Strength of Bituminous Mixtures and Their Behavior Under Repeated Loads, Part II

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At the 1956 meeting data were presented which showed a relationship existing among temperature, rate of deformation and maximum compressive stress for a sheet-asphalt mixture. Data were also presented depicting a relationship among temperature, rate of deformation, applied stress and the number of load repetitions necessary to cause failure. Both relationships were developed for a sheet-asphalt mixture tested in the unconfined state.

Data have now been developed which indicate that the expression relating temperature, rate of deformation, and maximum compressive stress developed for a sheet-asphalt mixture tested in the unconfined state, holds true for the same mixture tested using varying degrees of confinement. Also, unconfined compression tests were conducted on a bituminous concrete mixture composed of a crushed-stone aggregate with ½-in. maximum size which showed the validity of the expression for this mixture type.

In addition, repeated load tests with varying degrees of confinement were conducted on a sheet-asphalt mixture. The relationship among temperature, rate of deformation, applied stress, and number of load repetitions developed for the unconfined state appeared valid for the confined state.

• A PREVIOUS PAPER (*1*) presented two fundamental mathematical relationships for sheet-asphalt mixtures tested in the unconfined state. The first expression related the strength of these mixtures to the temperature and the rate of deformation. The second expression related the number of repetitions of applied stress necessary to cause failure as defined by some suitable criterion, the temperature and the rate of deformation.

The investigation has been continued to include the evaluation of strength and deformation characteristics of a sheet-asphalt mixture subjected to repeated loads and with varying degrees of lateral support. The information from this study was used to verify further the above mentioned relationships. The inclusion of lateral support as a variable made this study more realistic from the standpoint of actual field performance in bituminous pavement where some degree of confinement is known to exist. Lateral support was obtained by use of the triaxial cell.

To establish the fact that the relationship among strength, temperature, and rate of deformation was valid for bituminous-aggregate mixtures other than sheet asphalt, specimens were formed from a bituminous concrete mixture with a maximum aggregate size of ½ in. This comparison was limited to relationships determined from tests performed in the unconfined state.

Finally, since it is known that a severe condition of loading for a flexible pavement or bituminous mixture is a stationary load, a test was included to evaluate the sheet-asphalt mixture under this condition. Variables of temperature and applied stress were included, and the testing was limited to the sheet-asphalt mixture tested in the unconfined state.

MATERIALS

The mixture chosen for the major portion of this study was a sheet-asphalt mixture designated as Mixture II. This designation is used for continuity with the data presented previously (*1*). In order to check portions of the findings based upon the sheet-asphalt mixture for wider application in the field of bituminous mixtures, specimens were molded from a crushed limestone having a ½-in. maximum size. This bituminous-concrete mixture conformed to the specifications for Indiana AH type B surface course and is so designated.

A complete description of the aggregate and asphaltic cement used in this study are included in two separate sections. Although the sand, mineral filler and asphalt are the same as those used previously, their description is included here for the convenience of the reader.

Aggregates

The sand used in this study was a local, natural material obtained from a river terrace. The gradation chosen met the requirements of ASTM D978-54 Standard Specifications for Asphaltic Mixtures, for Sheet Asphalt Pavements, Surface Course, Grading No. 2 (*2*) and Asphalt Institute 100-XI Sheet Asphalt Surface Course (*3*). The sieve analysis of the gradation is presented in Figure 1.

As the terrace sand was deficient in the minus 200 material, this fraction was obtained by adding pulverized limestone.

The bituminous-concrete mixture containing the ½-in. maximum size aggregate used crushed limestone obtained from a quarry at Greencastle, Indiana, as both the coarse and fine aggregate. The gradation chosen for this mixture meets the Indiana AH type B surface course requirements (*4*). The sieve analysis of this gradation is presented in Figure 1.

Specific gravity and absorption tests conforming to ASTM designations C127-42 and C128-42 were conducted on the aggregates (Table 1).

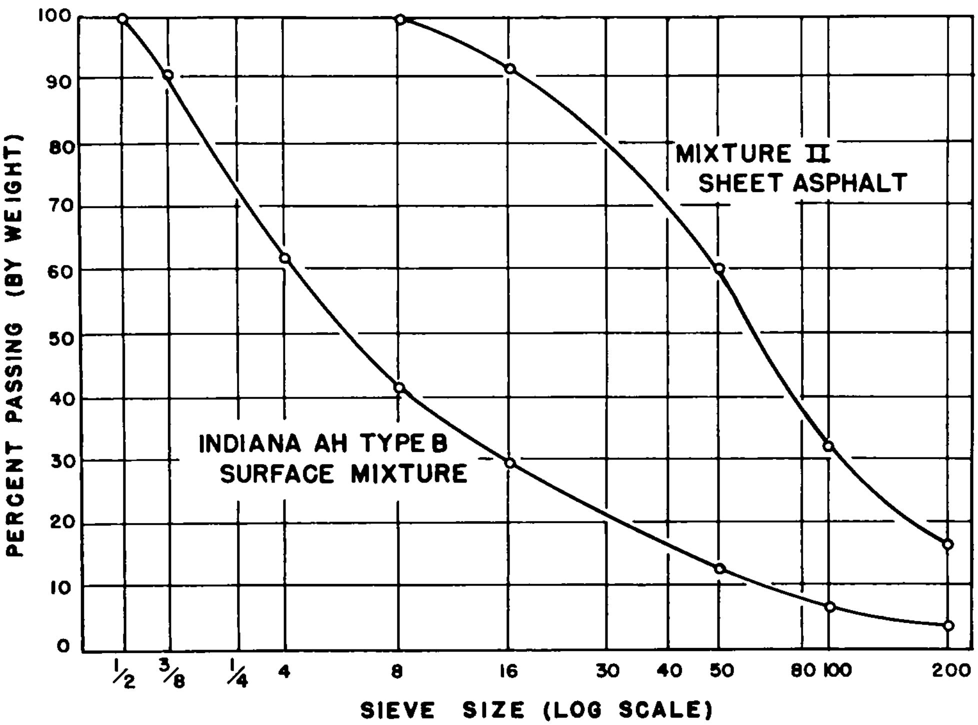

Figure 1. Gradation curves for mixtures.

TABLE 1

PHYSICAL PROPERTIES OF AGGREGATES

Aggregate	Bulk Spec. Gr.	Apparent Spec. Gr.	Absorption, %
Greencastle limestone	2.63	2.71	1.39
Lafayette sand	2.54	2.67	2.04
Mineral filler	—	2.73	—

The control of the gradations was obtained by drying the aggregate and recombining it by weight in the desired proportions.

Asphaltic Cement

Only one asphaltic cement was used throughout this study; it was a No. 65 Paving Cement (ASTM Penetration Grade 60-70) obtained from the Texas Company, Port Neches, Texas. Several standard ASTM tests were conducted on the asphaltic cement in the laboratory (Table 2).

TABLE 2

PHYSICAL PROPERTIES OF ASPHALTIC CEMENT

Test	Value
Penetration (100 gms, 5 sec., 77 F) 1/100 cm	66
Specific Gravity 77 F/77 F	1.015
Ductility (77 F, 5 cm/min) cm	150+
Solubility in CCl_4, %	99.8+
Softening Point, °F	125

The asphalt content used in the sand-asphalt mixture was obtained by using the Hubbard-Field design procedure (*5*). The asphalt content for the Indiana AH type B surface course gradation was selected from field experience. The asphalt contents of the sheet-asphalt mixture was 9.0 percent, and the Indiana AH type B was 7.0 percent, based on the weight of aggregate.

PROCEDURE

Preparation of Test Specimens

The mixtures used were those in which the aggregate and asphalt were heated separately and then combined in a mixing operation. The individual aggregate fractions were combined to give the correct gradations (Figure 1). The aggregate was heated in an electric oven to a temperature of about 325 F. The asphalt was heated in a gas oven to a temperature of 300 F.

For the sheet asphalt, the constituents were mixed by hand in a heated porcelain bowl using a metal spoon for a period of 2 minutes. The coated material was then molded into a specimen 2 in. in diameter and 4 in. in height by a double-plunger compaction method which included rodding the material into the mold.

For the bituminous concrete, the constituents were blended in a modified Hobart mixer with a flat-bottom mixing bowl and blade. The mixture was then molded into a specimen 3 in. in diameter and 6 in. in height using double plunger compaction with rodding.

The molding procedure consisted of placing the hot bituminous-aggregate mixture into a hot steel mold in three equal lifts. Each lift was tamped thirty times with a heated rod. A hydraulic-compaction device was used to compact the specimen (Figure 2). To control the densities of the specimens, care was taken

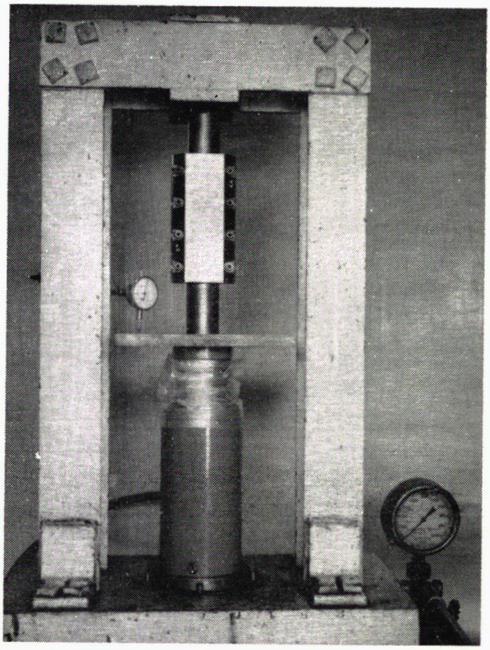

Figure 2. Compaction equipment showing Ames dial device.

to introduce the same amount of material into the mold each time. The specimen height was the determining factor for establishing the static axial load which was applied to each end of the specimen. An Ames dial device was used to insure that each specimen was compacted to the proper height (Figure 2). The specimen was left in the compaction device under load for 2 minutes after which the load was released and the specimen removed immediately from the mold. The specimens were allowed to cure for two days in laboratory air at a temperature of 75 ± 5 F. the specimen's height, diameter, and weight were obtained at this time for bulk density calculations. The specimens were then stored in a freezer at a temperature of 20 F until used in tests.

Methods of Testing

The bituminous concrete specimens were used to extend the validity of the relationship among maximum compressive stress, temperature of test, and rate of deformation established for mixtures of sheet-asphalt type. Specimens were tested to failure in the unconfined state at three rates of deformation: 0.2, 0.02, and 0.002 in. per min. At each of these rates, three temperatures were used: 40, 100, and 140 F. These temperatures were maintained during the test by means of a water bath. After reaching room temperature from cold storage, the specimens were placed in the bath for ½ hour before the start of the test.

Specimens molded from the sheet asphalt were tested with varying degrees of lateral confinement to obtain (a) results which could be used to check the validity of the relationship of temperature, rate of deformation, and maximum compressive stress, previously established for the unconfined condition, for varying degrees of confinement; and (b) the maximum compressive stress values, which were used for determining the magnitudes of the cycled applied stresses for the confined repeated-load test sequence.

Specimens which were tested for the purposes stated above were tested to failure at two confining pressures, 15 and 30 psi. Three rates of deformation were used: 0.2 in. per min, 0.02 in. per min, and 0.002 in. per min. Three temperatures were used: 40, 100, and 140 F. A water bath was used to maintain the test temperatures.

The confined, repeated-load sequence was performed by utilizing a combination mechanical and hydraulic system (Figure 3). The rate of deformation was controlled by the mechanical testing machine. A hydraulic jack was used in the system to obtain the immediate release of load when the desired load on the specimen was reached. The deformation was measured directly from the top of the specimen.

Specimens tested in the confined, repeated-load sequence also were tested at two confining pressures, 15 and 30 psi. Three rates of deformation were used: 0.2, 0.02, and 0.002 in. per min. Three temperatures were used: 40, 100, and 140 F. For each test condition loads were cycled which were equal to 50 percent and 25 percent of the maximum compressive stress for that particular test con-

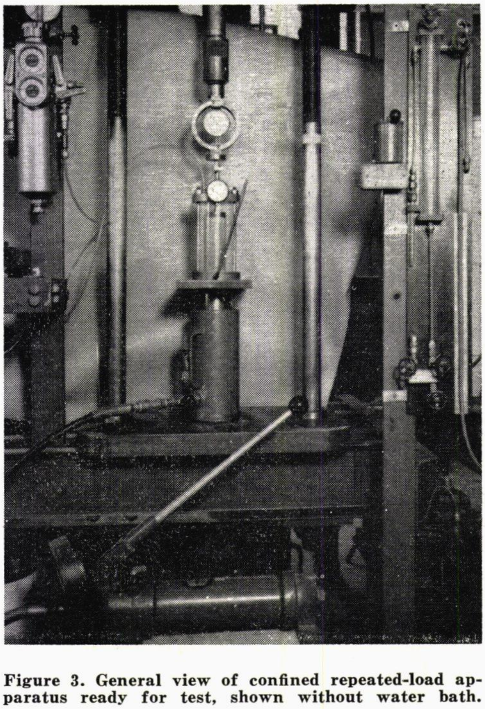

Figure 3. General view of confined repeated-load apparatus ready for test, shown without water bath.

dition. Deformation measurements were taken so that the elastic rebound and permanent deformation could be determined. A sufficient period of time was allowed between load applications in order to permit most of the retarded rebound to take place.

The static, unconfined test series was performed at five temperatures: 40, 55, 70, 100, and 140 F. A consolidation frame was used to apply the static load (Figure 4). The static load was placed on the specimen and the deformation at various time intervals was recorded. The criterion for halting the test was the ability or the inability of the specimen to withstand the applied test load. A specimen withstood the applied test load if the deformation increased only 0.001 in. per 100 seconds for 400 seconds. A specimen failed to withstand the applied test load when the deformation rate per unit time increased rather than decreased. When the deformation rate per unit time increased, it was noted that complete failure of the test specimen was imminent.

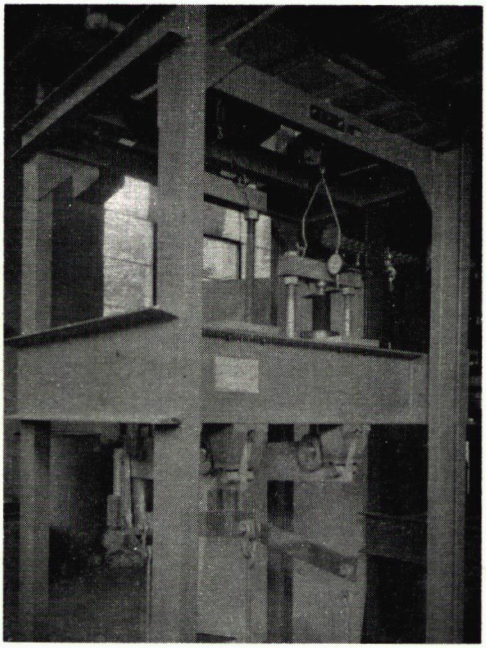

Figure 4. General view of static load apparatus ready for test, shown without water bath.

RESULTS

In this investigation, strength-deformation data of bituminous mixtures were obtained by means of conventional compression tests and by means of repeated-load tests. The type of test, the mixture tested, and the variables studied for each test series are outlined as follows:

1. Compressive strength tests
   - A. Unconfined compression tests
     Indiana AH type B surface course mixture
     Variables: (a) confining pressure
     (b) temperature
     (c) rate of deformation
   - B. Confined compression tests
     Sheet-asphalt mixture
     Variables: (a) confining pressure
     (b) temperature
     (c) rate of deformation
   - C. Unconfined static load tests
     Sheet-asphalt mixture
     Variables: (a) applied stress
     (b) temperature
2. Repeated Load Tests
   - A. Unconfined, repeated load test
     Sheet-asphalt mixture
     Variables: (a) applied stress
     (b) temperature
     (c) rate of deformation
   - B. Confined, repeated load test
     Sheet-asphalt mixture
     Variables: (a) confining pressure
     (b) applied stress
     (c) temperature
     (d) rate of deformation

Unconfined Compression Tests

In the unconfined compression series of tests, the effect of temperature and rate of deformation on the maximum unconfined compressive stress of specimens molded from a bituminous concrete having a ½-in. maximum size aggregate was determined. The results are given in Figure 5, in which the maximum unconfined compressive stress is plotted against the rate of deformation for the various temperatures.

In the previous paper (*1*) maximum compressive stress, temperature, and rate of deformation were related by

$$X_0 = A^{BX_1^{(CX_2 + D)}} \quad (1)$$

in which

X_0 = maximum compressive stress, in psi;
X_1 = rate of deformation, in in. per min;
X_2 = temperature in °F; and
A, B, C, and D = constants.

The numerical values of the constants for the model were determined by using a least squares approach (*6*). For the sheet asphalt tested this mathematical model showed a high degree of association when tested by use of multiple linear regression analysis (*7*).

With this close correlation, by using the above model it should be possible to define the relationship among maximum compressive stress, temperature, and rate of deformation for any chosen mix with a limited number of tests. From a limited amount of laboratory test data on specimens molded from this bituminous concrete, the parameters of the model were evaluated and the resulting expression was used as a prediction equation to estimate unconfined strength values for variour conditions of temperature and rate of deformation. To check the predictions, tests were made to obtain sufficient data to get a comparison between predicted values and observed values. The predicted values and observed values are given in Figure 5. Good correlation was observed at all levels between the observed values

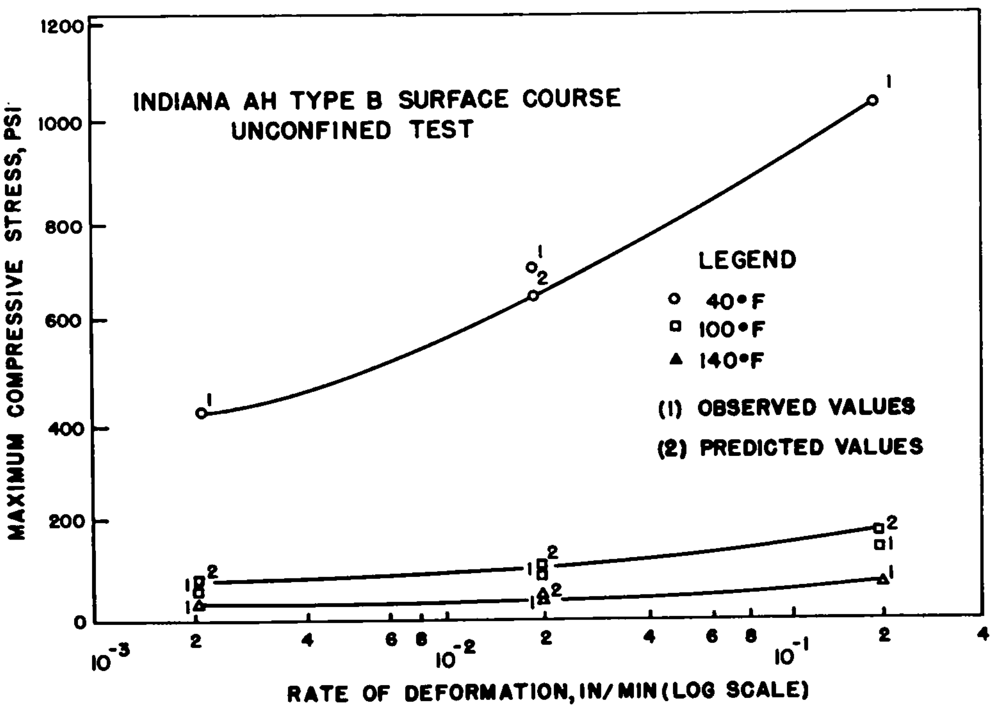

Figure 5. Relationship between rate of deformation and maximum compressive stress at various temperatures.

and the predicted values, indicating that the general expression was valid for the unconfined condition for bituminous-concrete mixtures.

Confined Compression Tests

The original model (Eq. 1) was derived for results obtained from the unconfined compression test. It was hoped that the original model would have wider applicability than for just the unconfined test condition. Since mixtures are loaded in the field in such a manner that some degree of lateral support is provided, it was decided to check the validity of Eq. 1 by performing compression tests at various confining pressures.

Compression tests were made at two confining pressures, 15 and 30 psi. At each of the confining pressures and at the extreme values of temperature (40 F and 140 F) and rate of deformation (0.002 in. per min and 0.2 in. per min) specimens from the sheet asphalt were tested to failure. The results from tests at these test conditions were used to evaluate the parameters of the regression equation. The regression equations, once established, were used to predict maximum compressive stresses at the other test conditions (100 F at 0.002, 0.02, and 0.2 in. per min and 0.02 in. per min at 40 and 140 F). Specimens were then tested at the above test conditions at both 15 and 30 psi. The predicted values and the observed values for this series of tests are presented in Figures 6 and 7, along with values for the unconfined compression tests, taken from previous data (*1*). There are discrepancies in the unconfined test data for the 40 F level which are attributed to experimental error.

From Figures 6 and 7, it can be seen that the introduction of lateral support increases the maximum compressive strength of the mixture more at the higher temperatures than at lower temperatures. At these higher temperatures the mixture is quite plastic in character. At 40 F the mixture loses most of its plastic nature and is relatively "stiff."

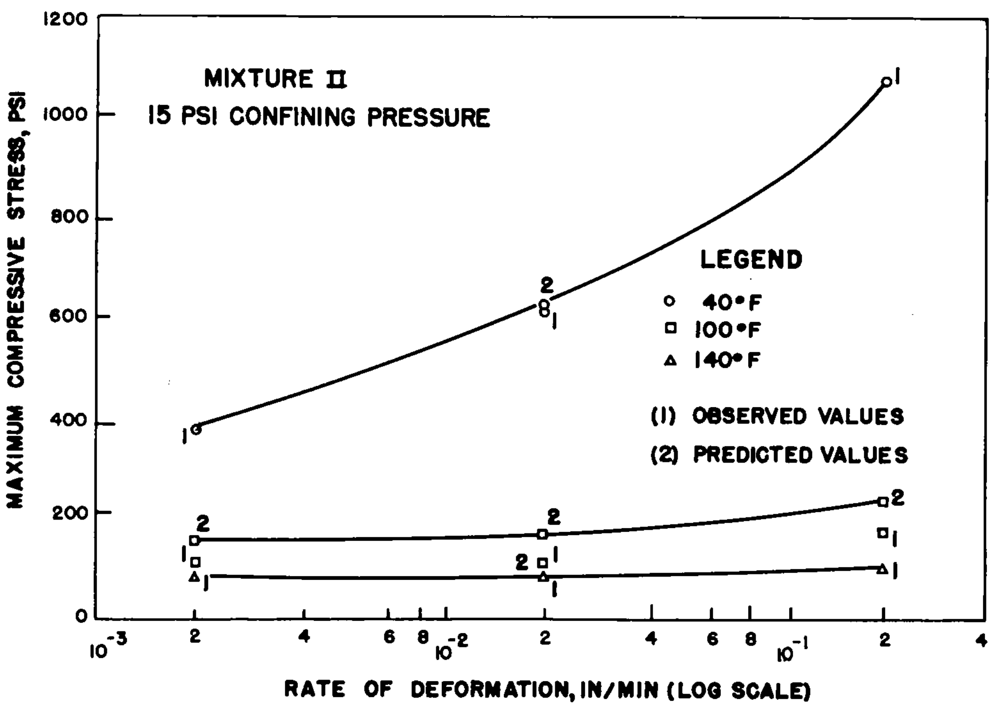

Figure 6. Relationship between rate of deformation and maximum compressive stress at various temperatures.

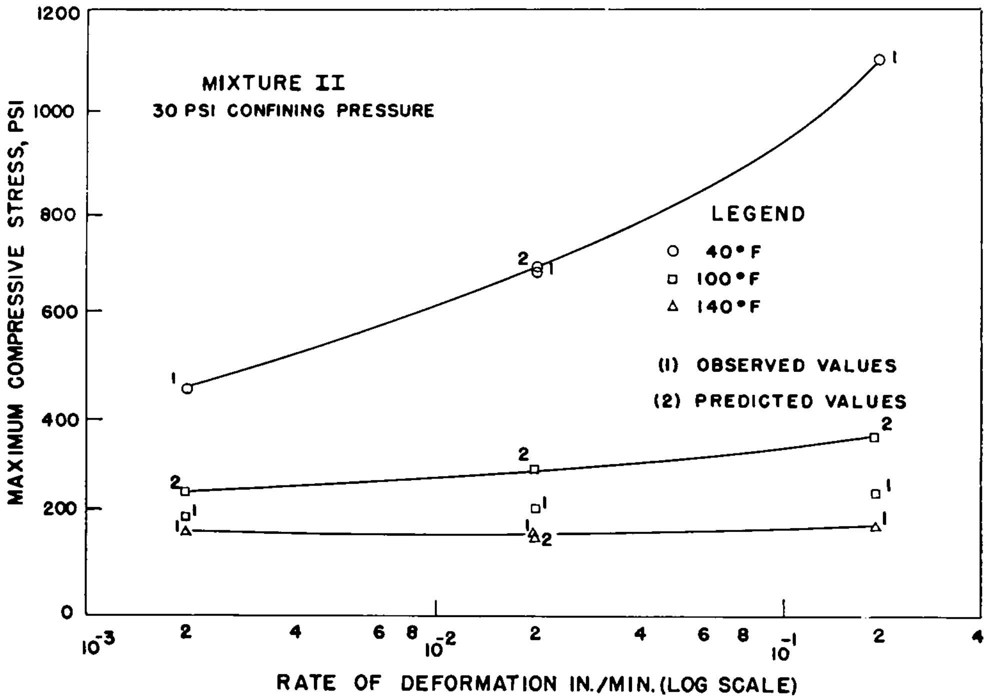

Figure 7. Relationship between rate of deformation and maximum compressive stress at various temperatures.

Therefore, the introduction of lateral pressure at 40 F resulted only in a small increase in the maximum compressive strength of the mixture. Also, it must be noted that for the 40 F test condition the confining pressures used were a small percentage of the maximum compressive stress. The proportional change of the maximum compressive strength of the mixture with temperature at any one rate of deformation is less pronounced under conditions of confinement than under conditions where no confinement exists. Including the results at 100 F in the regression analysis resulted in a much better fitting regression equation than was obtained by using limited data from the extreme conditions of temperature and rate of deformation.

Figure 6 shows both the predicted values and the observed values for a confining pressure of 15 psi. There was good correlation between observed and predicted values except in the case of tests made at 100 F. For all three rates of deformation at 100 F the predicted values were higher than the observed values.

Figure 7 shows the predicted values and the observed values for a confining pressure of 30 psi. There was good correlation between the predicted and observed values except for tests made at the 100 F temperature. For all three rates of deformation at 100 F, the predicted values were higher than the observed values.

The lack of correlation at the 100 F level between observed results and those predicted from an equation based upon tests made at the four extremes of rate and temperature (Figures 6 and 7) is in contrast to the unconfined test results in the sheet-asphalt mixture (*1*). This indicates that the introduction of confining pressure changes the relationship between compressive strength and temperature so that a prediction equation based upon tests made at the four extremes of rate and temperature is inaccurate for intermediate temperatures.

The addition of an interaction term involving the confining pressure and temperature to the original model might increase its effectiveness for application to the case of tests made under the confined condition.

Unconfined Static Load Tests

The unconfined static load test series was performed to evaluate the ability of a sheet-asphalt specimen to withstand a static load at five temperatures: 40, 55, 70, 100, and 140 F. Typical results of these tests are shown in Figures 8 and 9 where the deformation is plotted versus time (log scale) for various applied stresses at one temperature. The maximum static stress the specimen withstood at various temperatures is presented in Figure 10, where the maximum unconfined static stress is plotted against the temperature.

The data from the unconfined static load tests show again that temperature had a great influence upon the maximum stress that a specimen could withstand The change in character of the mixture with temperature is shown quite plainly by comparing the time-deformation curve for 40 F (Figure 8) with the time-deformation curve for 140 F (Figure 9). At 140 F the mixture was quite plastic in character as evidenced by the curve for the applied stress of 20 psi. Between 140 and 200 seconds the amount of deformation increased rapidly from a value of 0.05 in. to a condition where failure was imminent and the load had to be removed immediately in order to obtain a rebound value. At 40 F the mixture exhibited considerable viscous resistance. The curve for the applied stress of 375 psi was sloping upward gradually even after a deformation of almost 0.2 in. during a time interval of 2,500 seconds.

Unconfined, Repeated Load Tests

The results of a study in which the number of repetitions of applied stress, temperature, and rate of deformation were related for a sheet-asphalt mixture tested in the unconfined condition were previously reported (*1*). For each test condition there appeared to be an applied stress that could be cycled a number of times without excessive shear deformation occurring. This stress in each case was labeled the endurance limit. The

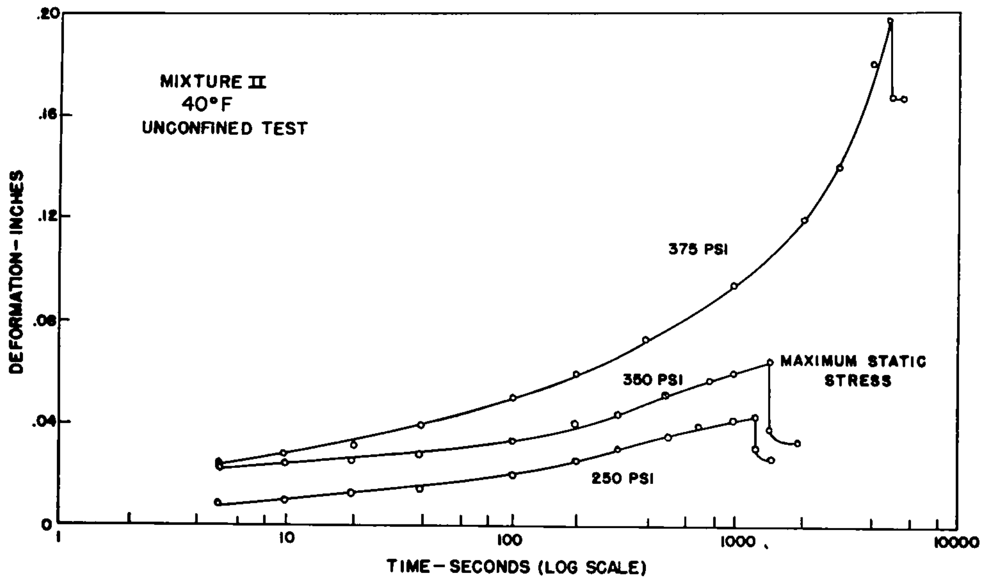

Figure 8. Relationship between deformation and time for various static loads.

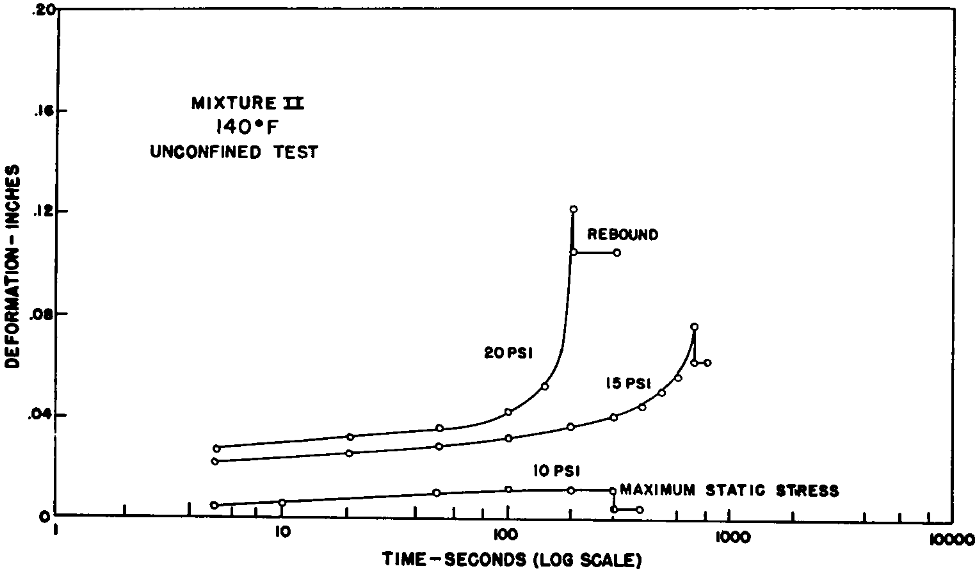

Figure 9. Relationship between deformation and time for various static loads.

results of that study are shown in Figure 11 where the endurance limit stress is given as a limiting value at the extreme right of the plot.

The family of curves (Figure 11) was expressed in a general mathematical model which related the applied stress, number of load applications, temperature, and rate of deformation, as follows:

$$x_c = \left[E\,10^{-\alpha(n-1)^{\beta}} + (1-E) \right] x_0$$

in which

- x_c = applied, cycled, unconfined compressive stress, psi;
- x_0 = maximum unconfined compressive stress for the test condition (fixed rate of deformation and temperature);
- n = number of load repetitions necessary to cause excessive shear deformations; and
- E, α, β = parameters that are dependent upon mixture ccmposition.

From this model it can be seen that when $n = 1$, $x_c = x_0$. This is not exactly correct according to the failure criterion developed because this means the specimen could withstand one cycle of the maximum unconfined compressive stress. However, in the interest of a general expression, the discrepancy was not considered a major source of error. As the magnitude of the applied stress is decreased, the number of loading cycles that a specimen will withstand before failure becomes greater. The limiting value for x_c, which was called the endurance limit, is approached as n gets large and the first term in the brackets approaches 0. In this situation, the endurance limit equals $(1 - E)x_0$. For the mixture used in this series of tests $(1 - E)$ was found to be about 0.25. Regression analysis was used to establish the numerical values of the parameters.

The unconfined repeated load test (Figure 11), gives results more severe than the unconfined static load test (Figure 10). For example, the endurance limit for 40 F and a rate of deformation of 0.002 in. per min (the slowest rate) was 105 psi; but at 40 F, the maximum static stress was 350 psi; for 100 F and a rate of deformation of 0.002 in. per min, the

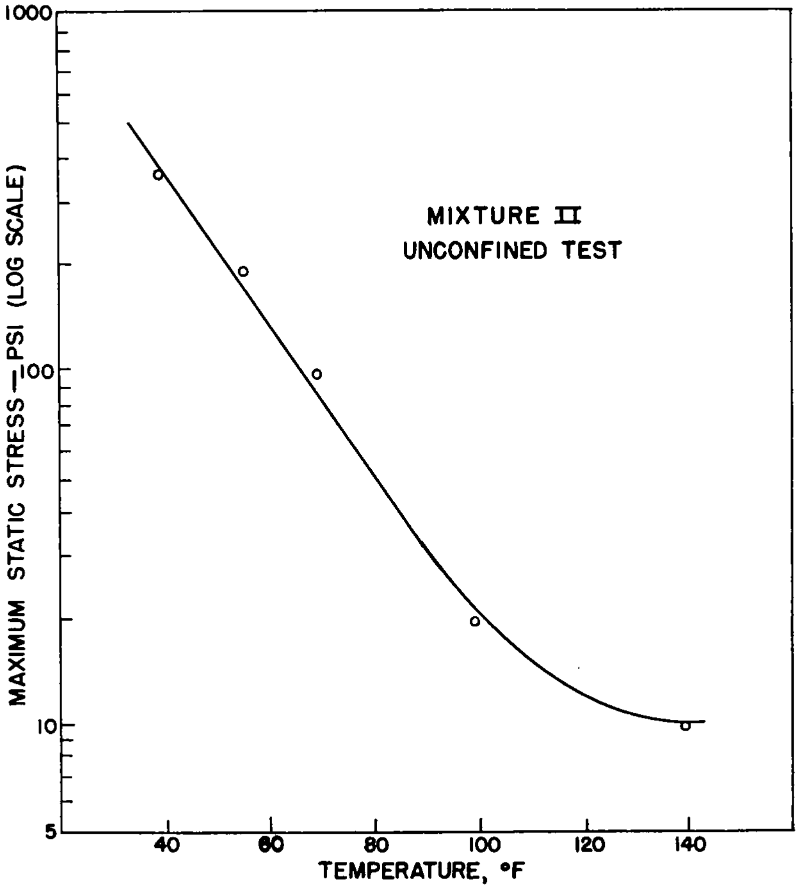

Figure 10. Relationship between maximum static stress and temperature.

endurance limit was 8 psi; but at 100 F, the maximum static stress was 20 psi; for 140 F and a rate of deformation of 0.002 in. per min, the endurance limit was 2 psi; but at 140 F, the maximum static stress was 10 psi. The failure criterion evolved for the unconfined repeated load test was more severe in mixture evaluation than was the failure criterion established for the static unconfined load test. Excessive shear deformations were noted in the unconfined, repeated load test before a large amount of aggregate particles were displaced. Therefore, the cross-sectional area of the specimen under test did not enlarge to any extent. In the case of the static load test, some specimen bulging was noted which meant that the cross-sectional area of the specimens under test was increasing. This meant that although the applied load remained constant during the test the applied stress was decreasing. This fact was not taken into account in determining the maximum static stress.

Confined, Repeated Load Tests

The confined repeated-load test series was performed to determine the effect of lateral support upon the relationship among the number of repetitions of applied stress, temperature, and rate of deformation.

Typical results of these tests are

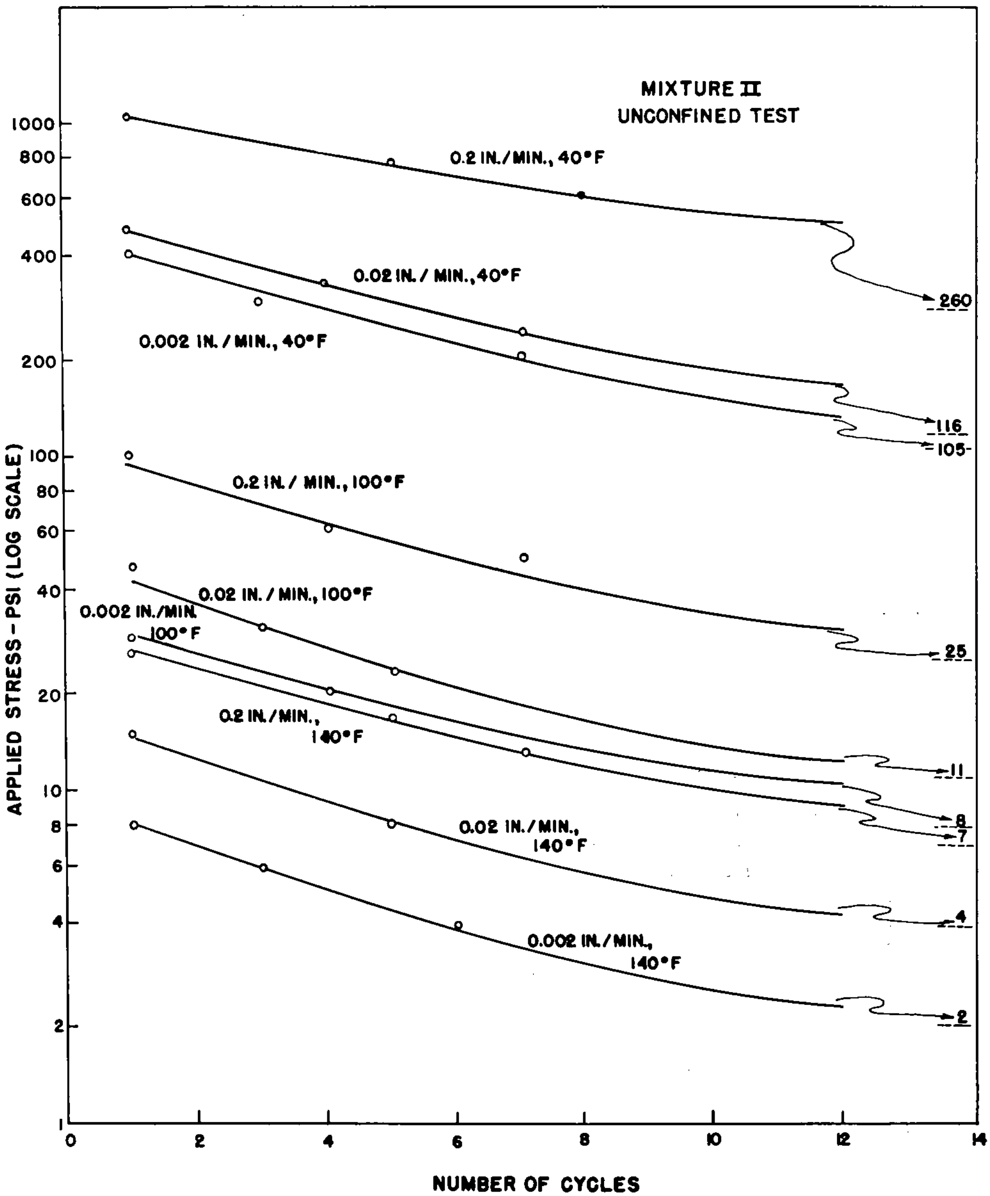

Figure 11. Applied stress — endurance limit relationships at various temperatures and rates of loading.

shown in Figures 12 and 13. The permanent deformation is plotted against the number of load applications for different applied stresses at various temperatures and rates of deformation.

The relationship starts out as a straight line when the permanent deformation is plotted against the logarithm of the number of load repetitions. At some stage, dependent upon the stress condition, the plot deviates sharply from the straight line, as is shown in the upper curves of the two figures. What occurs at this point is a matter of conjecture. It is

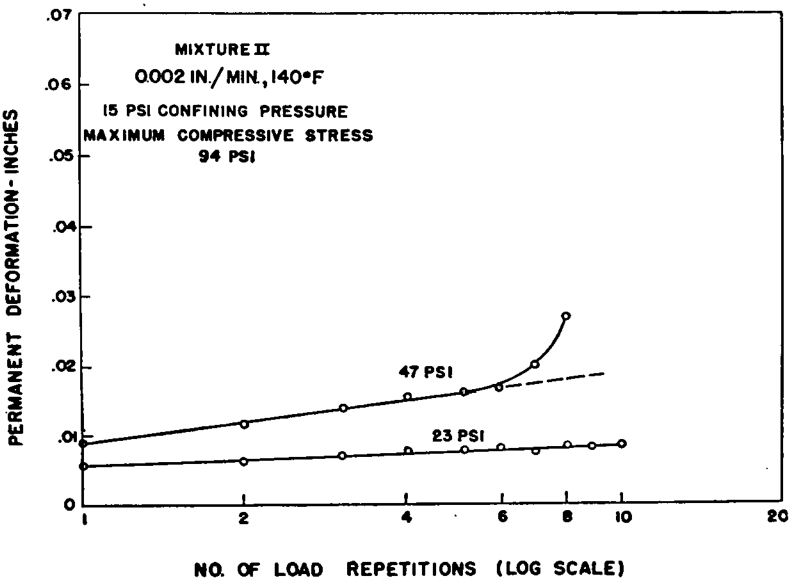

Figure 12. Relationship between permanent deformation and number of load repetitions for various applied stresses.

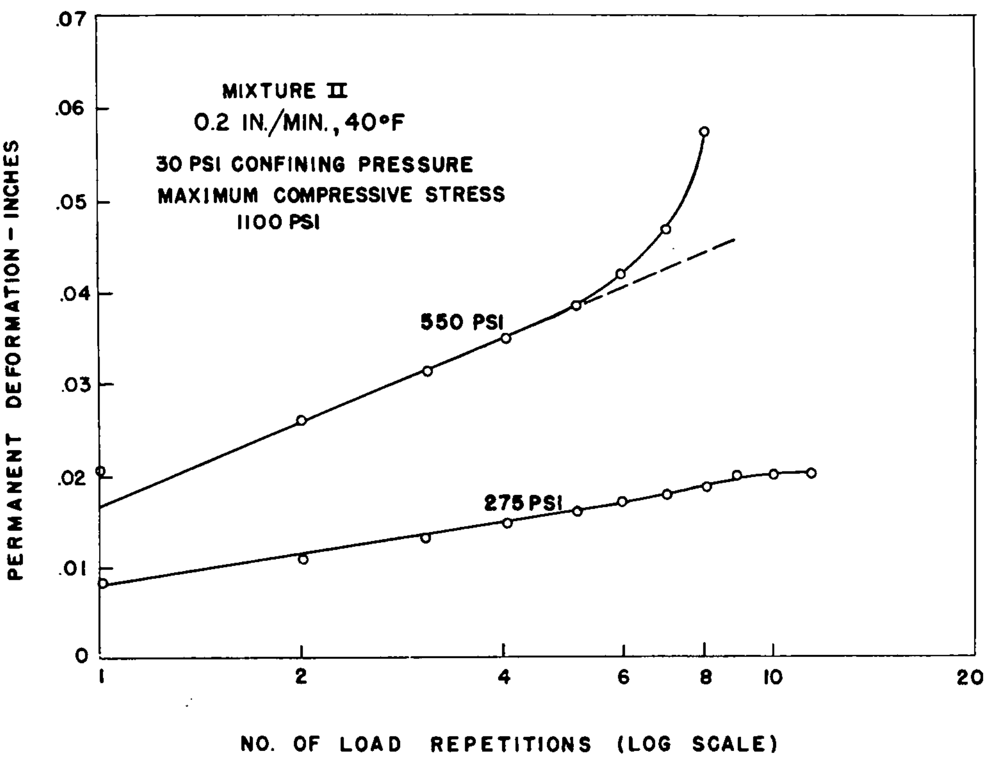

Figure 13. Relationship between permanent deformation and number of load repetitions for various applied stresses.

hypothesized that the asphalt film between aggregate particles is being reduced in dimension until some critical thickness is reached. At this point, in order to sustain the load, adjustment in the specimen takes place by reorientation of the aggregate particles themselves, giving rise to excessive shear deformations which are measured as permanent deformations. The point where excessive shear deformation occurs was taken as the failure criterion.

Under this hypothesis, the elastic part of the deformation would take place principally in the asphalt film which is bound firmly to the aggregate in a polymolecular layer. As the applied stress decreased, the number of loading cycles necessary to cause deviation from a straight line plot of deformation against log of load repetitions increased. When the applied stress was 25 percent of the maximum compressive stress, no deviation was observed for the number of load repetitions used in this sequence of observations. This stress in each case was labeled as the endurance limit. At 50 percent of the maximum compressive stress excessive shear deformations were noted in all cases, indicating that the endurance limit lies between 25 and 50 percent. No attempt was made to determine the endurance limit more closely.

The number of load repetitions necessary to cause failure under various confined test conditions is shown in Figure 14 where the applied stress (log scale) is plotted against the number of load applications necessary to cause failure for the various test conditions. The endurance limit stress is shown as a limiting value on the extreme right of the plot.

From Figure 14 it can be seen that for a temperature of 40 F and a rate of deformation of 0.2 in. per min, increasing the confining pressure from 0 psi to 15 psi and then to 30 psi increased the endurance limit from 260 psi, to 270 psi, and to 275 psi respectively. Thus, the introduction of lateral support at that test level did not affect the endurance limit appreciably. At that temperature and rate of deformation the viscosity of the binder is such that the introduction of a confining pressure in the range of 0-30 psi had little effect upon the endurance limit. The introduction of lateral support was not expected to affect the endurance limit at 40 F, because there was little increase in the maximum compressive stress between 0 and 30 psi.

At the other extreme of test conditions, a temperature of 140 F and a rate of deformation of 0.002 in. per min, increasing the confining pressure from 0 psi to 15 psi to 30 psi increased the endurance limit from 2 psi to 23 psi to 29 psi. In this case the confining pressure had a marked effect upon the endurance limit. At a temperature of 140 F and 0.002 in. per min, the viscosity of the binder was so low that the introduction of the confining pressure "stiffened" the mix appreciably.

Figures 12 and 13 indicate that an applied stress of 25 percent of the maximum compressive stress for each given test condition (represented by the lower line of each figure) could be cycled a number of times without excessive shear deformations occurring. Because the endurance limit for the unconfined condition also was approximately 25 percent of the maximum unconfined compressive stress determined at a given set of test conditions, the lateral support applied is shown to have little effect upon the endurance limit expressed as a percentage of maximum compressive stress.

The addition of lateral support does not change the basic behavior of the mixture in any unexpected manner. Although the endurance limit remained at about 25 percent of the maximum compressive stress, at the lower rates of deformation and the higher temperatures, introducing lateral support materially increased the maximum compressive strengths of the mixture. Thus, even though the endurance limit was approximately 25 percent of the maximum compressive stress for both the unconfined and the confined condition, the endurance limit for the confined case was numerically much higher for the high temperatures and low rates of deformation than for the unconfined case (Figures 11 and 14). Such a comparison also shows that

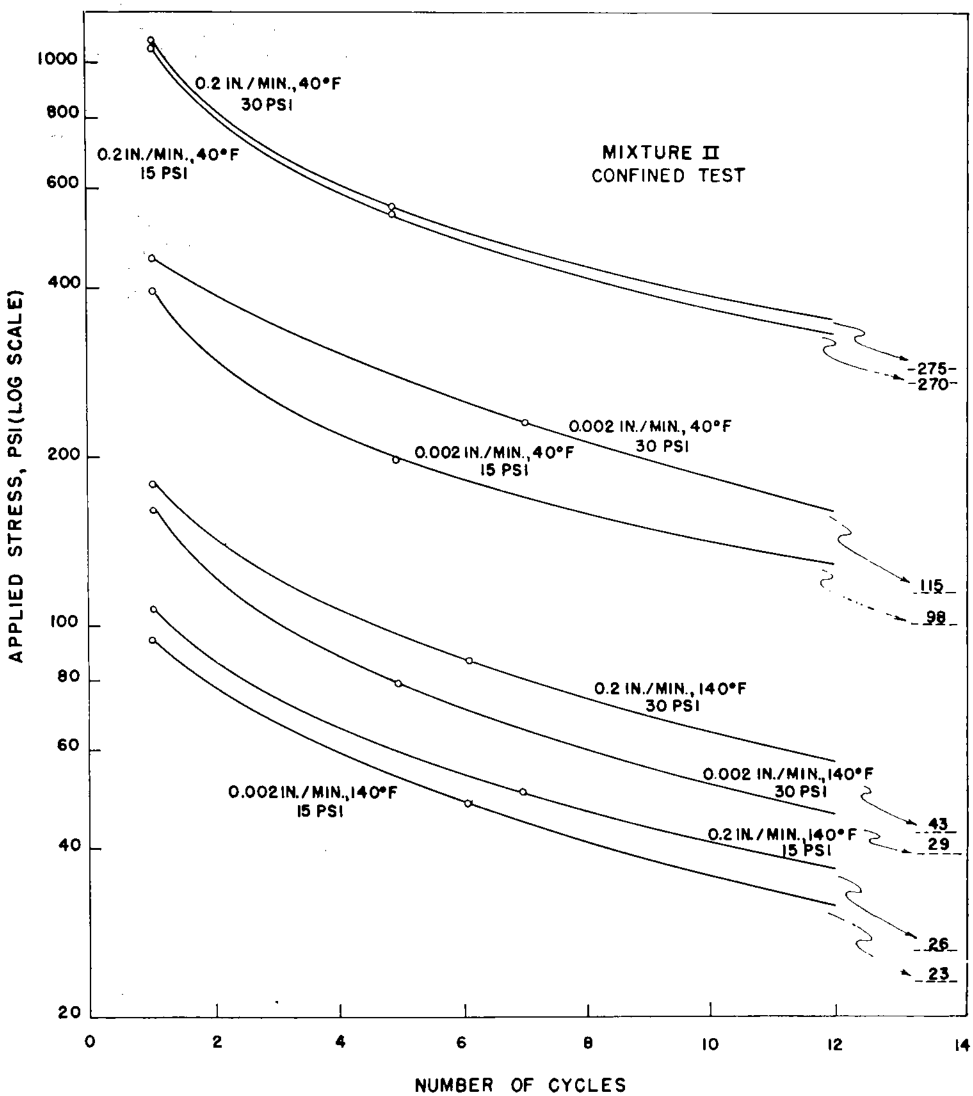

Figure 14. Applied stress — endurance limit relationships at various temperatures and rates of loading.

the curves for the confined, repeated load tests are quite similar to the curves for the unconfined, repeated load tests when permanent deformation is plotted against the log of the number of load repetitions.

CONCLUSIONS

Because this study was a continuation in which the additional testing included a wider range of mixture composition and compression tests with lateral support, the conclusions derived are similar to those reported earlier (*1*) but are applicable to wider ranges of test conditions and mixture composition.

This was a laboratory study in which the majority of tests were performed on a sheet-asphalt mixture. Although varying amounts of lateral support were used in these compression tests to approximate the field condition more closely than previously, the lateral support provided may not have been of the proper magnitude to simulate possible field conditions. With these limitations, the following conclusions are presented:

1. The relationship developed among the variables of maximum compressive stress (confined and unconfined), temperature and rate of deformation can be used to obtain information concerning the strength of a bituminous-aggregate mixture under many combinations of test conditions. This relationship can be established with results obtained under a limited number of test conditions.

2. The general relationship established among maximum compressive stress, temperature, and rate of deformation by means of the unconfined compression test holds true for the same variables when the test was conducted with varying degrees of lateral support.

3. For the sheet-asphalt mixture, the effect of the confining pressure upon the maximum compressive stress tends to diminish as the confining pressure is increased.

4. For the confined test condition, there was a combination of applied stress and number of load repetitions that resulted in excessive shear deformations. These excessive shear deformations appear in a plot of deformation against the logarithm of the number of load repetitions as a deviation from a straight line.

5. Under each test condition, both confined and unconfined, there was an applied stress that could be cycled without excessive shear deformations occurring. This stress was labeled the endurance limit.

6. The use of lateral support up to 30 psi increased, markedly, the maximum compressive stress at high temperatures, but this magnitude of lateral support had very little, if any, effect upon the maximum compressive stress at the temperature of 40 F.

7. The endurance limit was approximately 25 percent of the maximum compressive stress for all test conditions used. This endurance limit is an important mix property.

8. The failure criterion which was evolved for the repeated load test was more severe in mixture evaluation than was the failure criterion established for the static, unconfined load test. Thus, the static, unconfined load test was a less rigorous test for the bituminous mixtures tested than was the unconfined, repeated load test.

9. A promising means of evaluating the adequacy of a bituminous mixture for utilization in the field is to perform the confined, repeated load test on a rational specimen at a temperature of 140 F and a rate of strain of 0.0005 in. per in. per min. The degree of confinement to be introduced can not yet be recommended. From previous work on the strength of bituminous mixtures, it is known that some degree of confinement should be used in order to distinguish those mixtures whose strengths are particularly benefited by lateral support.

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