Evaluating the mechanical performance of asphalt mixtures in cyclic torsional shear test

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Abstract. In this paper, the mechanical performance of asphalt mixtures was examined in cyclic torsional shear test, in which the relationship between the averaged shear strain, γ̄av, and the number of cyclic loading, N, was obtained by using a short, about 25mm height, specimen. In these tests, the effects of some influencing factors such as the type of asphalt mixture, the thickness of specimen and the temperature were examined. In each test, four indices; i.e., the slope of plastic flow line, the slope of stripping line, the number of load applications at the inflection point for stripping and the averaged shear strain at the inflection point for stripping, were defined for the relationship between γ̄av and N. As a result of this study, we clarified that various performances such as rutting resistance, fatigue failure resistance and the stripping resistance of asphalt mixture can be appropriately evaluated by using the cyclic torsional shear test.

1. Introduction
In Japan, the importance of maintenance management of asphalt pavement is increasing. In order to efficiently repair asphalt pavement, it is necessary to properly evaluate the properties of existing asphalt pavement. Although there are many tests that directly evaluate the properties of existing asphalt pavement, it is extremely difficult to properly evaluate thin asphalt pavement like a pavement on bridge. For this reason, the authors have developed the cyclic torsional shear test and are studying methods of characterizing asphalt mixtures. This test can be appropriately evaluated not only for specimens about 40 to 60 mm height applied at the earthwork pavement but also for thin specimens about 30 mm height, collected in the pavement on bridge.

In this paper, we describe the influence on the test results when the type of asphalt mixture, temperature and specimen thickness were changed.

2. Cyclic torsional shear test

2.1. Test apparatus
The cyclic torsional shear test apparatus consists of four main components, a vertical loading unit, a torque loading unit, temperature control unit and a data acquisition and control unit. Figure 1 shows the test apparatus. The left side in the figure is the data acquisition and control unit. The center is the loading device which is the main device and the right side is the temperature control unit.
2.2. Testing procedure
For the cyclic torsional shear test, cylindrical specimens of asphalt mixture produced in the laboratory or cylinder cores taken from the site can be used. The diameter of the specimen is 100 mm. First, each face of the specimen is bonded to the top loading cap and the bottom loading cap using an epoxy adhesive (Figure 2a). Next, set the specimen in the loading unit and place an acrylic cylindrical water tank around the specimen (Figure 2b). Then, the hot water adjusted to the test temperature is put into the aquarium from the temperature control unit. After about an hour, which is sufficient time for the specimen temperature to reach test temperature, the cyclic torsional shear test is started. This test is prescribed torque is repeatedly loading by rotating the bottom loading cap. At this time, the vertical displacement is kept at zero. The repeatedly shear loading is continued till either the specimen ruptured or the torsion angle reached 45 degrees.

2.3. Testing condition
Table 1 shows the cyclic torsional shear test conditions. In this study, three torques of 14Nm, 28Nm and 42 Nm were set in order to confirm the influence of the difference of the loading torque on the test result. The loading waveform was a haversine wave with a loading time of 0.1 sec and a pausing time of 0.7 sec, and displacement in the vertical direction of the specimen was set to 0. The test temperature was set at 60 °C in consideration of the maximum pavement temperature in summer in Japan and the 50 °C and 40 °C tests were also confirmed in order to check the effect of temperature.


Table 1. Test conditions

| Item                        | Contents          | Remarks                                      |
|-----------------------------|-------------------|----------------------------------------------|
| Torque                      | 14Nm, 28Nm, 42Nm  |                                               |
| Torque wave                 | Haversine wave    | A loading time of 0.1 sec and a pausing time of 0.7 sec. |
| Vertical displacement of specimen | Kept 0          |                                              |
| Test temperature            | 60℃, 50℃, 40℃   |                                              |

2.4. Evaluation index

In the cyclic torsional shear test, average shear strain, $\gamma_{av}$, for each number of load applications is obtained from the following equation

$$\gamma_{av} = \frac{2R\theta}{3H}$$  \hspace{1cm} (1)

where $\gamma_{av}$ is average shear strain, $\theta$ is torsion angle (rad), $R$ is specimen radius (m) and $H$ is specimen height (m).

In this test, the relationship between the number of cyclic loading and the average shear strain as shown in Figure 3 is obtained [1]. First, the average shear strain rapidly rises immediately after the start of loading, and then gradually increases as the specimen stripping, fatigue and plastic deformation progress. And as it progresses to some extent, the average shear strain rapidly increases again and the specimen breaks. This deformation behavior is similar to those observed in Hamburg wheel-tracking test on asphalt mixtures (ASSHTO 2008). In this study, tangent lines of the curves shown in Figure 3 are called consolidation line, Plastic flow line, and stripping line [2, 3]. Then, the point of intersection between plastic flow line and stripping line is called the inflection point of stripping. The cyclic torsional shear test evaluates the characteristics of the asphalt mixture with the following indicators; the number of cyclic loading at the inflection point for stripping, the average shear strain at the inflection point for stripping, the slope of the plastic flow line, and the slope of stripping line. The slope of the plastic flow line shows that the plastic flow is high when the slope is small. And the slope of stripping line shows tenacity until failure sufficiently progresses, and the tenacity is strong when the slope is small.
2.5. Asphalt mixtures
The properties of the asphalt mixture are shown in Table 2. In this study, two types of asphalt mixture were used.

| Table 2. Properties of asphalt mixture |
|---------------------------------------|
| Types of asphalt mixture               |
|                                       |
| sieve (mm)                            |
| 19 100 -                               |
| 13.2 98.6 -                            |
| 4.75 62.1 -                            |
| Gradation (%)                         |
| 2.36 42.4 -                            |
| 0.6 24.8 -                             |
| 0.3 17.5 100                           |
| 0.15 8.5 25.0                         |
| 0.075 5.6 20.3                        |
| Asphalt content (%)                   |
| 5.4 5.4 11.1                          |
| Binder type                           |
| Straight asphalt                      |
| Polymer-modified binder               |
| Density (g/cm³)                       |
| 2.383 2.384 2.112                     |
| Air void (%)                          |
| 4.8 4.6 6.4                           |
| Stability (kN)                        |
| 6.4 10.5 3.3                          |
| Flow value (1/10cm)                   |
| 25 34 36                              |
| Dynamic stability (cycles/mm)         |
| 340 7500 -                            |

3. Test results

3.1. Loading torque
Figure 4 shows the relationship between the number of cyclic loading and the average shear strain according to the cyclic torsional shear test results using a dense-graded asphalt mixture. The thickness of the specimen is 50 mm. In the Polymer-modified binder loading torque of 14 Nm, although the number of loading operations was up to 300 thousand times, destruction of the specimen was not observed and the test was interrupted.

As a result of the test, when the loading torque (shear stress) increased, the number of cyclic loading at the inflection point of stripping was reduced. In addition, compared with the difference of binder, it can be said that a Polymer-modified binder has more the number of cyclic loading at the inflection point of stripping and better fatigue fracture resistance compared with a Straight asphalt. On the other hand, the average shear strain at the inflection point of stripping is nearly constant regardless of the type of binder when the asphalt mixture is the same.

Table 3 shows each evaluation index obtained from the cyclic torsional shear test result. When Polymer-modified binder was used and the loading torque is 14 Nm, the specimen was not destroyed. Focusing on the slope of the plastic flow line, the Polymer-modified binder is smaller than that of Straight asphalt. That is, it can be seen that the plastic flow resistance of the Polymer-modified binder is excellent. This trend is similar to the dynamic stability obtained in the general wheel tracking test [4] for evaluating the plastic flow resistance.
Figure 4. Relationships of average shear strain with number of cyclic loading for dense-graded asphalt mixture

Table 3. Evaluation indices for dense-graded asphalt mixtures

| Binder type       | Torque | Inflection point for stripping | Average shear strain | slope of plastic flow line (%/times) x 10^4 | slope of stripping line (%/times) x 10^4 |
|-------------------|--------|--------------------------------|----------------------|---------------------------------------------|-----------------------------------------|
| Straight asphalt  | 14Nm   | 1,830                          | 15                   | 685                                         | 58,275                                  |
|                   | 28Nm   | 410                            | 16                   | 3,275                                       | 150,538                                 |
|                   | 42Nm   | 166                            | 16                   | 7,573                                       | 367,434                                 |
| Polymer-modified  | 14Nm   | The specimen was not destroyed |                      |                                             |                                        |
| binder            | 28Nm   | 5,467                          | 10                   | 142                                         | 72,039                                  |
|                   | 42Nm   | 1,022                          | 13                   | 927                                         | 188,384                                 |

3.2. Temperature

Figures 5 and 6 show the relationship between the test temperature and the number of cyclic loading at the inflection point of stripping or the slope of the plastic flow line by the repeated torsional shear test using a dense-graded asphalt mixture. The thickness of the specimen was 50 mm which was the same as the examination of the loading torque. In both straight asphalt and polymer-modified asphalt, when the temperature rises, the number of cyclic loading at the inflection point of stripping decreases and the slope of the plastic flow line increases, because plastic flow resistance decreases. It was found that the torsional shear test can clearly evaluate the temperature sensitivity characteristics of the asphalt mixture.
3.3. Thickness of specimen

3.3.1. Test results
Cyclic torsional shear tests were conducted on specimens with different thicknesses of dense-grade asphalt mixture and asphalt mortar used polymer modified asphalt. Figure 7 shows the relationship between the thickness and the number of cyclic loading at the inflection point of stripping, and Figure 8 shows the relationship between the thickness and the slope of plastic flow line. Although values differ for each asphalt mixture when the thickness of a specimen increases, the number of cyclic loading at the inflection point of stripping decreases and the slope of plastic flow line tends to increase.

By the way, although the results are omitted in this paper, there was no effect of thickness on the average shear strain and the slope of stripping line.
3.3.2. Study on thickness correction

When evaluating various asphalt mixtures in the cyclic torsional shear test, it is desirable to be able to evaluate with the same index when the thickness is different. In this study, we tried to obtain the thickness correction value from the cyclic torsional shear test results with different thickness. That is, the reference thickness was 50 mm, and the correction value was obtained from the ratio of the values of the thicknesses of the specimens. A specific derivation method is as follows.

1. The average value of the test results at the thickness of the specimen of 50 mm is obtained. Let this value be the test result $Y_{50}$ of the reference thickness.

2. The correction factor $\alpha$ is obtained by the following equation. Then, the average value of the correction factor of each index is obtained.

$$\alpha = \frac{Y_{50}}{Y}$$

(2)

where $\alpha$ is correction factor, $Y_{50}$ is test results with a reference thickness of 50 mm, $Y$ is test results of arbitrary thickness.
3. Find the relationship between the specimen thickness ratio \((H / H_0)\) and the correction factor. Then, a correction coefficient for an arbitrary thickness \((H)\) is obtained by the following equation.

\[
\alpha = a_1 \times \left(\frac{H}{H_0}\right)^{a_2}
\]

where \(H_0\) is Reference thickness (50 mm), \(H\) is arbitrary thickness, \(a_1, a_2\) are Regression factor.

The relationship between the specimen thickness ratio \((H/H_0)\) of each evaluation index and the correction coefficient \((\alpha)\) is shown in Figures 9 and 10.

The correction factor for the number of cyclic loading at the inflection point of stripping increases with increasing thickness, and it can be expressed well by the proposed regression equation. Also, polymer-modified dense-graded asphalt mixture and asphalt mortar have almost the same correction factor. Even if the properties of asphalt mixture are different, it is possible to use the same correction factor.

The correction factor of the slope of plastic flow line decreases with increasing thickness, and it can be expressed well by the proposed regression equation. However, there are differences in correction factors depending on the asphalt mixture type. Whether the same correction factor can use for evaluating the flow resistance should be studied in the future.

By the way, although omitted in this paper, it was found that the average shear strain and the slope of stripping line had no effect of thickness. For this reason, correction of thickness is not required for these indexes.

![Figure 9](image1.jpg)

**Figure 9.** Relationship between \((H/H_0)\) and correction factor

![Figure 10](image2.jpg)

**Figure 10.** Relationship between \((H/H_0)\) and correction factor
4. Summary
The findings obtained in this study are as follows.
1. Amongst the polymer-modified dense-graded asphalt mixture, and straight-asphalt dense-graded asphalt mixture, the polymer-modified dense-graded asphalt mixture exhibited the highest plastic flow resistance. This trend was similar for the magnitude of dynamic stability.
2. The higher the temperature, the lower the plastic flow resistance and the fatigue fracture resistance, implying that the cyclic torsional shear test enables us to properly evaluate some basic behavior of asphalt mixtures.
3. The test results of the cyclic torsional shear test were influenced by the thickness of specimen. Accordingly, the correction factor regarding the specimen thickness was proposed.

References
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