Effect of Mix Conditioning on Properties of Asphaltic Mixtures

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ABSTRACT

The serviceability of asphalt pavements is controlled by many factors, such as expected load, mixture, and environmental variables. In order to provide satisfactory serviceability, an asphalt mixture must have several characteristics: stiffness, tensile strength, resistance to fatigue, permanent deformation, and resistance to water damage. Recently, water-induced damage of asphalt mixtures has caused serious distress, reduced performance, and increased maintenance for pavements in Oregon. The information from tests performed at Oregon State University concerning three projects built between 1978 and 1980 was used to determine relationships between asphalt concrete pavement performance as indicated by resilient modulus, indirect tensile strength, fatigue life, and mix level of compaction for both as-compacted and conditioned samples. It was found that the rate of water-induced damage of asphalt mixtures was strongly related to aggregate quality and air void content of the mixture--the higher the air void content and the poorer the aggregate, the larger the loss of strength.

The performance of asphalt pavement materials is affected by many factors, including type of mixture, degree of compaction, stress level, rate of loading, and environmental factors. Currently, the effects of the environment under which pavements serve, including both climatic and loading factors, are receiving increased notice. For example, several studies have recently been performed to investigate the effect of water on asphalt pavement performance, including the effect of additives to reduce moisture damage (1-5). The loss of adhesion between the asphalt cement and aggregate surface, which affects the asphalt mixture properties, is primarily due to the action of water. Decreases in strength and modulus because of moisture reduce the performance of the asphaltic mixtures and, consequently, should be considered in pavement and mixture design practice.

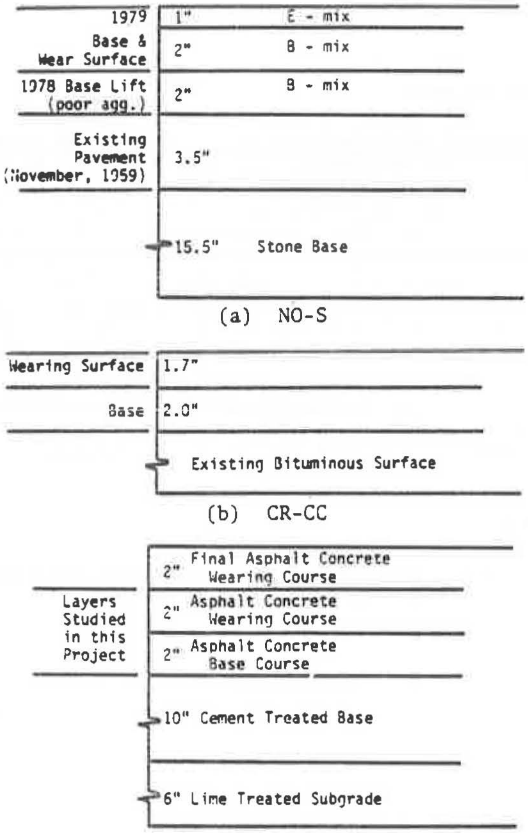
The purpose of this paper is to (a) summarize the test results for three recent projects in Oregon, (b) obtain a better understanding of the causes of the pavement problems with respect to moisture, and (c) develop relationships between mixture performance (resilient modulus, fatigue life, and indirect tensile strength) and the different mix variables for as-compacted and conditioned samples.

PROJECTS EVALUATED

The projects studied were North Oakland-Sutherlin (NO-S), Castle Rock-Cedar Creek (CR-CC), and Warren-Scappoose (W-S). These three projects were constructed between 1978 and 1980 in Oregon, and each project used an Oregon class B mix (Table 1). The construction reports of top lift and base lift of the pavement indicated that several mix variables were ranging within a very wide band, which indicated quality control problems during mixing (asphalt content, gradation) and during compaction (air void content) (6-8). The pavement cross sections are illustrated in Figure 1.

TABLE 1 Aggregate Gradation for Oregon Class B Mix for Each Project

		Job Mix Tolerance		
Sieve Size	Opening (mm)	NO-S	CR-CC	W-S
1 in.	25		100	100
3/4 in.	19	95-100	95-100	92-100
1/2 in.	12.5	80-92	81-93	82-94
3/8 in.	9.5			73-85
1/4 in.	6.25	54-66	57-69	54-66
No. 4	4.75			46-56
No. 10	2.00	21-29	22-30	26-34
No. 40	0.425	8-16	8-16	8-16
No. 200	0.075	3-7	3-7	2.6-6.6



(a) NO-S

(b) CR-CC

(c) W-S

FIGURE 1 Cross sections of projects studied.

North Oakland-Sutherlin Project

The North Oakland-Sutherlin (NO-S) project is a section of Interstate 5 located approximately 12 miles (19 km) north of Roseburg. Its overall length is 3.21 miles (5.14 km). The recommended asphalt content was 6.9 percent of an AR 8000 asphalt cement treated with 0.85 percent "pavebond" (an antistrip agent). The asphalt concrete base on this project was paved in October through December 1978 and showed problems of raveling and potholing shortly thereafter. An investigation performed by the Oregon Department of Transportation (ODOT) indicated that the reduced quality of the paving was basically the result of using varying amounts of unsound and nondurable aggregate in the mix. The aggregate used in this project was a submarine basalt that contained seams of sulfate compounds of calcium, sodium, and magnesium. Soundness test results for produced aggregate used in the paving ranged from 4.16 to 38.94 percent loss for coarse aggregate and 11.56 to 48.23 percent loss for fine aggregate (6).

Castle Rock-Cedar Creek Project

The Castle Rock-Cedar Creek (CR-CC) project, built in 1979, is a section of the Hebo-Valley Junction Highway located in Tillamook and Yamhill counties. The overall length is 11.7 miles (18.7 km). Asphalt contents of 6.1 percent for wearing surface and 6.7 percent for the base course were recommended. The average for the as-constructed thickness is 2.0 in. (5.1 cm) for the base course and 1.7 in. (4.3 cm) for the wearing surface. The asphalt grade recommended was an AR 4000. Progressive pavement raveling and potholing was noticed during the months following construction of this project. In this case the ODOT investigation indicated that the reduction in pavement life resulted from excess variability in aggregate gradation, inadequate asphalt coating of aggregate, and high air void content (7).

Warren-Scappoose Project

The Warren-Scappoose (W-S) project is a section of the Columbia River Highway located in Columbia County. The overall length is 5.05 miles (8.13 km). The base course was constructed in 1979 and the wearing surface was constructed in 1980. The recommended asphalt content was 5.1 percent for the wearing surface and 5.7 percent for the base course. The asphalt grade recommended was an AR 4000. Progressive pavement raveling and potholing were noticed in the base course during the months following construction. The core data obtained for this project indicated that the reduction in pavement life resulted from high air void content and variability in aggregate gradation (8).

SAMPLE PREPARATION AND TEST METHODS

Laboratory samples were prepared at Oregon State University to determine the resilient modulus, tensile strength, fatigue life, and permanent deformation of the asphaltic mixtures. For each project the percent passing the No. 200 sieve material was 6 percent and the asphalt contents were as follows: NO-S = 6.0 percent, CR-CC = 6.0 percent, and W-S = 5.5 percent.

For each project samples were prepared at the range of compaction levels given in Table 2. All tests were run on standard laboratory samples by using the repeated load indirect tensile test.

TABLE 2 Range of Compaction Levels Considered

	Percent of Maximum Compaction		
Extent of Laboratory Compaction	NO-S	CR-CC	W-S
2nd compaction[a]	100	100	100
1st compaction[a]	96	97	97
95 blows at 100 psi, 500 psi leveling load	92	92	93
30 blows at 100 psi, 300 psi leveling load	91	90	90

[a] See Laboratory Manual of Test Procedures (9).

Sample Preparation

Following the standard ODOT procedure (9), 4-in.-diameter (100 mm) by 2.5-in.-high (63 mm) samples were fabricated for each project by using the same materials (asphalt and aggregate) employed during construction. Sixteen samples were prepared for each mix condition. Eight samples were tested as compacted and eight samples were tested after moisture and freeze-thaw conditioning (Figure 2). All samples were tested in the diametral mode for elastic modulus, fatigue life, and permanent deformation. MTS equipment was used for measurement of indirect tensile strength. The results of permanent deformation tests are not included in this paper.

Test Method

Dynamic diametral tests were run to obtain the data of modulus, fatigue life, and permanent deformation. The dynamic load duration was fixed at 0.1 sec and the load frequency at 60 cycles per minute. All tests were carried out at room temperature [22° ± 2°C (71.6 ± 3.6°F)]. The Lottman conditioning procedure (3) was used to evaluate the influence of moisture and freeze-thaw conditioning. The main steps of this conditioning procedure are as follows:

1. Determine the resilient modulus of the as-compacted samples;
2. Vacuum saturate [26 in. (66 cm Hg)] the samples for 2 hr;
3. Place the saturated samples in a freezer at -18°C (0°F) for 15 hr;
4. Place the frozen, saturated specimen in a warm water [60° ± 2°C (140° ± 3.6°F)] bath for 24 hr;
5. Place the specimen in a water bath at room temperature [22.8° ± 1°C (73° ± 1.8°F)] for 3 hr; and
6. Rerun the modulus test along the same sample axis as the as-compacted modulus was measured (step 1) [22.8° ± 1°C (73° ± 1.8°F)].

RESULTS

All tests were run at horizontal tensile strains ranging between 50 and 150 microstrain. The bulk specific gravity and air void content corresponding to each level of compaction for the three projects are given in Table 3.

Resilient Modulus

The following equation was used to determine the modulus (10):

$$M_R = [P/(\Delta H \times h)](0.2692 + 0.9974\nu) \qquad (1)$$

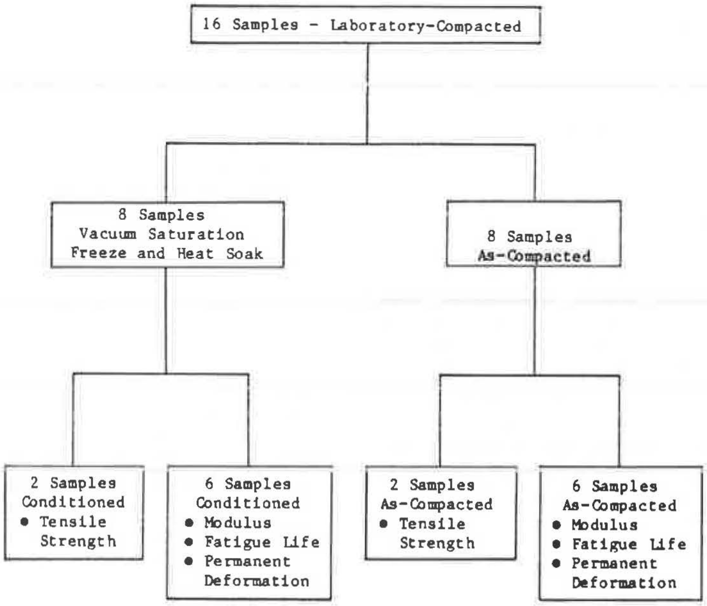


FIGURE 2 Test program.

TABLE 3 Bulk Specific Gravity and Air Void Content

Degree of Compaction (%)	Bulk Specific Gravity			Air Void Content (%)		
	NO-S	CR-CC	W-S	NO-S	CR-CC	W-S
100	2.41	2.30	2.45	3.3	5.3	1.6
97	2.31	2.23	2.38	7.3	8.2	4.4
92	2.22	2.11	2.29	10.9	13.2	8.0
90	2.19	2.08	2.20	12.0	14.4	11.6

where

M_R = resilient modulus (psi),
P = dynamic load (lb),
ΔH = horizontal elastic tensile deformation (in.),
h = sample thickness (in.), and
ν = Poisson's ratio.

Poisson's ratio was assumed constant and equal to 0.35, which simplifies Equation 1 to

$$M_R = (P \times 0.6183)/(\Delta H \times h) \qquad (2)$$

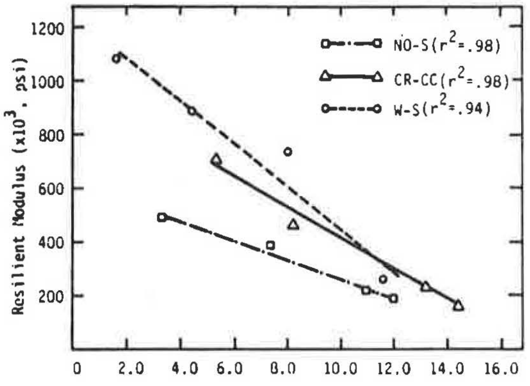
Moduli values of as-compacted and conditioned samples from all projects are given in Table 4. In order to determine the effect of conditioning on mixture performance, two parameters--RCL_{mod} and $R100_{mod}$--were computed for each level of compaction; they are also given in Table 4. These parameters are defined as follows: RCL_{mod} is the ratio of retained stiffness at the same compaction level [(Modulus of conditioned sample) ÷ (Modulus of as-compacted sample)], and $R100_{mod}$ is the ratio of retained stiffness compared to the modulus at 100 percent compaction of as-compacted samples [(Modulus of conditioned sample) ÷ (Modulus of as-compacted sample at 100 percent compaction)]. The moduli of as-compacted and conditioned samples and the values of RCL_{mod} for the North Oakland-Sutherlin project were the lowest, whereas those for the Warren-Scappoose project for each compaction level were the highest. The Warren-Scappoose project also exhibited higher bulk specific gravities or lower air void content than the others (Table 3) and had lower asphalt content.

Figure 3 shows the variation of resilient modulus with air void content. As indicated for both as-compacted (Figure 3a) and conditioned samples (Figure 3b), the diametral modulus has a strong linear relationship to the air void content. The coefficients of determination of each project are around 1.0. In general, as the air void content decreased from 10 to 4 percent, the moduli increased about twofold for both as-compacted and conditioned samples.

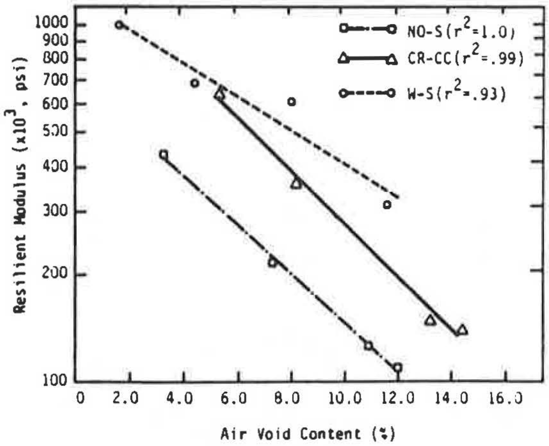
Values for $R100_{mod}$ increase as the air void content decreases (Figure 4). As would be expected, $R100_{mod}$ has a strong linear relationship with air void content. Values for RCL_{mod} are given in Figure 5. As indicated, most of the RCL_{mod} for the North Oakland-Sutherlin project are less than 70 percent, whereas those for the others are greater than 70 percent. The RCL_{mod} less than 70 percent for the North Oakland-Sutherlin project is a result

TABLE 4 Resilient Modulus and Retained Resilient Modulus Ratio

Degree of Compaction (%)	Resilient Modulus ($\times 10^3$, psi) As-Compacted			Conditioned			RCL_{mod}			$R100_{mod}$		
	NO-S	CR-CC	W-S	NO-S	CR-CC	W-S	NO-S	CR-CC	W-S	NO-S	CR-CC	W-S
100	488	710	1,082	435	638	1,008	0.89	0.90	0.93	0.89	0.90	0.93
97	389	466	887	214	357	688	0.55	0.77	0.78	0.44	0.50	0.64
92	220	238	736	126	147	610	0.57	0.62	0.83	0.26	0.21	0.56
90	191	163	265	109	139	312	0.57	0.85	1.18	0.22	0.20	0.29



(a) ·As - Compacted



(b) Conditioned

FIGURE 3 Influence of air void content on resilient modulus for each project.

of using poor quality aggregate. Hence the parameter RCL_{mod} demonstrates clearly that with poor quality aggregate there is a rapid loss of performance if satisfactory compaction is not maintained. The parameter $R100_{mod}$ shows the importance of mixture compaction more strongly than RCL_{mod}, but it does not indicate the influence of aggregate quality. In summary, the effect of moisture conditioning on the stiffness of the three projects is significantly affected by the quality of aggregate used and has a linear relationship to air void content.

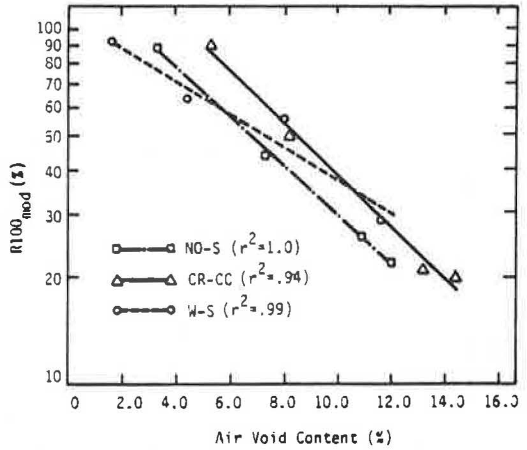


FIGURE 4 Influence of air void content on $R100_{mod}$ for each project.

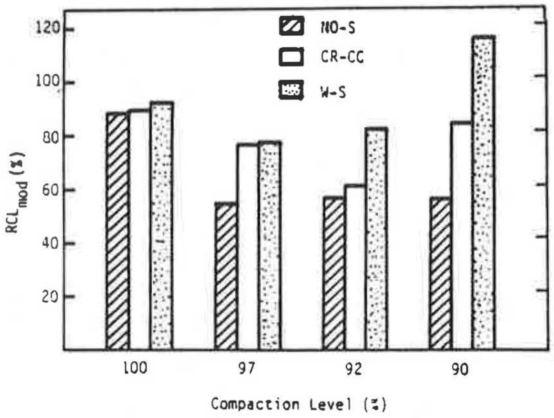


FIGURE 5 RCL_{mod} for each project at four compaction levels.

Indirect Tensile Strength

Values for indirect tensile strength of as-compacted and conditioned samples of each project are given in Table 5 together with their ratios of retained indirect tensile strength (i.e., $R100_{ts}$ and RCL_{ts}). For the North Oakland-Sutherlin project, the indirect tensile strength of as-compacted and conditioned samples are generally lower than the other two projects. Also, RCL_{ts} and $R100_{ts}$ for the North Oakland-Sutherlin project are lower at all compaction levels. The Warren-Scappoose project again exhibits the highest strength and $R100_{ts}$ value, particularly at high levels of compaction. Figure 6 shows that indirect tensile strength of both as-compacted and conditioned samples have strong linear relationships

TABLE 5 Indirect Tensile Strength and Retained Indirect Tensile Strength Ratio

Degree of Compaction (%)	Indirect Tensile Strength (psi)											
	As-Compacted			Conditioned			RCL_{ts}[a]			$R100_{ts}$[b]		
	NO-S	CR-CC	W-S	NO-S	CR-CC	W-S	NO-S	CR-CC	W-S	NO-S	CR-CC	W-S
100	199	230	362	109	227	371	0.55	0.99	1.02	0.55	0.99	1.02
97	123	142	273	84	170	321	0.68	1.20	1.18	0.42	0.74	0.89
92	113	67	108	50	105	105	0.44	1.57	0.97	0.25	0.46	0.29
90	95	71	65	27	84	75	0.28	1.18	1.15	0.14	0.37	0.21

[a] RCL_{ts} = retained indirect tensile strength ratio at same compaction level = (Tensile strength of conditioned sample) ÷ (Tensile strength of as-compacted sample).

[b] $R100_{ts}$ = retained indirect tensile strength ratio compared to 100 percent of as-compacted samples = (Tensile strength of conditioned sample) ÷ (Tensile strength of as-compacted sample at 100 percent compaction).

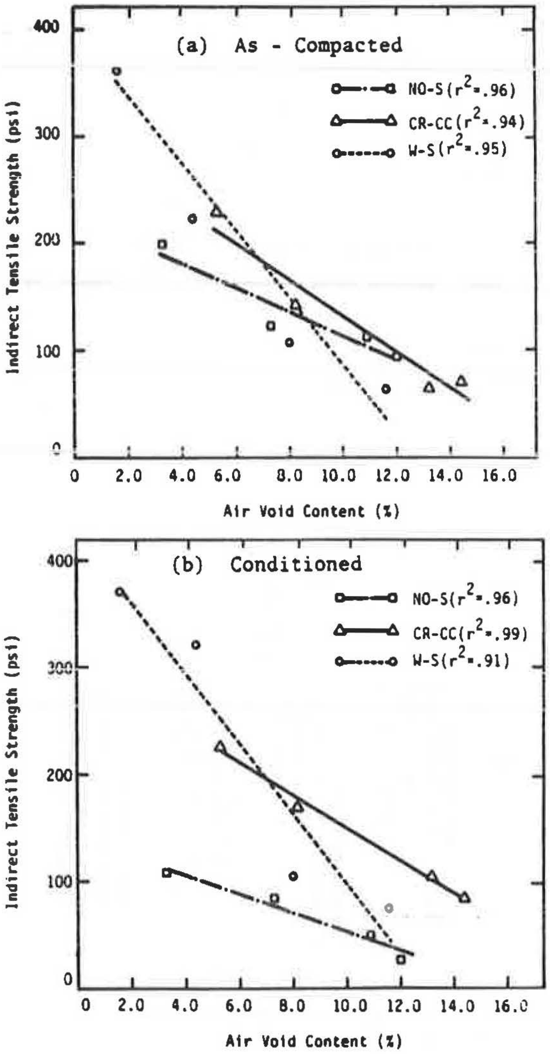


FIGURE 6 Influence of air void content on indirect tensile strength for each project.

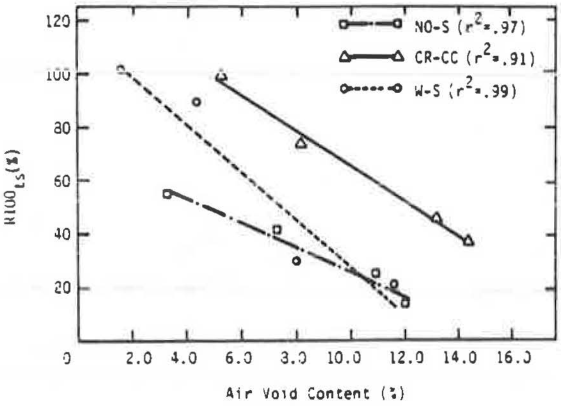


FIGURE 7 Influence of air void content on $R100_{ts}$ for each project.

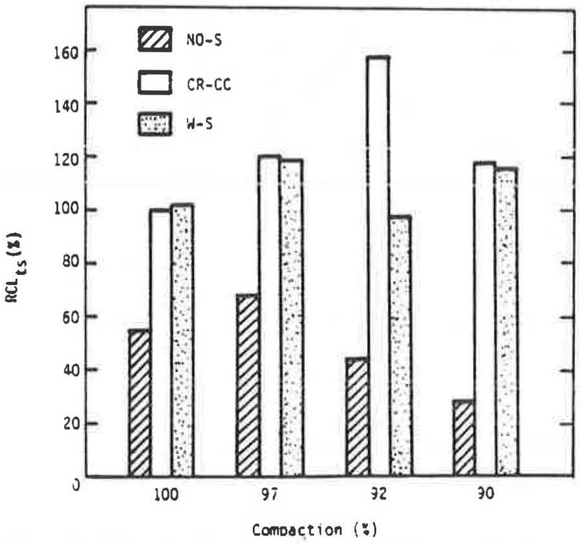


FIGURE 8 RCL_{ts} for each project at four compaction levels.

with air void content. Like $R100_{mod}$, there is a strong linear relationship between $R100_{ts}$ and the air void content (Figure 7). In general, as the air void content decreases from 12 to 4 percent, the indirect tensile strength increases about twofold in both as-compacted and conditioned samples. Figure 8 shows RCL_{ts} of each project at all compaction levels tested. Again note that values of RCL_{ts} for the North Oakland-Sutherlin project remain less than 70 percent, whereas those of the other projects rise greater than 100 percent; that is, the retained indirect tensile strengths of conditioned samples are greater than those of as-compacted samples in the test of the Castle Rock-Cedar Creek and Warren-Scappoose project for each compaction level.

The data in Figure 9 indicate that indirect tensile strengths of as-compacted and conditioned samples also have fairly linear relationships with resilient modulus at the corresponding air void content. In summary, the results of the indirect tensile strength of each project are similar to those of resilient modulus; that is, the effect of aggregate quality on RCL_{ts} is similar to RCL_{mod}. For poor quality aggregate, RCL_{ts} is consistently less than 70 percent, whereas for good quality aggregate RCL_{ts} is greater than 70 percent.

Fatigue Life

Fatigue life is characterized by the number of load applications required to cause failure of the sample. Attempts to relate the number of load applications to the state of stress or strain have shown that the best correlation exists between the tensile strain and the number of load applications, as follows:

$$N_f = K(1/\varepsilon_t)^m \tag{3}$$

where

N_f = number of load repetitions to failure,
ε_t = initial elastic tensile strain, and
K,m = regression constants.

The fatigue life of a specific mix is, therefore, defined by the constants K and m. Both K and m are affected by the mix variables. The horizontal tensile strain for the diametral test specimen is calculated from the following equation (10):

$$\varepsilon_t = H \times [(0.03896 + 0.1185\nu)/(0.0673 + 0.2494\nu)] \tag{4}$$

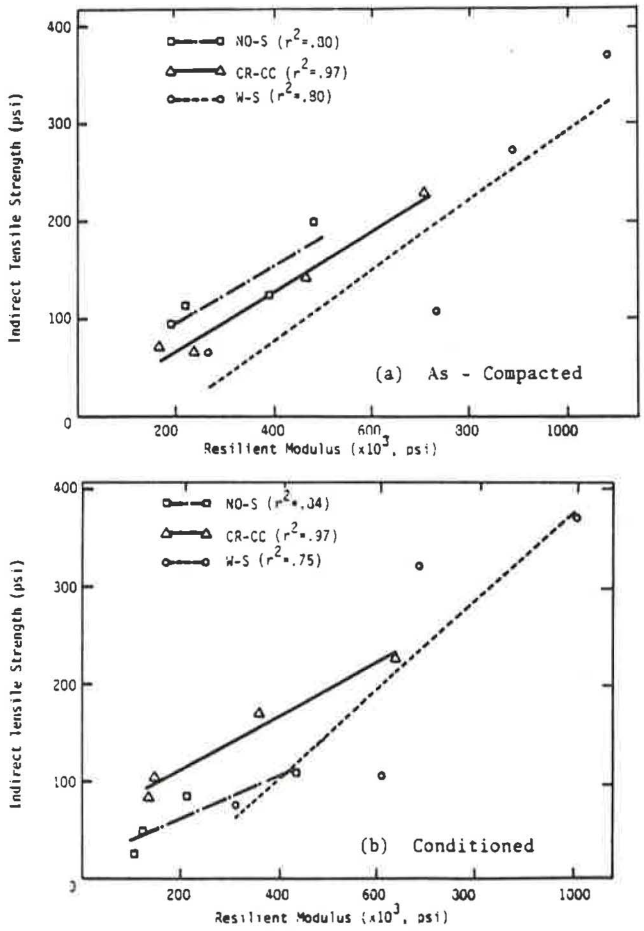


FIGURE 9 Relationship between indirect tensile strength and resilient modulus for each project.

Assuming that the Poisson's ratio is constant and equal to 0.35, Equation 4 becomes

$$\varepsilon_t = H \times 0.5203 \qquad (5)$$

Horizontal tensile strains versus number of load repetitions to failure of each project are shown in Figures 10-12, together with the level of compaction. The results for both as-compacted and conditioned specimens show a substantial decrease in fatigue life when the level of compaction drops. For the North Oakland-Sutherlin project, the fatigue relationship is affected significantly at a low level of compaction and is not affected greatly at a high level of compaction. This may be due in part to the low quality aggregate used on this project. For the Castle Rock-Cedar Creek and Warren-Scappoose projects, good quality aggregates were used. The fatigue life after conditioning generally increased compared with that of the as-compacted samples. This is due in part to the fact that the load applied for conditioned samples, in order to maintain the initial strain, was lower than that for the as-compacted samples. The samples from the Warren-Scappoose project had the highest moduli and generally the shortest fatigue life for both compaction levels. Although the North Oakland-Sutherlin project gave lowest moduli at a compaction level of 96 percent, the fatigue life was shorter than that for the Castle Rock-Cedar Creek project. In addition, the fatigue life for the North Oakland-Sutherlin project at 50 microstrain and compaction level of 96 percent decreased slightly after conditioning, but at a low compaction level it decreased drastically at all strain levels even though the conditioned samples had lower moduli than as-compacted ones. This result is due principally to the quality of aggregate used.

The initial tensile strain, air void content, and aggregate quality are predominant factors to the fatigue life. This result indicates that the durability of asphalt pavement is dependent on the quality of aggregate, the load applied and the level of compaction, or the air void content.

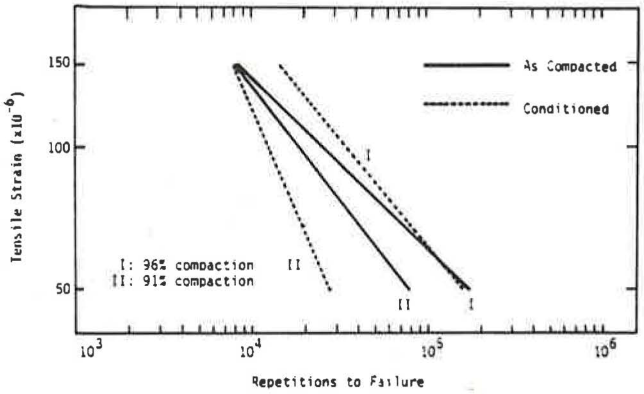


FIGURE 10 Horizontal tensile strain versus number of load repetitions: North Oakland-Sutherlin.

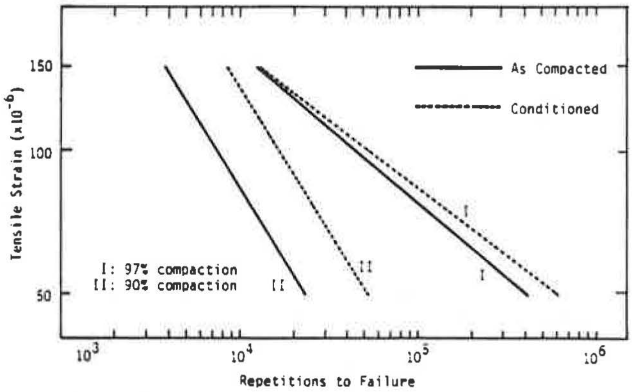


FIGURE 11 Horizontal tensile strain versus number of load repetitions: Castle Rock-Ceder Creek.

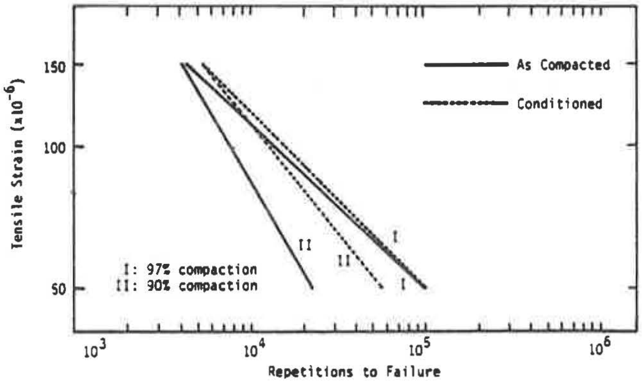


FIGURE 12 Horizontal tensile strain versus number of load repetitions: Warren-Scappoose.

DISCUSSION OF RESULTS

The results of tests on mixtures from the three projects indicate that damage to the pavement is increased with the low values of tensile strength and resilient modulus, or with relatively large drops in strength after conditioning the sample. The data from the tests demonstrate that values of modulus and indirect tensile strength for the North Oakland-Sutherlin project are considerably lower than those for the Castle Rock-Cedar Creek and Warren-Scappoose projects. The fatigue life for each project generally increased after conditioning for each compaction level and initial tensile strain. The exception was the North Oakland-Sutherlin project, for which the fatigue resistance decreased especially at a low compaction level.

Fatigue life is expressed as a function of modulus, initial tensile strain, and air void content. Thus fatigue life can be used as a valuable mix characteristic to evaluate the effect of conditioning. One possible parameter is the conditioning effectiveness factor (CEF). CEF represents the effects of material used and conditioning in reducing the modulus and prolonging the mixture life. When good quality aggregate was used (Castle Rock-Cedar Creek and Warren-Scappoose projects), the modulus after conditioning decreased and the fatigue life increased at the same initial tensile strain used for measuring modulus before conditioning. When poor quality aggregate was used, the fatigue life as well as the modulus of conditioning samples decreased, compared to as-compacted samples, as occurred in the North Oakland-Sutherlin project. A high value of CEF, therefore, represents poor materials and a low value represents good materials, and are less susceptible to conditioning. From the results of the test, the CEF for the North Oakland-Sutherlin project is 1.61, whereas the CEF for the Castle Rock-Cedar Creek and Warren-Scappoose project is 0.37 and 0.43, respectively (Table 6). The CEF clearly shows the effect of the quality of aggregate with conditioning.

TABLE 6 CEF at 90 Percent Compaction and 50 Microstrain

Project	RCL_{mod}	Fatigue Life		CEF[a]
		As-Compacted	Conditioned	
NO-S	0.57	79,142	28,006	1.61
CR-CC	0.85	23,084	52,851	0.37
W-S	1.18	20,684	57,331	0.43

[a] CEF = conditioning effectiveness factor = $RCL_{mod} \div (N_f$, conditioned/N_f, as-compacted).

CONCLUSIONS

Performance of as-compacted and conditioned mixtures used in the construction of three Oregon State projects was evaluated by using dynamic testing of laboratory-compacted samples. Mix resilient modulus, indirect tensile strength, and fatigue life of as-compacted and conditioned samples were determined for samples prepared within the following range of variables:

1. Mix level of compaction: 100, 97, 92, and 90 percent;
2. Asphalt content: 6 percent; and
3. Percent passing No. 200 sieve: 6 percent.

The following major conclusions are drawn from the findings of this study:

1. There is a strong linear relationship between air void content and the properties of the conditioned as well as the as-compacted samples;
2. At low air void content as-compacted and conditioned samples of each project have high values of resilient modulus, indirect tensile strength, and fatigue life;
3. The resilient modulus, indirect tensile strength, and fatigue life of conditioned samples are affected by the quality of aggregate used and the air void content;
4. The results of this study indicate the importance of obtaining good quality aggregate and a low level of air void content in mixture through a high level of compaction; and
5. The CEF is used for evaluating the quality of aggregate and the effectiveness of conditioning; a high CEF represents a mixture more susceptible to moisture damage.

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