Evaluation of Indentation Test to Characterize Asphalt Concrete Mixtures in Pavements

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ABSTRACT: The primary material property for characterizing asphalt concrete in the USA is the dynamic complex modulus. However, the dynamic complex modulus test is expensive and time consuming, making it impractical for use as a quality control test in the field. Therefore, there is a need for a test which can characterize asphalt concrete mixtures and can be performed, relatively simply, in the field immediately after construction. In the present study, the indentation test, which measures deflection under a constant load, was investigated for this purpose. Three replicates of the following four mixtures, having a nominal aggregate size of 12.5 mm and a PG64-22 binder, were fabricated and tested at 60ºC: 3.7% asphalt content and 4% air voids; 3.7% asphalt content and 7% air voids; 4.2% asphalt content and 4% air voids; and 4.2% asphalt content and 7% air voids. Air voids and asphalt content were varied since these are the volumetric parameters which are most likely to vary in the field and at the plant, respectively, and which have the greatest influence on pavement performance. The shear compliance obtained from the indentation test was found to be repeatable and sensitive to a change in air voids. However, the results do not seem to show a significant sensitivity to asphalt content, which is believed to be due to the localized nature of the indentation test. These results suggest that the indentation test may have limited applicability as a quality control and quality acceptance test in the field.

KEY WORDS: Asphalt, concrete, indentation.

1 INTRODUCTION

The primary mechanical property of asphalt concrete in the upcoming American Association of State and Highway Transportation Officials (AASHTO) Mechanistic Emperical Pavement Design Guide is the dynamic complex modulus *(*NCHRP 2002, Andrei et al. 1999, Witczak et al. 2002*)*. In National Cooperative Highway Research Program (NCHRP) Project 9-19, dynamic complex modulus test data showed a strong correlation with field performance. Criteria differentiating good versus poor performance were developed using performance models that will be incorporated in the latest AASHTO Pavement Design Guide. These performance criteria were validated using pavement performance data throughout the United States. As AASHTO begins implementation, agencies are discovering that it takes some time and experience to perform dynamic complex modulus tests. As a result of the cost of the equipment and personnel to run the tests on a regular basis, many agencies may choose not to perform them. It takes several days to obtain a full dynamic complex modulus master curve from specimen fabrication through analysis, making it unsuitable as a quality control and quality acceptance test in the field.

In the present study, the indentation test was investigated for use as a quality control test for newly constructed pavements. In the indentation test, a constant load is applied through a steel sphere to the material being tested. In the case of asphalt concrete, the deflection increases over time under the constant load due to the viscoelastic nature of the asphalt. It is emphasized here that although the applied load is constant during the indentation test, it is not a constant stress test. The small initial contact area results in high initial stresses. The contact area increases as the ball indents into the material and as the deflection increases.

The contact stress was calculated using the results of Lee and Radok (1960). They give the deflection of a point, w(r,t), at a distance r from the center of the indenting sphere at time t as:

$$w(r,t) = \frac{[l(t)]^2}{R} - \frac{r^2}{2R} \qquad \text{for } r \leq l(t) \tag{2}$$

where R is the radius of the sphere and l(t) is the contact radius. So the central deflection, $\alpha(t) = w(0,t)$ is given by:

$$\alpha(t) = \frac{[l(t)]^2}{R}. \tag{3}$$

The contact stress, $\sigma(t)$, depends on the projected area of contact and was therefore calculated as:

$$\sigma(t) = \frac{P}{\pi R \alpha(t)}, \tag{4}$$

where P is the applied load. A schematic of the situation is shown in Figure 1.

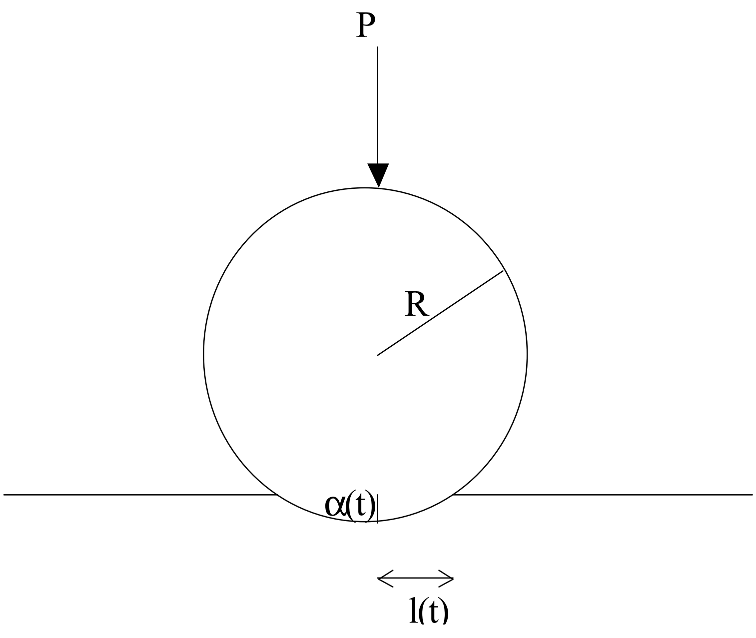

Figure 1: Indentation configuration.

The relation between deflection and shear compliance is given as (Lee and Radok, 1960):

$$[\alpha(t)]^{3/2} = \frac{3}{16\sqrt{R}} J_e(t)PH(t), \tag{5}$$

where $\alpha(t)$, R, and P are as defined above, $J_e(t)$ is the shear compliance, and H(t) is the heaviside step function. Using this relation, the shear compliance of an asphalt concrete mixture can be measured by the indentation test. The objective of this study is to show that the shear compliance obtained from the indentation test is repeatable and sensitive to changes in asphalt content and air voids.

2 MIXTURES

The specimens tested were fabricated from asphalt concrete mixtures which were based on a mixture commonly used by the New Jersey Department of Transportation (NJDOT). The same binder grade, PG64-22, and aggregate gradation were used for all specimens. The relative amounts of aggregates used are shown in Table 1. The overall aggregate gradation (Figure 2) conforms to the Superpave requirement of respecting the control points and restricted zone.

Table 1: Percentages of aggregate sources used in mixtures.

Aggregate	Percentage by Weight
12.5 mm Gneiss	20.8
9.5 mm Gneiss	44.2
Gneiss screenings	24.0
Wash Sand	10.0
Filler	1.0

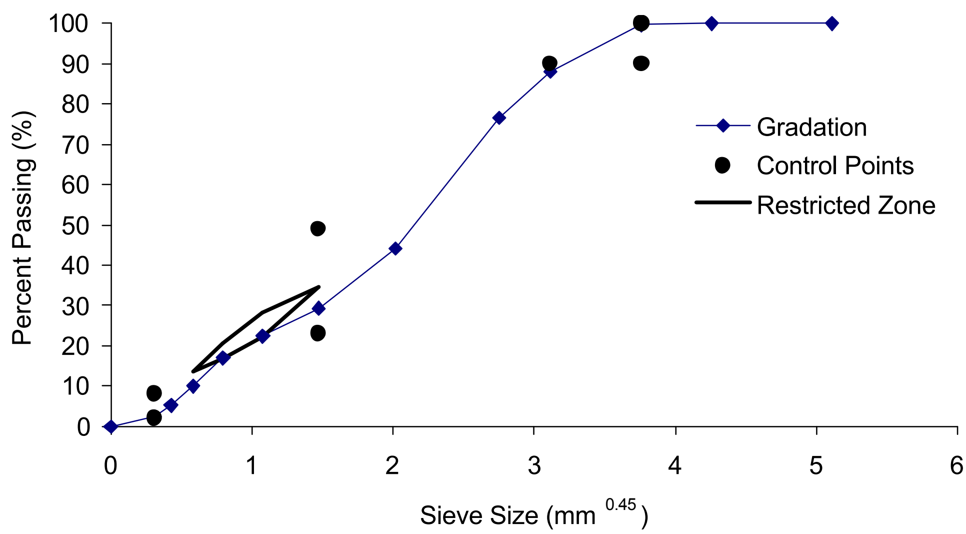

Figure 2: Aggregate gradation.

The design asphalt content for the NJDOT mixture is 4.2% with 4% air voids at N_{des}. Specimens were tested with the design asphalt content and air voids as well as with 3.7% asphalt and 7% air voids. The complete matrix of the specimens tested in this study is shown in Table 2.

Table 2: Number of replicates tested for each mixture.

Target Air Voids (%)	Asphalt Content (%)	
	3.7	4.2
4	3	3
7	3	3

Specimens with 3.7% asphalt content were tested because asphalt content is more likely to be lower than design during construction. Specimens with 7% air voids were tested since pavements are generally compacted to 93% of the maximum specific gravity during construction. The specimens were compacted in a Superpave gyratory compactor to a height of 150 mm using a 100 mm diameter mold.

3 TESTING PROCEDURES

A constant load of 178 N was applied for 30 seconds to each specimen through a 50 mm diameter steel sphere. The resulting deflections were measured during the 30 seconds at 0.2 second intervals. An MTS load machine was used to apply this load and record deflections. The MTS ramp-up time to the desired load was set to zero so that the applied load was as close to instantaneous as possible. In applying this load, however, the MTS machine overshot the desired load considerably if there was no initial contact with the load cell. To avoid this problem, a 22 N load was applied to the specimen as a seating load before the 178 N load was applied. The 22 N load was the smallest load which resolved the overshooting problem. In effect, the applied load for compliance calculation purposes was 156 N. Also, the deflections were zeroed at the time when the 156 N load was applied.

The 178 N load was chosen since it was the smallest load which produced a smooth creep curve. A small load was desirable to prevent excessive damage to the specimen.

All specimens were heated to 60ºC and tested in an environmental chamber. This temperature was chosen since the indentation test is intended to be conducted on pavements immediately after construction.

4 RESULTS AND ANALYSIS

4.1 Specimen Fabrication and Testing Results

Volumetric parameters of asphalt concrete are difficult to accurately achieve in the laboratory, this is especially true for air voids. The actual asphalt contents and air voids of the specimens tested in this study are shown in Table 3 along with the shear compliance values at 10 and 20 seconds as calculated from the indentation tests using Eq. (1). To account for small fluctuations in compliance values, which result from small fluctuations in the MTS load and measured deflections, the compliance values shown are averages of five data points around 10 and

20 seconds, respectively. A typical shear compliance versus time curve is shown in Figure 3. Also shown in Figure 3 are the contact stress values over time.

Table 3: Specimen fabrication and testing results.

Specimen	Asphalt Content (%)	Air Voids (%)	Average Shear Compliance, 10s (1/GPa)	Average Shear Compliance, 20s (1/GPa)
3.7-4-1	3.71	3.38	24.6	27.1
3.7-4-2	3.70	3.61	32.4	34.6
3.7-4-3	3.70	3.30	25.3	27.2
3.7-7-1	3.70	6.45	27.5	30.4
3.7-7-2	3.70	6.33	33.1	35.4
3.7-7-3	3.70	6.37	29.9	32.0
4.2-4-1	4.19	4.11	28.1	29.9
4.2-4-2	4.20	4.46	27.7	30.0
4.2-4-3	4.19	4.35	26.0	28.0
4.2-7-1	4.21	7.14	30.4	35.0
4.2-7-2	4.20	6.60	28.9	32.0
4.2-7-3	4.20	6.83	30.4	34.0

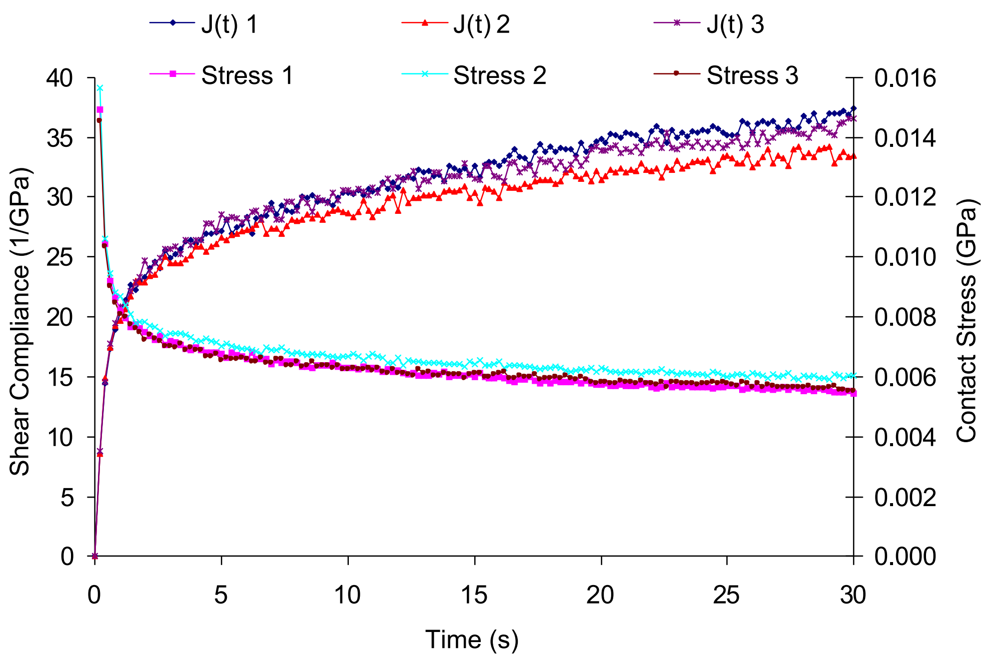

Figure 3: Shear compliance and stress versus time for 4.2% asphalt content and 7% air voids.

4.2 Descriptive Statistics

Table 4 shows the average shear compliance values at 10 and 20 seconds for each mixture. Specimen 3.7-4-2 was removed from this analysis since a loss of data during testing required it to be retested. It is felt that the results of the second test may have been affected by damage caused by the first test. The standard deviations and coefficients of variation are also shown in the table.

Table 4: Descriptive Statistics of Shear Creep Compliance

	Average (1/GPa)		Standard Deviation (1/GPa)		Coefficient of Variation (%)	
Mixture	10 s	20 s	10 s	20 s	10 s	20 s
3.7-4	25.4	27.1	0.23	0.071	0.90	0.26
3.7-7	30.2	32.6	2.8	2.6	9.2	7.8
4.2-4	27.3	29.3	1.1	1.1	4.1	3.8
4.2-7	29.9	33.7	0.91	1.5	3.0	4.5

The coefficients of variation were less than 10% in each case, which indicates that the results of the indentation tests were fairly repeatable for asphalt concrete testing.

4.3 Statistical Analysis

A statistical analysis using SPSS software was performed on the data in Table 3, for the shear compliance at 10 seconds and for the shear compliance at 20 seconds. The results of the analysis are discussed in Section 5.

Visual representations of the data for 10 and 20 seconds are provided as Figures 4 and 5, respectively. In these cases the compliance values, as shown in Table 3, were averaged for each mixture. As stated above, specimen 3.7-4-2 was removed as an outlier. The error bars at the top of each data bar represent the 95% confidence intervals.

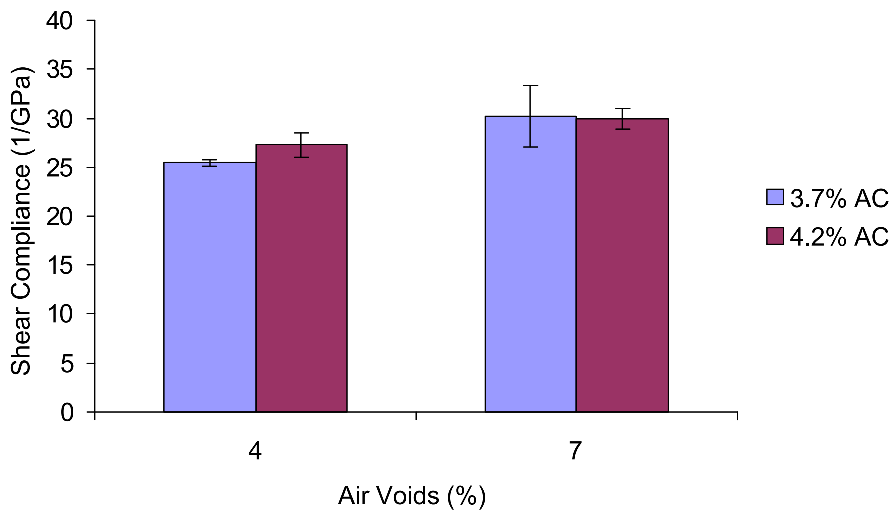

Figure 4: Average shear compliance values at 10 seconds.

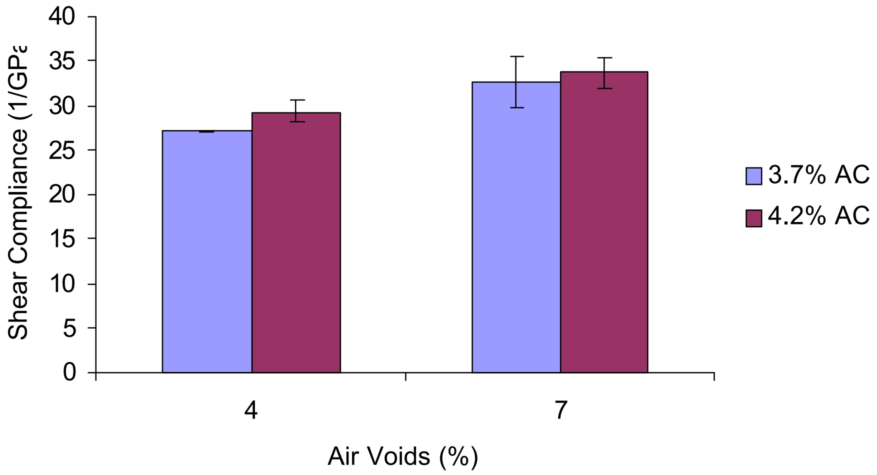

Figure 5: Average shear compliance values at 20 seconds.

5 DISCUSSION

5.1 Sensitivity to Air Voids

As a result of the statistical analysis conducted with SPSS, the calculated shear compliance values varied significantly with air voids. This is also evident from Figures 4 and 5 in that the 95% confidence intervals, between 4 and 7% air voids for both asphalt content levels do not overlap.

For the case of 4.2% asphalt content, although the confidence intervals do not overlap, the difference between the 95% confidence upper limit for 4% air voids and the lower limit for 7% air voids is very small, about 0.3 GPa^{-1} at 10 seconds and 1.4 GPa^{-1} at 20 seconds. This is about a 1 and 4% difference at 10 and 20 seconds, respectively. In the case of 3.7% asphalt content, these differences are about 5 and 8% for 10 and 20 seconds, respectively. Therefore, although the difference in shear compliance values between 4 and 7% air voids for 4.2% asphalt content was statistically significant, this difference was taken to be practically insignificant.

5.2 Sensitivity to Asphalt Content

Statistical analysis of the data revealed no significant relationship between shear compliance and asphalt content. The 95% confidence intervals, as shown in Figures 4 and 5, do not overlap for the case of 4% air voids. However, with reference to the discussion above in regards to the sensitivity to air voids, the 95% confidence limits differ by only 1 and 3% for 10 and 20 seconds, respectively. Further, in the case of 7% air voids, the 95% confidence intervals clearly overlap. For these reasons it is concluded that the indentation test did not significantly detect a change in asphalt content in this study.

As stated earlier, the stresses caused by the indentation test are localized stresses and the response depends only on the local properties at the point of contact. It is believed that this fact prohibits the indentation test from being able to detect a change in asphalt content. As the asphalt content increases, the aggregates are coated with a thicker film of asphalt. There is a cumulative effect of this increase in aggregate coating over the whole specimen which may allow asphalt content to be detected by a test in which the entire specimen is in compression. However, when measuring the response of only a small area of the specimen, it is believed that the effects of this increased coating are not great enough to be detected.

6 SUMMARY

The results of the indentation tests are summarized as follows:

- The results of the indentation tests were found to be repeatable. The coefficients of variation for shear compliance were all below 10%.
- The shear compliance was found to be sensitive to a change in air void level from 4 to 7%.
- The shear compliance was not sensitive to a change in asphalt content from 3.7 to 4.2%. This appears to be due to the localized nature of the indentation test.

7 CONCLUSION

In conclusion, the indentation test was found to be sensitive to a change in air void level. The indentation test, however, was not sensitive to a change in asphalt content. These results suggest that the indentation test may have limited applicability as a quality control and quality acceptance test in the field.

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