DEVELOPMENT OF A NEW LABORATORY ACCELERATED MACHINE-MULTIVARIABLE ACCELERATED ABRASION MACHINE

W REN, S HAN*, J ZHANG and Y MA*****

School of Highway, Chang'an University, Middle Section of South Erhuan Road, Xi'an, Shaanxi 710064, China
Tel: +86 18729294225; Email: renwanyan@126.com
* School of Highway, Chang'an University, Middle Section of South Erhuan Road, Xi'an, Shaanxi 710064, China
Tel: +86 13709258916; Email: hyram_hs@chd.edu.cn
** School of Highway, Chang'an University, Middle Section of South Erhuan Road, Xi'an, Shaanxi 710064, China
Tel: +86 15091282189; Email: haoge105@163.com
** School of Highway, Chang'an University, Middle Section of South Erhuan Road, Xi'an, Shaanxi 710064, China
Tel: +86 15863316766; Email: sddzmyx@163.com

ABSTRACT

Road surface texture affects both vehicle performance and road characteristics. It affects tire/pavement noise, skid resistance, splash and spray, rolling resistance, tire wear, discomfort and wear in vehicles. Corresponding performances may change with the evolution of the road surface texture. It is important to understand the changes of the road surface. Two methods are always used to investigate the deterioration of road surface texture, laboratory accelerated/polishing machine and road surface texture measurement on road sections at certain intervals. Laboratory accelerated/polishing machine is favourable due to smaller specimens, more convenient measurement and easier environmental control. Many researchers attempt to develop laboratory accelerated machines to mimic the interaction between tire and road. Previous accelerated/polishing machines can be divided into two main types. One is to utilize tire in circular movement to shape the abraded section. The other is to use rubber pad or rollers to simulate interaction between tire and road to shape the polished section. However, little has been considered about slip rates in previous accelerated/polishing machines. In this research, a new laboratory accelerated machine, multivariable accelerated abrasion machine (MAAM), was developed. It can simulate effects of the one-way driving on the road surface texture. It can also accomplish different slip rates to simulate tire/pavement interaction more exactly.

Keywords: accelerated/polishing machine, road surface deterioration, move direction, slip rate

1 INTRODUCTION

Road surface texture can affect both vehicle performance and road characteristics. It influences many aspects of tire/pavement interaction, such as anti-skidding especially on wet roads, tire/pavement noise, rolling resistance, splash and spray and tire wear (Henry, 2000). It can cause discomfort and vehicle wear (ISO, 1997). Pavement macrotexture and micortexture have large impacts on the skid resistance and tire/pavement noise.

A number of studies have built relation between friction and road surface texture. Britton, Ledbetter and Gallaway (1975) studied the correlation between texture and skid numbers. It was found that the skid numbers were governed by three macrotexture parameters and three microtexture parameters. The six parameters can be expressed by the texture size, spacing/distribution and shape. Miao, Cao, and Liu (2011) selected six parameters: mean profile depth, skewness, kurtosis, fractal dimension, average slope and average curvature to describe asphalt pavement macrotexture through correlation analysis. A significant quadratic polynomial relation between macrotexture and skid resistance was built by the multiple regression analysis. Microtexture and macrotexture measurements were conducted on the road pavements and they are linked to the friction values (Kanafi et al., 2015).

Road surface texture has also been linked to tire/pavement noise and rolling resistance in many studies. Influence of the road surface texture on tire/pavement noise has been investigated by many researchers (Mak, Hung, & Lee, 2012; Li et al., 2014; Liao et al., 2014; Boere et al., 2009). The relationship between the surface texture and rollling resistance has also been investigated (Sohaney & Rasmussen, 2013; Boere et al., 2009; Ejsmont et al., 2017). In these researches, mean profile depth (MPD) is commonly used as a descriptors of road surfaces.

Road surface texture changes with time due to traffic loading, temperature, etc. So the tire/pavement related performances may also change. It is important to understand the evolution of the road surface texture. According to previous research, there are mainly two research methods, road surface texture measurement at certain intervals on road sections (Kanafi et al., 2015) or laboratory research by the accelerated machine. Laboratory accelerated machine has advantages of relatively smaller specimen size, lower economic cost, more convenient measurement and easier environment control. Many researchers have attempted to develop laboratory accelerated machines to conduct laboratory tests. However, slip rates and the abrasion direction of road surface are not considered in previous accelerated machines. In this research, a new accelerated machine, multivariable accelerated abrasion machine (MAAM), was developed. It covered the two limitations. The slip rate can be adjusted according to experiment design.

2 LITERATURE REVIEW- LABORATORY ACCELERATED/POLISHING MACHINE

2.1 Previous accelerated/polishing machine

Laboratory accelerated machine is a favourable way to understand the road surface texture evolution. Many relevant researches have been read. From the previous documents, five main accelerated machines have been described. They were listed in detail below. The 1/3rd scale model mobile load simulator (MMLS3) is not mentioned here because the specimen in the test is a little small when investigating the road surface performance, especially skid resistance (Shen et al.,2012).

(1) Wehner/Schulze device (W/S)

W/S machine (Figure 1, left) is a standard testing method of polishing (BSI, 2014). It has two main units. One is to realize the polishing (Figure 1, middle) and the other is to measure friction (Figure 1, right). The polishing unit is to accomplish the accelerated polishing to mimic effect of the traffic load on the road. It consists of three conical rubber rollers (Figure1. middle). They rotate at a speed of 17km/h with a contact pressure of 0.4MPa (0.2MPa for light cars). The slip rate between the cones and specimen surfaces is between 0.5% and 1% (Do et al., 2009). During the polishing process, a mixture of quartz powder(＜0.063mm) and 95% water is sprayed 5L per minutes. The surface is polished on a ring of about 16cm in diameter and 6cm in width. An annular area is shaped in the last. In the friction measurement unit, there are three rubbers in a circular path with diameter of 180mm. Each rubber is 14.5mm wide and 30mm long (Figure 1, right). Their Shore scale hardness is 65. During a friction test, they are accelerated to the speed of 100km/h and then dropped to the road surface until they decelerated to the stationary state. The friction coefficients are recorded in the process and the friction coefficient corresponding to 60km/h is often utilized to characterize friction coefficient. The repeatability of the test procedure is approximately± 0.026 according to the BS EN 12697-49. If the difference between the two specimens exceeds 0.03, a further specimen will be prepared and tested.

Figure 1 Wehner/Schulze machine (left),polishing unit (middle) and skid measuring unit (right) (BSI, 2014).

(2). Aachen Polishing Machine (APM)

APM was developed by the Institute of Road and Traffic Engineering (ISAC) at RWTH Aachen University (Figure 2, left) (Wang et al., 2015). It uses real vehicle tires. The plates are with the dimension of 32×26×4cm. In a test, two specimens are subjected to the polishing and wearing. The two plates are fixed onto a movable sled. Specimens withstand stress from a superimposed translational and rotational motion. The translational motion is accomplished by the movable sled, while the rotational motion is realized by rotating vertical axle with two wheels (Figure 2, right). Polishing and wearing are accomplished by a tire with 200kg imposed load. The inner tire pressure is 0.2MPa. The sled moves back and forth horizontally 9 times per minute. The two wheels revolve around the vertical axle 41 rotations per minutes. The middle points of the two wheels are 55cm apart, so the circular motion speed is 1.2m/s. The polishing effect on the plate is almost equal in this way. The three dimensional state of stress can be considered by the superimposed translational and rotational motion, as well as real tires. During the test, water and different polishing agents, such as quartz sand, quartz powder, are selected. Different polishing agents have different polishing results (Wang et al., 2013; Wang et al., 2015). Wang et al (2015) found that the polishing lasted 600 minutes. After 600 minutes of polishing, the two specimens reached a stable state and changed only a little or not at all through further polishing or wearing.

Figure 2 Aachen Polishing Machine (left), detail on the specimens and tire (right) (Wang et al., 2015)

(3)National Center for Asphalt Technology (NCAT) Accelerated Polishing Machine

NCAT accelerated abrasion machine is designed using three wheels attached to a turntable so that the wheels track in a circle (Figure 3, left) (Vollor, Hanson, & Brownb, 2006). The wheels are equipped with ball bearings which help to line up the wheels in a circular path. The traffic effect on the road surface is simulated by the wheel/specimen interaction. The traffic load can be imposed by the circular iron plates on the turntable, which is adjustable by adding or subtracting iron plates. Wheels and turntable are free to move up and down. A laser light counter is utilized to counter the revolutions of the turntable automatically. It is programmed to input the predetermined number of the revolutions and when the number of revolutions is obtained, the machine is stopped automatically. Tire is easily abraded and the abraded tire powder will affect the polishing process. So it’s necessary to wash away the tire powder by spraying water (Figure 3, right).

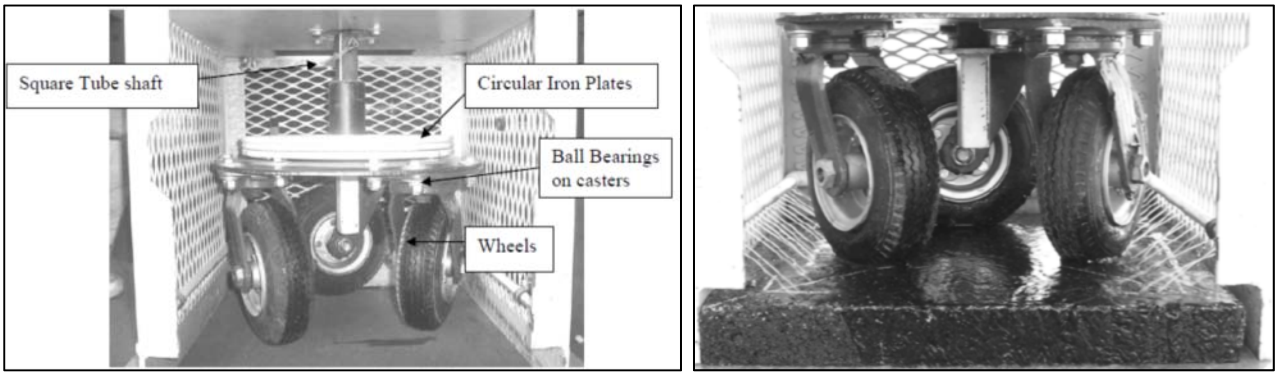

Figure 3 NCAT accelerated abrasion machine (left), water spray system(right) (Vollor, Hanson, & Brownb, 2006)

(4) Driving-Wheel Accelerated Loading System (ALS)

Driving-Wheel ALS was developed by the South China University of Technology (Figure 4, left) (Lei, 2010). In the system, a tire is driven by a motor. A circular specimen sample, consisting of eight specimens with a plane dimension of 30×30cm is driven by the rolling tire through friction effect (Figure 4, right). The tire utilized is a real motor car tire. The driven wheel depth is 5 cm, which means the specimen thickness should be between 0 and 5 cm. The whole system is in a close environment in which the temperature is controlled by a temperature sensor and heating device. Moreover, in the close system, the road aging process can be simulated by the ultraviolet light and effect of water on the road performance can be imitated by water spraying.

Figure 4 Accelerated Loading System (ALS) (left), detail on tire/specimen interaction (right) (Lei, 2010)

(5)Ohio accelerated polishing machine

Ohio accelerated polishing machine (Figure 5, left) was developed by the Ohio Department of Transportation (Liang, 2013). The polishing machine allows for pressing a polishing pad made of styrene-butadiene-rubber (SBR) onto road surface at a constant vertical load. The rubber pad is rotated at a predetermined rotational speed. The machine can accommodate two specimen dimensions: 45.72×45.72×5.08cm, and cylinder with 15.24cm in diameter by 10.16cm in height. The former is compacted by the roller. The latter is shaped by the Superpave Gyratory Compactor. In order to accommodate different sizes of specimens, the rubber pad is designed differently. For the gyratory compacted specimen, a solid rubber disc with a diameter of 15.24 cm and a width of 3.81 cm (Figure 5, right) is designed, while for the roller compacted specimen, a rubber ring with an outer diameter of 33.02cm and an inner diameter of 22.86cm (Figure 5, middle) is shaped. After polishing, an annular polished area is shaped. This is done to fit with the required area for Dynamic Friction Tester (DFT) and Circular Texture Measurement (CTM) device.

Figure 5 Overall view of Ohio accelerated polishing machine (left), slab specimen mounting (middle), gyratory compacted specimen mounting (right) (Liang, 2013**)**

In a research conducted in France to investigate the evolution of the road surface (Ech et al., 2007), a simple accelerated polishing machine was developed similar with what is described above. Road surface modification is achieved by imposing the repeated sinusoidal loading at controlled temperature on a rubber cylindrical membrane.

Besides what is described above, there are other standard test processes to test aggregate polishing or wearing properties. Polished stone value (PSV) is the friction coefficient of aggregate after polishing. It is specified in T 0321-2005 in the Chinese specification JTG E42-2005 (Ministry of Transport of the People's Republic of China (MOT of P.R.C.), 2005). The abrasion characterization method of aggregate is the Micro-Deval (MD) test or the Los Angeles Abrasion Machine. They are all used for aggregates.

2.2 Summary of previous accelerated polishing machine

From previous research, accelerated polishing machines can be divided into two main types. One is using rubber pads or rollers to shape polished area. The other is to use real tire to simulate the interaction between the tires and road specimens.

Previous accelerated polishing machines have the following characteristics:

(1) Most or even all the machines polish the specimens in circular motion. This is not compatible with real conditions. In most cases, cars drive on the road in straight line.

(2) Driving direction, for example one-way driving or two-way driving, is not considered in previous accelerated polishing machines. In fact, road surface related properties may be different under one-way and two-way driving conditions. So, it will be perfect if the driving direction can be considered.

(3) From previous accelerated polishing machines, we can know that the slip rate is not considered. However, slip rate affect the road surface evolution. This may be why many places where cars accelerate or decelerate frequently, such as parking lots, road surface problems develop easily.

In this research, a new accelerated polishing machine, covering the above mentioned existing problems, is developed. It is named multivariable accelerated abrasion machine (MAAM).

3 A NEW DEVELOPED ACCELERATED MACHINE-MAAM

3.1 Research aim of the MAAM

The aim of developing MAAM is attempting to overcome existing problems of the previous accelerated polishing machines so that the MAAM can be closer to a real tire/pavement interaction state. In this research, the slip rate and the driving direction are considered. The solid rubber wheel, driven by electric motor, moves in a single direction, which is in accordance with channelization. The slip rate is adjustable according to necessity.

3.2 Mechanism and composition of the MAAM

The MAAM was developed by the Highway and Airport Pavement Research Center (HAPRC) in Chang'an University (Han et al., 2017). Its overview appearance is shown in Figure 6, left. Its control system is shown in Figure 6, right. The MAAM is made of two main parts. One is the solid tire driving system. The other is the braking system by which the slip rate can be set. This means two motors are used in this MAAM. The slip rate is calculated by the diameter of the solid tire with internal iron wheel hub, speed reducer ratios, gear ratios, and motor speeds. In the driving system, the motor system, including motor speed, gear ratio and speed reducer, is kept stable. The solid tire is driven by the crank gear whose power is from the motor from the source. The other system is controlled by a small motor to conduct the decelerating process, by which the slip rate is produced. In the control system, the slip rate is characterized by the small motor in the braking system. Different slip rates are obtained by adjusting the different speeds of the small motor in the braking system.

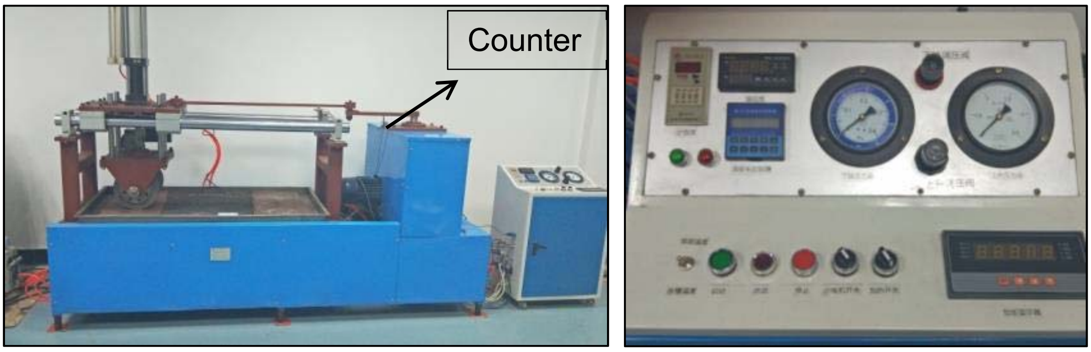

Figure 6 Overall appearance of the MAAM (left), control system (right)

In the MAAM, the one-way driving is achieved by the cylinder system. The cylinder system needs air pump. During the accelerated abrasion process, the cylinder system moves along two tracks. At both ends of a track, there existed a sensor which leads the cylinder system to lift/load the tire, and turns the moving direction (Figure 7). When the tire moves to the left side of the track, the left sensor (Figure 7, left) leads the cylinder system to lift the tire. When it moves to the right side, the right sensor (Figure7, right) leads the cylinder system to impose load on the tire. The load is controlled in the control system and can be predetermined. A switch of the small motor is also installed at each side of the track (Figure 7). It controls the solid tire rolling conditions. A counter is installed under the right arm of the crank (Figure 6, left). The number of round trips of the tire is displayed in the controlled system. The number of round trips can be predetermined and the motion is stopped when the round trip number reaches the predetermined value.

Figure 7 Sensors on the left side (left), sensors on the right side system (right)

3.3 Description of the control system

The control system includes the slip rates (speed of the small motor), the counter, the imposed load (imposed cylinder pressure), lifting up cylinder pressure and temperature. All the numbers of controlled system can be displayed on the dial (Figure 6, right). The mechanisms of the slip rates, counter, the imposed load and the lifting up load have been described. The temperature on the dial can be the water temperature in the tank in which the specimen is immersed or the heating temperature for the heating plate. There is a button to choose test temperature and it will be displayed on the dial. This means there are two temperature sensors in corresponding places. One is to control the water bath temperature and the other is to control the heating plate temperature. The heating plate is to heat the tank and attempt to investigate the influence of the temperature on the road performance. It is installed under the tank, which is to contain the specimens.

A close environment environmental cabinet is currently being developed. When it is finished, the environment of accelerated abrasion machine can be easily controlled.

3.4 Parameters of the developed MAAM

In the research, the width of the wheel is 245mm and the diameter with the internal wheel hub is also 245mm. The width of the tire is determined from two aspects: width of commonly used motor cars and the accelerated polishing width to conduct other tests, such as a laboratory tire/pavement noise measurement method. The detailed information of the test tire is shown in Table 1.

Table 1 Information of the tire

Items	Wheel diameter （mm）	Tire width （mm）	Tire thickness （mm）	Tire international standard hardness	
				20℃	60℃
Results	245	245	50	84±4	78±2

According to the preliminary test, the slip rate should be controlled within 40% due to limited power in the decelerating process and power transmission. The maximum travelling speed is 12.5 round trips per minute. The upper speed is limited by the cylinder system, sensor response, as well as great shock and vibration of the system. The travelling direction change by the sensor needs response time and this restricts the upper speed greatly.

3.5 MAAM abrasion effect

The MAAM is utilized to accelerate the road surface abrasion. Its abrasion effect test was conducted on a Stone Mastic Asphalt (SMA) slab preliminarily. The slip rate was set as 15%, and the imposed load of the cylinder system was 0.3MPa, which can make the contact pressure near 0.7MPa. The Mean Profile Depth (MPD) was tested at certain load passes interval (1000 passes interval before 7000 total passes and 2000 passes interval after that). The MPD was obtained by the Laser Texture Scanner according to the specification (ISO, 1997). In this research, almost the same place and the same area 104×72.01mm, was scanned after polishing. 163 lines with a length of 104mm was obtained by the scanner. The average MPD of the 163 lines was used to characterize the road surface texture. MPD changes with the increase of load passes and this is shown in Figure 8. In the polishing process, at first, we add no polishing agent on the SMA slab. The polishing effect is not evident. This happened in the first 5000 passes. Later we added river sand of 50g per 2000 passes (from 5000 to 12000 passes) and quartz sand (from12000 to 19000 passes) to accelerate the polishing process. The abrasion is evident and this may be related with the imposed load of 0.3MPa, a slip rate of 15%, as well as polishing agent. The original slab surface and abrasion effect at 19000 load passes are shown in Figure 9.

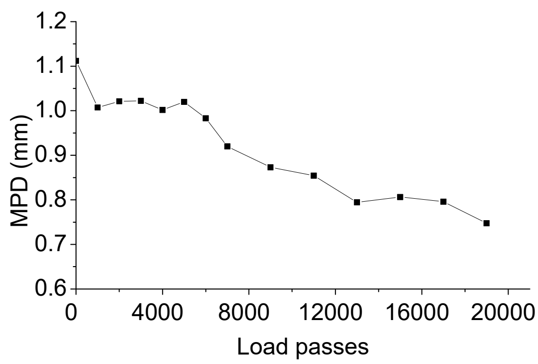

Figure 8 MPD deterioration with load passes

Figure 9 Before abrasion (left), abrasion effect at 19000 load passes (right)

4 CONCLUSIONS AND DISCUSSIONS

In this research, previous accelerated/polishing machines are summarized and their characteristics are compared. They all have features in common that the motion direction and slips rates are not considered. Therefore, a new MAAM is developed and the above shortcomings are overcome in the MAAM. In the MAAM, slip rates, lifting up cylinder pressure, counter number, temperature, imposed load are all displayed in the control system. The repeatability has not been verified. The specimen dimension is $50\times50\times5$cm， which is compacted via a single-drum walk-behind roller. It is found that the specimen surface should be flat; otherwise, some areas will not be abraded by the accelerated abrasion machine. This has strict requirements on the specimen fabrication. More feasibility tests and repeatability tests are needed to refine the MAAM.

ACKNOWLEDGEMENTS

The authors are grateful for financial support from National Natural Science Foundation of China (grant number 51578076). The authors also would like to give sincere thanks to Professor Fwa for providing constructive suggestion.

REFERENCES

Boere, S.W., Arteaga, I.L., Nijmeijer, H., & Kuijpers, A.H.W.M. (2009). Prediction of road texture influence on rolling resistance and tyre/road noise. Proceedings of Euronoise 2009. Edinburgh, Scotland.

Britton, S.C., Ledbetter, W.B., & Gallaway, B.M. (1975). Estimation of skid numbers from surface texture parameters in the rational design of standard reference pavements for test equipment calibration. Journal of Testing and Evaluation, 2(2), 73-83.

BSI. (2014). Bituminous mixtures—Test methods for hot mix asphalt—Part 49: Determination of friction after polishing. Standard NO. BS EN 12697-49, British Standards Institution.

Do, M.T., Kane, M., Tang, Z., & Larrard, F.D. (2009). Physical model for the prediction of pavement polishing. Wear, 267(1–4), 81-85.

Ech, M., Morel, S., Yotte, S., Breysse, D., & Pouteau, B. (2007). Laboratory evaluation of road surface macrotexture durability. Loizos, Scarpas & Al-Qadi eds.,"Advanced Characterisation of Pavement and Soil Engineering Materials," London, 1483-1493.

Ejsmont, J.A., Ronowski, G., Świeczko-Żurek, B. & Sommer, S. (2017). Road texture influence on tyre rolling resistance. Road Materials and Pavement Design, 18(1), 181-198.

Han, S., Zeng, G., Niu, L., Ren, W., Ma, Y., & Gao, W. (2017). Low speed accelerated polishing machine with variable slip rates. Patent No. CN106872355A

Henry, J.J. (2000). Evaluation of pavement friction characteristics. Transportation Research Board. NCHRP Synthesis of Highway Practice 291. Washington, D.C. 2000.

ISO. (1997). Characterization of pavement texture by use of surface profiles—Part 1: Determination of Mean Profile Depth. Standard NO.13473-1, International Organization for Standardization.

MOT of P.R.C. (2005). Test methods of Aggregate for Highway Engineering JTG E42-2005. Beijing: China Communication Press.

Kanafi, M.M., Kuosmanen, A., Pellinen, T.K., & Tuononen, A.J. (2015). Macro- and micro-texture evolution of road pavements and correlation with friction. International Journal of Pavement Engineering, 16(2), 168-179.

Lei, C. (2010).Study on pavement surface function accelerated loading system. Ph.D. Dissertation, South China University of Technology, Guangzhou.

Li, M., Keulen, W.V., Ven, M.V.D., Molenaar, A., & Tang, G. (2014). Investigation on material properties and surface characteristics related to tyre–road noise for thin layer surfacings. Construction and Building Materials, 59(3), 62-71.

Liang, R.Y. (2013). Long term validation of an accelerated polishing test procedure for HMA pavements (No. FHWA/OH-2013/3). Ohio Department of Transportation, Research.

Liao, G., Sakhaeifar, M. S., Heitzman, M., West, R., Waller, B., Wang, S., & Ding, Y. (2014). The effects of pavement surface characteristics on tire/pavement noise. Applied Acoustics, 76(1), 14-23.

Mak, K.L., Hung, W.T., & Lee, S.H. (2012). Exploring the impacts of road surface texture on tyre/road noise – A case study in Hong Kong. Transportation Research Part D Transport & Environment, 17(2), 104-107.

Miao, Y.H., Cao, D.W., & Liu, Q.Q. (2011). Relationship between surface macrotexture and skid resistance of asphalt pavement. Journal of Beijing University of Technology, 37(4), 547-553.

Shen, A.Q., Guo, Y.C., Che, F., Yin, W. & Li, Y.L. (2012) Influence of asphalt mixture segregation on long-term high temperature performance of asphalt pavement based on MMLS3 test. China Journal of Highway and Transport, 25(3):80-86.

Sohaney, R.C., & Rasmussen, R.O. (2013). Pavement texture evaluation and relationships to rolling resistance at MnROAD (No. MN/RC 2013-16). Department of Transportation, Research Services Section.

Vollor, T.W., Hanson, D.I., & Brownb, R. (2006). Development of laboratory procedure for measuring friction of HMA mixtures–Phase I. Final report of NCAT, (06-06).

Wang, D., Chen, X., Xie, X., Stanjek, H., Oeser, M., & Steinauer, B. (2015). A study of the laboratory polishing behavior of granite as road surfacing aggregate. Construction and Building Materials, 89, 25-35.

Wang, D., Chen, X., Yin, C., Oeser, M., & Steinauer, B. (2013). Influence of different polishing conditions on the skid resistance development of asphalt surface. Wear, 308(1–2), 71-78.