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Laboratory Characterization of Compaction and Damping Properties of Stone Matrix Asphalt

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Abstract: Stone Matrix Asphalt (SMA) is referred to gap graded Hot Mix Asphalt (HMA) that is designed to maximize rutting resistance and durability by using a structural basis of stone-on-stone contact. SMA mixture designs with gap graded aggregate gradations and polymer modified binders often have special field compaction requirements. To better understand differences in compaction behavior between SMA and dense graded HMA mixtures, laboratory tests were conducted on field collected loose samples at typical field densities and loading conditions. The goal of the first phase of this study was to investigate the growth of density and the mobilized shear stress in the specimen as a function of applied normal stress, gyration numbers, and the compactive effort. In the second phase, damping ratio tests were performed on the compacted samples at close to field compaction temperatures by applying dynamic loading at various frequencies and different confining pressures to determine the mixture damping properties. The test results indicated that SMA mixtures with the gap graded aggregate structure achieved higher densities in comparison to HMA mixtures. The frequency of dynamic loading had a significant effect on the damping ratios of the SMA mixtures and the effect of confining pressure, linked to proper lift thicknesses in the field, was found to be dependent on compaction pressure levels as well as mixture properties.

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***Key words**: Damping ratio, Dense graded HMA mixtures, Gap graded gradation, Gyratory compaction, SMA mixtures.*

Introduction

Depending on the availability of high quality aggregate sources and locally available asphalt binder, different types of mixtures can be developed to satisfy pavement performance demands [1]. Stone Matrix Asphalt (SMA) is gap graded Hot Mix Asphalt (HMA) that is designed to maximize deformation (rutting) resistance and durability by using a structural basis of stone-on-stone contact. Because the aggregates are all in contact, rut resistance relies on aggregate properties rather than asphalt binder properties. Since aggregates do not deform as much as asphalt binder under load, this stone-on-stone contact greatly reduces rutting. These mixtures have been successfully used in Europe for over 20 years to provide better rutting performance as well as resisting studded tire wear in cold regions [2].

In the United States (US), SMA has become a common mixture in wearing surface course applications. Brown et al. [3] inspected and evaluated over 100 SMA mixtures that were constructed in US since 1991. They were able to show that in over 90% of the SMA projects, rutting measurements taken were less than 4 mm and 25% of the projects had no measurable rutting. Therefore, excellent resistance to rutting was reported when considering the high traffic volumes most of the under inspected SMA mixtures successfully served. In the state of Illinois SMA is normally used with steel slag aggregates having superior friction properties. SMA with steel slag aggregate is used for constructing the surface layer anywhere from 38 to 102 mm (1.5 to 4 in.) on top of existing concrete or dense graded HMA layers.

SMA is generally more expensive than a typical dense graded HMA (about 20-25%) because it requires more durable aggregates, higher asphalt content and, typically, a modified asphalt binder and fibers. In the right situations, it should be cost-effective because of its increased rut resistance and improved durability. Other reported SMA benefits include wet weather friction (due to a coarser surface texture), lower tire noise (due to negatively-textured road surface and less low frequency noise production [4]) and less severe reflective cracking [5]. Mineral fillers and additives are usually added to minimize asphalt binder drain-down during construction, increase the amount of asphalt binder used in the mix and to improve mix durability. For designing SMA mixes, one can use the Superpave or Marshall procedure with modifications [6, 7]. In mix design, a test for voids in the coarse aggregate (AASHTO T19) is also used to ensure there is stone-on-stone contact. SMA mixes also require higher mixing temperatures and longer mixing times at the plant, higher compaction temperatures during paving, and more intensive quality control at plant and on job site.

Achieving adequate compaction level is an important factor that impacts the field performance of asphalt mixtures. Linden et al. [8] summarized the effect of compaction on flexible performance based on literature, a questionnaire survey of 48 state highway agencies on compaction practice, and performance data from Washington State Pavement Management System (WS-PMS). They were able to show with data from all three sources that correlations existed between the degree of compaction and improved performance of flexible pavements [8]. Several factors including type of asphalt binder, gradation, aggregate shape and strength characteristics, layer thickness, and the subgrade condition influence the damping properties of the mixture as well as the achieved quality of vibratory

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compaction. Damping ratio is a material property that shows the capability of absorbing vibrating energy. The damping ratio is one of the indicators of the stress relaxing capability of asphalt mixture as a viscoelastic material. A material with higher damping ratio is more suitable for building vibration attenuation and also performs better under dynamic cyclic loads. Shimazaki et al. [9] developed a high performance SMA mixture with increased historic damping ratio (calculated from hysteresis curve) for the purpose of preventing the reflective cracking. Zeng et al. [10] measured the stiffness and damping ratio of rubber-modified asphalt (RMA) samples with different rubber contents and mixed by different methods. Their findings indicate that adding rubber to asphalt binder increases the damping ratio. The stickiness of the rubber-tired rollers to polymer in SMA mixtures may restrict the use of pneumatic compactors in the field.

In case of vibratory compactors, the frequency and amplitude of the compactor need to be adjusted according to the mixture properties. By understanding differences in compaction behavior of SMA in comparison to HMA, compaction equipment can be adequately developed to accomplish needed tasks most effectively in the field. For this purpose, gyratory compaction and damping ratio tests to be conducted on field collected loose samples would help to simulate close to field compaction conditions in the laboratory and evaluate differences in mixture response. For example, high stability SMA mixtures, often with fiber or polymer modified binders, have different compaction demands for larger rollers which can apply higher dynamic force or compaction energy during compaction. If high-amplitude compaction can be achieved to get the initial density behind the screed at a lower frequency, this minimizes aggregate breakdown when dealing with soft, nondurable aggregates in thin SMA lifts. In 2007, Anochie-Boateng [11] showed the effects of loading frequency and applied wheel load deviator as well as confining stresses on a bituminous sand with viscoelastic properties by measuring damping ratio and modulus properties. Another recent research study by Austroads on gyratory compaction confirmed that type of mixture was quite important in establishing relationships between laboratory and field compaction [12].

This paper describes an investigation of the compaction behavior and damping properties of SMA in comparison to dense graded HMA type asphalt mixes through a laboratory testing program. Loose samples of both SMA and dense graded HMA mixes collected from field projects with known job mix formulas/designs are compacted to typical field densities and tested to determine dynamic loading characteristics. Gyratory compaction tests conducted by controlling applied normal stress contrast the different trends observed in the shear stresses imparted and the changes in air voids in the specimens with number of gyrations until a desired target density. The damping ratio tests conducted on the compacted SMA and dense graded HMA specimens are used to establish the significance of loading frequency on the damping properties.

Objective and Scope

The overall objective of this research was to evaluate differences in compaction behavior of SMA and dense graded HMA mixes by conducting laboratory tests on field collected loose samples that can simulate the field densities and loading conditions. The scope of the study included compacting specimens at three different compaction pressures to achieve maximum densities using a gyratory compactor. Compaction growth curves were recorded to provide a comparable signature of the material behavior during densification process. In the second phase, damping ratio tests were performed on the compacted samples at field compaction temperatures by applying dynamic loading to investigate the effect of loading frequency, confining pressure as well as temperature on the damping properties. The intent was to determine dynamic damping ratios, which are important indicators of proper field compaction and also can be used for improving compaction equipment for SMA projects.

Materials, Sample Preparation and Testing

Tables 1 and 2 list the properties of both the dense graded HMA and SMA mixes, respectively, collected as loose samples from field projects belong to Illinois Department of Transportation (IDOT). Note that asphalt concrete mixtures were usually at around 15% air voids (very loose stage) right after paver operation in the field. Then, operating the roller compactor, the field density was typically achieved at approximately 4% to 7% air voids. All the laboratory

Table 1. Dense Graded HMA Job Mixture Formula.

Aggregate Batching			Final Aggregate Gradation		Optimum design data	
Quarry Location	Type & Number	Blend (%)	Sieve Size (mm)	Percent Passing	Number of Gyrations	90
Gary	Steel Slag CM13	35.70	25.00	100.0	PG70-22 (SBS) (%)	5.1
MacCook	Steel Slag CM16	26.00	19.00	100.0	Bulk Specific Gravity	2.594
MacCook	Steel Slag FM20	19.50	12.50	100.0	Maximum Specific Gravity	2.702
Antioch	Steel Slag FM02	7.80	9.50	92.9	Target Air Void (%)	4.0
Hodgkins	Mineral Filler MF01	1.00	4.75	48.8	VMA (%)	14.5
Hodgkins	RAP CM13	10.00	2.36	29.9	VFA (%)	72.4
Notes			1.18	20.9	Aggregate Effective Specific Gravity	2.958
[1] RAP: Recycled Asphalt Pavement			#30	14.9	Aggregate bulk specific gravity	2.876
[2] Virgin asphalt content in RAP = 4.7%			#50	10.4	Aggregate apparent specific gravity	3.021
			#100	6.7	Tensile Strength Ratio (TSR)	0.99
			#200	5.2	Dust proportion ratio	1.01

Table 2. Gap Graded SMA job Mixture Formula.

Aggregate Batching			Final Aggregate Gradation		Optimum Design Data	
Quarry Location	Type & Number	Blend (%)	Sieve Size (mm)	Percent Passing	Number of Gyrations	80
E. Chicago	Steel Slag CM11	27.00	25.00	100.0	PG76-22 with Fibers (SBS) (%)	6.0
E. Chicago	Steel Slag CM13	57.00	19.00	100.0	Bulk Specific Gravity	2.858
Thornton	Steel Slag FM20	9.00	12.50	81.6	Maximum Specific Gravity	2.961
Thornton	Mineral Filler FM01	7.00	9.50	64.3	Target Air Void (%)	3.5
			4.75	30.5	VMA (%)	17.6
			2.36	18.2	VFA (%)	80.2
Notes			1.18	14.8	Aggregate Effective Specific Gravity	3.365
			#30	12.9	Aggregate Bulk Specific Gravity	3.261
[1] Fibers Added at 0.4% by Weight to Address Drain Down at 175 °C			#50	11.1	Aggregate Apparent Specific Gravity	3.441
			#100	10.1	Tensile Strength Ratio (TSR)	0.99
			#200	8.8	Dust Proportion Ratio	1.46

Table 3. Gyratory Compactor Test Variables.

Test variable	Value		
Gyration External Angle (Degree)	1.25		
Compaction Pressure (kPa)	344	600	827
Compaction Temperature (Degree Celsius)	HMA 150		SMA 165
Curing Time to Warm up the Cold Mixtures (hrs)	2-3		
Air Void (%)	Target 4 or Minimum Achievable		

Fig. 1. University of Illinois RaTT Cell Shown in the Temperature Control Chamber.

tests were performed at the University of Illinois Advanced Transportation Research and Engineering Laboratory (ATREL).

Gyratory Compaction Test

Compaction tests were performed by using an Industrial Process Control (IPC) Servopac type gyratory compactor. Compaction density or percent air voids and shear stress as a function of applied normal stress and number of gyrations were recorded. The IPC gyratory compactor allows users to control the applied normal stresses and reports the applied shear stresses on the specimen during compaction. Therefore, increase in density was monitored with increasing number of gyrations while the applied shear stress levels and the change in air voids were recorded. The differences in densification trends were evaluated by applying equal compaction effort on the dense graded HMA and gap graded SMA samples. Table 3 lists the applied compaction pressure as well as other test variables. The goal was to establish compaction growth curves corresponding to different compactive efforts. After conducting few trial tests, the amount of loose mixture in the gyratory mold could be adjusted to keep the final compacted specimen height as close as possible to 150 mm (close to 6 in.) with the maximum achievable density.

Damping Ratio Test

Damping ratio is a property used to measure the dissipated energy when a material is subjected to cyclic loading. The procedure for determining damping ratio using cyclic triaxial equipment has been originally developed for soils [13]. In this study, a modified version of ASTM D3999 test method was developed using the University of Illinois RaTT cell to evaluate the damping properties of SMA and HMA mixes at close to field compaction temperatures. Damping ratio is considered as an important factor to characterize the behavior of asphalt mixture during compaction [14]. Fig. 1 shows a photo of the RaTT cell device, which is equipped with IPC's universal testing machine UTM-5P system, and an environmental chamber that is temperature controlled. The tested specimen dimensions were typical of gyratory sample sizes, 150 mm in diameter by 150 mm height. Horizontal confining pressure was applied by pneumatic air using an internal membrane that can be inflated to surround the specimen. Vertical loading was applied using vertical air actuator. Additionally, sample deflections under

Fig. 2. Compacted Specimens Heated in the Oven and Prepared for Damping Ratio Test.

Table 4. Damping Ratio Test Specimen Characteristics.

Sample ID	Compaction Pressure (kPa)	Height (mm)	Weight (gr)	Oven Heating Temperature (C)	Target Test Temperature (C)
SMA PSG 2/9	344	148.3	7064.1	120	90
SMA PSG 3/9	344	150.7	7187	135	115
SMA PSG 4/9	600	147.5	7125.9	135	115
SMA PSG 5/9	600	149	7218.6	120	90
SMA PSG 7/9	827	146.8	7295.8	135	115
SMA PSG 9/9	827	146.1	7199.9	120	90
HMA PSG 1/9	344	150	6981.4	120	90
HMA PSG 3/9	344	150	6774.5	135	115
HMA PSG 5/9	600	150	6789.6	135	115
HMA PSG 6/9	600	150	6712.2	120	90
HMA PSG 7/9	827	150	6730.8	120	90
HMA PSG 8/9	827	151.9	6681.2	135	115

the testing loads were recorded using two LVDTs.

According to the project tasks, there was a time delay between compacting the specimens and running the damping ratio tests. As a result, the compacted samples were heated in the oven up to 120^{o}C to 135^{o}C for 5 hours to achieve damping ratio test temperatures in the range of 90^{o}C to 115^{o}C, respectively (see Fig. 2). Oven heating temperatures were higher than the test temperatures because the samples started to cool down while transferring from the oven into the RaTT cell and during the test setup. Table 4 lists the test specimen characteristics and the testing matrix.

Test Procedures and Interpretation of Test Results

HMA and SMA field collected loose mixes were heated in the oven at 150^{o}C and 165^{o}C respectively before compaction. Using the IPC gyratory compactor, the decrease in height of the samples and the density growth curves were monitored during the compaction process at different compaction pressures.

Using Eq. (1) and the measurements of resistance to the shear force in the Servopac gyratory compactor, the applied shear stress was recorded in the specimens as a function of gyration numbers [15].

$$G_S = \frac{2PL}{Ah} \qquad (1)$$

where

G_s = Gyratory shear stress (kPa), P = Average force measured in gyratory actuators (kN),

L = Distance to the mid point of actuator (m), A = Sample area (m2), h = Sample Height (m)

Figs. 3 through 5 compare density growth curves of HMA with dense graded aggregate structure to SMA with gap graded aggregate gradations at various compaction temperatures. Additionally these figures show that by increasing compaction pressure the density in a typical SMA sample increases at a faster rate than that of HMA.

It was observed that at equal gyration numbers, SMA was consistently achieving higher densities in comparison to HMA especially at compaction pressures 600 kPa and 827 kPa. The coarse graded nature of SMA as well as higher aggregate bulk specific gravities are the main contributing factors for achieving greater densities.

As indicated in Figs. 6 and 7, an increase in compaction pressure resulted in higher shear stresses generated during SMA compaction. The same trend was observed in HMA for pressure levels in the range of 344 kPa to 600 kPa. However, exceeding the pressure beyond 600 kPa did not change the shear stress levels in the case of HMA. One possible explanation of no increase in shear stress beyond 600 kPa is that based on Table 5, the HMA reaches its ultimate density level at 600 kPa to 827 kPa . The other reason can be related to lower fines content and dense graded gradations in HMA, which may cause breakage of aggregate particles at higher

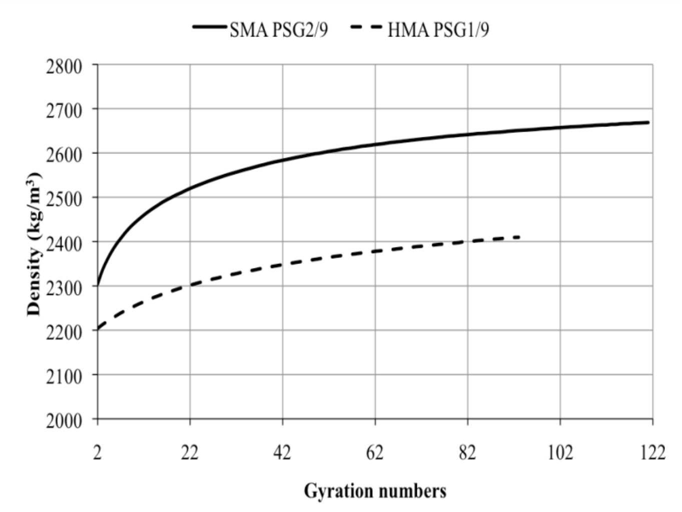

Fig. 3. HMA and SMA Density Growth Curves at 344 kPa Compaction Pressure.

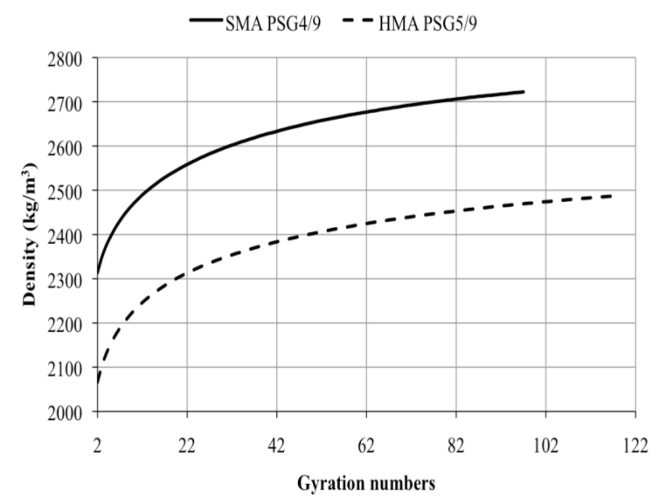

Fig. 4. HMA and SMA Density Growth Curves at 600 kPa Compaction Pressure.

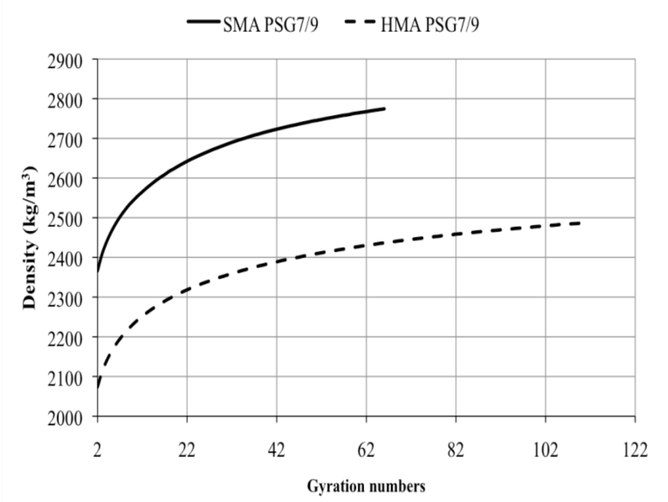

Fig. 5. HMA and SMA Density Growth Curves at 827 kPa Compaction Pressure.

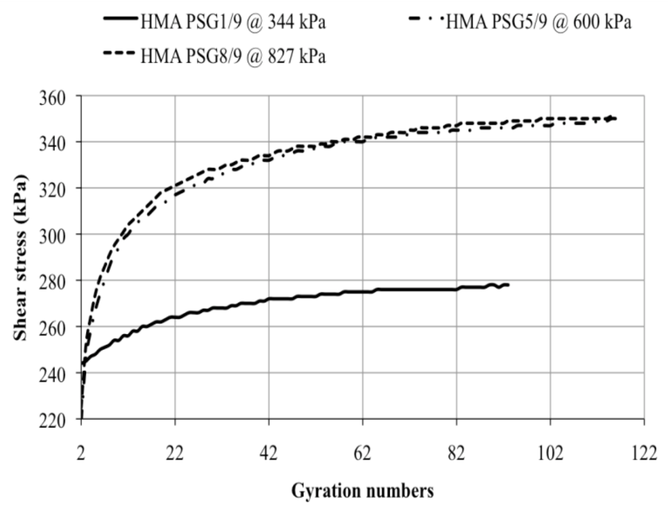

Fig. 6. Effect of Compaction Pressure on Shear Stress Growth for HMA Mixtures.

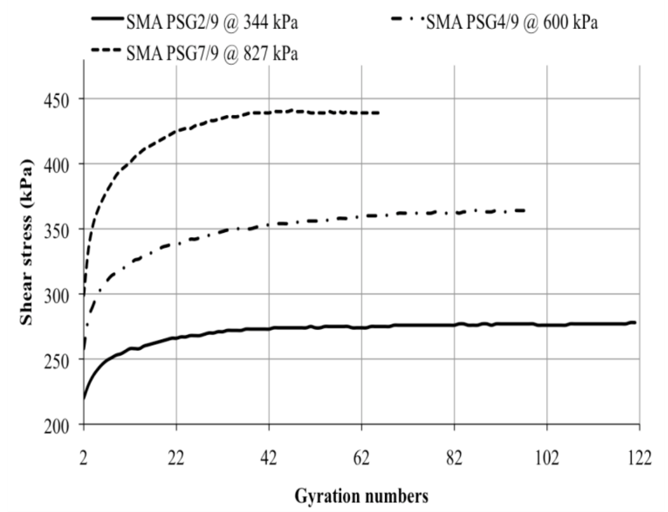

Fig. 7. Effect of Compaction Pressure on Shear Stress Growth for SMA Mixtures

compaction pressures. Table 5 presents a summary of all gyratory compaction test results including initial and maximum densities and shear stresses achieved and the maximum number of gyrations.

Damping is defined as the measure of hysteretic energy dissipated by the test specimen during cyclic loading proportional to the area of hysteresis loop. Complete sinusoidal load waveform was applied at loading frequencies of 2, 5, 10, and 20 Hz with no rest period. Fig. 8 shows typical loading curves obtained at 2-Hz frequency.

Eq. (2) provides a generalized formula for computing the area of a polygon with n vertices used to determine the area of a typical hysteresis loop shown in Fig. 9.

$$Area = \frac{1}{2}\sum_{i=1}^{n}(X_i Y_{i+1} - X_{i+1} Y_i) \qquad (2)$$

where

X, Y = Coordinates of the vertices of polygon.

The hysteresis loop was closed by replacing X_{n+1} by X_1 and Y_{n+1} by Y_1. Finally, damping ratio values were calculated for each

Table 5. Summary of Gyratory Compaction Test Results.

Sample ID	Compaction Pressure (kPa)	Initial Density (kg/m^3)	Maximum Density (kg/m^3)	Initial Shear Stress (kPa)	Maximum Shear Stress (kPa)	Sample Weight (gr)	Maximum Gyration Number
SMA PSG 2/9	344	2304	2669	220	278	7064.1	121
SMA PSG 3/9	344	2299	2673	212	273	7187.0	119
SMA PSG 4/9	600	2313	2722	258	364	7121.0	97
SMA PSG 5/9	600	2303	2711	248	360	7218.6	90
SMA PSG 7/9	827	2365	2774	299	439	7300.0	66
SMA PSG 9/9	827	2338	2771	280	446	7203.0	70
HMA PSG 1/9	344	2203	2409	244	278	6981.4	93
HMA PSG 3/9	344	2064	2433	203	286	6774.5	100
HMA PSG 5/9	600	2066	2486	219	350	6789.6	117
HMA PSG 6/9	600	2062	2473	224	349	6712.2	111
HMA PSG 7/9	827	2073	2486	226	352	6730.8	110
HMA PSG 8/9	827	2057	2480	225	351	6681.2	116

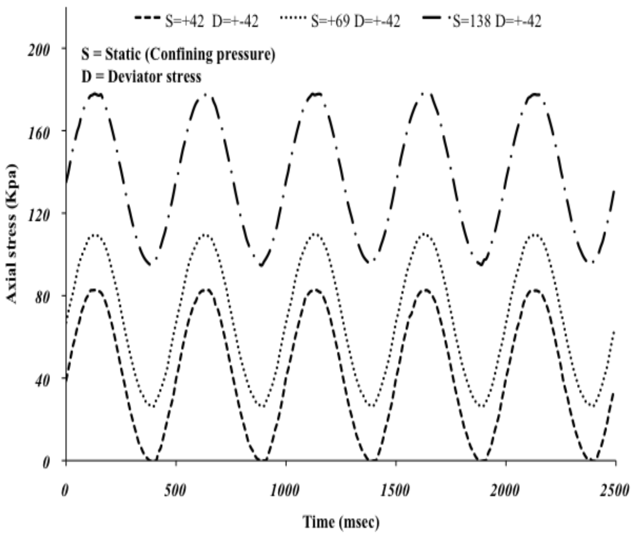

Fig. 8. Typical Sinusoidal Loading at 2-Hz Frequency.

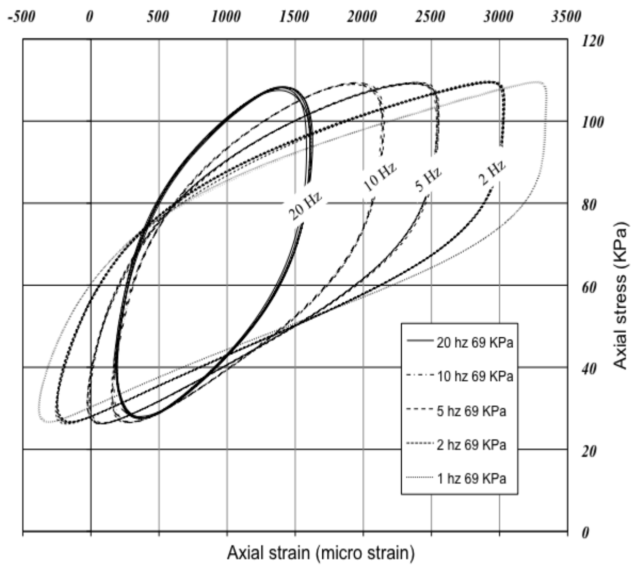

Fig. 9. SMA Hysteresis Loops (90^{o}C) for Different Frequencies at 69 kPa Confining Pressure.

separate loading frequency using Eq. (3).

$$D = \frac{2\Delta W}{\pi \Delta\sigma \Delta\varepsilon} \tag{3}$$

where

ΔW = Area of the hysteresis loop, $\Delta\sigma$ = Maximum applied stress level;

$\Delta\varepsilon$ = Difference between maximum and minimum strain level, D = Damping ratio

The initial goal was to test the specimens at similar field compaction temperatures, i.e., 150^{o}C and 165^{o}C for HMA and SMA mixtures, respectively. Additionally, oven heating temperatures were higher than the testing temperatures because the samples were starting to cool down while transferring from the oven into the RaTT cell as well as during the setup process. This means the compacted samples had to be heated at 175^{o}C and 195^{o}C for HMA and SMA mixtures, respectively, to achieve the aforementioned field compaction temperatures. It was observed that the gyratory compacted samples started to become unstable at these high temperatures. Thus, placing the samples inside the RaTT cell was not possible. Therefore, for both HMA and SMA, the damping ratio tests were conducted at 90^{o}C to 115^{o}C as the highest achievable testing temperatures. Tables 6 and 7 summarize the damping ratio test results obtained at different loading frequencies, confining pressures and temperatures. As indicated in Tables 6 and 7, increasing the loading frequency will increase the damping ratios in both HMA and SMA. Effect of loading frequency can be related to the loading rate dependency behavior of the bitumen used in the mixtures.

Moreover, at identical testing conditions in terms of compaction pressure, confining pressure, and temperature, the average damping ratios for SMA was observed to be higher than the values for HMA. This can be due to the higher bitumen contents as well as greater VMA values in SMA.

Increasing the confining pressure from 42 to 69 kPa was found to have an insignificant effect on damping ratios for both HMA and SMA. However, increasing the confining pressure to 132 kPa in HMA samples resulted in a significant decrease in the damping ratios. The probable explanation is that the material becomes stiffer

Table 6. Damping Ratio Test Results for HMA Mixtures.

HMA PSG1/9 P = 344 kPa T= 90°C				HMA PSG3/9 P = 344 kPa T= 115°C				HMA PSG5/9 P = 600 kPa T= 115°C			
Frequency	Confining Pressure (kPa)			Frequency	Confining Pressure (kPa)			Frequency	Confining Pressure (kPa)		
(Hz)	42	69	132	(Hz)	42	69	132	(Hz)	42	69	132
1	19.1	19.3	8.7	1	17.6	18.8	8.8	1	16.7	17.3	7.6
2	18.8	20.4	11.2	2	18.2	19.6	8.9	2	17.5	17.9	8.8
5	19.5	22.2	9.3	5	19.7	21.1	8.5	5	19	19.6	8.7
10	21.2	24.6	15.4	10	22.1	23.6	12.1	10	21.6	21.8	9.1
20	24.1	29.8	16.5	20	26.6	29.2	13.5	20	26.6	27.6	13.4
HMA PSG6/9 P = 600 kPa T= 90°C				HMA PSG7/9 P = 827 kPa T= 90°C				HMA PSG8/9 P = 827kPa T= 115°C			
Frequency	Confining pressure (kPa)			Frequency	Confining Pressure (kPa)			Frequency	Confining Pressure (kPa)		
(Hz)	42	69	132	(Hz)	42	69	132	(Hz)	42	69	132
1	18.1	20.2	9.1	1	18.5	19.8	8.6	1	17.1	17.9	4.8
2	18.5	20.9	10.1	2	18.6	20.3	11.5	2	17.5	18.6	7.3
5	19.8	22.9	9.7	5	19.9	22.8	11.2	5	19.2	20.4	6.4
10	21.7	25.6	11.5	10	21.8	24.8	9.7	10	21.4	22.7	12.8
20	24.6	29.7	15.8	20	25.7	30.5	13.6	20	26.3	28.2	12.9
Note: P = Compaction Pressure & T = Testing Temperature											

Table 7. Damping Ratio Test Results for SMA Mixtures.

SMA PSG2/9 P = 344 kPa T= 90°C				SMA PSG3/9 P = 344 kPa T= 115°C				SMA PSG4/9 P = 600 kPa T= 115°C			
Frequency	Confining Pressure (kPa)			Frequency	Confining Pressure (kPa)			Frequency	Confining pressure (kPa)		
(Hz)	42	69	132	(Hz)	42	69	132	(Hz)	42	69	132
1	22.3	20.9	10.7	1	18.9	21.6	11.4	1	18.8	22.7	22.8
2	21.9	21.6	11.8	2	19.8	22.2	10.5	2	20.4	23.8	24.5
5	23.2	23.5	13.2	5	22.1	24.1	12.5	5	23.6	26.9	25.9
10	24.8	26.9	8.9	10	24.8	26.6	15.2	10	26.7	30.1	26.8
20	28.1	30.7	19.1	20	31.2	32.2	15.3	20	32.6	37.5	32.8
SMA PSG5/9 P = 600 kPa T= 90°C				SMA PSG7/9 P = 827 kPa T= 115°C				SMA PSG9/9 P = 827 kPa T= 90°C			
Frequency	Confining Pressure (kPa)			Frequency	Confining Pressure (kPa)			Frequency	Confining Pressure (kPa)		
(Hz)	42	69	132	(Hz)	42	69	132	(Hz)	42	69	132
1	18.1	21.6	12.9	1	19.1	19.8	22.3	1	21.5	27.8	23.1
2	19.1	22.6	12.1	2	21.4	21.6	23.8	2	23.8	24.4	22.6
5	21.8	25.8	16.5	5	24.5	25.2	26.6	5	26.7	28.3	26.4
10	24.5	28.7	17.8	10	27.8	29.3	30.9	10	28.9	31.2	29.3
20	29.1	34.3	20.5	20	34.2	36.8	35.4	20	33.2	36.4	33.8
Note: P = Compaction Pressure & T = Testing Temperature											

at higher confining pressure, which results in less energy dissipation. Additionally, it was observed that a threshold value existed when the level of confinement started to affect the material damping property. SMA samples were typically showing the same trend except for those, which were compacted at 827 kPa pressure. In other words, considering the gap and coarse graded aggregate structure in SMA samples, the threshold value in terms of the level of confinement can be higher than 132 kPa.

The effect of testing temperature on damping ratio was not following a clear trend in both HMA and SMA mixtures. One possible explanation is that the temperature control chamber of RaTT cell was not capable of providing temperatures higher than 60°C and accordingly, samples were continuously loosing heat throughout testing.

Conclusions

The main objective of this research was to evaluate the densification and damping properties of two types of mixtures, dense graded hot mix asphalt and gap graded stone matrix asphalt, collected as loose samples from Illinois DOT field projects. The laboratory test results indicated that the gap graded aggregate structure of SMA mixtures played an important role in the gyratory compaction based density growth by achieving higher densities in comparison to HMA mixtures. The compaction pressure was found to have a significant effect on shear stresses imparted in specimens of both mixtures before any aggregate breakage occurred. The frequency of dynamic loading strongly influenced the damping ratios of SMA mixtures. The mixture properties such as gradation, VMA and bitumen content in SMA resulted in higher damping ratios. Furthermore, the effect of confining pressure, linked to proper lift thicknesses in the field, was found to be dependent on compaction pressure levels as well as mixture properties. Note that steel slag aggregate was used in both HMA and SMA mixtures; the effect of using natural mineral aggregate, as opposed to steel slag, on the damping and compaction properties would be recommended as a topic for future research.

The current experimental study was not comprehensive to include many other factors and variables that may influence damping properties of asphalt mixtures and the quality of the compaction. On the other hand, research findings presented in this paper clearly proved that frequency and mixture properties are two important factors that significantly influence the damping and compaction properties. Constructing field test strips is highly recommended to study operating conditions of the compaction equipment in terms of speed, loading frequency, amplitude, compaction pressure, lift thickness, and material properties corresponding to the type of mixture and developing field requirements for establishing specifications. Accordingly, manufactures may need to implement changes in their equipment designs to accommodate the compaction requirements of each mixture type. Finally, effects of rheological properties of the bitumen as well as the aggregate type and shape properties on the densification and damping properties of different asphalt mixtures need to be also taken into account for the ultimate goal of achieving proper field compaction.

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