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Fatigue resistance of reinforced asphalt concrete for flexible pavement

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ABSTRACT
Fatigue model of asphalt mixture is a major factor determining the life of pavement in mechanical-empirical pavement design. Tensile strength is a very important factor in this fatigue model. The purpose of this study is to confirm the resistance to fatigue fracture through the tensile strength of various modifiers of asphalt mixture. A total of 15 specimens were prepared and the data of indirect tensile tests of asphalt concrete mixed with rubber and polymer-based modifiers at 10, 20, and 30°C are analyzed and introduced.

KEYWORDS*: fatigue resistance, asphalt mixture, reinforced asphalt, indirect tensile strength test*

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I. INTRODUCTION

The distress of asphalt concrete pavement falls into two groups; fatigue failure that causes cracks in the asphalt concrete layer and plastic deformation that leaves wheel marks [1]. The relationship between expected traffic volume and strain is used as a criterion to evaluate the degree of these failures. In the case of structural failure, the tensile strain at the bottom of the asphalt concrete layer, and in the case of functional failure the tensile strain at the top of the subgrade. For the development of the structural failure standard, the method using laboratory test results and the method of analyzing the site measured data or design specifications are used.

Griffith established the theory of fracture which is the base of fracture mechanics [2], and in 1967 Moavenzadeh conducted theoretical and experimental studies for the investigation of fracture phenomena occurs in asphalt mixture [3]. Subsequent studies revealed that the fracture mode and tensile strength of asphalt mixtures were affected by several variables such as temperature, load ratio, thickness, and stiffness of the mixture. Asphalt deformation is the result of the complex process and shear flow, of which shear flow is the dominant factor, Monismith and his colleagues found [4].

II. ASPHALT MIXTURE FAILURE CRITERIA

2.1 Fatigue failure criteria

The evaluation of the structural capacity of the pavement can be estimated form the $logN_f - log\varepsilon$ diagram, which is the relationship between the maximum tensile strain at the bottom of the asphalt concrete induced by the standard axial load and the passable traffic that the pavement can accommodate up to a specific fracture condition. The methods are as follows.

Method that use the design specification

When the amount of traffic applied to the existing design formula is represented by the equivalent axial load, the failure criterion formula can be set from the design formula. In this case, the tensile strain is calculated by the multilayer elastic theory, and the traffic volume is estimated inversely from the design formula.

This method is simple and has the advantage of being well matched to reality and it is especially effective in the case where the design formula has been developed or shows similarity in climatic conditions. As a disadvantage, only the representative condition of the pavement throughout the year is considered. In addition, although the development of a design formula is effective only if it is developed by analysis of the fracture characteristics due to fatigue, most of the design formula consider all the fracture behaviors of the pavement at the same time. It is difficult to apply if the mixture in the asphalt concrete is new or different [5].

Method that use the site measured data

The necessary data for the establishment of failure standards can be obtained directly from the pavement that knows the traffic volume data and serviceability history. By estimation of the physical properties of materials through laboratory and field tests, it is possible to increase the accuracy in the setting the fracture standards. The analysis is limited to the section where failure is confirmed due to fatigue. Because the physical properties of the pavement change throughout the year, Miner's rule is required [6].

Method that use the laboratory test results

The test specimen is subjected to cyclic loading until failure, and the repeated deformation is measured by LVDT and then strain is calculated. The relation between the cyclic load applied until failure and the strain can be directly established. However, the failure criterion by actual test requires conversion for field application [7].

III. COMPOSITIONS OF EXPERIMENTAL MATERIALS

There the three types of asphalt mixtures are prepared to be investigated, first type A is the asphalt mixture reinforced with rubber binder, the second mixture is with polymer base binder, and the last type is simple asphalt mixture (table 1).

Table 1 Components Weight Percentage of specimens

	A (GmB)	B (PmB)	C (B 50/70)
Sound stone silt	4 %	4%	4%
0/4 Sand	27 %	27 %	27 %
4/11 Gravel	38 %	38 %	38 %
11/16 Gravel	31 %	31 %	31 %
Bitumen	4 %	4 %	4 %

Experimental specimens were prepared using the gyration compactor method. The specimen was cut to a diameter of 150 mm and a height of 60 mm. Total 15 specimens were prepared, and three test temperatures were chosen.

Table 2 Test temperature and Specimen IDs

Test temperature	Specimen IDs		
10 ℃	A22	B22	C22
20 ℃	A11, A12, A21	B11, B12, B21	C11, C12, C21
30 ℃	A41	B41	C41

For the case of the indirect tensile fatigue test, a compression load with a constant amplitude is repeatedly applied to the specimen, but since it is a biaxial stress state, the stress changes according to the Poisson's ratio. When the specimen exists within the range of linear viscoelasticity, the Poisson's ratio is constant, but when it is not in the boundary of linearity the Poisson's ratio increases due to the damage accumulated in the specimen. However, it is difficult to measure the Poisson's ratio accurately during the experiments. Thus, in this study the Poisson's ratio is assumed to be 0.35 for the calculation.

IV. INDIRECT TENSILE STRENGTH TEST

4.1 Test standards and analysis method

The indirect tensile strength test is an experiment to calculate the maximum shear strength (S_t) by applying the load to a cylindrical specimen in a horizontal plane.

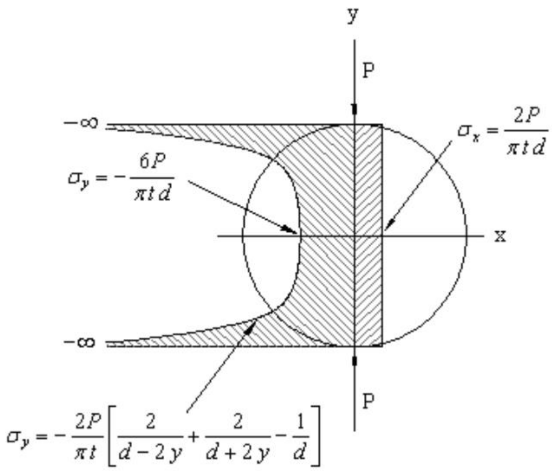

Figure 1: Theoretical Stress Distribution on Vertical Diametral Plane for Indirect Tensile Test

This test simulates the stress state of the part under the asphalt concrete layer (tensile part, figure 1) in the area where the temperature changes in the surface layer under the action of the traffic load. Resistance to fatigue fracture and low temperature crack can be evaluated. In this study, tests were conducted based on EN 12697-24-2018.

The maximum values of horizontal stress (compression) and vertical stress (tensile) are expressed as the following equations (1-4). P is the applied load (N), d is the diameter of the specimen (mm), and t is the thickness of the specimen (mm).

$$\sigma_x = S_t = -\frac{2P}{\pi t \mathrm{d}} \quad (1)$$

$$\sigma_y = \frac{6P}{\pi t \mathrm{d}} \quad (2)$$

$$\varepsilon_0 = 2.1\frac{\Delta H}{\mathrm{d}} \cdot 10^6 \quad (3)$$

$$N_f = k_\varepsilon \left(\frac{1}{\varepsilon_0}\right)^{n_\varepsilon} \quad (4)$$

Where ε_0 is the initial strain at the center of the specimen, in micrometers per meter ($\mu m/m$), ΔH is the total horizontal deformation between pulse 60 and 100, in millimeters (mm), k_ε and n_ε are material constants of the fatigue function and N_f is the number of cycle to fracture.

4.2 Indirect Tensile Test Results

The test was carried out based on EN 12697-24-2018. The specimen was manufactured with a diameter of 150 mm and a height (t) of 60 mm$\pm$2 mm using a compactor. This test was conducted to measure the material properties of the asphalt mixture according to the temperature. The test temperature was selected at 10 and 20 degrees, and the loading rate was peak-to-peak with a pulse width of 0.1s and a rest of 0.4s with a 0.5s cycle. A load of 750 kPa was applied. The tensile strength (S_t) of the asphalt mixture can be calculated from the load and stress at the moment of failure. The table shows the indirect tensile strength of each specimen according to temperature.

Table 3 shows the summary of the test results.

Table 3 Summary of the Indirect Tensile Strength Test

Mix	Test Temp (℃)	Tensile Strength (s_t, MPa)	Initial Strain (ε_0)	Thickness (mm)	Elastic modulus (MPa)	Fracture Energy (Nmm/mm2)
A	10	2.271660173	97.624035	61	12193.48	452.93
	20	2.394701949	187.16521	60.8	2061.811	340.81
	20	1.897558746	193.236519	61.8	1956.871	935.50
	20	2.304945444	178.431012	60.2	2118.429	420.24
	30	3.829010321	1050.311492	61	501.3301	4.21
B	10	2.272270135	80.452632	60.2	14890.49	452.31
	20	2.170569853	178.050398	61.8	1840.11	563.13
	20	2.497817024	184.498969	60.1	1732.846	264.51
	20	2.230727692	225.886097	62.2	1478.273	495.57
	30	3.692113376	1391.178249	60.2	353.5966	6.80
C	10	19.76568401	51.313524	59.5	9001.194	-
	20	2.916690388	261.941624	60.3	1303.409	83.67
	20	2.350133733	274.477732	60.7	1253.499	378.68
	20	2.675382142	286.625465	59.9	1205.395	166.02

	30	4.088679547	3397.824974	60.7	260.8447	1.66

A fracture life is obtained from the relationship between the log value of the load and the total horizontal deformation (mm). In the table 3, the tensile strength as the crack resistance evaluation factor and fracture energy as the factor describes the fracture characteristic of asphalt mixture are shown [8].

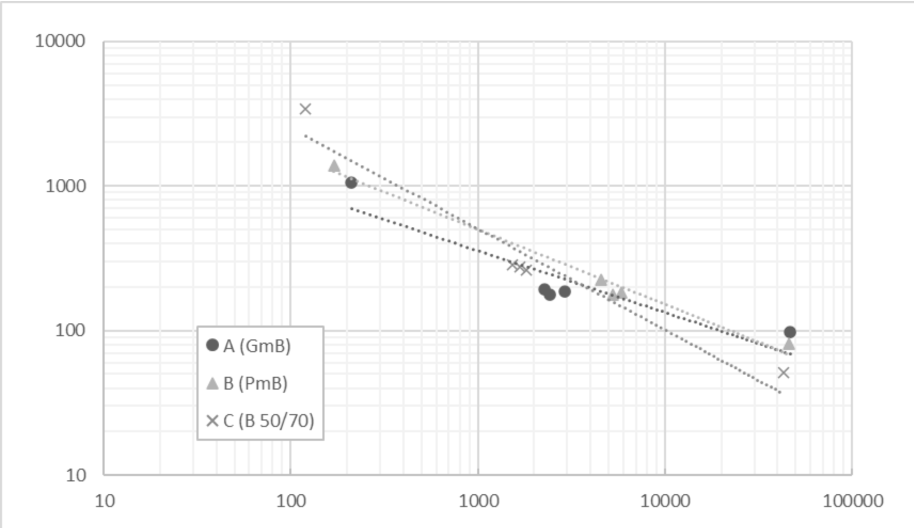

Figure 2 Initial total strain versus fracture life at different strain levels

Figure 3 shows the correlation between initial strain and fracture life. The fatigue line for each of the asphalt mixtures is drawn with the deformation concept, shown in equation (2).

It was confirmed during the experiment that the local deformation occurring at the point of application of the load occurred after the point of failure.

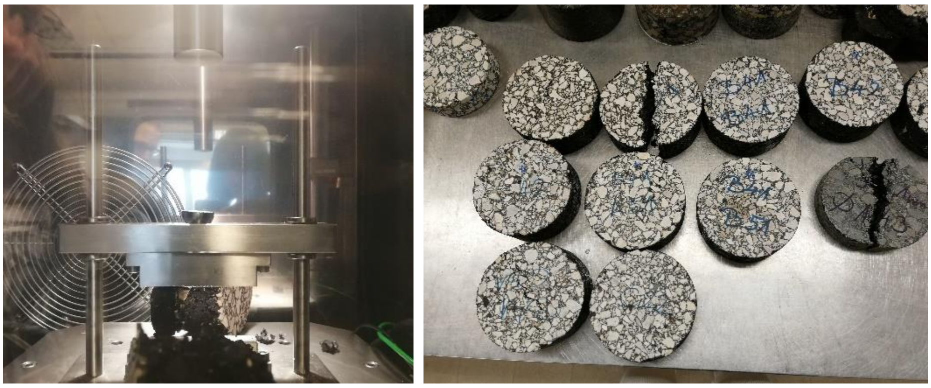

Figure 3 Fractured specimens

Figure 3 shows the destruction of the specimen, and table 4 shows the fracture model coefficients according to the experimental results performed at three temperatures for three mixtures.

Table 4 Fracture model coefficients

	A (GmB)	B (PmB)	C (B 50/70)
R^2	0.9484	0.9982	0.9922
k_ε	4.036e4	2.565e4	3.288e5
n_ε	0.6822	0.5675	0.9551

V. CONCLUSION

The goal of this study was to check the improvement of fatigue resistance by the different type of mixes in the asphalt concrete. A study was conducted to confirm the fracture resistance quality of the asphalt mixture using the indirect tensile test results, at three different temperatures (10, 20, 30 ℃) with 0.5 sec cycle. The following conclusions were drawn from the limited indoor tests.

(1) The response to fatigue cracking of the modified asphalt mixture in which rubber-based and polymer is mix

ed into the heated asphalt mixture was confirmed. It was confirmed that the physical properties of the aspha lt mixture were improved, that is, the fatigue life increased and the internal shear deformation resistance inc reased.

(2) Judging from the results of the physical property test for general mixtures, it is expected to prepare for plast ic deformation and premature fatigue failure of the modified asphalt concrete pavement, and it is expected t hat it will play a role as a pavement with a long lifespan.

(3) Reflect on the results of the different type of mixes, the initial strain level is important variable influencing on fatigue life regardless of the mix type. Since the performance of the modifier has been confirmed, verific ation through on-site accelerated test is required in the future.

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