Dynamic Modulus of Asphalt Concrete Mixtures Using Small-Scale Specimens

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Paper prepared for presentation

at the Testing and Modelling of Road and Embankment Materials Session

of the 2019 TAC-ITS Canada Joint Conference

Halifax, NS

Acknowledgements

The authors of this paper would like to acknowledge Manitoba Infrastructure and City of Winnipeg for supporting this research

Abstract

The dynamic modulus of asphalt concrete (AC) mix is a primary engineering property that relates to the performance of AC pavements. This parameter is commonly measured using a cylindrical specimen having a 150mm height and a 100mm diameter (full-size specimens). This geometry is easy to obtain when a specimen is extracted from a laboratory-prepared gyratory sample, however, a gyratory sample does not represent an as-built asphalt pavement. Testing of the in-place AC pavement for the dynamic modulus, using the full-size cylinder specimens, is not possible because the required specimen height is greater than the typical AC lift thickness. In this study, the feasibility of using small-scale cylindrical specimens to measure the dynamic modulus of AC mixtures was investigated. Three different loose mixtures were obtained from the field. Specimens were extracted from laboratory prepared gyratory samples. Dynamic modulus test was conducted on two small-scale specimens having diameters of 38mm and 50mm, and a height of 110mm, in addition to the test on full-size specimens. A uniaxial hydraulic loading frame was used to test the specimens at various temperatures and frequencies. The test results from the small-scale specimens were found to be very similar to that of full-size specimens at low and intermediate temperatures. However, small specimens showed greater dynamic modulus values at a high temperature of 38°C in comparison to full-size specimens. The coefficient of variation for 38mm-diameter specimens was found to be higher than two other geometries.

Keywords: Dynamic modulus, small-scale specimens, asphalt concrete mixtures, horizontal coring

Introduction

The dynamic modulus of an AC mixture is a viscoelastic temperature-and time-dependent property (dynamic response) under an applied load. The dynamic response of AC mixtures under traffic load is an important property in the design of flexible pavements and evaluation of flexible pavement performance using mechanistic methods. According to the Mechanistic-Empirical Pavement Design Guide (MEPDG), the dynamic modulus ($|E^*|$) is the critical design parameter to quantify the performance of AC mixtures and pavement structures. Advanced testing, simulating the applied traffic loads and environmental exposure, are required to determine the dynamic modulus, i.e., to characterize and investigate the viscoelastic behaviour of AC mixtures for use in the MEPDG's AASHTOWare Pavement ME design software (M-E design method).

Depending on the significance of an asphalt paving project and availability of testing equipment or data, the M-E design method uses $|E^*|$through three hierarchical levels of inputs (Level 1 with the highest level of reliability and Level 3 with the lowest level of reliability) to determine the structural capacity of AC layers. In the absence of required properties for input Level 1, the next levels' inputs would be considered for the design or analysis. Table 1 shows the three M-E design hierarchical levels based on the required tests and methodologies for obtaining the AC $|E^*|$master curve in the design of new construction and rehabilitation of existing AC pavement projects.

Table 1 Required methodologies for constructing the AC $|E^*|$ master curve in three M-E hierarchical levels

M-E Design Level	$\|E^*\|$ of a new AC mixture	$\|E^*\|$ of as-built AC layer (Rehabilitation)
Level 1	Laboratory measurement of $\|E^*\|$	Non-Destructive Test (NDT) such as Falling Weight Deflectometer (FWD) + Prediction models
Level 2	Prediction models + laboratory measurement of mix and binder properties	% Alligator cracking or other material properties such as resilient modulus (M_R) + Prediction models
Level 3	Prediction models + default (or typical local) mix and binder properties	Visual pavement rating + Prediction models

The laboratory procedure requires a cylindrical specimen with a height of 150mm and a diameter of 100mm, referred to as full-size (full-scale or standard) specimen, to be extracted from a gyratory compacted asphalt sample. This geometry is required to reduce the effect of particle size and ensure a uniform distribution binder and aggregates. However, this geometry cannot generally be obtained from an individual as-built AC layer due to the insufficient AC lift thickness that varies from 25mm to 75mm (typically 35mm to 60mm). In the M-E design, the dynamic modulus prediction models for Levels 2 and 3 inputs were generated based on data obtained from $|E^*|$ testing results of several AC mixtures. The models do not require laboratory tests, but aggregate gradation, mix volumetric properties, and binder stiffness indicators including viscosity and shear modulus. Additionally, for the rehabilitation of existing

AC pavements, the $|E^*|$ master curve should be developed for both new AC overlay and the as-built AC layers. For predicting the dynamic modulus of as-built AC layers, the M-E design method has introduced an "undamaged" and a "damaged" modulus that use prediction models, and laboratory/field experiments to predict the in-service $|E^*|$ master curve by accounting for present damage in the existing AC layers before applying the overlay. There are advantages and limitations associated with both of these two methods for measuring the $|E^*|$ as listed in Table 2.

As indicated in Table 2, the $|E^*|$ of in-service AC layers and field cores cannot be obtained by the current laboratory testing procedure, and the prediction models are not able to predict the as-built $|E^*|$of AC layers accurately and without additional measurements or experiments such as FWD. As a result, there is a great need for an alternative testing methodology to measure the dynamic modulus of as-built AC layers to minimize error and with lesser possible effort.

A promising approach has been investigated in a few recent studies to extract small-scale specimens from field cores, and run the standard dynamic modulus test on them to obtain the as-built $|E^*|$ of AC layers at the standard test frequencies and temperatures. This study has explored the feasibility of this new methodology of utilizing the small-scale specimens to determine the dynamic modulus of asphalt mixes that are in use in Manitoba.

Table 2 Summary of the main advantages and disadvantages/limitations of major dynamic modulus measurement methods

Measurement method	Advantages	Limitations
Laboratory Method	• Non-destructive test • Accurate measurement of $\|E^*\|$	• Long and laborious sample preparation • Lengthy test time (3 days at least) • Cannot readily test field cores
Prediction Models	• No special testing is required • Predicting the $\|E^*\|$ for in-service AC mixtures	• Inaccurate prediction of $\|E^*\|$ for both new and in-service AC layers • Considerable variability at high temperatures • Extra experiments are required for predicting in-service $\|E^*\|$

Review of the current progress on using small-scale specimens

A few research studies have been conducted to evaluate the feasibility of using small-scale specimens to measure the $|E^*|$ of AC mixtures. The small specimen extraction can be performed in either horizontal or vertical directions (Figure 1). Although the vertical coring procedure can increase the laboratory testing efficiency by producing more number of specimens per gyratory compacted sample, the horizontal coring would provide a better comparison with field samples since small specimens could only be extracted from the field cores in the horizontal direction due to the thickness limitation. Table 3 shows the summary of small specimen sizes that were investigated in different studies together with their method of compaction and core extraction.

The $|E^*|$ of small-scale specimens at high temperatures of 37.8 ºC and 54.4 ºC showed a greater coefficient of variation (COV) (>10% to 20% between specimens as compared to that of two other temperatures of 4.4 ºC and 21.1 ºC (5% to 8%) [1]. No significant statistical difference was observed between the $|E^*|$ values of full-size and small-scale specimens at low and intermediate temperatures, while higher $|E^*|$ and lower phase angle values were reported for small-scale specimens at lower reduced frequencies [2].

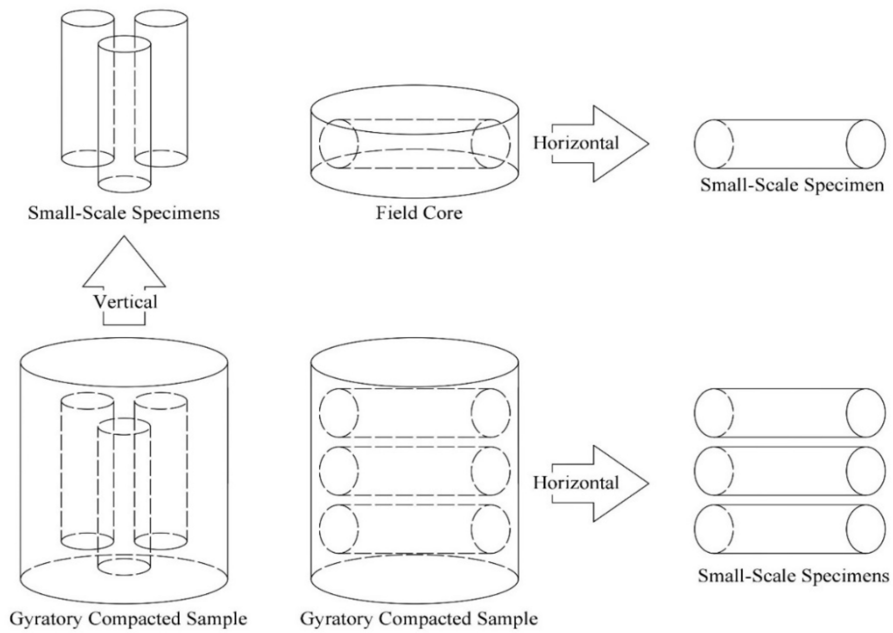


Figure 1 Coring direction of small specimens

Table 3 Summary of the small specimen sizes used for $|E^*|$ testing

Study	Size(s) - Diameter X Height	Source	Compaction	Coring direction
Kutay et al. (2009) [3]	38.1mm X 100mm 71.4mm X 150mm	Laboratory prepared	Gyratory compaction	Vertical
Mbarki et al. (2012) [4]	38.1mm X 100mm	Field cores	-	Horizontal
Li et al. (2013) [5]	38mm X 110mm 38mm X 140mm	Laboratory prepared	Gyratory compaction	Vertical
	38mm X 110mm	Field cores	-	Horizontal
Bowers et al. (2014) [1]	38mm X 135mm 38mm X 110mm 50mm X 135mm 50mm X 110mm	Laboratory prepared	Gyratory compaction	Horizontal
Park et al. (2014) [6]	38mm X 100mm	Field cores	-	Vertical
Lee et al. (2017) [2]	38mm X 110mm	Laboratory prepared	Gyratory compaction	Vertical/Horizontal

Results of the dynamic modulus test showed a statistically insignificant effect of anisotropy, suggesting that the aggregate orientation is not a significant factor for measuring the mechanical response of AC mixes using small-scale specimens [6]. However, the repeatability of dynamic modulus test using the small-scale specimens was reported to be dependent on the Nominal Maximum Aggregate Size (NMAS) with an NMAS of 25mm producing high COV values between specimens of 38 X 110mm size [7].

Castorena et al. (2017) proposed the first draft testing protocol for the dynamic modulus test using the small-scale specimens with Asphalt Mixture Performance Tester (AMPT) [7]. Table 4 summarizes the main differences between the proposed dynamic modulus testing protocol and the current AASHTO dynamic modulus testing standards (AASHTO T378 and AASHTO T342).

Table 4 Summary of the main differences between the small and full-size specimens dynamic modulus testing protocols

Parameters	Proposed testing standard [7]	AASHTO T378 [8]	AASHTO T 342 [9]
Sample size	38mm X 110mm (Small)	100mm X 150mm (Full)	100mm X 150mm (Full)
LDVT gauge length	70 ± 1mm	70 ± 1mm	101.6 ± 1mm
Peak-to-peak strain	50 to 75 µstrain	50 to 125 µstrain	50 to 150 µstrain

Objectives of this study

The goal of this study is to correlate the dynamic modulus results of small-scale to that of full-size specimens. The main objectives are as follows:

- Compare the $|E^*|$values and master curves resulted from small-scale and full-size specimens.
- Evaluate the suitability of small-scale specimens to determine the dynamic modulus of in-situ AC mixes and identify challenges.
- Prepare a testing protocol for determining the $|E^*|$ of as-built AC layers using small-scale specimens.

Materials and Methodology

In this research, in order to investigate the feasibility of using small-scale specimens for measuring the dynamic modulus of AC mixtures, three loose AC mixtures were collected from the construction projects in Manitoba to produce gyratory compacted samples for laboratory testing. Cylindrical specimens with full diameter of 100mm and small diameters of 38 and 50mm were extracted from the compacted samples for dynamic modulus testing. Table 5 shows the RAP and RAS contents, and the virgin binder Performance Grade (PG) of the collected mixes. The aggregate gradations of studied mixtures are shown in Table 6.

Table 5 RAP and RAS contents and the virgin binder Performance Grade (PG) of the collected mixes

Mix ID	RAS %	RAP %	Virgin Asphalt Binder PG
Mix 1	3%	10%	PG 58-28
Mix 2	0%	20%	PG 58-34
Mix 3	0%	0%	PG 58-34

Table 6 Studied mixtures aggregate gradation

Mix ID	Aggregate Gradation (Passing %)								
	19 mm	16 mm	12.5 mm	9.5 mm	4.75 mm	2.0 mm	425 µm	180 µm	75 µm
Mix 1	100	100	92.4	82.9	66.1	53.2	20.4	7.7	4.8
Mix 2	100.0	97.0	89.6	76.1	61.9	49.0	26.6	7.1	3.1
Mix 3	100.0	99.2	91.9	81.6	62.3	50.5	22.9	5.9	4.3

In order to produce the small-scale specimens for dynamic modulus test, the gyratory samples were initially compacted to the height of 170mm to extract two small horizontal cores from each compacted sample with the target air void content of 4±0.5%. However, it was found that the small specimens extracted from the bottom part of gyratory samples are over compacted as they resulted in approximately 1% lower air void content as compared to the small specimens extracted from the top part.

In order to overcome this problem, the gyratory samples were compacted to the height of 140mm for the production of small-scale specimens. Two small cores were extracted, as close together as possible, from the center of each gyratory sample in order to minimize the variation of air voids between the specimens. Figure 2 shows the air void contents of a few trial small specimens extracted by coring from 140mm and 170mm height gyratory samples. The difference in air void contents between the upper and lower small specimens have been reduced favourably by decreasing the height of gyratory compacted samples from 170mm to 140mm. The gyratory samples were compacted to 80, 70, and 100 gyrations to produce full-size specimens, and 60, 50, and 80 gyrations to produce small-scale specimens for Mix 1, Mix 2, and Mix 3, respectively.

Figure 3 shows the vertical and horizontal coring of full-size and small-scale specimens. After extraction of cores, both ends of full-size and small-scale cores were sawed equally to produce 150mm and 110mm tall specimens, respectively.

Figure 4 shows the final full-size and small-scale dynamic modulus testing specimens produced from gyratory samples. For each mixture, two full-size specimens (100mm-diameter), four 50mm-diameter small-scale specimens, and four 38mm-diameter small-scale specimens were prepared for the dynamic modulus testing program. Following the AASHTO T342 method, the dynamic modulus test was performed on each specimen under six frequencies of 0.1, 0.5, 1, 5, 10, and 25 Hz, and at four temperatures of -10, 4.4, 21.1, and 37.8 °C.

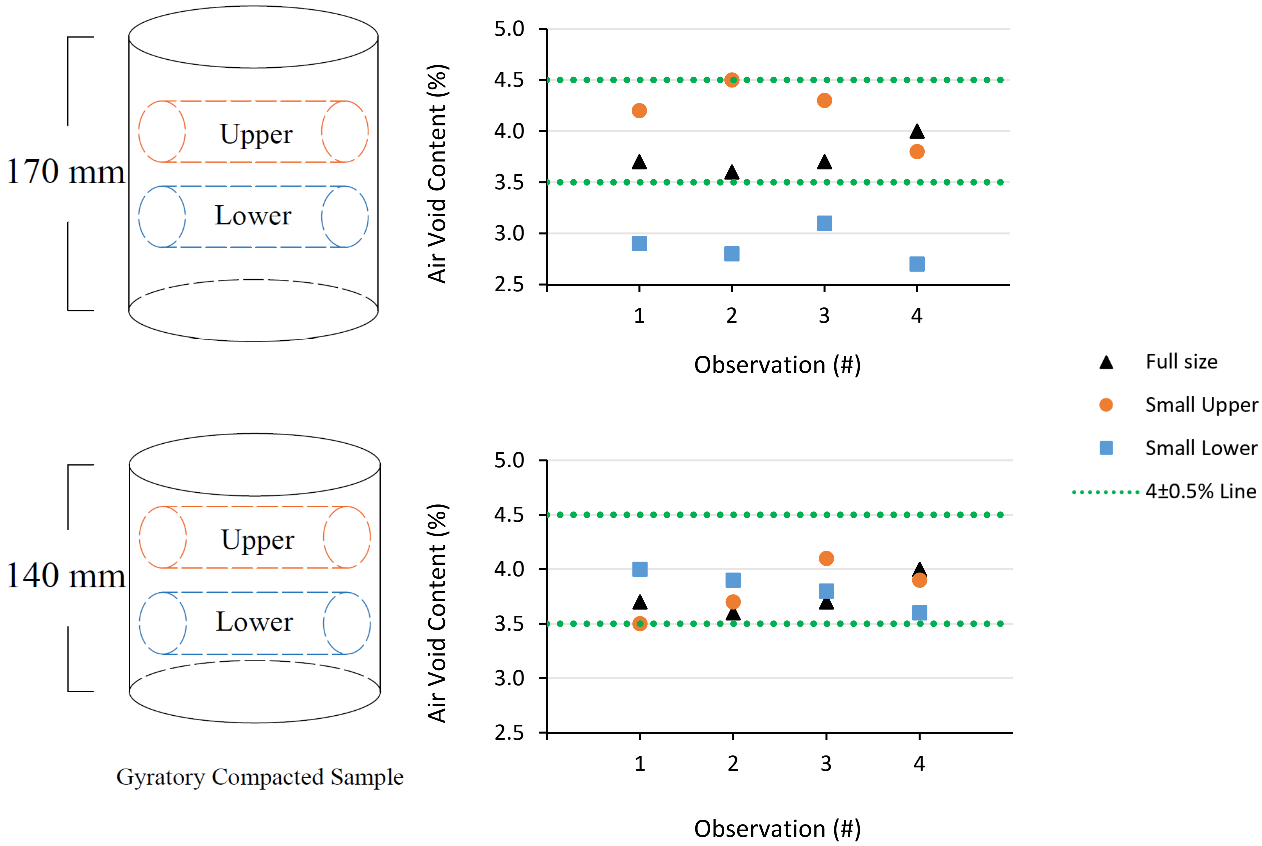


Figure 2 Variation of air void contents between small specimens extracted from the top and bottom parts of gyratory samples

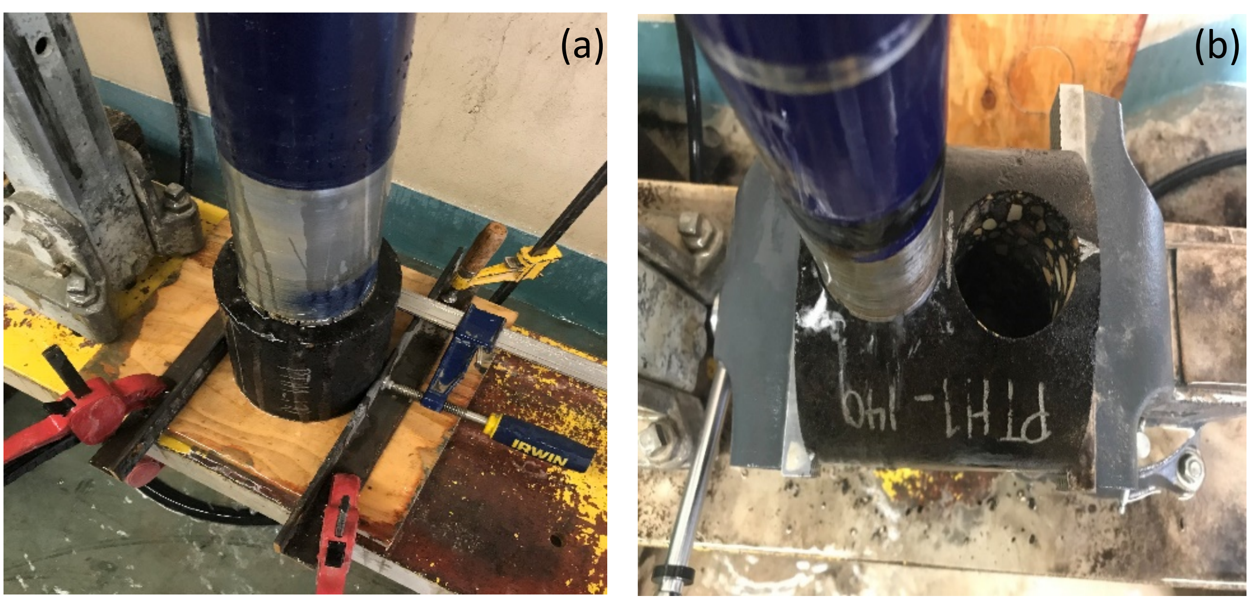


Figure 3 (a) Vertical, and (b)horizontal extraction of full-size and small-scale specimens from gyratory samples, respectively

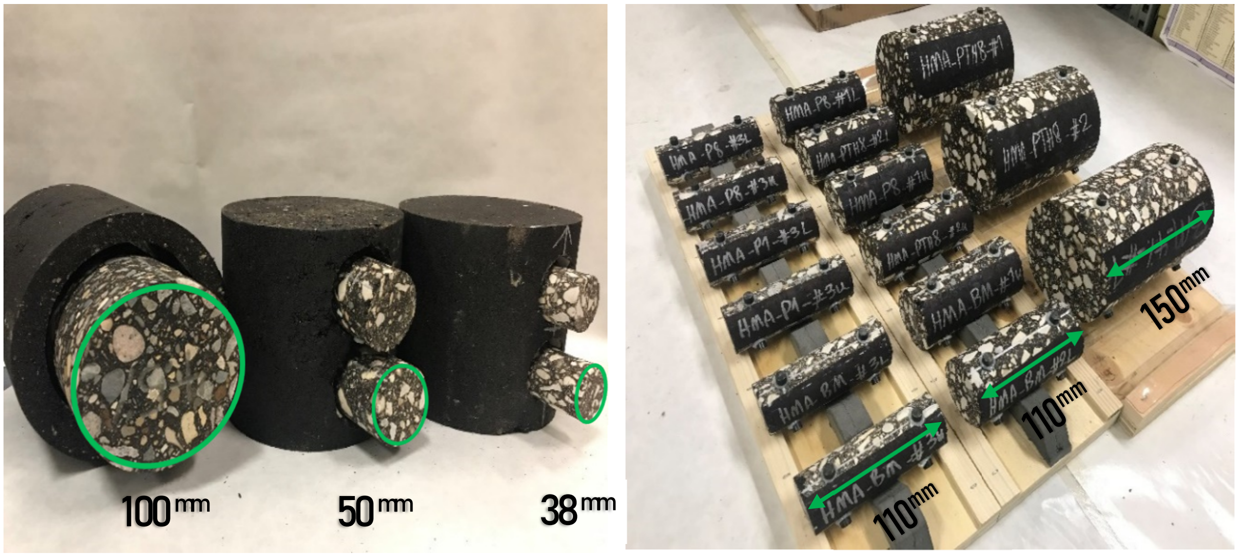


Figure 4 Full-size and small specimens extracted from gyratory samples

To conduct tests for the dynamic modulus of AC mixture using small-scale specimens, smaller size loading platens were designed that can adequately transfer the applied load to the top and bottom of specimens. Three small studs were welded to each loading platen in order to prevent from lateral movement of small specimens under high loads at low temperatures.

The gauge lengths of 70mm and 100mm were used to measure the axial deformations for small and full-size specimens, respectively, and by using three vertical extensometers mounted at 120 degrees apart. Figure 5 shows the loading platens and the dynamic modulus test arrangement for small-scale specimens.

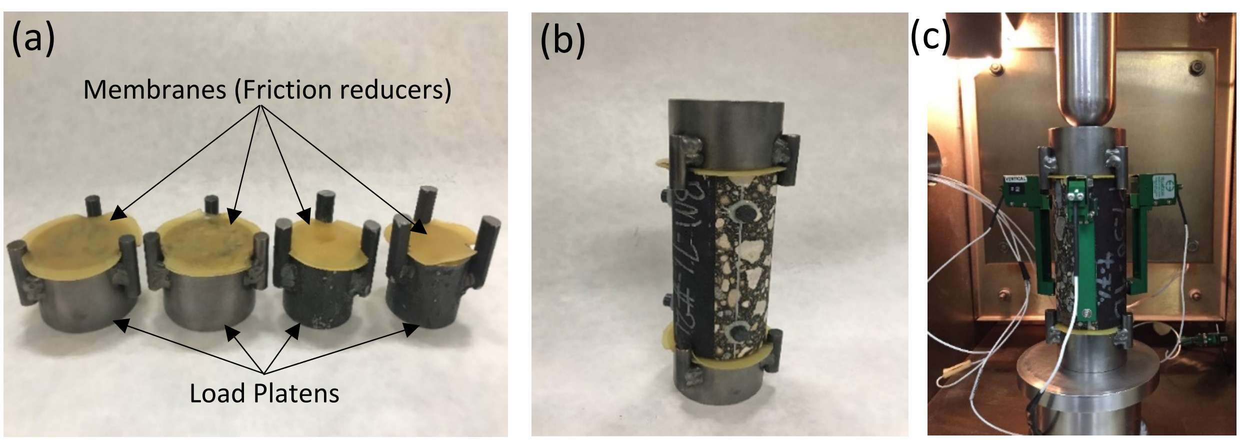


Figure 5 (a) Load platens and friction reducers for two small-scale geometries, (b) placement of a specimen between load platens, and (c) dynamic modulus test arrangement for a small-scale specimen

Test Results and Discussion

The dynamic modulus test was performed on small and full-size specimens at six different frequencies and four different temperatures. Figures 6, 7, and 8 show the comparisons of the average $|E^*|$values between two small-scale and the full-size specimens for the three AC mixtures used in this study.

Tables 7, 8 and 9 present the ratios of dynamic modulus values at all studied frequencies and temperatures with respect to the size of specimens for the studied three mixtures. In these Tables, the dynamic modulus ratios within the ±10% of equality line, between the ±10% and ±20%, and beyond the ±20% are not highlighted, hatched, and highlighted, respectively. Following AASHTO PP62 [10], and using the second-polynomial method, the reduced frequencies and shift factors were calculated to construct dynamic modulus master curves for each specimen geometry. Figures 9, 10, and 11 present the master curves of evaluated geometries for studied mixtures.

According to the result of the Mix 1 dynamic modulus test as shown in Figure 6 and Table 7, the small specimens generally resulted in higher $|E^*|$ values than those of the full-size. At lower temperatures of -10 °C and 4.4 °C, the $|E^*|$ ratios of full-size to small specimens were in the range of 0.90-1.01 which are close to equality. At the intermediate temperature of 21.1°C, the $|E^*|$ values of full and small sizes were in good agreement at frequencies higher than 1 Hz (ratios of 0.9-1.01), whereas at the lower frequencies the ratios were between 0.84-0.88 which is in the acceptable range. The dynamic modulus values at 37.8°C were more variable compared to that at other temperatures. The ratios of full-size to small-scale specimens varied from 0.72 at the low frequency of 0.1 Hz to 1.05 at the high frequency of 25 Hz. Similar ratios resulted from both small geometries, which suggests no apparent difference between the performances of two geometries to measure the $|E^*|$.

According to Figure 9, a good agreement was evident between the master curves of full-size and small-scale specimens at the low and intermediate temperatures. However, starting from the medium to lower reduced frequencies, the 50mm-diameter specimens resulted in noticeably higher dynamic modulus values. This will presumably produce a better rut resistant behaviour compared to the full-size, which may not be practically correct. The master curve obtained from 38mm-diameter specimens were closer to that of full-size geometry as compared to that of the 50mm-diameter specimens.

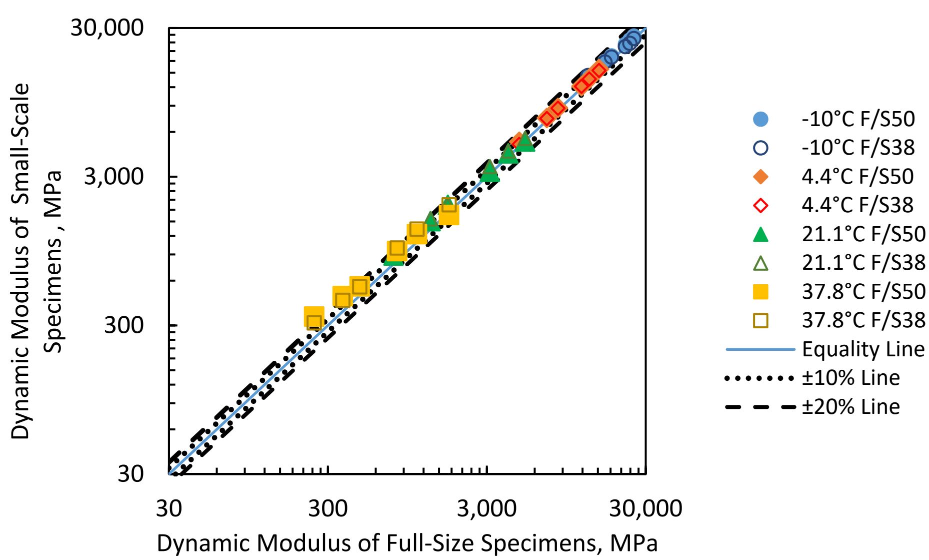


Figure 6 Comparison of average dynamic modulus values of the full-size and small-scale specimens (F=Full-size, S50= 50mm-diameter, and S38= 38mm-diameter)-Mix 1

Table 7 The ratios between the average dynamic modulus values of the full-size and small-scale specimens-Mix 1

Full-Size/50mm-Diameter Specimens Dynamic Modulus Ratios - Mix 1						
Temp./Freq.	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
-10°C	0. 91	0.93	0.94	0.96	0.96	0.95
4.4°C	0.93	0.96	0.97	0.97	0.97	0.96
21.1°C	0.88	0.88	0.88	0.97	0.95	1.01
37.8°C	0.72	0.79	0.87	0.87	0.89	1.05
Full-Size/38mm-Diameter Specimens Dynamic Modulus Ratios - Mix 1						
Temp./Freq.	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
-10°C	0.90	0.94	0.96	0.9 9	1.01	0.99
4.4°C	0.97	0.97	0.97	0.97	0.97	0.98
21.1°C	0.84	0.85	0.88	0.9	0.92	0.96
37.8°C	0.79	0.84	0.87	0.82	0.82	0.90

Less than 10% difference
10% to 20% difference
More than 20% difference

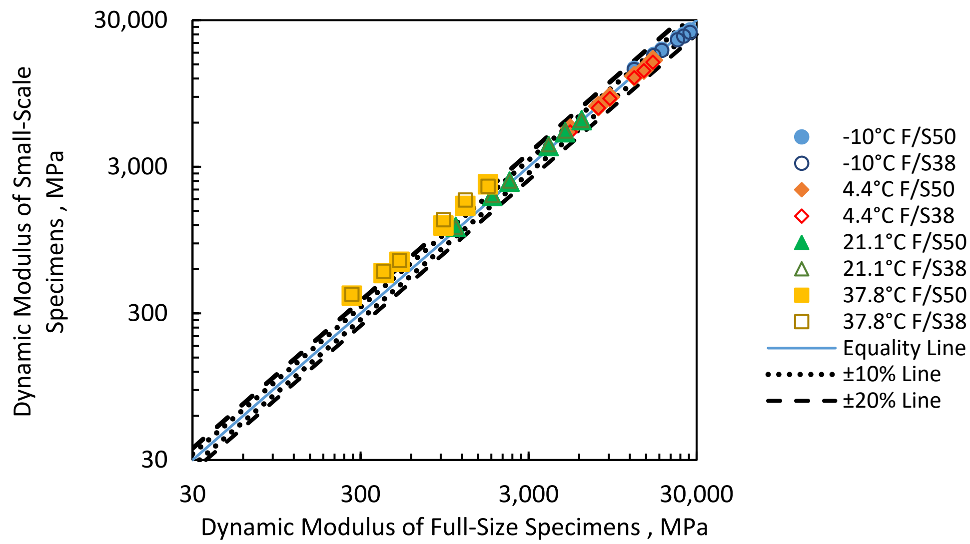


Figure 7 Comparison of average dynamic modulus values of the full-size and small-scale specimens (F=Full-size, S50= 50mm-diameter, and S38= 38mm-diameter)-Mix 2

Table 8 The ratios between the average dynamic modulus values of the full-size and small-scale specimens-Mix 2

Full-Size/50mm-Diameter Specimens Dynamic Modulus Ratios – Mix 2						
Temp./Freq.	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
-10°C	0.90	0.95	0.98	1.02	1.04	1.06
4.4°C	0.97	1.00	1.02	1.03	1.05	1.03
21.1°C	0.95	0.96	0.97	0.95	0.96	0.99
37.8°C	0.67	0.73	0.76	0.78	0.78	0.76
Full-Size/38mm-Diameter Specimens Dynamic Modulus Ratios – Mix 2						
Temp./Freq.	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
-10°C	0.92	0.97	1.00	1.05	1.08	1.10
4.4°C	1.02	1.03	1.04	1.05	1.07	1.06
21.1°C	0.95	0.95	0.96	0.93	0.94	1.00
37.8°C	0.66	0.71	0.74	0.72	0.71	0.78

Less than 10% difference
10% to 20% difference
More than 20% difference

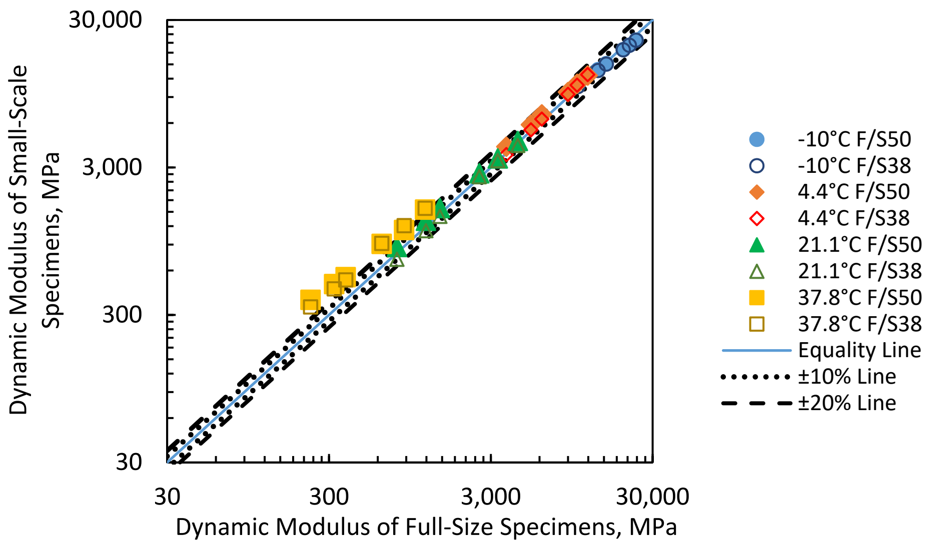


Figure 8 Comparison of average dynamic modulus values of the full-size and small-scale specimens (F=Full-size, S50= 50mm-diameter, and S38= 38mm-diameter)-Mix 3

Table 9 The ratios between the average dynamic modulus values of the full-size and small-scale specimens-Mix 3

Full-Size/50mm-Diameter Specimens Dynamic Modulus Ratios – Mix 3						
Temp./Freq.	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
-10°C	0.93	1.00	1.02	1.05	1.07	1.08
4.4°C	0.90	0.91	0.90	0.92	0.92	0.95
21.1°C	0.91	0.91	0.91	0.93	0.96	0.97
37.8°C	0.61	0.67	0.70	0.70	0.77	0.76
Full-Size/38mm-Diameter Specimens Dynamic Modulus Ratios – Mix 3						
Temp./Freq.	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
-10°C	0.98	1.01	1.03	1.05	1.07	1.08
4.4°C	1.02	0.99	0.97	0.96	0.95	0.93
21.1°C	1.10	1.07	1.04	0.98	0.99	1.04
37.8°C	0.68	0.72	0.74	0.69	0.72	0.74

Less than 10% difference
10% to 20% difference
More than 20% difference

According to Tables 8 and 9 (and Figures 7 and 8), the $|E^*|$ratios of full-size to small sizes at various temperatures and frequencies were found to be similar to each other for both Mix 2 and Mix 3. At the low and intermediate temperatures of -10 °C, 4.4 °C, and 21.1 °C, the ratios were within the range of ±10% of the equality line. These suggest a comparable performance from both 50mm-diameter and 38mm-diameter small specimens with the full-size geometry to predict thermal and fatigue cracking distresses. At the high temperature of 37.8°C, small specimens could not achieve $|E^*|$values similar to those of full-size samples by resulting in ratios ranging from 0.61 to 0.78 resembling the trend for Mix 1. Figure 10 shows a perfect agreement between the master curves of full-size and both of the small geometries of Mix 2 at all temperatures, except negligible differences at low reduced frequencies. According to the Figure 11, the difference in master curves between the full-size and 50mm-diameter geometry at low reduced frequencies was found to be considerable for Mix 3, while the 38mm-diameter specimens resulted in a master curve that is more comparable to the full-size specimens.

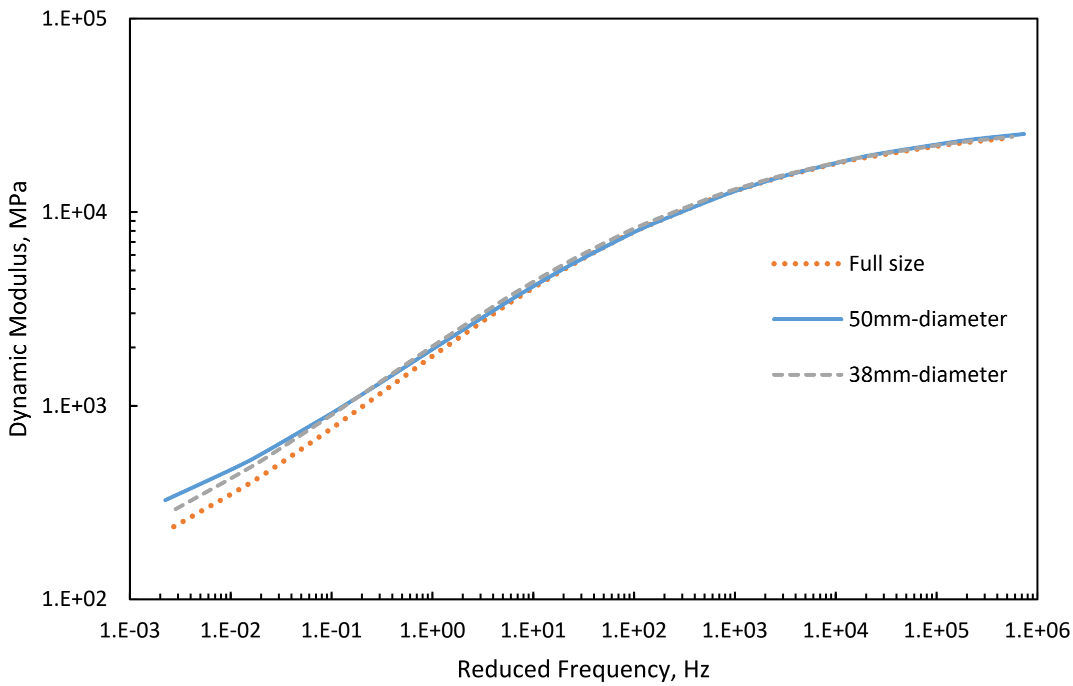


Figure 9 Dynamic modulus master curves constructed using small and full-size specimens-Mix 1

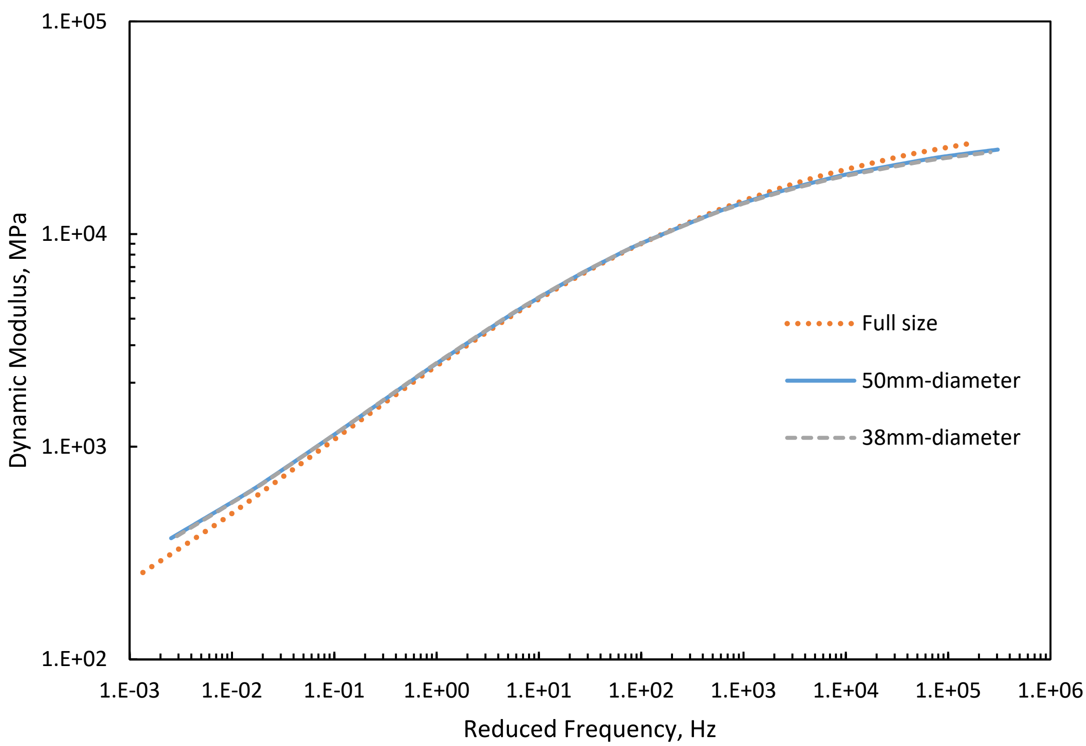


Figure 10 Dynamic modulus master curves constructed using small and full-size specimens-Mix 2

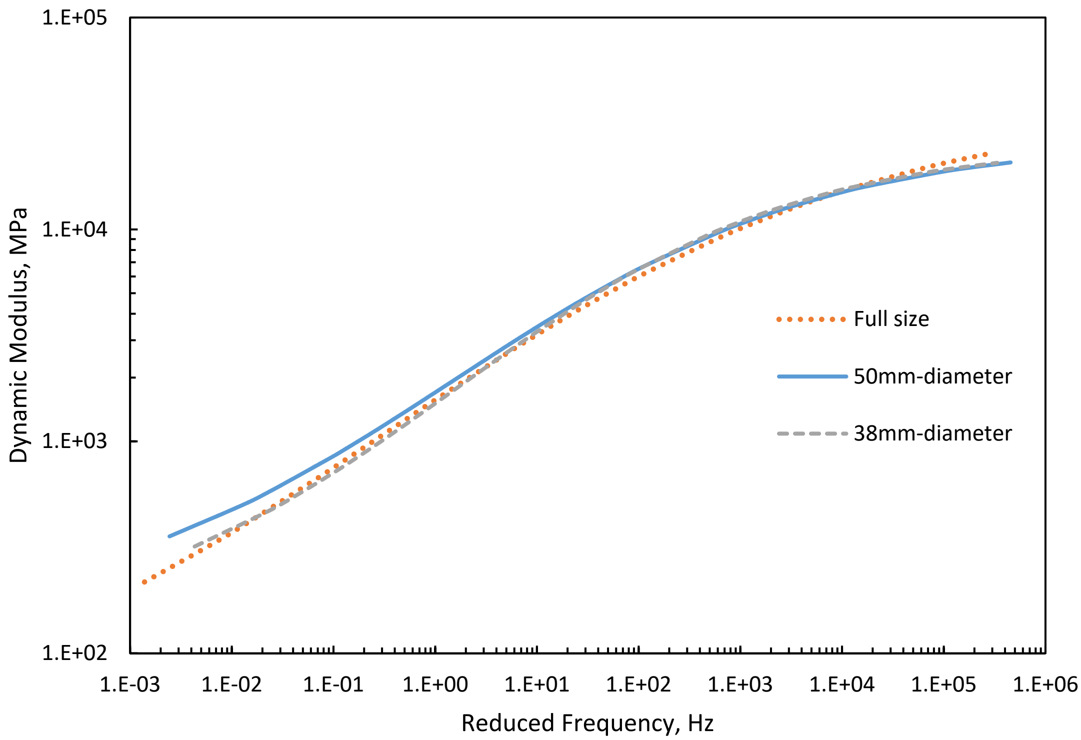
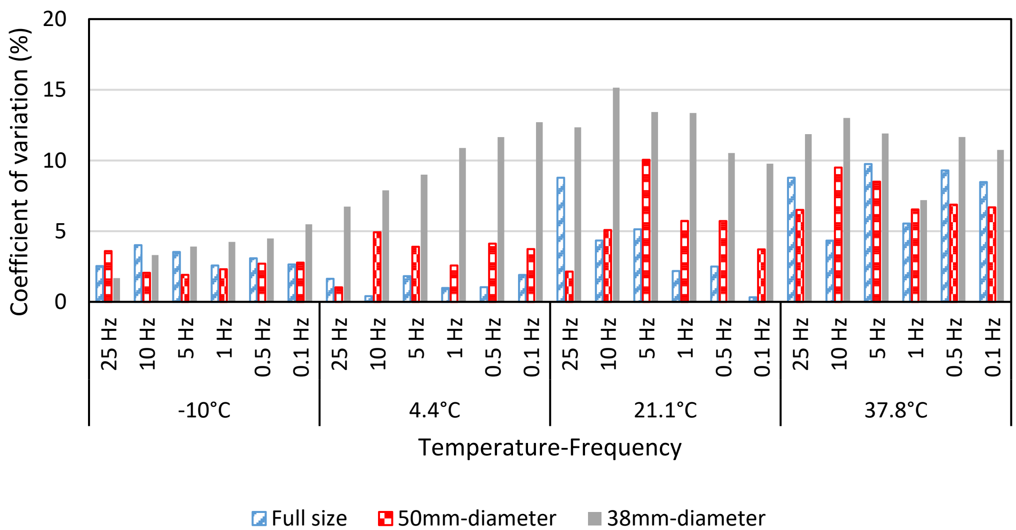


Figure 11 Dynamic modulus master curves constructed using small and full-size specimens-Mix 3

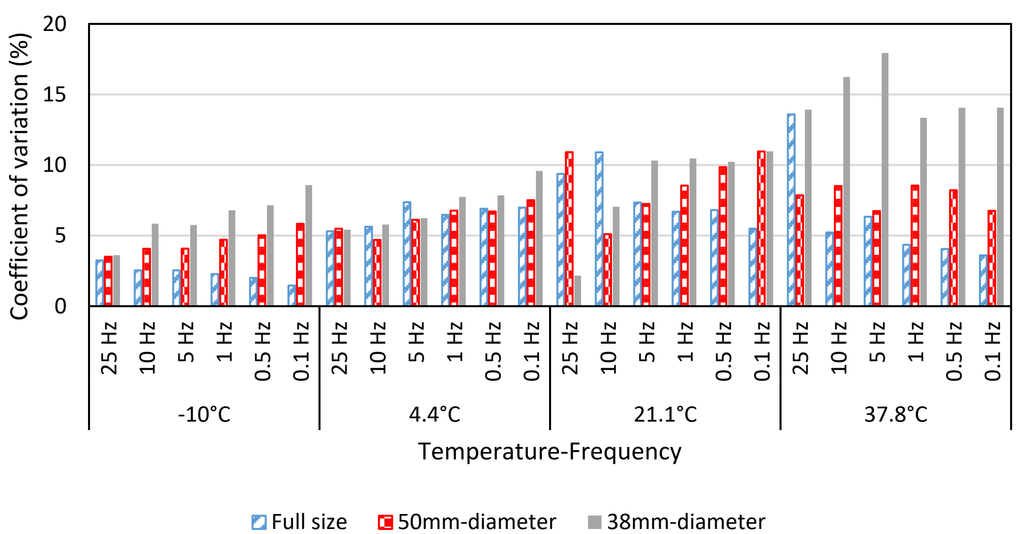
Previous studies [1,2] reported similar findings, where the small specimens resulted in higher $|E^*|$values as compared to the full-size geometry at higher temperatures. However, this trend cannot be generalized as the opposite findings were also reported for 38mm-diameters small specimens [5]. In this study, the performance of 38mm-diameter specimens was found to be slightly closer to full-size geometry than that of 50mm-diameter cores at the high temperature of 37.8°C. However, it was more difficult to keep the cumulative peak-to-peak strains between the required 50-150 microstrain range for the 38mm-diameter specimens at this temperature, while maintaining the acceptable efficiency of loading machine during applying small loads. Additionally, minimizing the eccentricity of loading was found to get more challenging by reducing the diameter of specimens from 100 to 38mm.

The anisotropy of asphalt mixtures is mainly divided into two categories, including the inherent and induced anisotropies. The induced anisotropy is based on the material response under applied stress, and the inherent component is representative of the internal structure, including aggregate orientation and air void distribution with respect to the compaction direction. In this study, the anisotropy effect was certainly found to be negligible at three temperatures of -10 °C, 4.4 °C, 21.1 °C because full-size and small-scale specimens resulted in a similar dynamic response; although, they were extracted in different orientations (coring directions) with respect to the direction of compaction. The resulted dissimilar$|E^*|$values between small and full-size geometries at the temperature of 37.8°C cannot necessarily be attributed to the effect of anisotropy as the previous studies showed reasonable sample-to-sample variation based on the dynamic modulus test results obtained from different coring directions and specimen geometries [6,11].

The COV values of full-size and small specimens were calculated at each frequency and temperature (Figure 12). The COV values are mostly higher for small specimens and especially for 38mm-diameter cores as compared to that of full-size samples. The majority of the COV values for full-size and 50mm-diameter geometries are less than 10%, which suggests an acceptable performance of 50mm-diameter small specimens and a low variability between the specimens of this size [7]. However, higher but acceptable COV values were found for 38mm-diameter specimens as compared to two other geometries, which suggests higher dispersion around the average $|E^*|$ and less repeatability. This can be explained by the smaller specimen size (lower diameter) and the higher proportion of cross-sectional area that aggregate particles may occupy in these specimens. As can be seen, no specific pattern was observed for COV values with respect to the testing frequency, while they generally grow by increasing the testing temperature of small specimens. The reason can be explained by softening of the binder at higher temperatures, and eventually, higher variability between the specimens [7].



(a)



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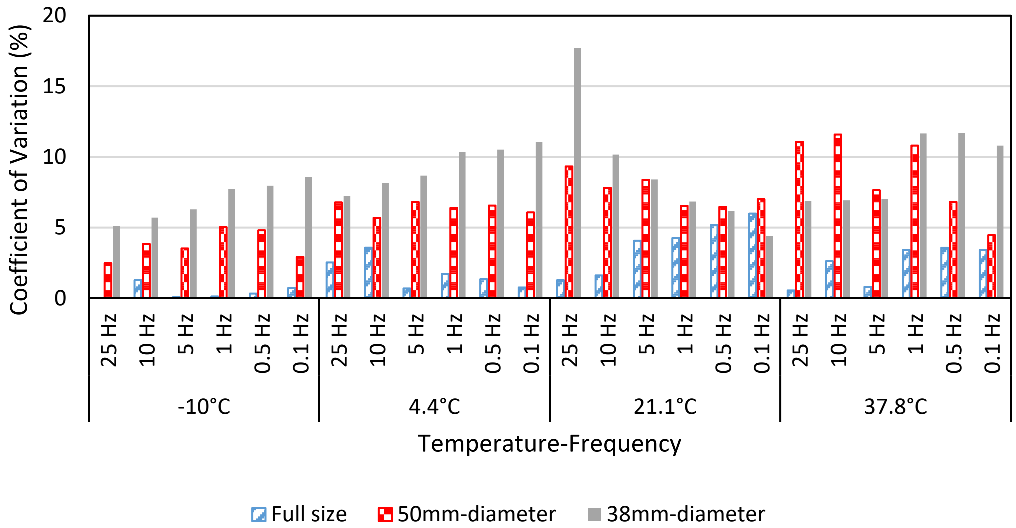

(c)

Figure 12 Coefficient of variation of small and full-size specimens: (a) Mix 1, (b) Mix 2, and (c) Mix 3

Although the COV for 38mm-diameter specimens were higher than 50mm-diameter or full-size specimens, both of the 50mm-diameter and 38mm-diameter small-scale geometries showed similar performances in terms of measuring the dynamic modulus of AC mixtures regardless of the NMAS. In this study, the NMAS was 12.5mm for Mix 1 and 16mm for Mixes 2 and 3. This finding is comparable with a similar previous study that investigated the same small geometries and mixtures with NMAS values up to 25mm [11]. They concluded that for mixtures with NMAS equal to 19mm and higher, it is beneficial to use specimens with larger diameters to reduce the between-specimens COV and obtain $|E^*|$ values closer to those of full-size samples [12].

In this research, the greater COV values and the difference between the dynamic modulus of small-scale specimens and full-size samples at higher temperatures can be attributed to the less elastic behaviour of AC mixtures and more dependency of the test on the size and inherent structure of test specimens. In order to enable the application of small-scale specimens to measure the dynamic modulus of as-built AC layers, the $|E^*|$ data should be calibrated at higher temperatures.

Conclusions

This study evaluated the feasibility of using small-scale specimens instead of full-size (standard) specimens to measure the dynamic modulus of AC mixtures. The dynamic modulus of as-built AC layers cannot be measured according to the current laboratory standard dimensional requirements for specimens due to the low thickness of asphalt lifts. Measuring the dynamic modulus of AC mixtures using the small specimens extracted horizontally from field cores of thin asphalt lifts could enable the highway agencies to measure the stiffness of in-service AC layers for rehabilitation purposes, forensic investigations, and design for a new construction. In this preliminary phase of a larger study, two small cylindrical geometries of 50mm x 110mm and 38mm x 110mm were horizontally extracted from gyratory compacted samples to be compared with the full-size cylindrical dynamic modulus specimens of 100mm x 150mm. This research concluded the main findings as follows:

- The gyratory samples with the height of 140mm were found to be efficient for producing two horizontally-cored small specimens with low between-specimens air void content variations.
- The small-scale specimens were able to measure the dynamic modulus values that are within the range of 10% difference with those of full-size specimens at the standard test temperatures of -10 °C, 4.4 °C, and 21.1 °C. However, they resulted in considerably higher $|E^*|$ values than the full-size specimens at the high temperature of 37.8°C.
- In comparison with 50mm-diameter specimens, the 38-diameter specimens resulted in master curves that are slightly in a better agreement with the master curves of full-size specimens. However, the 38mm-diameter geometry generally suffered from the highest COV values at all temperatures, which suggested the lower repeatability of dynamic modulus test using smaller geometries.
- The effect of NMAS up to 16mm was found to be insignificant in the performance of small-scale specimens. However, more research is required to validate the findings.
- The small-scale specimens are capable of measuring the dynamic modulus of as-built AC layers using the current laboratory procedure and a few testing modifications. However, the $|E^*|$ values at higher temperatures will require calibration.

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