High-speed pavement macrotexture measurements for assessing homogeneity of paved mixes

Mohammad Shafiqur Rahman, Safwat F. Said, Thomas Lundberg, Abubeker Ahmed and Terence McGarvey

VTI- Swedish National Road and Transport Research Institute, Linköping, Sweden

shafiqur.rahman@vti.se

High-speed pavement macrotexture measurements for assessing homogeneity of paved mixes

Non-destructive testing, used to quantify asphalt pavement layers' homogeneity, may be used for quality assurance purposes in paving contracts. This paper summarizes the findings from a field study and laboratory investigations which focused on segregation in bituminous pavement mixes. The study relates pavement layer surface macrotexture with the homogeneity of the paved bituminous layer by distinguishing between different mix-segregated areas. The macrotexture values, characterized as mean profile depth (MPD) (ISO 1997), of the paved layers were measured using VTI's Laser Road Surface Tester (RST). Measurements were carried out on base and binder courses directly after the paving was complete. Based on the MPD values, three locations on the surface of the base course and binder course were identified as having either low, intermediate or high MPD values. Core samples were taken from these locations and were tested for stiffness modulus. Thereafter moisture conditioning of the specimens was performed by the moisture induced sensitivity test (MIST). Finally, the samples´ air void content was determined. Results clearly showed that the samples from the locations with high MPD values were mostly affected by the moisture conditioning. In these cases, the stiffness moduli were significantly reduced. The samples with high MPD values also had the highest content of air voids. Thus, in this study it has been possible to demonstrate that a procedure for detecting and measuring segregation may be used to estimate the impact segregation can have on the stiffness modulus of bituminous mix and to evaluate the construction quality of a pavement. The correlation between MPD values and change in stiffness modulus suggests that MPD measurement values may be a reliable and non-destructive method for evaluating the construction quality of a pavement. The values can be used to develop pavement performance quality assurance criteria that can be used in pavement surfacing contracts.

Keywords: mean profile depth; moisture induced sensitivity test; stiffness modulus; segregation

Introduction

Construction quality is a very important factor associated with the performance and durability of a pavement structure. Shortcomings in construction work quality may lead to segregation in the asphalt concrete (AC) mixture that results in premature damage and early maintenance of the structure (Stroup-Gardiner and Brown 2000, Stroup-Gardiner et al. 2007, Eisenman and Hilmer 1987, Zeiada et al 2014). Local variations in the aggregate size distribution or excessive binder content, both created by segregation, results in non-uniformity in bituminous layers. Areas with a high proportion of coarse aggregate often have a low binder content and a high air void content. The combination of low binder and high void content often leads to accelerated pavement distresses such as ravelling, potholes, and cracking. On the other hand, areas with a high proportion of fines often have high binder and low air void content. This may give rise to flushing and rutting in the asphalt layers and a greater risk of low friction. Mixes are also likely to have inferior resistance against traffic loading and climatic conditions. Segregation, in certain cases, may lead to significant reductions in pavement service life, incurring high costs for the road authorities (Stroup-Gardiner and Brown 2000). If potential agency and contractor risk levels are to be ascertained, an approach that describes quality control and acceptance levels is therefore necessary. The approach must be able to measure the extent of segregation in the pavement structure and determine its relation to service life. However, the difficulty lies in the lack of any objective and practical approach for assessing the homogeneity of paved mixes and its effect on service life (Karimi et al. 2014, Zeiada et al. 2013, Lundberg 2012).

Generally, segregation is assessed through determination of mix composition that requires testing of core drilled specimens. Laboratory testing of cores is time consuming and limits testing to a few random spot locations. There are, however, several other methods for assessing segregation. Segregation through the full depth of the asphalt concrete mat can be determined by nuclear density gauges, infrared thermography and ground penetrating radar (GPR) (Stroup-Gardiner and Brown 2000, Lundberg 2012, Meegoda et al. 2005, Meegoda et al. 2013, Zelelew et al. 2013). In general, investigators established a correlation between the testing method and segregation in asphalt mixture. Advantages and drawbacks of the testing methods are described by Meegoda et al. (2005).

In this work, laser surface macrotexture measurements have been adopted. The method is widely used at network level and can be carried out at normal traffic speed without any disruption to traffic flow. In an attempt to describe segregation in newly paved asphalt concrete layers and evaluate the construction quality of a pavement, two objectives were determined. The first was to find correlations between MPD values and the bulk densities, air voids, and stiffness moduli. The second was to assess the impact moisture conditioning had on the stiffness modulus. The ultimate purpose was to establish quality control and assurance criteria procedures, based on pavement performance, which can be used in pavement surfacing contracts.

Experimental programme

This study involved measuring MPD values along a motorway test section. MPD is a measure that is characterizing the structure of the road surface. The texture profile is obtained from laser measurements and it is underlying for the MPD calculation. The MPD value is calculated as an average value from the mean segment depth (MSD) which is profile height for a single 100 mm section of the road. MPD values of 1 meter has been used in the analysis in this project. The principles for calculating MSD on a single 100 mm section can be described as the mean value of the height from an average level of the texture profile to the peaks of the texture profile, see Figure 1.

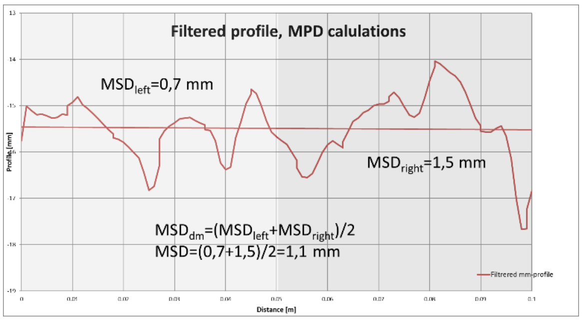


Figure 1. The principles for calculating MPD.

Road surface macrotexture data was obtained using non-contact laser measurement technology. Surveys were carried out with VTI’s Road Surface Tester (RST), see Figure 2, and were performed at approximately 50 km per hour.

Figure 2. The VTI Road Surface Tester (RST).

Based on the MPD values, three locations on the test section were identified as having either low, intermediate or high MPD values. Core samples were taken and tested for bulk density, air voids, and stiffness modulus. The samples were then subjected to moisture conditioning by conducting the moisture induced sensitivity test (MIST). After moisture conditioning was complete, stiffness moduli were re-determined.

The surface macrotexture data used for this work was obtained during the construction phase of a road, located on road RV40 at Ulricehamn in central Sweden. The annual average daily traffic (AADT) is about 10,000, 18 % being heavy vehicles.

The road structure is presented in Figure 3 and mixes are according to Swedish specifications.

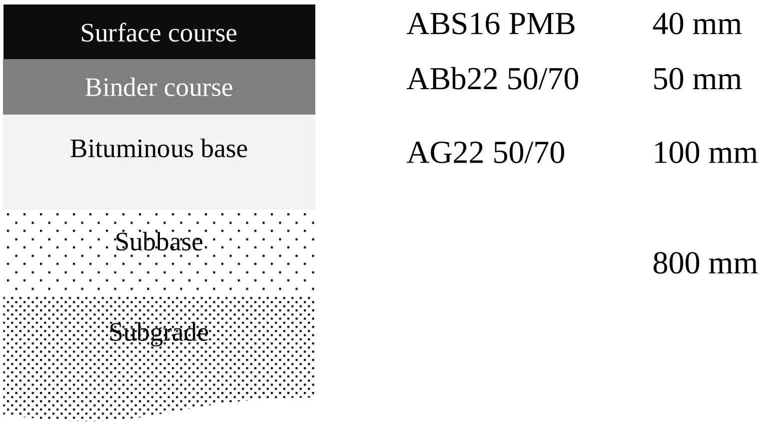
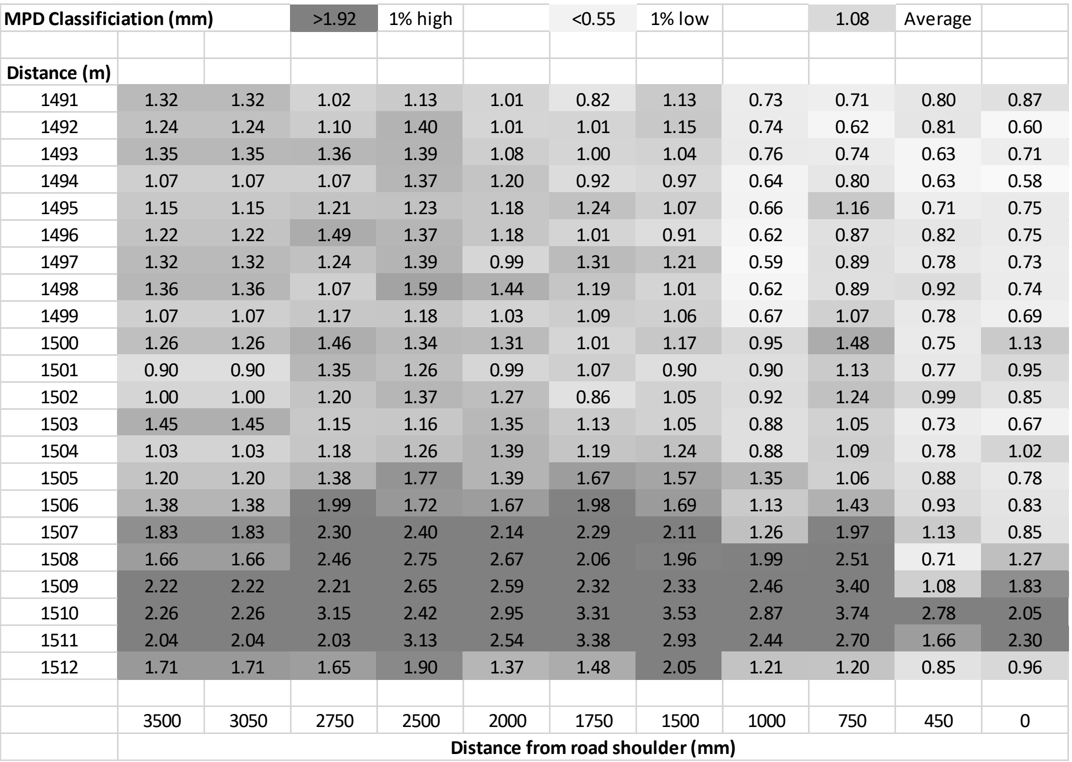


Figure 3. Test section road structure.

Measurement of MPD – Laser RST

Texture measurements were performed in 2015. Measurements were taken on base course and binder course layers during the initial construction phases. The final phase, which included the surface course layer, was carried out in 2016. Measurement data, for each asphalt layer, was obtained from eleven 4000 m long longitudinal survey lines. The survey lines were evenly distributed in the 3.5 m wide right hand side lane. The data was analysed on site and MPD values were classified as being either high (MPD = highest 1%), intermediate (MPD = average value) or low (MPD = lowest 1%). Figure 4 illustrates an example of the categorized MPD values. For the purpose of this paper, the values have been conditionally formatted using a grey scale. This provides a useful graphical image that allows the three segregation classifications to be easily identified. Based on this classification method, several coring locations were identified at low, intermediate and high locations on the test section. Figure 5 shows two images with various segregations. The first image can be associated with a high MPD value and this will be detailed as dark grey in the condition formatting. The other image shows lower MPD values and this will be detailed as light grey. Figure 6 shows a common problem called end-of-the-truck segregation. The corresponding MPD data can be seen as dark grey (distance 1510) in Figure 4.



MPD Classificiation (mm)			>1.92	1% high		<0.55	1% low		1.08	Average	
Distance (m)											
1491	1.32	1.32	1.02	1.13	1.01	0.82	1.13	0.73	0.71	0.80	0.87
1492	1.24	1.24	1.10	1.40	1.01	1.01	1.15	0.74	0.62	0.81	0.60
1493	1.35	1.35	1.36	1.39	1.08	1.00	1.04	0.76	0.74	0.63	0.71
1494	1.07	1.07	1.07	1.37	1.20	0.92	0.97	0.64	0.80	0.63	0.58
1495	1.15	1.15	1.21	1.23	1.18	1.24	1.07	0.66	1.16	0.71	0.75
1496	1.22	1.22	1.49	1.37	1.18	1.01	0.91	0.62	0.87	0.82	0.75
1497	1.32	1.32	1.24	1.39	0.99	1.31	1.21	0.59	0.89	0.78	0.73
1498	1.36	1.36	1.07	1.59	1.44	1.19	1.01	0.62	0.89	0.92	0.74
1499	1.07	1.07	1.17	1.18	1.03	1.09	1.06	0.67	1.07	0.78	0.69
1500	1.26	1.26	1.46	1.34	1.31	1.01	1.17	0.95	1.48	0.75	1.13
1501	0.90	0.90	1.35	1.26	0.99	1.07	0.90	0.90	1.13	0.77	0.95
1502	1.00	1.00	1.20	1.37	1.27	0.86	1.05	0.92	1.24	0.99	0.85
1503	1.45	1.45	1.15	1.16	1.35	1.13	1.05	0.88	1.05	0.73	0.67
1504	1.03	1.03	1.18	1.26	1.39	1.19	1.24	0.88	1.09	0.78	1.02
1505	1.20	1.20	1.38	1.77	1.39	1.67	1.57	1.35	1.06	0.88	0.78
1506	1.38	1.38	1.99	1.72	1.67	1.98	1.69	1.13	1.43	0.93	0.83
1507	1.83	1.83	2.30	2.40	2.14	2.29	2.11	1.26	1.97	1.13	0.85
1508	1.66	1.66	2.46	2.75	2.67	2.06	1.96	1.99	2.51	0.71	1.27
1509	2.22	2.22	2.21	2.65	2.59	2.32	2.33	2.46	3.40	1.08	1.83
1510	2.26	2.26	3.15	2.42	2.95	3.31	3.53	2.87	3.74	2.78	2.05
1511	2.04	2.04	2.03	3.13	2.54	3.38	2.93	2.44	2.70	1.66	2.30
1512	1.71	1.71	1.65	1.90	1.37	1.48	2.05	1.21	1.20	0.85	0.96
	3500	3050	2750	2500	2000	1750	1500	1000	750	450	0
	Distance from road shoulder (mm)										

Figure 4. Illustration of conditionally formatted MPD data.

Figure 5. Core locations; open and dense areas of base course located using MPD data.

Figure 6. Area known as end-of-truck-load segregation (corresponds to the distance 1506 m in Figure 4).

Laboratory testing

Measurement of bulk densities and air voids

Bulk densities of the cored specimens were measured before moisture conditioning. Moisture conditioning was carried out using the moisture induced sensitivity test (MIST). Air voids in the samples were determined after the determination of stiffness moduli following MIST conditioning. Measurement of bulk densities and air voids was performed in accordance with the European standards EN 12697-6 (2012a) and EN 12697-8 (2003), respectively. Air void content values are presented in Table 1. It is obvious that the MPD categories are related to the air void content.

Stiffness modulus and moisture sensitivity tests

Stiffness modulus tests were conducted in indirect tension mode and in accordance with the method prescribed by the European Standard EN 12697-26 (2012b). Tests were performed on dry, 100 mm diameter specimens at 10°C. The indirect tensile test apparatus is shown in Figure 7. To evaluate what impact non-uniformity in asphalt concrete has on pavement deterioration, the testing programme was performed by cyclic pore pressure conditioning. Cyclic pore pressure can significantly weaken asphalt mixes depending inter alia on the degree of bitumen coverage and void content (Varveri et al. 2015, Terrel and Shute 1989).

Figure 7. Indirect tensile test apparatus.

To investigate the impact moisture has on stiffness, the MIST conditioning method was adopted for this study. MIST conditioning has apparent benefits over some other procedures such as the AASHTO freeze-thaw conditioning method (AASHTO T283) (Mallick et al. 2005, Chen and Huang 2007, Htet 2007, Shu et al. 2012). The MIST equipment is illustrated in Figure 8. For the road base layer, MIST conditioning was conducted at 40°C, at 0.28 MPa (40 psi) pressure and for 3500 cycles. In order to detect any significant impact of moisture in the binder layer, the number of cycles was increased to 7000. In all cases, the specimens were submerged in 10°C water for two hours after the MIST conditioning. The stiffness modulus tests were then re-performed on the wet samples.

Frequency sweep dynamic shear tests were conducted on specimens from the binder layer. Due to the limited number of available specimens, only four specimens from the binder layer were tested with shear test. The shear box used in the present study (Said et al. 2014) consists of two guide plates. A cylindrical asphalt specimen with a diameter of 150 mm is glued to two loading steel disks. The specimen is then exposed to a sinusoidal cyclic shear loading. The movement of the disks relative to each other (the shear deformation) is measured using two strain gauges. The tests were conducted at four temperatures (-5, 10, 30 and 50°C) and 8 frequencies (16, 8, 4, 2, 1, 0.5, 0.1 and 0.05 Hz).

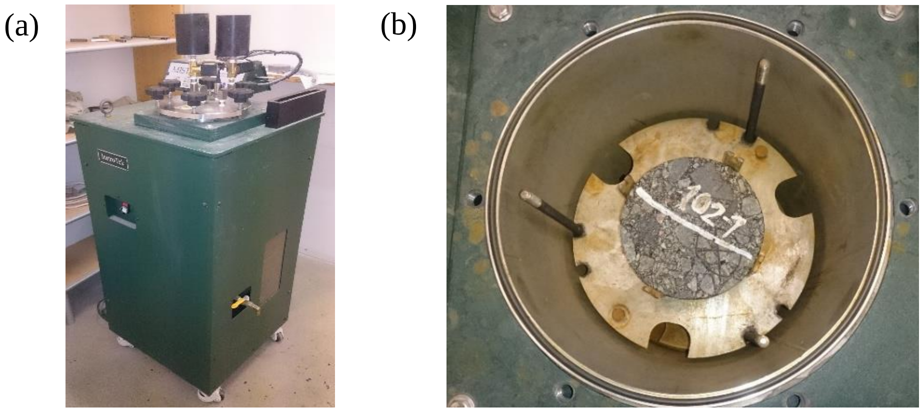


Figure 8. (a) MIST equipment, (b) specimen inside the MIST chamber prepared for conditioning (water not added yet).

Test results

Using the Laser RST measurement data, three locations along the test section were classified as having either low, intermediate or high MPD values. Average MPD values for these three locations are presented in Table 1 and Figure 9(a). Average air voids of the samples, taken from these locations, are also presented in Table 1 and Figure 9(b). The tables also show the stiffness moduli of the specimens before and after MIST conditioning. Stiffness moduli values are also presented graphically in Figure 10.

Observing the results presented in the previously mentioned tables and figures, it appears that, for both the AC base and binder layers, air voids increased. Similarly, stiffness moduli are higher for samples with low MPD values and lower for samples with high MPD values. For the base layer, the average stiffness of the samples with intermediate and high MPD values were, respectively, 17% and 49% lower compared to the samples with low MPD values. Similarly, for the binder layer, the average stiffness of the samples with intermediate and high MPD values were 21% and 30%, respectively, lower compared to the samples with low MPD values. The impact MIST conditioning had on the stiffness moduli is also more pronounced in the samples with high MPD values. Reductions in stiffness were highest for the high-MPD samples (Table 1). Generally, comparisons between AC binder and base layers show that the samples from the AC base layers were more affected by the MIST conditioning. This should be related to the air void.

Table 1. Laboratory test results (samples for stiffness modulus tests).

	AC base layer						AC binder layer					
MPD class	Tests	Avg. MPD value (mm)	Avg. air voids (%)	Average stiffness modulus (Mpa)			Tests	Avg. MPD value (mm)	Avg. air voids (%)	Average stiffness modulus (Mpa)		
				Before MIST	After MIST	% change				Before MIST	After MIST	% change
Low	6	0.44	3.6	10349	9862	-4.7	4	0.45	1.4	15857	15601	-1.6
Intermediate	6	1.1	5.1	8612	7924	-8	6	1.1	4.5	12638	12550	-0.7
High	6	2.78	13.5	5275	4776	-9.5	5	2.13	6.4	11083	10594	-4.4

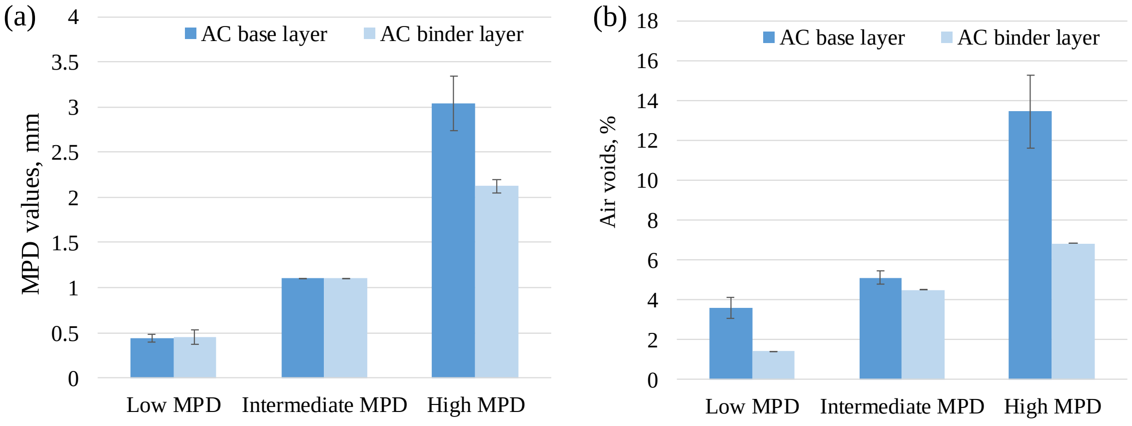


Figure 9. (a) Average MPD values and (b) average air voids.

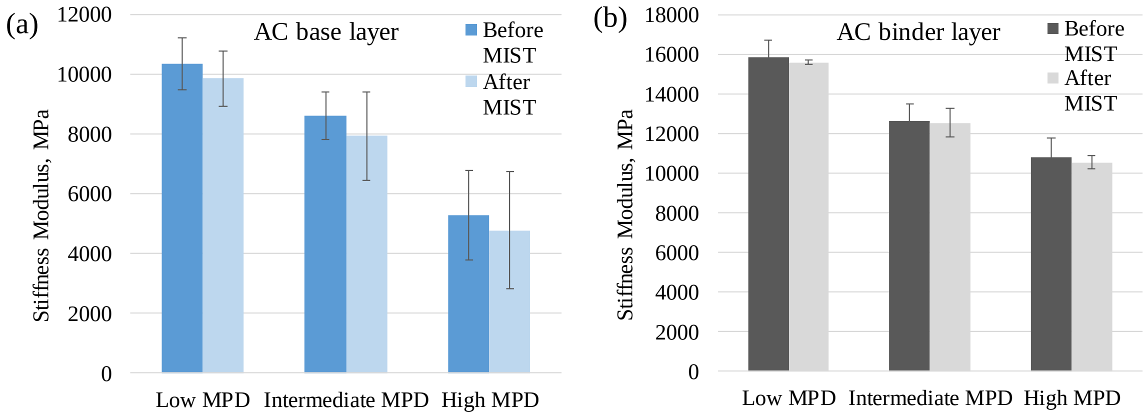


Figure 10. Average stiffness moduli before and after MIST conditioning (a) AC base layer (MIST for 3500 cycles) and (b) AC binder layer (MIST for 7000 cycles).

Dynamic shear modulus tests

To further validate the observed patterns over a wider range of loading frequency and temperature ranges, frequency sweep dynamic shear modulus tests were conducted on AC binder layer specimens from the low and high MPD areas, respectively. Average air voids of the samples and average MPD values for these locations are presented in Table 2. The resulting master curves for the dynamic shear modulus and phase angle at a reference temperature of 10°C are shown in Figures 11(a) and 11(b). Arrhenius equation was used as a shifting function. The master curve data of the shear modulus was fitted to a sigmoidal function and the phase angle data to a compound sigmoidal and unimodal function (Said et al. 2014).

Table 2. Test results from the AC binder layer specimens (shear modulus tests).

MPD level	Average MPD value (mm)	Samples tested	Average air voids (%)
Low	0.45	2	1.4
High	2.13	2	6.4

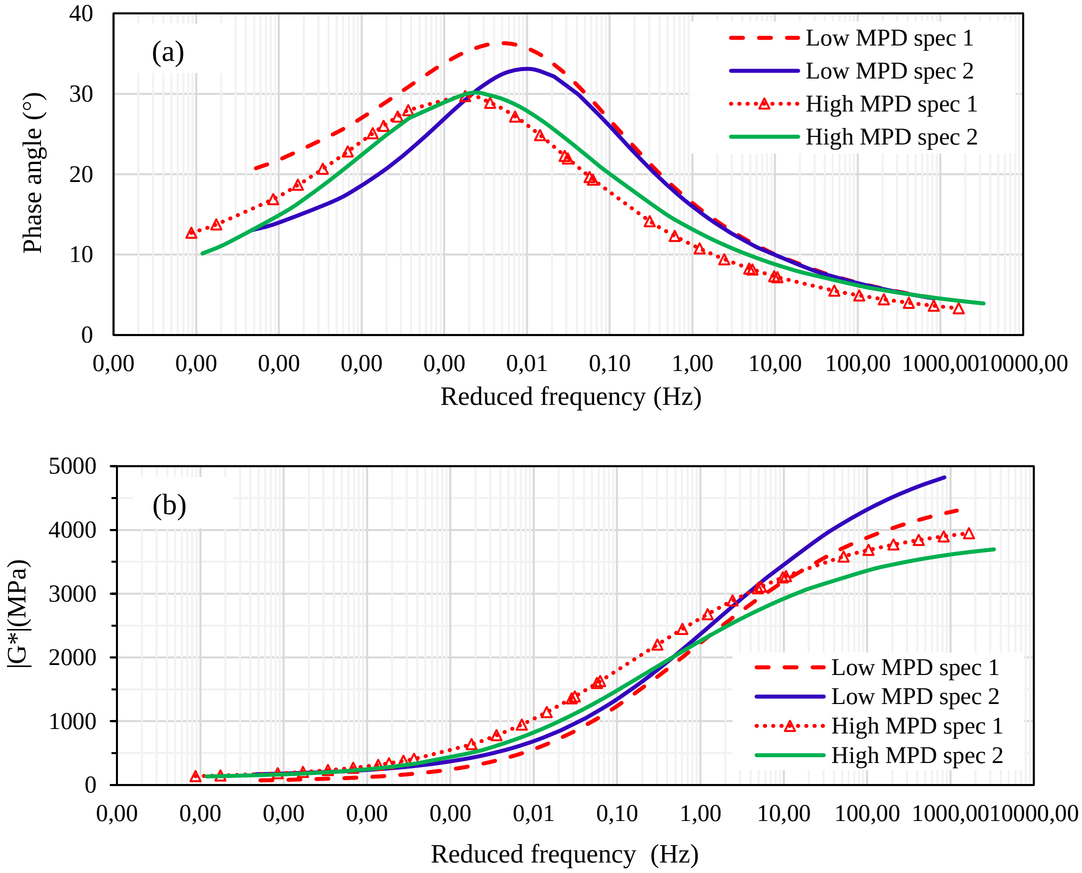


Figure 11. Master curves for (a) phase angle, (b) dynamic modulus (AC binder layer).

The master curves for phase angle, Figure 11(a), showed a higher phase angle for specimens from low MPD areas indicating a more viscous behaviour of the mix that is the result of a higher binder content. Furthermore, the master curves for dynamic modulus in Figure 11(b) demonstrated higher modulus at low temperature and high frequency regions for specimens from low MPD areas. However, at high temperature and low frequency regions, no significant differences in dynamic shear modulus between low and high MPD areas were observed. This might be due to the fact that at low temperature and high loading frequency, both the internal aggregate structure (i.e. aggregate to aggregate contact) and the binder contribute to the load-carrying mechanism, while at higher temperature and lower loading frequencies the load is primarily carried by the aggregate structure. The difference in the shear modulus between the low MPD and high MPD sections might therefore be insignificant.

Conclusions

In this study it has been demonstrated that construction quality, described by segregation (variation in air voids and MPD values) in the paved asphalt mix, has a significant impact on stiffness moduli of asphalt mixes. This is an essential parameter in pavement design and affects the moisture sensitivity performance of the pavement layers.

Construction quality described by segregation in the paved asphalt mix appears to have a significant impact on the pavement`s performance. It was found that:

- Segregated part of the pavement, as detected by having high MPD values through Laser RST measurements, shows inferior stiffness characteristics as well as higher air void contents.
- Segregated portion of the pavement having high MPD values also showed increased susceptibility to moisture during the MIST conditioning since the reduction in stiffness was most significant for samples from this location.

The correlation between the MPD values and stiffness properties and change in stiffness modulus due to moisture impact thus suggests that measurement of the MPD values may be a quick, reliable and non-destructive method for evaluating the construction quality of a pavement and in developing quality assurance criteria based on stiffness modulus measurements that can be used in paving contracts. Based on the findings of this study, it may also be recommended that the design of pavements be performed taking into account the variation in stiffness, specifically in base layers, related to segregation due to shortcomings in construction work.

A more comprehensive study would be valuable to check the possibility to use MPD measurements for evaluating construction quality, since encourage results are reported in this work, including correlation between mix composition, e.g. particle size distribution, binder content, air void content and MPD values.

References

CEN-European Committee for Standardization. (2003). Bituminous mixtures. Test methods for hot mix asphalt. Determination of void characteristics of bituminous specimens. Brussels: European Standard, EN 12697-8.

CEN-European Committee for Standardization. (2012a). Bituminous mixtures. Test methods for hot mix asphalt. Determination of bulk density of bituminous specimens. Brussels: European Standard, EN 12697-6.

CEN-European Committee for Standardization. (2012b). Bituminous mixtures. Test methods for hot mix asphalt. Stiffness. Brussels: European Standard, EN 12697-26.

Chen, X.& Huang, B. (2007). Evaluation of moisture damage in hot mix asphalt using simple performance and superpave indirect tensile tests. Construction and Building Materials, 22 (2008), 1950-1962.

Eisenmann, J. & Hilmer, A., (1987). Influence of wheel load and inflation pressure on the rutting effect at asphalt pavements – experiments and theoretical investigations. 6th International Conference on Structural Design of Asphalt Pavements. The University of Michigan, Ann Arbor, USA, Vol 1, 392-403.

Htet, Y.Z.M. (2007). An assessment of moisture induced damage in asphalt pavements. Master’s thesis, Worcester Polytechnic Institute, Worcester, United States.

ISO 1997, Characterization of pavement texture by use of surface profiles – Part 1: Determination of mean profile depth. ISO 13473-1:1997.

Karimi, S. S., Goulias, D. G. & Schwartz, C. W. (2014). Risk and expected pay factor analysis for assessing gap and dense-graded superpave mixture specifications. Journal of Pavement Engineering, http://dx.doi.org/10.1080/10298436.2014.916404.

Lundberg, T., (2012). Kontrollmetod för nya vägbeläggningar – makrotextur. VTI Notat 35-2012, Swedish Road and Transport Research Institute, Linköping, Sweden.

Mallick, R. B., Pelland, R., & Hugo, F. (2005). Use of accelerated loading equipment for determination of long term moisture susceptibility of hot mix asphalt.

International Journal of Pavement Engineering, 6:2, 125-136, DOI: 10.1080/10298430500158984.

Meegoda, J. N., Gao, S., Liu, S. & Gephart, N. C. (2013). Pavement texture from high-speed laser for pavement management system. Journal of Pavement Engineering, 14:8, 697-705.

Meegoda, J.N., Rowe, G. M., Jumikis, A. A., Hettiarachchi, C. H., Bandara, N. & Gephart, N. C. (2005). Estimation of surface macrotexture in hot mix asphalt concrete pavements using laser texture data. Journal of Testing and Evaluation, 33(5), 1-11.

Said, S., Hakim, H. & Eriksson, O. (2014). Rheological Characterization of Asphalt Concrete Using a Shear Box. *Journal of Testing and Evaluation*, Vol. 41, No. 4, pp. 602–610, doi: 10.1520/JTE20120177. ISSN 0090-3973.

Shu, X., Huang, B., Shrum, E.D., & Jia, X. (2012). Laboratory evaluation of moisture susceptibility of foamed warm mix asphalt containing high percentages of RAP. Construction and Building Materials, 35 (2012), 125–130.

Stroup-Gardiner, M. & Brown E. R. (2000). Segregation in hot-mix asphalt pavements. NCHRP Report 441. Transportation Research Board, Washington D. C., USA.

Stroup-Gardiner, M., Law, M. & Nesmith, C. (2007). Using infrared thermography to detect and measure segregation in hot mix asphalt pavements. Journal of Pavement Engineering, 1:4, 265-284.

Terrel, R.L. & Shute, J.W., (1989). Summary report on water sensitivity, SHRP-A/IR-89-003.

Varveri, A., Avgerinopoulos, S., & Scarpas, A. (2015). Experimental evaluation of long- and short-term moisture damage characteristics of asphalt mixtures. Road Materials and Pavement Design, DOI: 10.1080/14680629.2015.1066705

Zeiada, W. A., Kaloush, K. E., Underwood, B. S. & Mamlouk, M. E. (2014). Improved method of considering air void and asphalt content changes on long-term performance of asphalt concrete pavements. Journal of Pavement Engineering, 15:8, 718-730.

Zelelew, H. M., Papagiannakis, A. T.& de Leon Izeppi, E. D. (2013). Pavement macro-texture analysis using wavelets. Journal of Pavement Engineering, 14:8, 725-735.