A Research on Measurement of Stiffness of Asphalt Mixture in High Temperature

Y. Hisari
Hanshin Expressway Management Technology Center, Osaka, Osaka, Japan

N. Kanjo and A. Sato
Hanshin Expressway Co., LTD., Osaka, Osaka, Japan

O. Kamada and J. Haga
Kajima road Co., Ltd., Chofu, Tokyo, Japan

N.Yoshida
Research Center for Urban Safety and Security, Kobe University, Kobe, hyogo, Japan

ABSTRACT: The stiffness of asphalt mixture is measured by indirect tensile test or unconfined compression test in generally. But, measurement in high temperature like 60°C is not generalized, and the test method used cutting core that diameter is about 50mm in real road is not established. In this study, it was tried that diameter and height of specimens were changed from 50 to100 mm and stiffness of the asphalt mixture from 5 to 60°C was measured by unconfined compression test.

In a usual unconfined compression test, height of the specimen must be twice as long as diameter. But, from the result of this study, within strain is small enough in liner area of asphalt mixture, it was cleared that the stiffness of specimen that the length of height is equal to the diameter and the stiffness of specimen that height is twice as long as the diameter were almost equal. So, it was understood that the specimen that the lengths of height and diameter were 50mm was able to measure stiffness of asphalt mixture. It became possible to examine the core that was obtained in real road and measured steady in high temperature by this study.

Stiffness at each temperature and loading time of dense graded asphalt mixture, porous asphalt mixture, SMA and mastic asphalt mixture were measured by established unconfined compression test. Results of this test corresponded to stiffness shown generally up to 40°C in Japan. In this study, the stiffness of each mixture in 60°C was able to be assumed.

KEY WORDS: asphalt mixture, stiffness, high temperature, creep test, mastic asphalt.

1 INTRODUCTION

Fatigue cracks found in steel decks of bridges have been reported in recent years. In the bridge structures of the Hanshin Expressway, too, fatigue cracks have been found in, for example, welds between U-ribs and deck plates. In order to identify the cause of fatigue cracks in steel decks and consider remedial measures, structural analyses of bridges including pavements may be conducted. When conducting such analyses, it is necessary to input the modulus of elasticity of asphalt mixtures. By the results of measurements, it was cleared that the temperature of pavement rose up to around 60°C in the steel bridge of Hanshin Expressway. However, there is no established method for measuring the stiffness of asphalt mixtures at temperatures around 60°C in Japan. In this study, existing test methods were studied to identify problems with the test methods, and a test method was developed so that the stiffness of asphalt mixtures for bridge deck pavements can be measured under realistic conditions.

The newly developed test method was used to measure the stiffness of four types of asphalt mixtures, namely, dense-graded asphalt (hereafter referred to as "dense-graded As") mixtures used for the Hanshin Expressway, porous asphalt ("porous As") mixtures, stone mastic asphalt ("SMA") mixtures and mastic asphalt ("mastic As") mixtures.

This paper reports on a basic study on the stiffness of asphalt mixtures including measuring methods conducted with the aim of determining the modulus of elasticity that can be used for FEM analysis of asphalt pavements.

2 TEST METHODS

In Japan, the T_A method is widely used as pavement design method, and the modulus of elasticity of asphalt mixtures is seldom taken into consideration when designing pavements. In France, however, a theoretical design approach has already been introduced, and a method for measuring the modulus of elasticity of asphalt mixtures has been specified. The Laboratoire Central des Ponts et Chaussées (LCPC) requires that the modulus of elasticity of asphalt mixtures must be determined for pavements higher than a certain level. In this test method, stiffness is determined by applying dynamic loads to a specimen 100 mm in diameter and 200 mm in height. The highest temperature in this test is 40°C for modified asphalt mixtures (RST Working Group, 2007). The European Standard specifies the methods for characterising the stiffness of asphalt mixtures by alternative tests, including bending tests and direct and indirect tensile tests. It is difficult to execute those tests at 60 °C (EN ,2004).

AASHTO's Pavement Design Guide published in 2002 also specifies a method for measuring the modulus of elasticity. This design guide recommends that the dynamic modulus and the time shift factor must be determined by conducting the dynamic modulus test specified in NCHRP 1-28A or the shear test specified in ASSHTO T320 (AASHTO, 2002). NCHRP 1-28A is a method similar to AASHTO T307-99, Determining the Resilient Modulus of soils and Aggregate Materials, and resembles LCPC's resilient modulus test (AASHTO, 2003). Test specimens are prepared with a gyratory compactor. Judging from the shape of the specimen, it may be difficult to conduct the test at 60°C. AASHTO T320 (AASHTO, 2003) is similar to Superpave Shear Test (SST) (Ikeda, 1997). SST can be conducted at temperatures of up to 80°C, while the AASHTO T320 specifies 20°C for standard testing and 40°C for high-temperature testing.

In Japan, Pavement Survey and Test Method Handbook describes a resilient modulus test method for asphalt mixtures (Japan Road Association, 2007). Test temperature in this method is 5°C to 40°C. There was also a study on the measurement of the modulus of elasticity of asphalt mixtures by unconfined compression testing (Minegishi and Abe, 1991). According to that study, the modulus of elasticity and Poisson's ratio can be measured in an unconfined compression test by using specimens that are 100 mm in diameter and 200 mm in height ("d100 mm–h200 mm") if temperature is within the range between −10°C and 10°C. At 60°C, however, the specimen swells laterally and fails, and measurement results are not indicated clearly. From these, methods for measuring the stiffness of asphalt mixtures can be largely classified into indirect tension testing and unconfined compression testing. Though it was thought that suitable test method was changed by the condition and structure of pavement, the unconfined compression test which had high possibility to measure stiffness in 60°C was executed in this paper.

It was decided to use specimens prepared by using a roller compactor, taking into consideration the use of field-cut specimens. It was also decided to use pavement thicknesses of 50 mm to 100 mm in view of the pavement structures used for bridges and identify conditions and methods that make testing possible.

3 DIMENTION OF SPECIMEN

Specimens widely used for unconfined compression testing have a diameter-to-height ratio of 1:2. In a study on concrete, it was reported that compressive strength was affected by the size effect if the diameter-to-height ratio of the specimen was 1:1, but the measurement of the modulus of elasticity was not affected (Yotsuto and Saichi, 1980). It is possible, therefore, that in the case of an asphalt mixture, stiffness that can be attained is not affected even when the diameter-to-height ratio is changed as long as the size of the specimen is within the range in which Boltzmann's superposition principle holds where linear loads remain in the linear viscoelastic

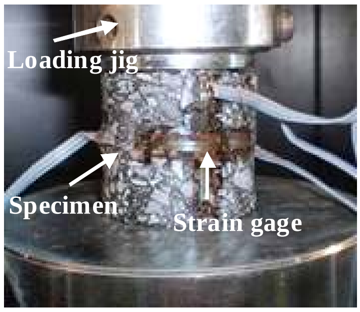


Figure 1: Unconfined compression test of d45mm,h50mm specimen

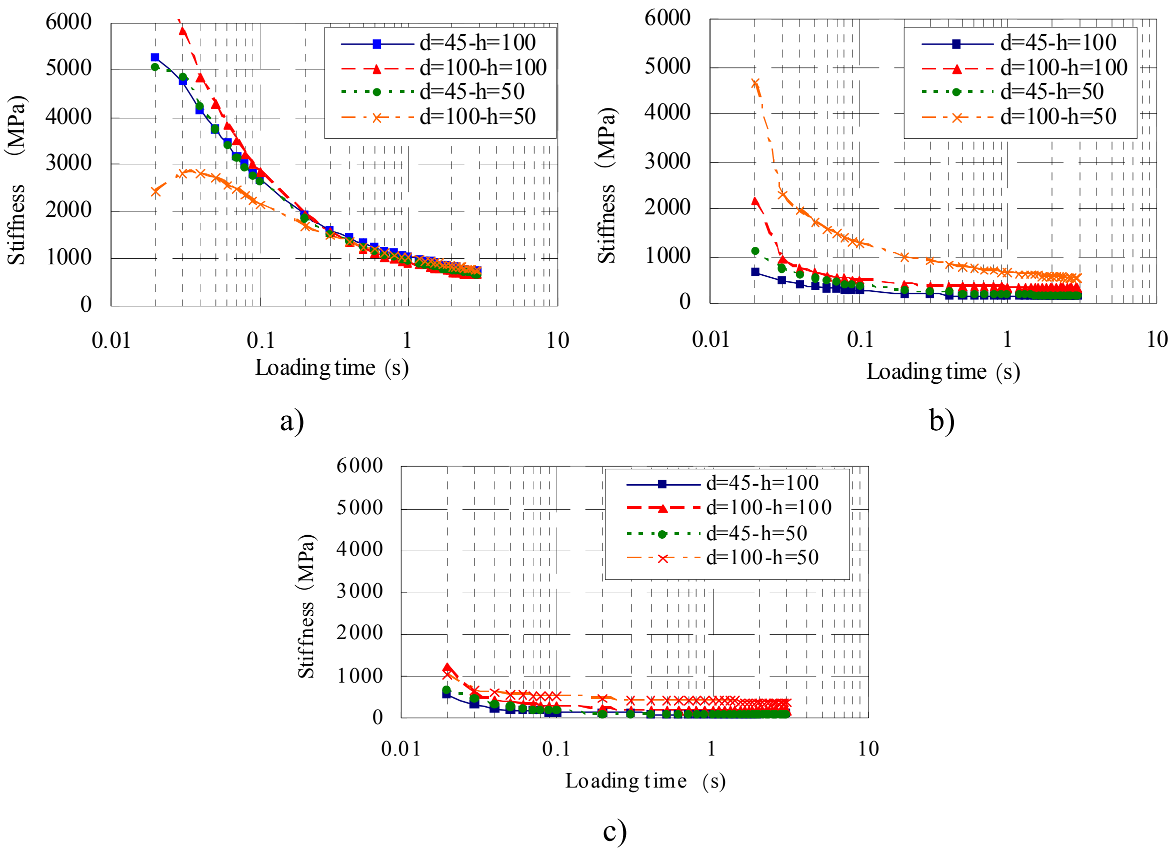


Figure 2: Relationship between stiffness and time (a) 20°C, b) 40°C, c) 60°C).

range. Dimensions of specimens, therefore, were considered by using a diameter at least three times as large as the maximum size of coarse aggregate and varying the diameter-to-height ratio of specimens. Because the maximum size of coarse aggregate was 13 mm and in view of available core barrels, it was decided to use specimens of the following dimensions:

(a) d45mm, h100mm
(b) d45mm, h50mm
(c) d100mm, h100mm
(d) d100mm, h50mm

The influence of the dimensions of specimens was investigated by conducting tests using dense-graded As mixtures at 20°C, 40°C and 60°C. The tests conducted were creep tests in which constant loads were applied. Loads to be applied were determined on the basis of the results obtained, by using a wheel load of 49 kN, from the relation

Radius of contact r (cm) = 12 + Wheel load P (tf) which is widely used in the multi-layer elasticity theory, and the target value was calculated by multiplying 0.55 MPa by the cross-sectional area. In the tests at 20°C and 40°C, loading of each specimen was performed more than one time, and the value obtained from the fourth loading, in which measured values tended to become stable, was used. At 60°C, the d45 mm–h100 mm specimen failed at the second loading, so the measured value obtained at the first loading was used. Figure 2 shows the relationship between stiffness and loading time at temperatures from 20°C to 60°C. Figure 3 shows the relationship between Poisson's ratio and loading time at 60°C. As shown, the d100 mm–h50 mm specimen shows a stiffness–time curve that differs from the curves for the other specimens, indicating that test results for the stubby specimen with a diameter-to-height ratio of 2:1 are greatly affected by the size effect.

The stiffness of the d100 mm–h100 mm specimen showed a tendency similar to the tendencies shown by the d45 mm–h50 mm specimen and the d45 mm–h100 mm specimen, but there were cases in which Poisson's ratios that were considered to be anomalous were obtained. A likely reason is that the mixture had a layered structure because when preparing a 100 mm high specimen, the mixture was compacted in two 50 mm thick layers so that a d100 mm high specimen was more affected than a d45 mm high specimen.

The d45 mm–h100 mm specimen is a specimen with a standard diameter-to-height ratio. In the tests at 60°C, however, the specimen failed during the second loading cycle. When the diameter-to-height ratio is 2:1, measurement involving the cyclic loading of a specimen at a temperature as high as 60°C is difficult to conduct.

These results have shown that when a specimen with a diameter-to-height ratio of 1:1 is used, stiffness can be measured under loads within the linear viscoelastic range without being affected by the diameter-to-height ratio, and the same specimen can be used in case of cyclic loading even in the high temperature range. If a specimen is compacted in two layers,

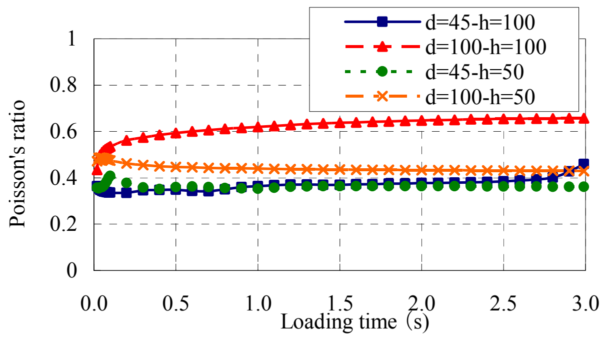


Figure 3: Relationship between Poisson’s ratio and time at 60°C.

Poisson's ratio is affected. It is therefore desirable that specimens be compacted in one layer. In view of the thickness of the bridge pavement structure, therefore, it was decided to use 50 mm high specimens in this study after the study on the shapes of specimens.

4 MEASUREMENT METHOD

4.1 Test Method

There are three loading test methods that can be used: cyclic loading test, stress relaxation test and creep test. In this study, stress relaxation test and creep test were conducted. These tests were conducted on dense-graded As mixture specimens at 60°C.

4.2 Loading Test Method

4.2.1 Stress Relaxation Test

In this study, strain rates was decited to 30 mm/s or 35 mm/s. The test machine was stopped when 0.03 seconds passed. Figures 4 and 5 shows the test results. As shown, if the same specimen is subjected to multiple cycles of loading, the stress that occurs increases in each cycle. In the case of Specimen No. 1 loaded at a strain rate of 30 mm/s, the stress that occurred in 0.03 seconds was about 0.4 MPa, which is smaller than the target value of 0.55

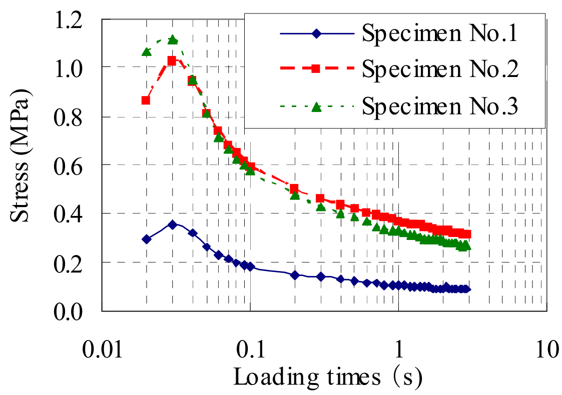


Figure 4: Stress-time relationship in stress relaxation test.

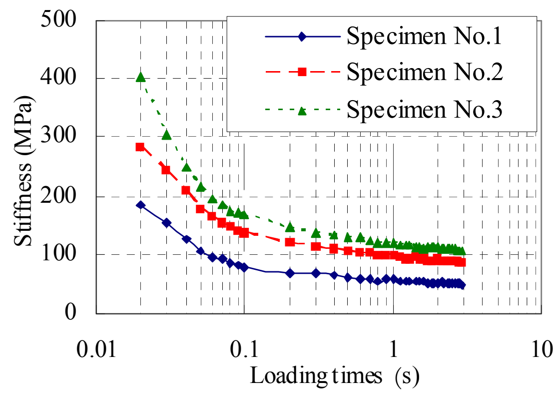


Figure 5: Stiffness-time relationship in stress relaxation test.

MPa. In the cases of Specimen No. 2 and Specimen No. 3 loaded at a strain rate of 35 mm/s, the stress that occurred in 0.03 seconds in the first loading cycle was about 0.55 MPa, which is roughly the same the target value. As the loading progressed, however, stress increased considerably to 1.0 to 1.2 MPa.

The results described above have shown that stiffness can be measured in a stress relaxation test, but at the same time the test results have revealed that stress in some specimens changed considerably at a temperature as high as 60°C. The fact that the occurrence of stress cannot be predicted is a problem for a study like this in which loading needs to be done in a low linear viscoelasticity range because of the size of the specimen.

4.2.2 Creep Test

The creep test was conducted at 60°C by using the same mixtures as those used in the stress relaxation test. Figure 6 shows the results of the creep test. test. The stiffness values were similar to those obtained in the stress relaxation test.

As a next step, the effect of increasing the number of loading cycles when loading the same specimen was investigated. Figure 7 shows the relationship between stiffness and the number of loading cycles. From the stiffness values for different numbers of loading cycles, it can be concluded that the influence of the number of loading cycles is smaller in the creep test than

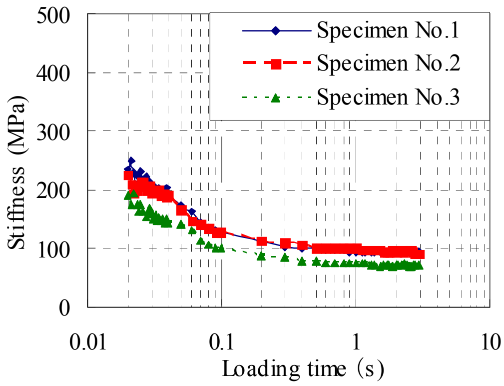


Figure 6: Relationship between stiffness and time in creep test.

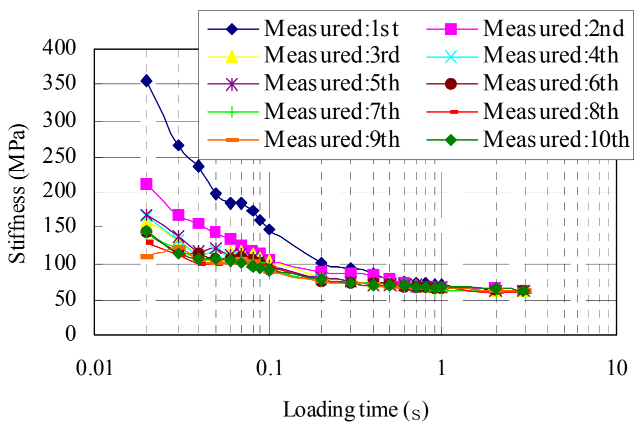


Figure1 7: Stiffness-time relationship in the case where the number of loading cycles is increased in creep test.

in the stress relaxation test.

Thus, it has been shown that strain occurring in a creep test conducted at a temperature as high as 60°C becomes stable in early loading cycles, and stiffness can be simulated with good accuracy and the influence of the number of loading cycles is small.

4.3 Applied Loads

The target load was calculated by multiplying 0.55 MPa by the cross-sectional area. Since, however, it was thought that 0.55 MPa might cause the specimen to be damaged during high-temperature testing, the effects of reducing the load to 1/2, 1/4 and 1/8 were investigated.

Left figure of Figure 8 shows the results obtained by applying the full load and 1/2 of the load to dense-graded As mixture specimens at 40°C. Right figure of Figure 7 shows the results obtained by applying 1/2, 1/4 and 1/8 of 0.55 MPa at 60°C. The test showed that in a linear viscoelastic range in which the specimen is not be damaged regardless of applied loads or longitudinal strains, there are no significant differences in stiffness values obtained.

From above, it was decided to follow the procedures described below in this study. As a first step, a load of 0.55 MPa is applied at each temperature, and if the specimen is damaged at an early stage, the load is reduced to 1/2. If damage still occurs, the load is further reduced to 1/4. If necessary, the load is further reduced to the smallest allowable load of 0.138 MPa (1/8).

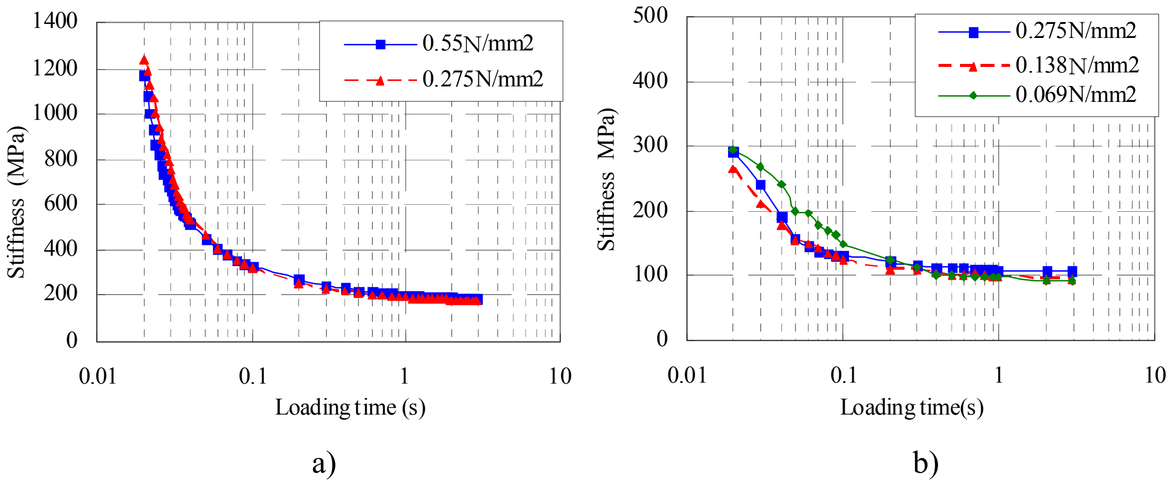


Figure 8: Effect of different loading on stiffness (a) 40°C, b) 60°C).

4.4 Summary on Test Method

In view of the results related to test methods mentioned above and the fact that in real pavements, strain does not remain constant while vehicle loads act on the asphalt mixture, asphalt mixtures should be subjected creep tests conducted by the load control method instead of the strain control method.

5 MEASUREMENT RESULTS FOR DIFFERENT MIXTURES

5.1 Stiffness Measurement Results.

Creep tests were conducted at 5°C, 20°C, 40°C and 60°C by using four types of mixtures, namely, dense-graded As mixtures, porous As mixtures, SMA mixtures and mastic As mixtures. Since the diameter-to-height ratio of 1:1 is appropriate for test specimens, a core barrel capable of taking cores 50 mm in diameter was made to prepare d50 mm–h50 mm specimens. The number of specimens is three to nine for each type of mixture. Figure 9 shows the stiffnesses of different mixtures at 60°C, 40°C, 20°C and 5°C, respectively. The stiffness values are the averages of measured values.

At temperatures from 5°C to 40°C, SMA mixtures and dense-graded As mixtures showed similar stiffnesses at each temperature. A likely reason for this is that the asphalt used in these mixtures was Type II polymer modified asphalt. At 60°C, the stiffness of the SMA mixtures became small. The asphalt content is thought to be a factor in this case. The stiffness of the mastic As mixtures (StAs.20/40+T.L.A.) was higher than those of the dense-graded As mixtures and SMA mixtures, and the stiffness of the porous As mixtures containing Type H polymer modified asphalt was low. The reason why the stiffness of the porous As mixtures was small is thought to be due considerably to not only the influence of asphalt but also structural factors.

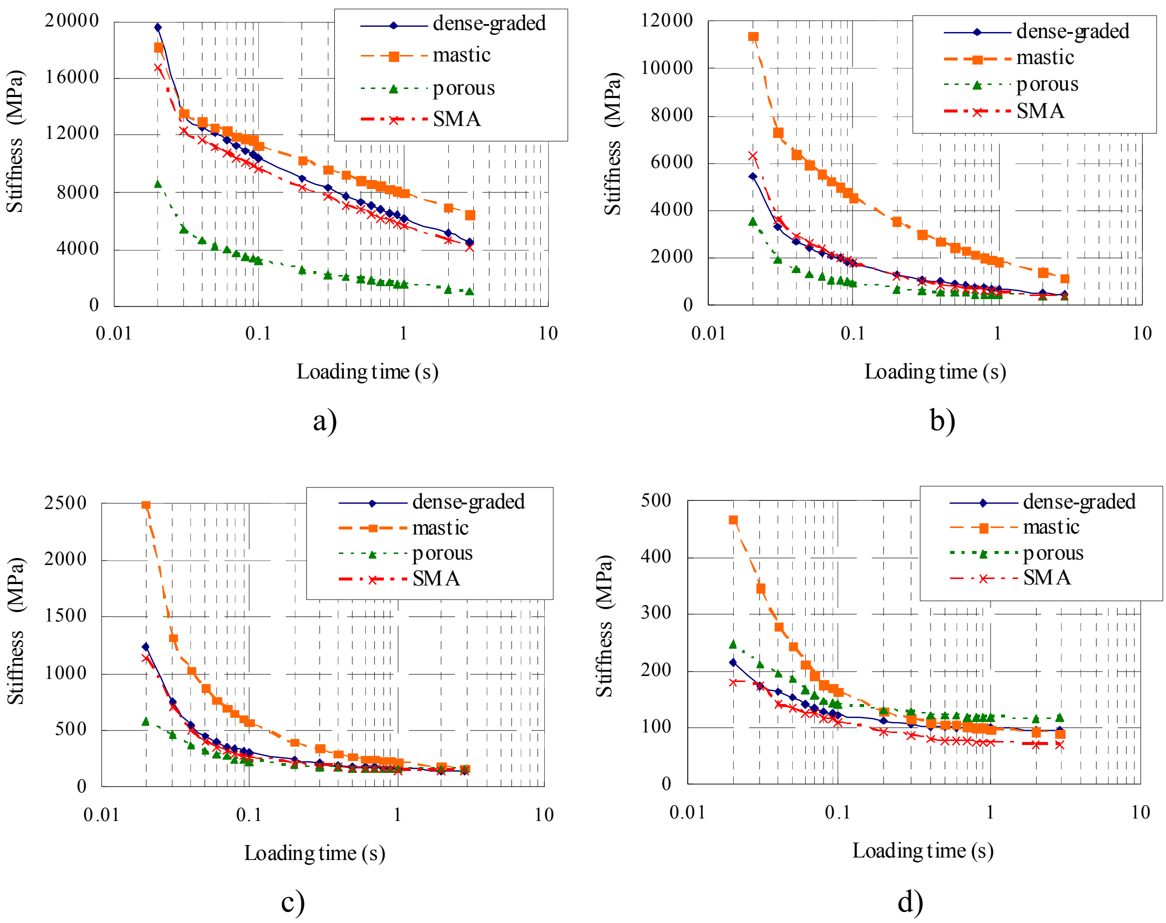
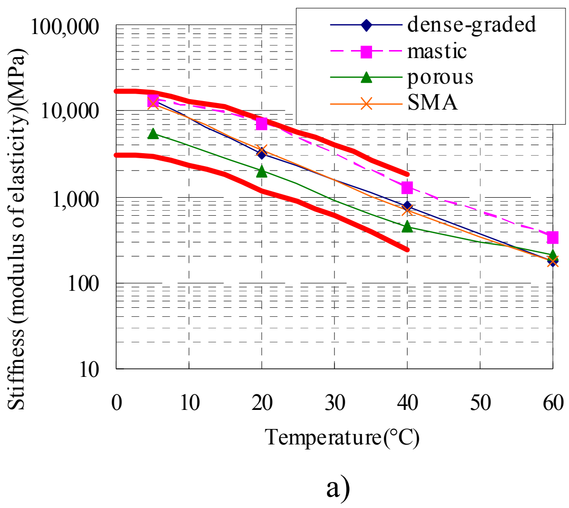


Figure 9: Relationship between the stiffness of each mixture and time
(a) 5°C, b) 20°C, c) 40°C, d) 60°C).

Pavement Design Handbook (Hoso Sekkei Binran, Japan Road Association) shows examples of modulus of elasticity of asphalt mixtures (Japan Road Association, 2007). These modulus of elasticity were obtained from various studies and research including FWD (falling weight deflectometer) and resilient modulus tests. The loading time in the FWD test is 0.03 seconds (Abe and Tadaka, 2007). If the resilient modulus test is conducted at 10 Hz, the maximum load is likely to be reached in about 0.05 seconds because haversine wave loading is conducted. Comparison was made, therefore, between the 0.03-second stiffness and the 0.05-second stiffness obtained from the tests. As shown in Figure 10, almost all values at temperatures from 5°C to 40°C fall within the modulus of elasticity range shown in Pavement Design Handbook. The values for the dense-graded As mixtures and the SMA mixtures are located more or less in the middle, the values for the mastic As mixtures near the upper limit, and the values for the porous As mixtures near the lower limit. This shows fair agreement with the previously reported findings.

5.2 Poisson's Ratio Measurement Results

Figure 11 shows the results of Poisson's ratio measurement. Poisson's ratio after the elapse of 2.5 seconds in the fourth loading cycle. Poisson's ratios vary considerably, probably because,



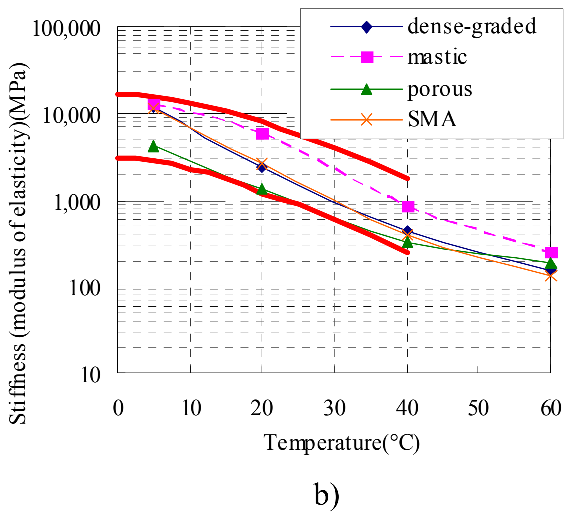


Figure 10: Stiffness and the modulus of elasticity as Pavement Design Handbook (a)0.03-second, b)0.05-second).

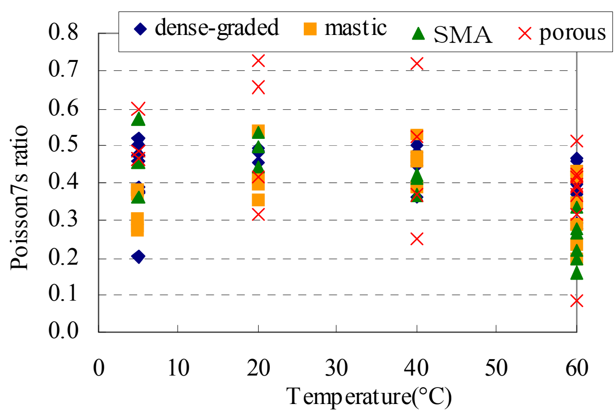


Figure 11: Poisson ratio of each mixtures on different temperature.

in part, of strain gauge measurement. The reason why values for the porous As mixtures varied widely is thought to be due largely to structural factors as in the case of stiffness.

6 CONCLUSION

In order to determine the modulus of elasticity of asphalt mixtures for use in structural analyses of bridges including pavement structures, a study on the measurement of the stiffness of asphalt mixtures was conducted, taking high temperatures into consideration. The study has shown that stiffness can be measured by conducting an unconfined compression test using specimens with a diameter-to-height ratio of 1:1 in the linear viscoelastic range. Also, by measuring the stiffness of different types of asphalt mixtures, the relationship between the loading rate and stiffness has been determined.

The authors intend to further enhance the accuracy of measurement of the stiffness and Poisson's ratio of mixtures. Because the longest loading time that can be covered in the test is 0.02 seconds (which translates to a vehicle speed of about 35 km/h), the authors also intend to develop an analysis model for estimating stiffness at a loading rate corresponding to the actual vehicle speed.

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