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THE EFFECTS OF AGGREGATE SIZE ON SHEAR DYNAMIC MODULUS FROM TORSION BAR

An Honors Thesis submitted in partial fulfillment of the requirements for Honors Studies
in Civil Engineering

By
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Project Summary

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Title of Project: The Effects of Aggregate Size on Shear Dynamic Modulus from Torsion Bar

Summary:

PavementME Design is based on mechanistic-empirical principles, which take the properties of layer materials into account in predicting pavement responses and performance. Of these principles, dynamic modulus is one of the most important. Dynamic modulus measures strain in response to the applied stress, which mimics loads from traffic and the corresponding deformation of the asphalt pavement. The traditional test for dynamic modulus in the uniaxial configuration cannot be performed on field cores due to lift thickness. Owing to that, the Indirect Tension and torsion bar configuration were developed. This research will focus on the torsion bar, which requires specimens that are 10x12x50mm per ASTM D7552-09. The smaller size of torsion bar specimens is convenient for forensic evaluation. However, due to the small size of specimens, there are challenges with obtaining a sample that is representative of the global properties of the test material when the nominal maximum aggregate size, NMAS, is 12.5mm or greater.

The goal of this project is to determine if using aggregates of larger NMAS in asphalt concrete mixtures influences the shear dynamic modulus. Mixtures with a NMAS of 9.5mm and 25mm were tested. The results from the Torsion Bar test were used to generate master curves for each mix design using the time-temperature superposition technique. The results were analyzed by comparing test results from torsion bar test to other specimens of different NMAS and asphalt binders. Based on the analysis, the conclusion is the shear dynamic modulus from the torsion bar configuration is affected by the nominal maximum aggregate size used in asphalt concrete mixtures, `and the binder does not influence the results. RVE for torsion bar specimens falls between 9.5mm and 25mm, or even smaller.

The Effects of Aggregate Size on Shear Dynamic Modulus from Torsion Bar

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Mentor: Dr. Andrew Braham

Introduction

Dynamic modulus measures strain in response to the applied stress, which mimics loads from traffic and the corresponding deformation of the asphalt pavement (Yang *et al.,* 2015). However, asphalt concrete is a viscoelastic material, so the rate of strain application, frequency, and testing temperature influence the modulus. Dynamic modulus is a very important input for PavementME Design, and can be used to predict pavement performance such as the potential of asphalt concrete to rut and to crack (Yang *et al.,* 2015). The traditional test for dynamic modulus in the uniaxial configuration according to AASHTO T342 cannot be performed on field cores due to lift thickness requirement of 150mm. Owing to that, the Indirect Tension dynamic modulus (IDT |E*|) and torsion bar shear modulus (torsion bar |G*|) were developed as alternative test methods. The Indirect Tension test is performed on specimens of 150mm diameter and a thickness of 50mm, while the torsion bar requires specimens that are 10x12x50mm per ASTM D7552-09, as shown in Figure 1.

Figure 1: Dynamic modulus configurations: indirect tension (center), torsion bar (right) (Yang *et al.,* 2015).

The smaller size of torsion bar specimens is advantageous for forensic evaluation of in service pavements, especially when material quantities are limited (Yang *et al.,* 2015). However, due to the small size of torsion bar specimens, there are challenges with obtaining a representative volume element when large aggregates are used. This research seeks to determine if larger aggregates influence the tests results from the torsion bar configuration.

Background and Motivation

The torsion bar configuration is extremely helpful for forensic evaluation of in-service pavements, especially when material quantities are limited (Yang et al., 2015). This is because of the reduced size of test specimens. However, when the nominal maximum aggregate size used in the asphalt concrete mixture is 12.5mm or greater, one aggregate can span the size of the specimen. In such instances, there could be problems with obtaining a sample that is representative of the global properties of the test material, as shown in Figure 2. In the Figure 2, A1 is not representative of the overall properties and behavior of the asphalt concrete, and may influence results if used for testing. A test specimen is expected to satisfy established theoretical requirements, and is called a representative volume element (RVE) (Romero and Masad, 2001).

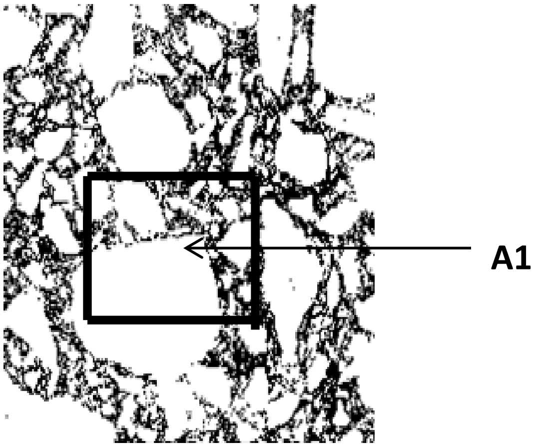

Figure 2: Representative Volume Element of Asphalt Concrete (Adapted from Velasquez, 2009).

The shear dynamic modulus is determined by using specimens of torsion rectangular geometry on a dynamic shear rheometer (DSR) (ASTM D7552). A shear stress is applied to the test specimen. According to the ASTM standards, ten frequencies and four temperatures are tested.

Determining if aggregate size affects the test results of the torsion bar configuration can lead to a better understanding of the limitations of the test method for determining shear modulus. The torsion bar configuration is advantageous because a significantly smaller number of cores are needed to perform tests, which is important because when cores are obtained from in service pavements, the pavements are weakened. In addition, collecting material from in service pavements is very time and cost intensive, including mobilizing work crews, closing roads, and reducing traffic flow.

Objective

The objective of this research is to determine if using aggregates of larger nominal maximum aggregate sizes in asphalt concrete mixtures influences the shear dynamic modulus obtained from the torsion bar configuration by potentially violating the RVE. This was achieved by comparing test results from torsion bar specimens with different nominal maximum aggregate size and different asphalt binders.

Materials and Methods

Four asphalt concrete mixtures were used for this research. Two mixtures had a PG 64-22 asphalt binder with a nominal maximum aggregate size of 9.5mm and 25mm. The other two mixtures had the same nominal maximum aggregate size mentioned above, but a PG 76-22 asphalt binder. A total of 12 samples were tested, three replicates from each of the four mix designs, and are summarized in Table 1.

Table 1 – Experimental Matrix

	9.5mm	**25mm**
PG 64-22	3 replicates	3 replicates
PG 76-22	3 replicates	3 replicates

Test specimens had an average size of 12.5x6.5x50mm. Test specimens were obtained from samples of a superpave mix design, and the binder content of the mix design are shown in Table

2. The gyratory compacted lab samples achieved 7% air voids having a 150mm diameter. 12.5mm thick slices were cut from the samples, from which test specimens of 50mm height were obtained.

Table 2 – Asphalt Binder Content

NMAS	Binder Content*
9.5mm	5.70%
25mm	4.02%

(*binder content applies for both PG 64-22 and PG76-22)

The tests were performed in accordance to ASTM D7552-09: Standard Test for determining the complex shear modulus (G*) of Bituminous mixtures using Dynamic Shear Rheometer, along with some modifications. A TA Instruments Discovery Hybrid Rheometer (DHR) in oscillatory mode was used to run the test and collect data. Specimens were tested at fifteen frequencies, (0.2, 0.3, 0.4, 0.6, 1.0, 1.6, 2.5, 4.0, 6.3, 10.0, 15.8, 25.1, 39.8, 63.1, and 100 rad/s) at eight temperatures (-10˚C, -0 ˚C, 20˚C, 30˚C, 40˚C, 50˚C and 60˚C). Strain levels of 0.01%, 0.05%, 0.1% and 0.2% were used. A normal force within 2N +-0.5 N was applied on the test specimens. For testing, one of the fixtures of the DHR was rotated with respect to the other “at a pre-selected % strain and a range of frequencies at the selected temperatures” (ASTM D7552-09). The test specimen was maintained within +- 0.1˚C of the testing temperature by encompassing the upper and lower fixtures in a thermally controlled chamber (ASTM D7552-09).

Discussion of Results

After obtaining data from the DHR, the data was exported to excel and used to make a master curve for each mix design using shift factors. Figures 3-6 are the master curves for each mix design. The techniques used in developing these master curves is time-temperature superposition. Initially, the graph for each temperature is stacked, but this technique is used to overlap the temperatures by shifting the curves. To do this, the curve corresponding to 30 ˚C was left in position, while the other curves were shifted using Equation 1 in 10.1.1 of AASHTO R62-13. The curves corresponding to lower temperatures are on top because asphalt is stiffer at low temperatures. Different fitting parameters and coefficients were used to minimize the error associated with shifting.

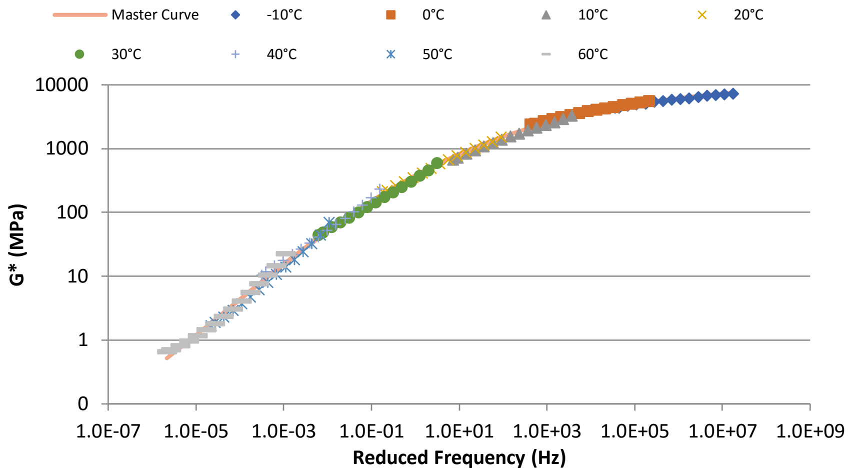

Figure 3: Master Curve of PG 64-22 with NMAS of 9.5mm

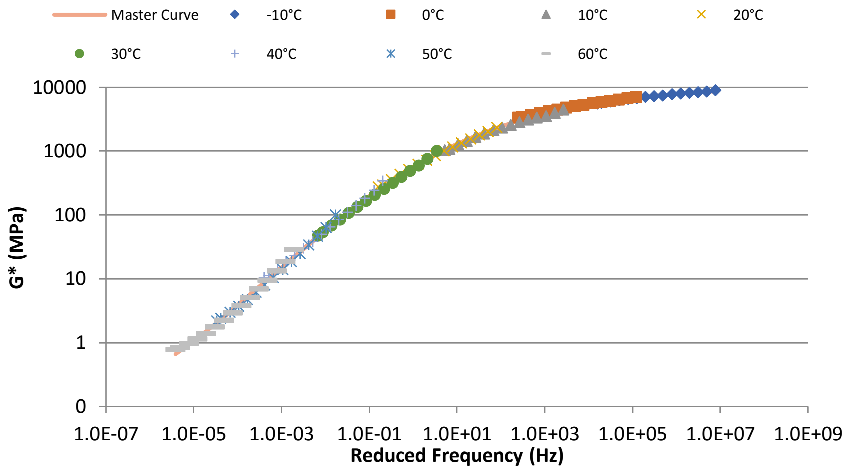

Figure 4: Master Curve of PG 64-22 with NMAS of 25mm

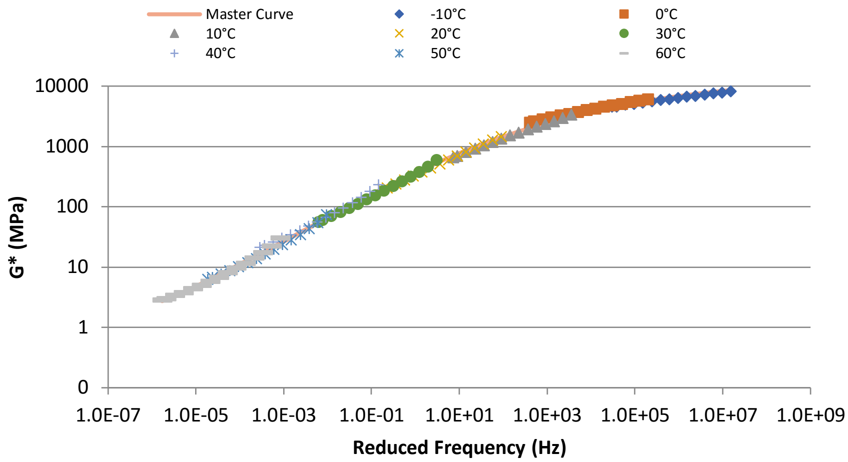

Figure 5: Master Curve of PG 76-22 with NMAS of 9.5mm

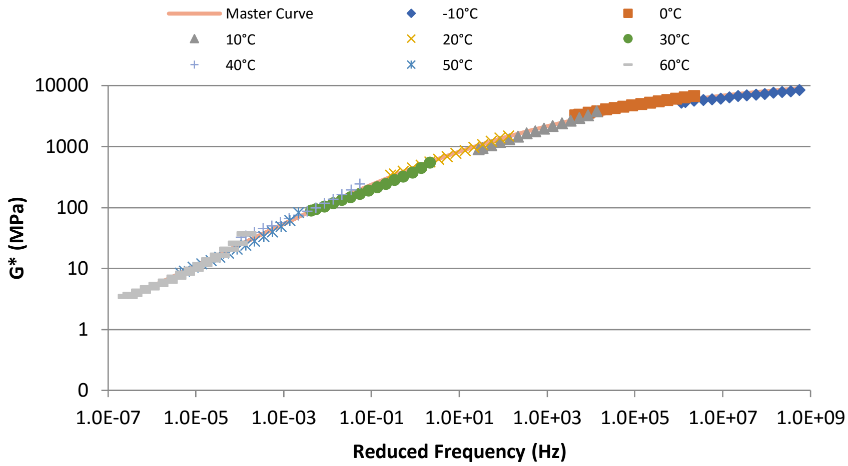

Figure 6: Master Curve of PG 76-22 with NMAS of 25mm

In general, the data shifted nicely and the fitted curve lays on top of the raw data. 0-degree curve shift factor is off a bit for PG 76-22 mixtures (the raw data is no quite on top of the fitted curve). However, to minimize variables associated with data analysis, additional analysis of this data was not pursued.

To determine if the aggregate size had an effect of the shear dynamic modulus values, a graph comparing the values obtained from specimens with a NMAS size of 25mm versus 9.5mm was plotted, as shown in Figure 7. For both binders, it was observed that the mix designs with 25mm NMAS were stiffer, as both lines plotted above the line of equality. The mixture is aggregate dominating since the mix designs with 25mm NMAS are stiffer.

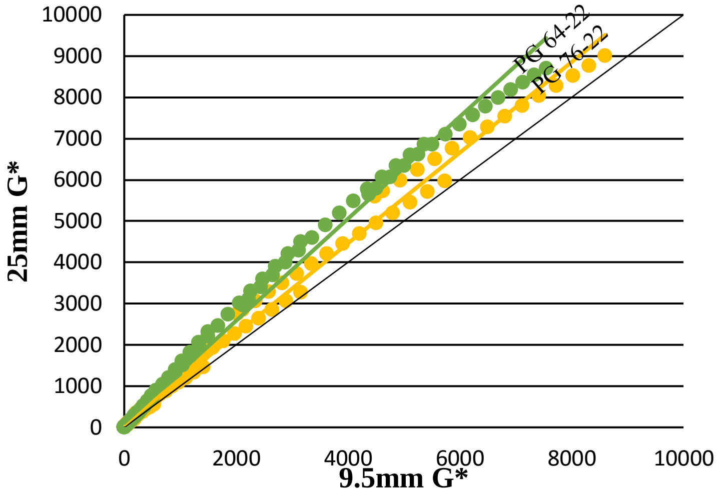

Figure 7: Aggregate Comparison of Shear Dynamic Modulus Values

In order to account for the variation between the data of the three replicates per mix design, the G* values within ± 1 standard deviation were also plotted, as shown in Figure 8. The values for PG 64-22 had a large standard deviation, whereas PG76-22 had almost no spread. Both graphs still plotted well above the line of equality. Therefore, using a NMAS of 25mm produced larger G* values, perhaps violating RVE. Based on the data, RVE may be either between these two NMAS or even smaller than 9.5mm.

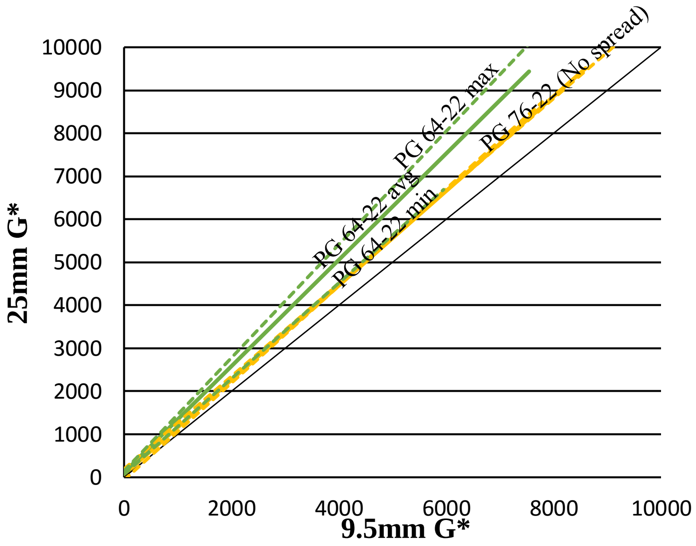

Figure 8: Aggregate Comparison of Data Within ± 1 Standard Deviation

Furthermore, to determine if the binder influences the shear dynamic modulus, the values from the mix designs of PG 64-22 versus PG 76-22 were plotted, as shown in Figure 9. For the mix design with a NMAS of 9.5mm, PG 64-22 binder was stiffer, while with the 25mm NMAS, PG 76-22 was stiffer. It is not possible to draw any conclusions because there is no general trend since the conclusion varies with the NMAS. As such, the data was analyzed within ± 1 standard deviation, as shown in Figure 10. From the graph, all values for mix design with 9.5mm NMAS are included within the cone of the values for 25mm. Therefore, neither binder is significantly stiffer than the other, and the binder does not influence G* values like aggregate size does.

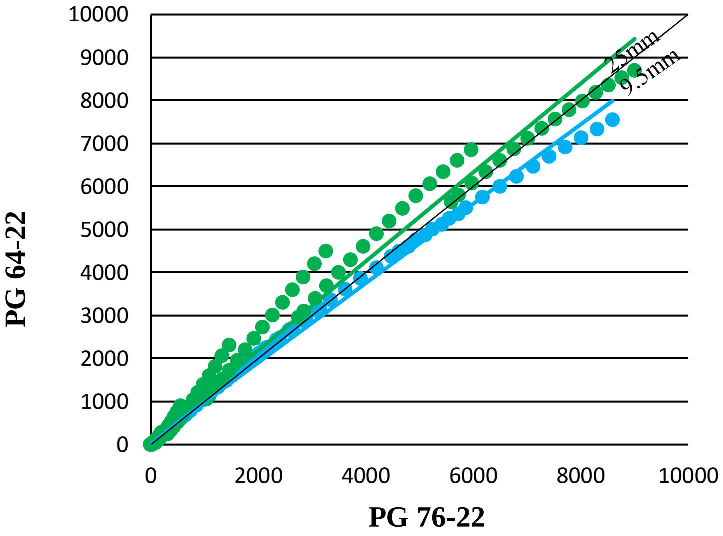

Figure 9: Binder Comparison of Shear Dynamic Modulus Values

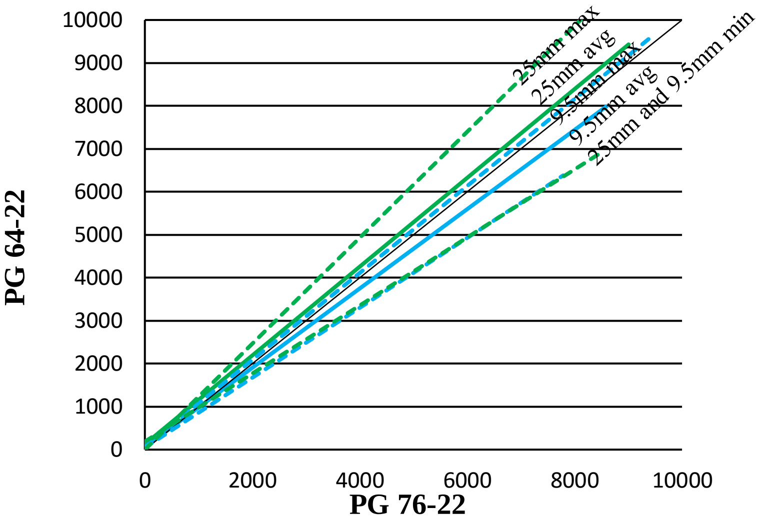

Figure 10: Binder Comparison of Data Within ± 1 Standard Deviation

It was expected that regardless of aggregate size, the mix design with PG 76-22 would have higher G* values because of polymer modification of the binder. However, based on the data, this is not so. There is a possibility that the aggregate is dominating both tests, and RVE is being violated. These mixtures should be run on larger samples (uniaxial dynamic modulus and/or IDT dynamic modulus) to determine if these trends continue with larger sample sizes.

Over the course of running the tests, the DHR was calibrated about 3 different times, thus, possibly introducing some error into the data. The tests were also very spread out, as half the tests were done before the summer and the other half after. In addition, the samples were cut from the middle of SGC samples, so there is a possibility of air voids being too low. These factors may have introduced some error in the data.

Conclusion

While the torsion bar test for shear dynamic modulus is helpful for forensic evaluation of in service pavements, due to the small size of the specimen, Representative Volume Element (RVE) is violated when running the test on mix designs with a NMAS greater than 9.5mm. In this project, specimens of two different binders with a NMAS of 9.5mm and 25mm were tested to determine if the aggregate size and binder affect the G* values.

Based on the data analysis, the mixtures with a NMAS of 25mm are stiffer than 9.5mm, and RVE may be between 9.5mm and 25mm or even smaller. While the size of the aggregate affects the shear dynamic modulus values obtained, the binder type did not. In the binder analysis, neither binder was necessarily stiffer than the other, as no general trends were observed. However, the results from the torsion bar test need to be compared to the IDT and/or uniaxial configuration test results to see the trends in the aggregate and binder analysis before a strong conclusion about the effects of aggregate size on shear dynamic modulus from torsion bar can be made.

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