tested. One set was subjected to a moisture saturation, freeze-thaw condition and the other was not. The tensile strength ratio was expressed as the ratio of the wet-conditioned tensile strength to the dry-conditioned tensile strength. The acceptance level of the tensile strength ratio was 0.70, which often is used to identify a non-moisture-susceptible aggregate mixture.

The tensile strength ratio was found to be significantly affected by the applied compaction effort

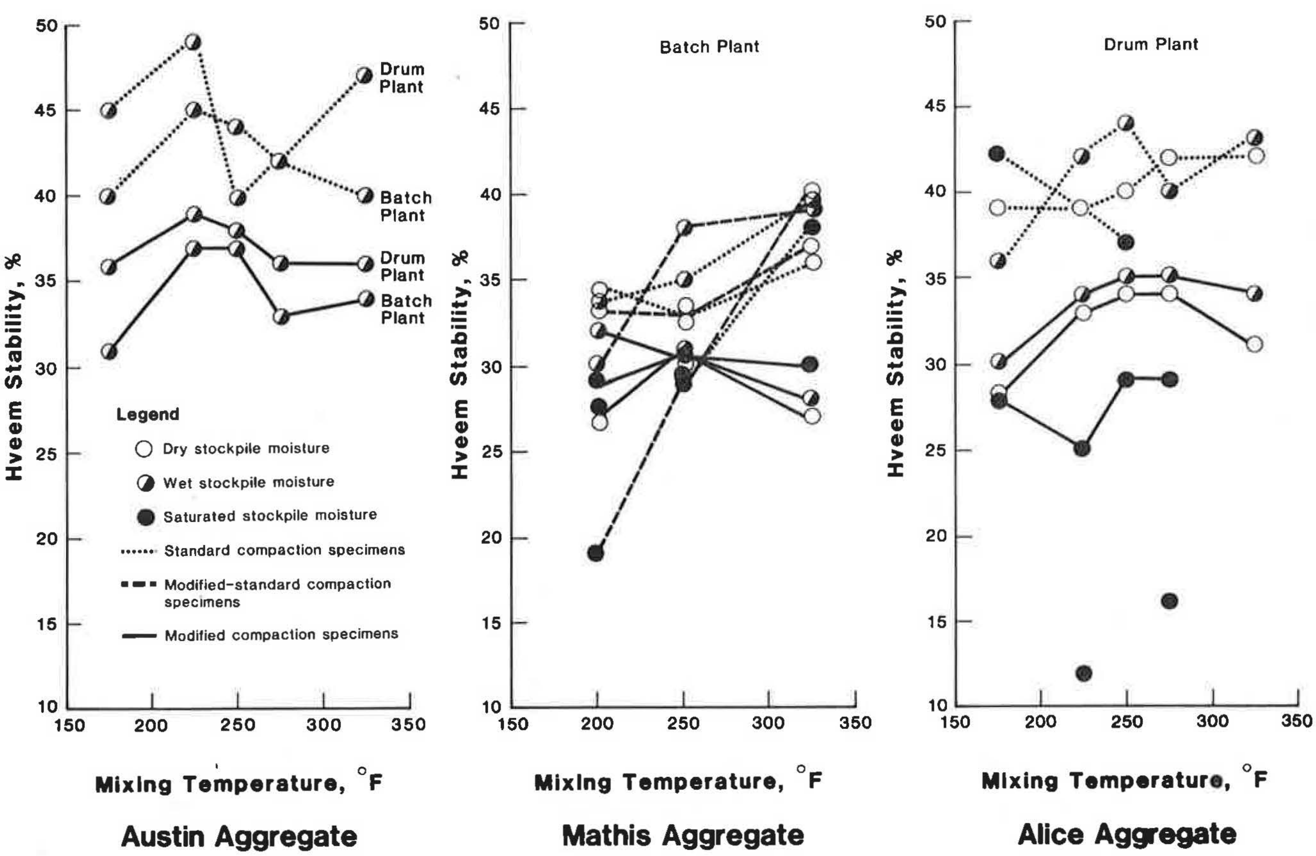

FIGURE 3 Relationship between mixing temperature and Hveem stability.

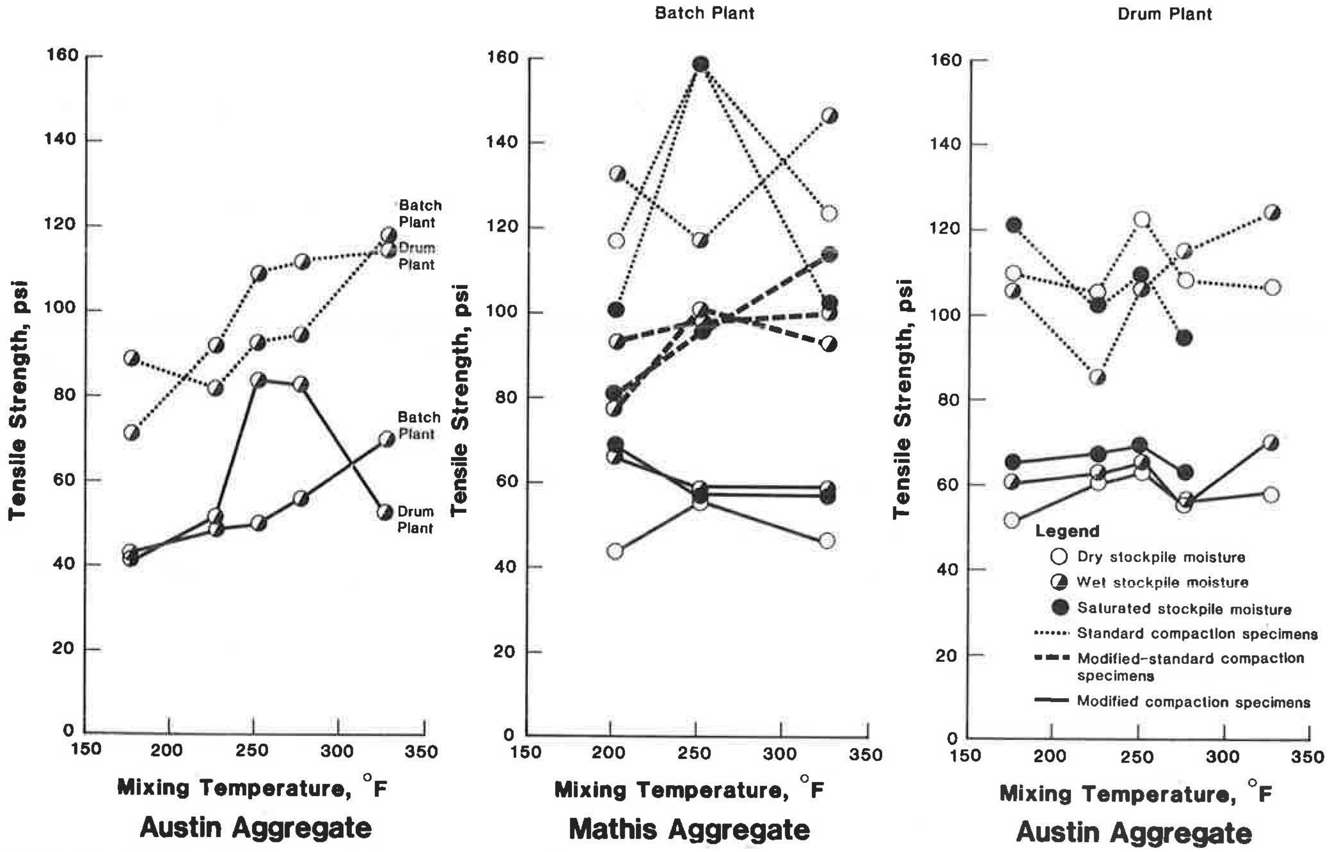

FIGURE 4 Relationship between mixing temperature and tensile strength.

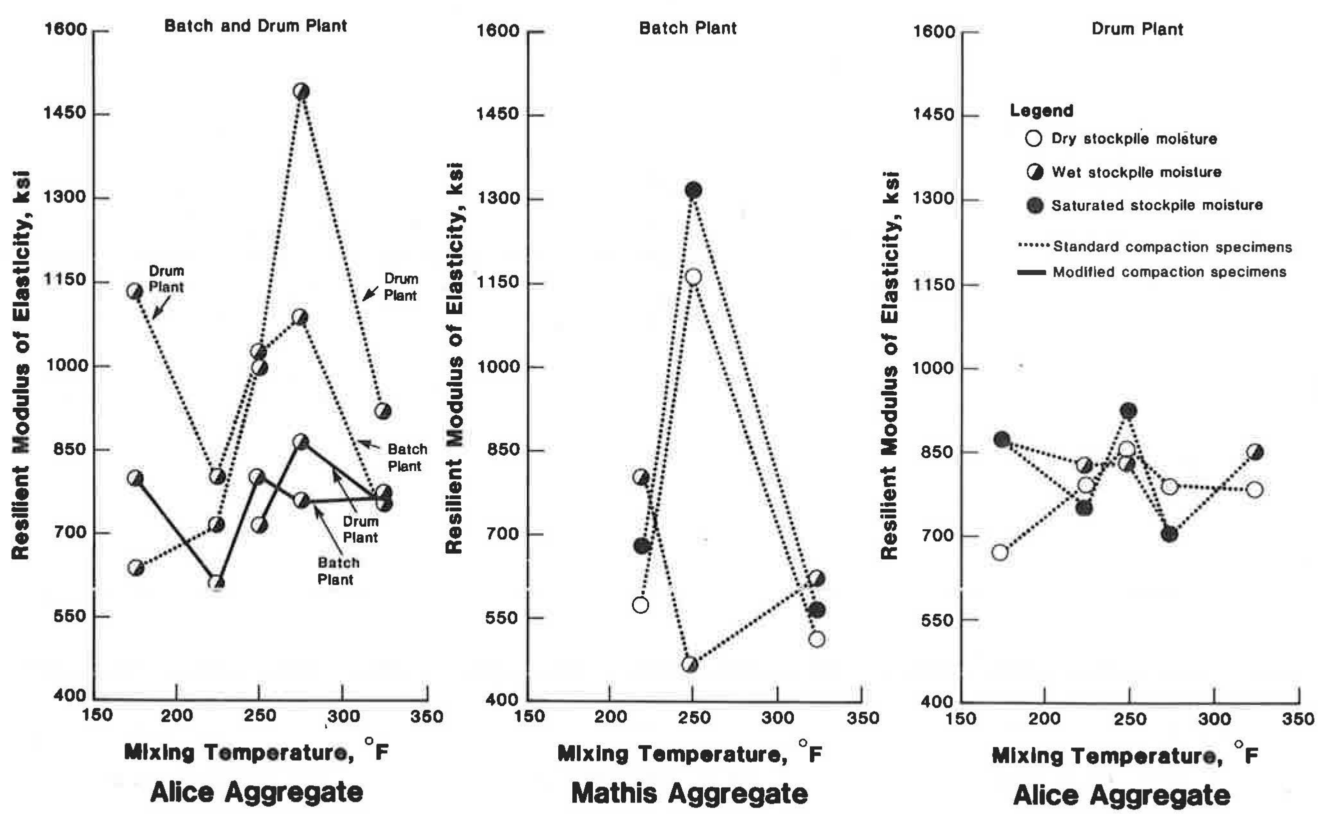

FIGURE 5 Relationship between mixing temperature and resilient modulus of elasticity.

(Figure 6). The modified compaction specimens had a lower density and were more susceptible to water entry during vacuum saturation. As a result these specimens lost a larger proportion of the dry tensile strength than did the standard specimens that were more resistant to water entry.

The effect of mixing temperature on the measured tensile strength ratios of the modified compaction specimens was not consistent for all the aggregates tested. Austin aggregate 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 Alice aggregate, no consistent effect was observed.

Boiling Test

The resistance to moisture damage as measured by the percentage of retained asphalt after the boiling test increased with increased mixing temperature (Figure 7). This trend is relatively consistent throughout the three aggregates and shows substantial changes in retained asphalt across the range of temperatures tested.

Mathis and Alice aggregates were known to be moisture susceptible aggregates, and as part of the nonexperimental work both were treated with a hydrated lime slurry before mixing to improve their resistance to moisture damage. The Austin aggregate, 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 nontreated 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 percentage of retained asphalt.

The percentage of asphalt retained after the boiling test is known to increase for asphalts that have lower penetrations. The penetration of the extracted asphalt discussed earlier did decrease somewhat with increasing mixing temperature; however, the change was not large enough to account for the significant changes that were observed in the percentage of retained asphalt.

Effect of Stockpile Moisture

The effect of stockpile moisture on each of the engineering properties is shown in the accompanying figures. The Austin aggregate was not considered because 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 (Figure 8). The saturated stockpile conditions caused a decrease but the change was neither consistent nor large. The major influence on the Hveem stability results was density. The values for each of the compaction methods generally lie in distinct groups.

Tensile Strength

The measured values of tensile strength were relatively uniform and generally did not vary with

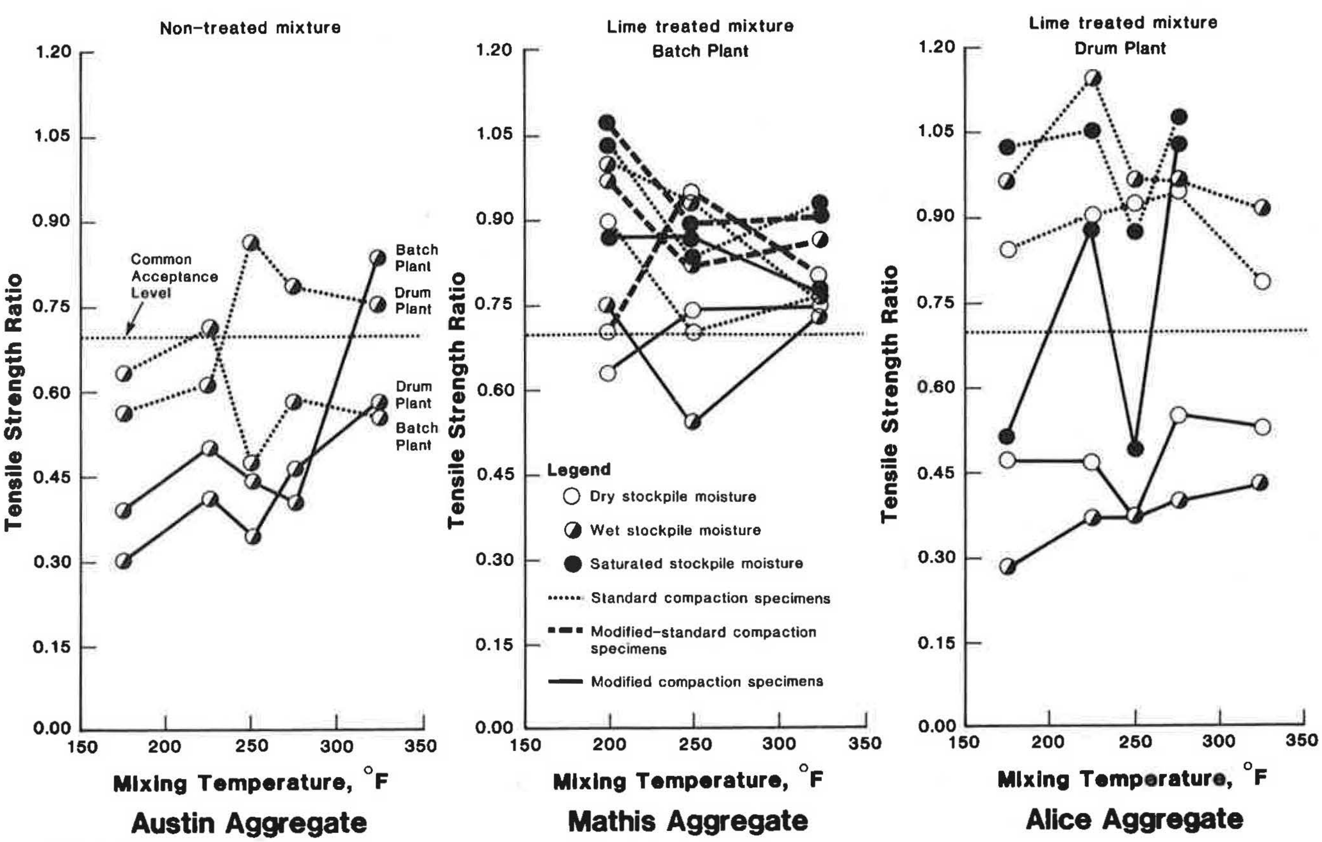

FIGURE 6 Relationship between mixing temperature and tensile strength ratio.

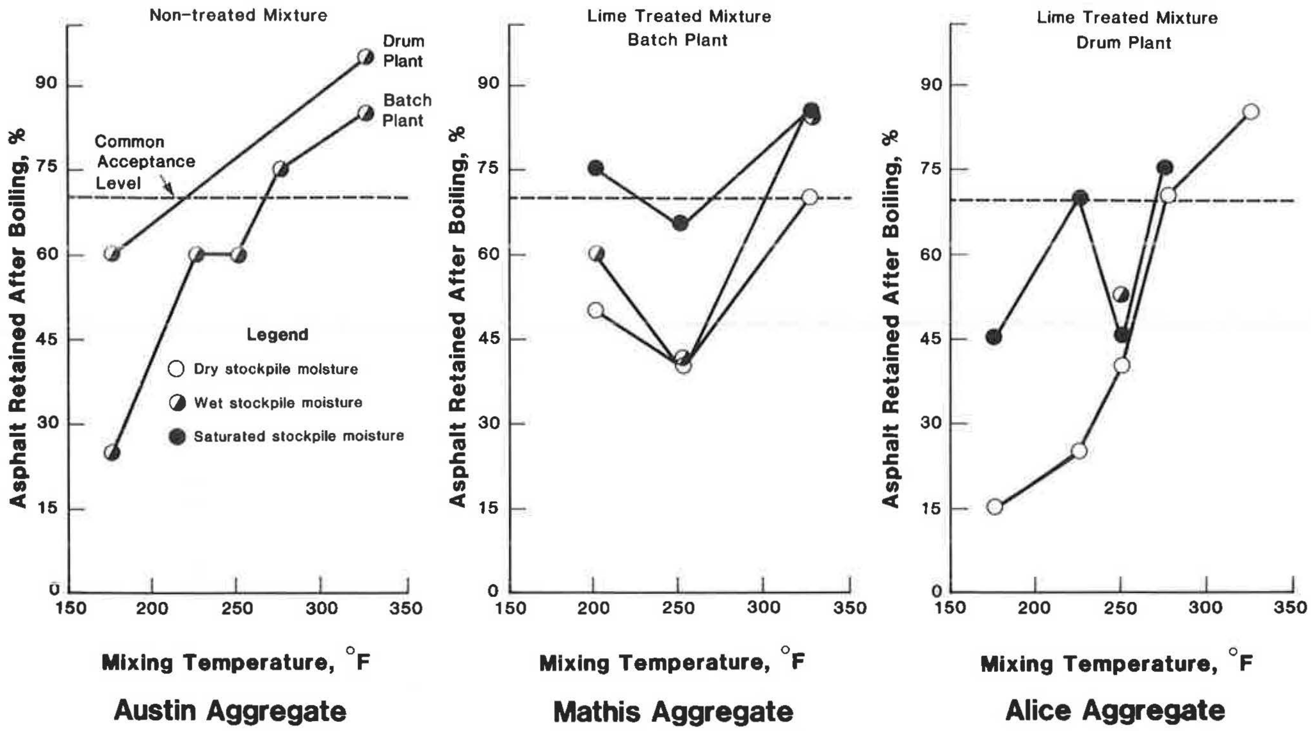

FIGURE 7 Relationship between mixing temperature and asphalt retained after boiling test.

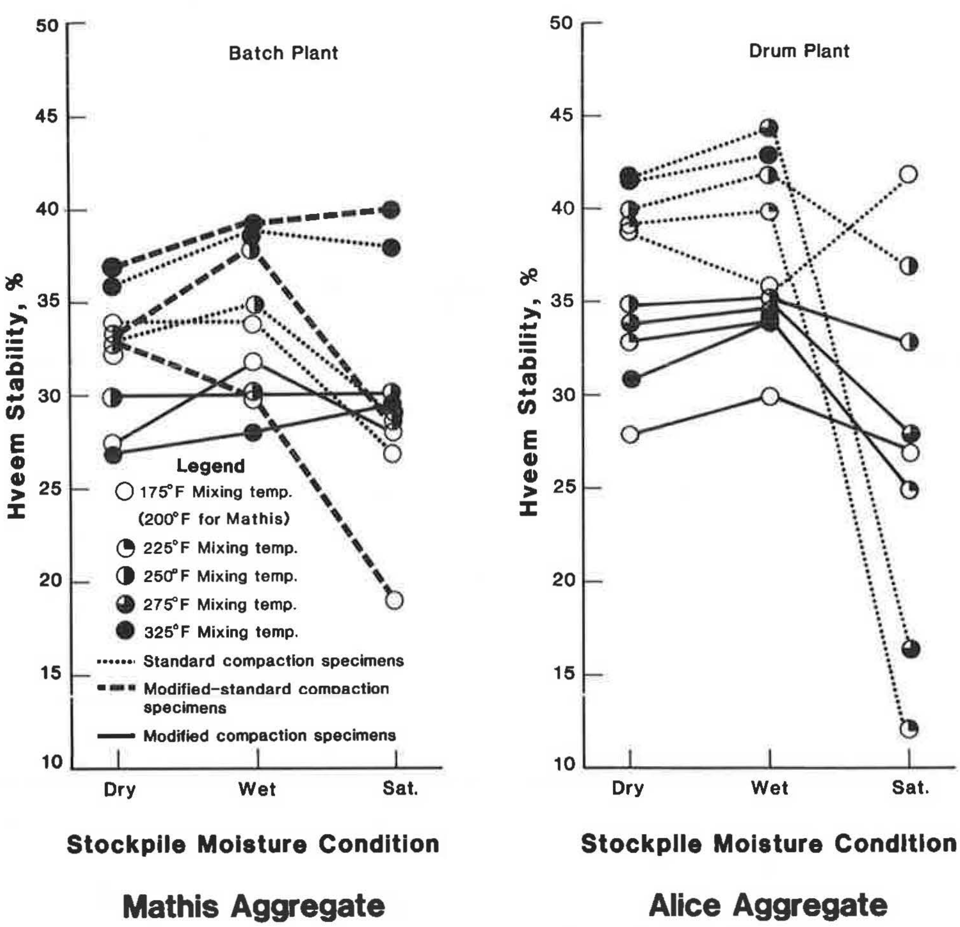

FIGURE 8 Relationship between stockpile moisture condition and Hveem stability.

stockpile moisture condition (Figure 9). The most significant variable that affected tensile strength was density, as shown by the separate groupings of the test results.

Resilient Modulus of Elasticity

The results indicated that the resilient modulus of elasticity was not affected by the stockpile moisture condition (Figure 10). The values for the Alice aggregate showed no change for varying stockpile moisture contents and the results for the Mathis aggregate, though varied, did not show a trend.

Moisture-Damage Resistance

Moisture-damage resistance was measured in terms of the tensile strength ratio and the percentage of retained asphalt as measured by the Texas boiling test.

Tensile Strength Ratio

A general trend existed between the stockpile moisture condition and the measured tensile strength ratio (Figure 11). The ratio, or the resistance to moisture damage, tended to increase with increasing stockpile moisture contents although the amount of the increase was generally not large.

Texas Boiling Test

A definite relationship between the asphalt retained after the Texas boiling test and the stockpile moisture content was evident (Figure 12). The retained asphalt significantly increased as the stockpile moisture content increased, indicating a higher resistance to moisture damage. The greatest increase in resistance occurred at the lower mixing temperatures. Generally the increase of retained asphalt became less as the mixing temperature increased.

Repeatability of Experiment

A detailed study of the repeatability of the experiment was not conducted as part of the project. During the Mathis experiment, however, the portion with saturated stockpile moisture and low mixing temperature was repeated and the resulting measured properties were compared. Most of the measured properties were similar except possibly the resilient modulus of elasticity and the Hveem stability, both of which exhibited variations.

These variations cannot be explained by the asphalt contents or the gradation, both of which were the same. Nevertheless, the results suggest that despite some variation of measured results the repeatability was acceptable for runs performed within a relatively short time span.

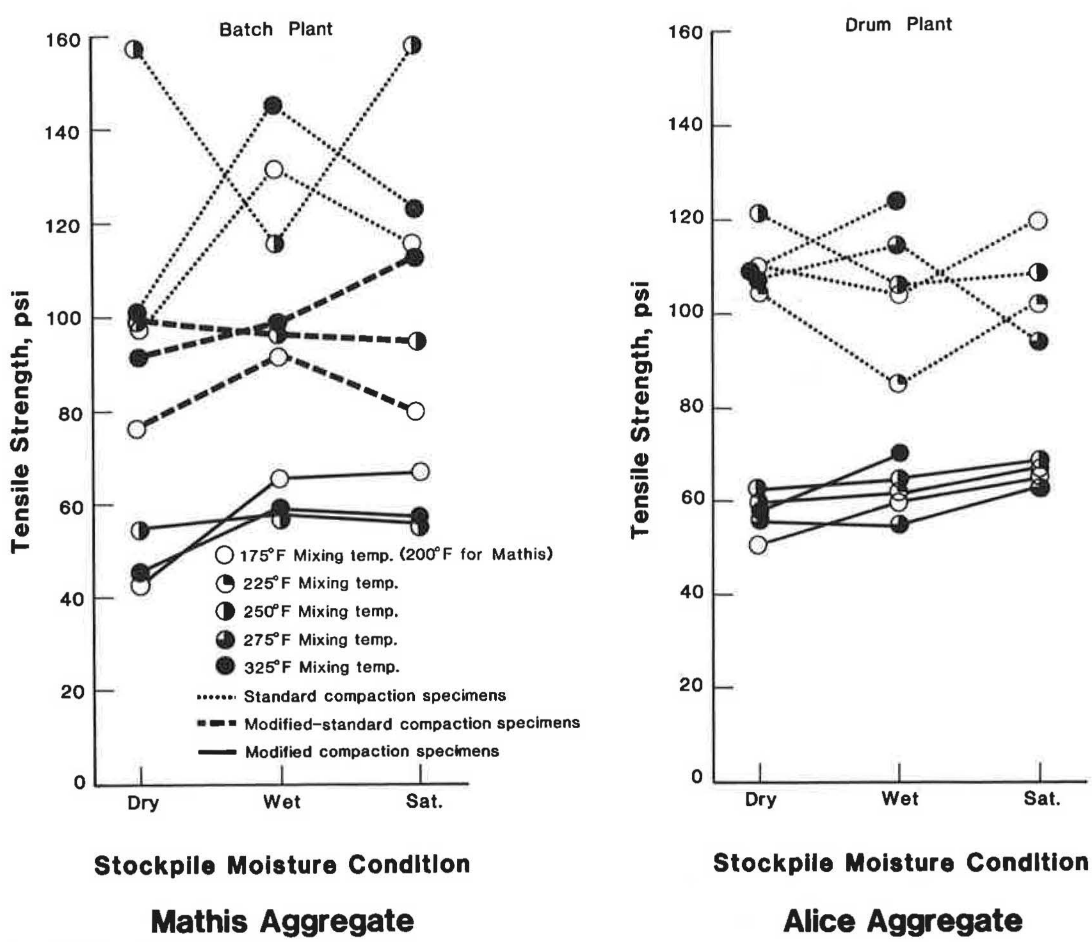

FIGURE 9 Relationship between stockpile moisture condition and tensile strength.

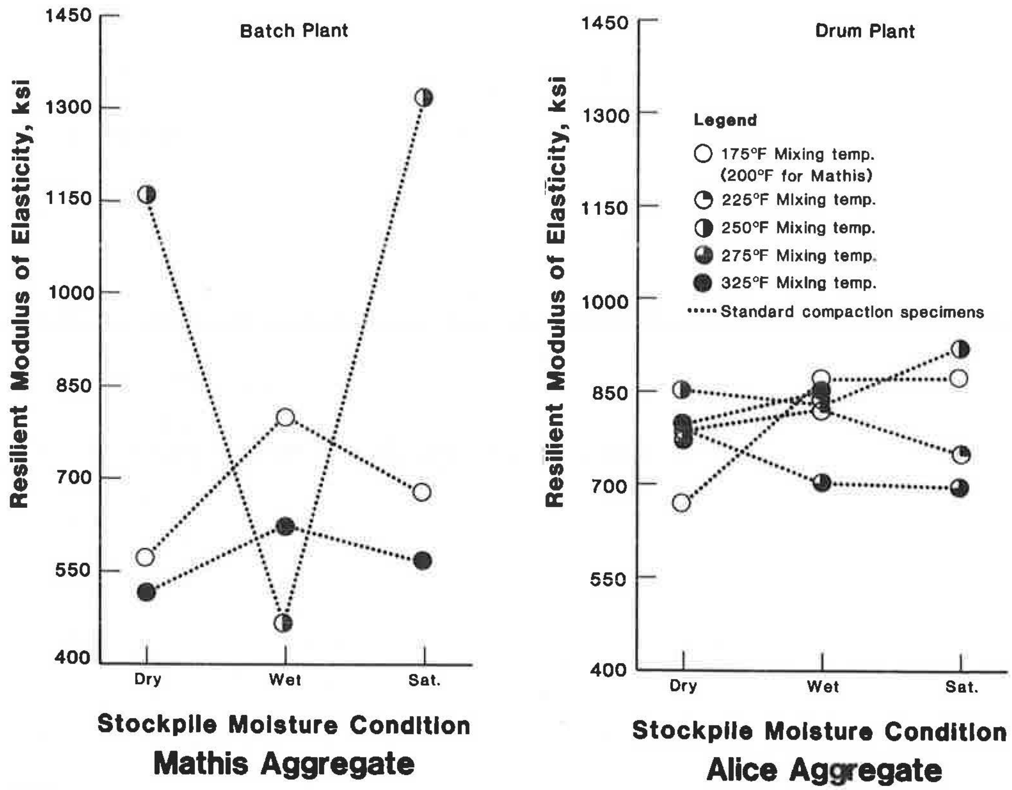

FIGURE 10 Relationship between stockpile moisture condition and resilient modulus of elasticity.

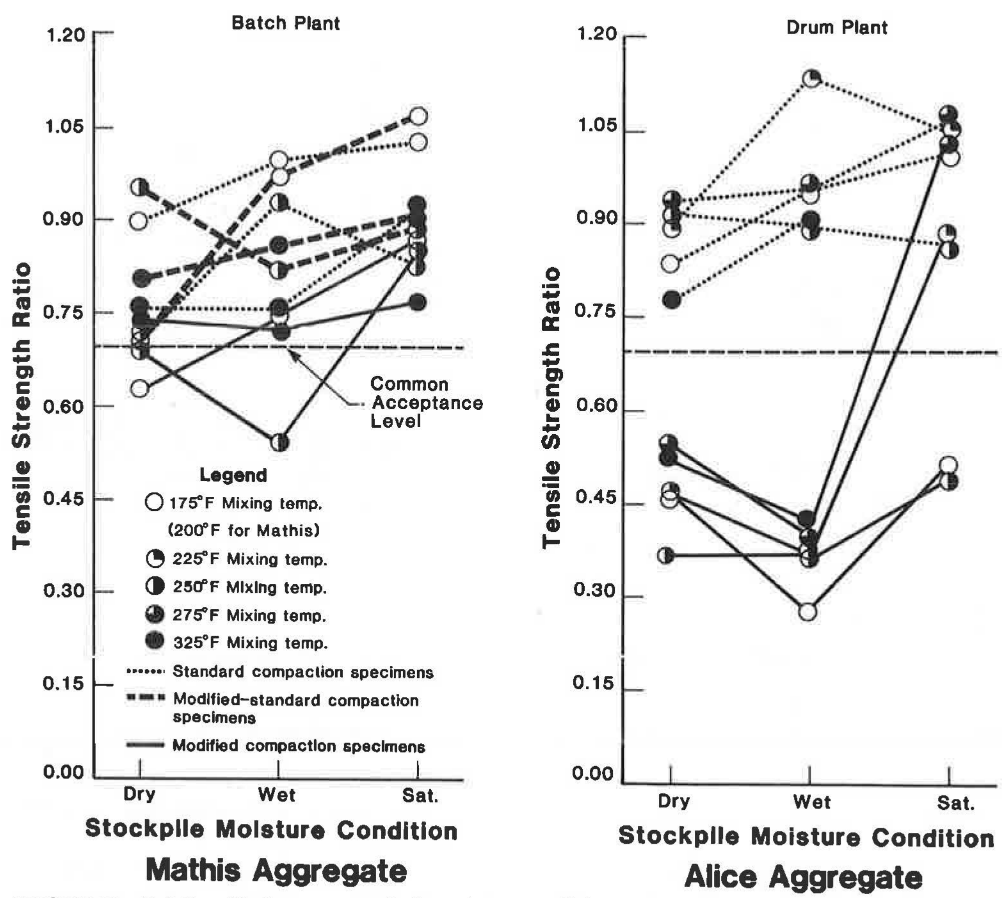

FIGURE 11 Relationship between stockpile moisture condition and tensile strength ratio.

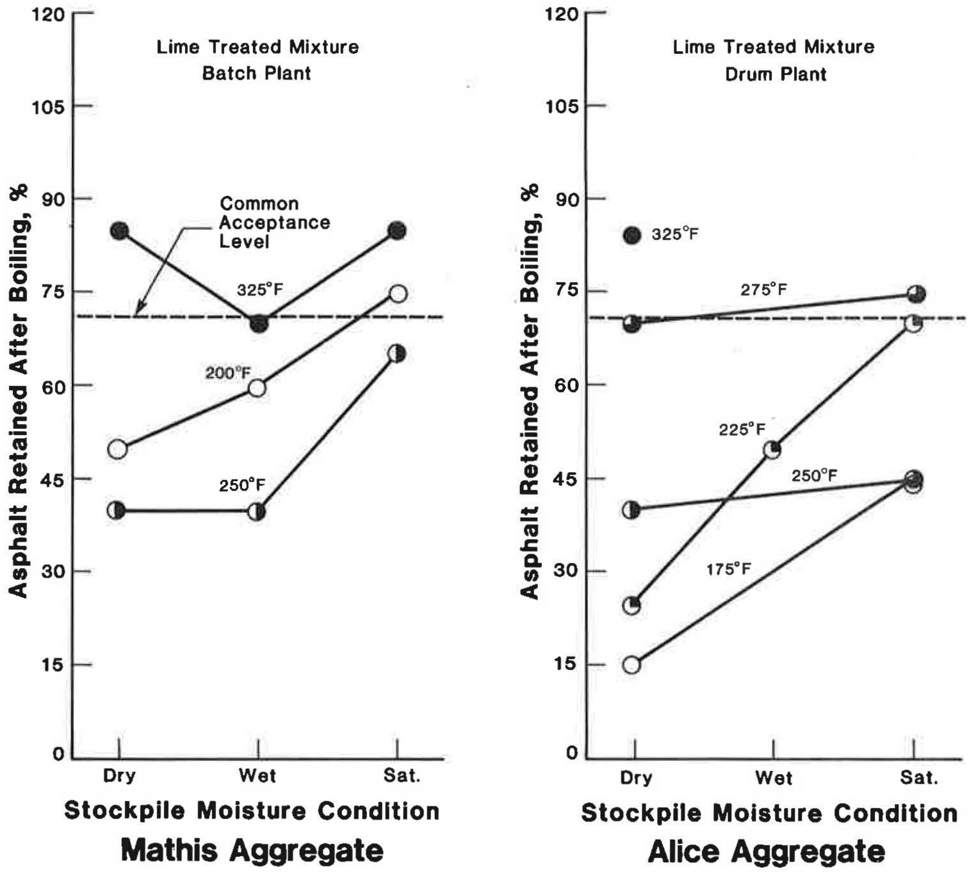

FIGURE 12 Relationship between stockpile moisture condition and asphalt retained after the boiling test.

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. On the basis of 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. Although 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 although removal resulted in higher fuel costs and lower production. The higher fuel costs were measured and documented for a drum mix plant and it is believed that the effect would be similar for a batch plant.
4. Density was the major factor that affected the properties of the experimental mixtures.
5. Asphalt mixtures with moisture contents above 1.5 percent were difficult to produce and then only at very low mixing temperatures.

Effects of Mixing Temperature

1. Mixing temperature had 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 (Austin) in both the drum and the batch plant. The standstone aggregate (Mathis and Alice) 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 variations were quite random.
4. There was an indication that resistance to moisture damage, as measured by the boiling test, improved with increased mixing temperature. A slightly improved tensile strength ratio with increased mixing temperature was also observed.
5. Increased mixing temperature did not significantly increase the amount of asphalt hardening that 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. Stockpile moisture content did not affect Hveem stabilities.
2. Stockpile moisture content did not affect tensile strengths.
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 with increased stockpile moisture contents.
5. Reduced asphalt hardening during mixing was observed for increased stockpile moisture contents.

Recommendations

1. The experimental study did not identify any clear relationships between mixing temperature, stockpile moisture content, and the properties of asphalt mixtures produced in either batch or drum mix plants for the aggregates studied. Further testing of other aggregates should be conducted 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 that are porous and retain moisture should be studied.
2. The results of the experimental study indicate that the measured engineering properties were primarily affected by the density of the mixture. Although the compaction procedure used on the roadways was not monitored and documented as part of the experiment, the location of the Mathis and Alice experimental mixtures is known and a coring program should be undertaken to determine the in-place densities. The results will determine the densities and engineering properties that were achieved without alteration of the regular compaction procedures.

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