Evaluating the asphalt pavement's surface characteristics by field testing

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Abstract
Pavement management systems are crucial because of monitoring the current pavement condition to supply safe, efficient, comfortable and durable riding surface for vehicles. Driving safety is the most important issue, which is closely related to pavement surface texture. The texture of the pavement surface and its ability to resist the polishing effect of heavy traffic is an important parameter in providing necessary skidding resistance during the service life. In this study, 4 different asphalt pavement sections located in Izmir/TURKEY which having different traffic characteristics were investigated every three months for two years aiming to evaluate the effect of traffic volume on the surface textural and frictional properties of the pavement. The textural properties were evaluated using sand patch test (SPT) and a 3D Laser Scanning System (LSS), while Dynamic Friction Tester (DFT) was employed to assess the frictional properties. As a result, lower Mean Texture Depth (MTD) and Mean Profile Depth (MPD) values were obtained for the increased traffic volumes. High correlation was derived between macro and micro textural properties of the asphalt pavement. Additionally, the textural and frictional properties were found highly related for the investigated asphalt pavement surfaces.

Keywords: Skid resistance; Friction resistance; Pavement surface texture; Mean texture depth; Mean profile depth.

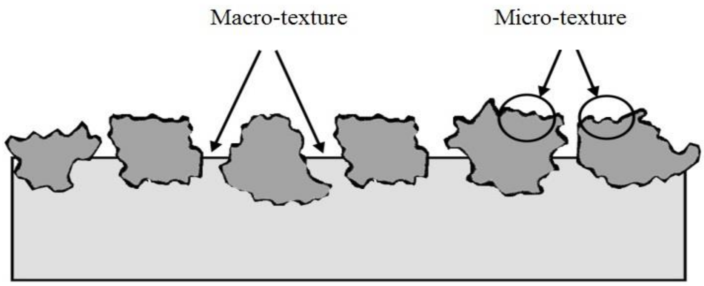
Introduction

Pavement design is not only important in terms of construction costs but also plays a major role in safety of users. Increased traffic volume as well as adverse weather affect the textural properties of surfaces negatively, which in turn causes an unsafe driving condition. For the past two decades, road users have been in expectation to have a safe and environmentally friendly roads due to the increased consciousness. National highway authorities are responsible to promote safe driving for the drivers, passengers and pedestrians (Araujo, Bessa, & Branco, 2015; Li & He, 2016).Therefore, traffic volume and climate condition should be considered while designing the pavement.

Skid resistance, which is the force developed with the friction values of the pavement surface and the tire of the vehicle, can be classified as the most important surface parameter contributing road safety (Buddhavarapu, Smit, & Prozzi, 2015; Montella & Imbriani, 2015). Reduced friction resistance of the pavement surface is directly related with longer braking distance, which can cause serious accidents especially on rainy weather. Based on the significance of the friction value this parameter should be considered both during the design and construction phases and especially controlled regularly during the service life of the road.

Skid resistance, which is identified as the deviation of a true planar and smooth surface, depends on micro and macro surface texture properties of the pavement (Hu et al., 2016; Kane, Artamendi, & Scarpas, 2013; Kogbara, Masad, Kassem, Scarpas, & Anupam, 2016). Microtexture refers to the small scale texture of the pavement aggregate component and it is characterized by wavelengths shorter than 0.5 mm and peak to peak amplitudes usually between 0.001 and 0.5 mm. On the other hand, macro texture of the pavement refers to the large scale texture and it is characterized by wavelengths between 0.5 and 50 mm and peak to peak amplitudes usually between 0.1 and 20 mm. Figure 1 demonstrates the macro and micro texture properties of pavement surface (Flintsch, De León, McGhee, & AI-Qadi, 2003).

Figure 1. Macro and micro texture properties of pavement surface (Flintsch, De León, McGhee, & AI-Qadi, 2003).



It is possible to say that, macrotexture is affected by gradation and aggregate size while microtexture is by the roughness of the aggregate particles. Friction resistance controls the contact between the tire and the pavement surface and it is generally related to the microtexture of the surface at low vehicle speed (Do, Tang, Kane, & de Larrard, 2007). Macrotexture of the pavement carries out the drainage of water from the surface, hence it prevents the loss of skid resistance with increasing speed which is very important for traffic safety (Hall et al., 2009). A comprehensive study, conducted by American Association of State Highway and Transportation Officials (AASHTO), indicated that pavement serviceability is related with the roughness of the surface (Sollazzo, Fwa, & Bosurgi, 2017). For this reason, it is suggested that, pavement surface properties should be monitored regularly during the service life.

Devices, employed for measuring pavement surface frictional resistance, are divided into two groups. The first group consists of the devices which are capable of high speed measurement, while the second group involves the measurement systems at low speed. First group includes methods such as; Full-Scale Tire, Side Force Friction Meter, Variable Slip Technique. On the other hand, Stopping Distance Meter, Deceleration Rate Meter, British Pendulum and Dynamic Friction Tester are the examples of the measurement systems at low speed (Ergun, Iyinam, & Iyinam, 2005). Pavement surface texture and skid resistance measurements have always been an interesting topic for researchers. Macrotexture measurement techniques commonly include the following standards: Sand Patch Test (SPT) (ASTM E965-96), Outflow Meter Test (ASTM E2380-M-09), and Circular Texture Meter (CTM) (ASTM E2157-01). In recent years, with the advances in computing and laser technologies, new methods have been developed to measure the pavement surface texture. The mini-texture-meter, the Selcom laser system and the noncontact high speed optical scanning technique are the examples of these novel systems, which measure the surface texture with different techniques (Gao, Liu, Wang, Xie, & Jia, 2019; F. G. Praticò & Astolfi, 2017; Sengoz, Topal, & Tanyel, 2012). Previous studies have depicted the relation between the surface texture and skid resistance. Britton et al. investigated the effect of pavement texture between the vehicle tire and the pavement friction. Based on their findings, they concluded that skid numbers (SN) are governed by six texture parameters which depends on the texture size, shape, distribution or spacing (Britton, Ledbetter, & Gallaway, 1974). Another study, conducted by Hu et al., indicated the effect of differences on microtexture and macrotexture of pavement surfaces on the peak brake coefficients of a standard test tire (Hu et al., 2016). Sengoz et al. (2012) produced calibration curves for 3D Laser Scanning System (LSS) by evaluating average profile depths obtained from the trial pavement segment by using 3D Laser Scanning Systems (LSS) and the Sand Patch Test (SPT) (Sengoz, Topal, & Tanyel, 2012).

Friction indices have been used in road engineering for years, PIARC sponsored an international friction harmonization study made in 1990. One of the main results of the PIARC experiment was the development of the International Friction Index (IFI). IFI can be defined simply as a statistical model, which describes the correlation between the speed constant and the pavement macrotexture (Fuentes, Gunaratne, de León Izeppi, Flintsch, & Martinez, 2012).

In this study 4 different flexible pavements, having different traffic volume and heavy vehicle profiles, have been measured every three months for two years to estimate the effects of traffic characteristics on the textural and frictional surface of the pavement. The mean profile depth (MPD) and the mean texture depth (MTD) of the pavement surfaces were monitored by employing the 3D LSS and SPT respectively in order to evaluate the texture properties of the pavement surfaces, while the frictional properties were measured by using (DFT).

Materials and Methods

Experimental

During the field measurements stage, 3D LSS was utilized to quantify the MPD values based on ASTM E 1845–09 standard, the SPT was applied to measure MTD values based on ASTM E 1845-09 standard and DFT was employed to survey friction indices of the test pavement. All the measurements were done at the similar weather conditions in order to eliminate the weather effect.

3D Laser Scanning System (LSS)

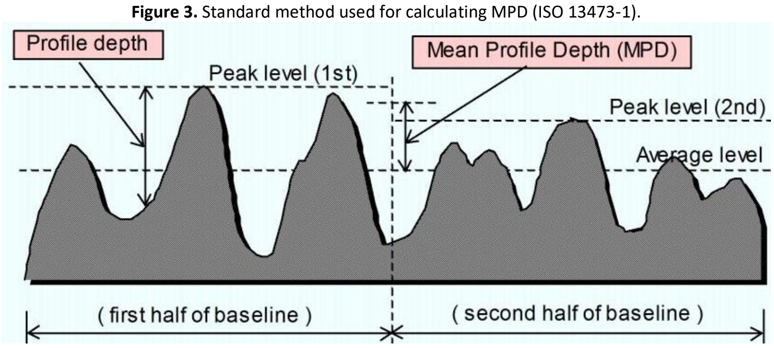
Advances in measuring devices make the measurement techniques faster and more reliable. 3D laser scanning system, developed in recent years, provides scanning and monitoring of macrotexture of the pavement surfaces. Metris Model Maker D100 3D laser scanner with enhanced sensor is designed based on ASTM E 1845–09 standard (Figure 2). This device was employed aiming to examine the full range of colors and depths on asphalt pavement surfaces.

Figure 2. Laser scanning system.

The system includes a 6-axis tool holder, a line laser scanner, data collecting system, and a built-in USB output to transfer scanned data to the portable computer in order to execute additional processing by software package which accompanies the device to give out MPD values. The MPD values can be computed from a sample baseline divided into two equal halves as presented in Figure 3. The following equation presents the computation of MPD value.

$$MPD = \frac{Peaklevel(1st) + Peaklevel(2nd)}{2} \quad (1)$$

Figure 3. Standard method used for calculating MPD (ISO 13473-1).



The laser scanner adapts the laser power to match the surface characteristics of pavement with enhanced scanning performance. During the scanning process, the laser device automatically controls the changes in surface conditions based on the color and reflectivity of the bitumen, based on the results, it adjusts the laser power and sensor settings accordingly.

Sand Patch Test (SPT)

Sand Patch Test (SPT) (ASTM E 965, 96), has been historically used as the main technique for measuring pavement macrotexture (Uz & Gökalp, 2017). The principle is fairly obvious, greater texture will require more sand to be taken up and smaller circle will be achieved from the standard quantity of sand. The texture depth of the surface on which the SPT is performed, is represented by MTD value. 25 mm^3 of fine glass beads (75µm in dimensions) are spread over cleaned surface in order to form a circle. The average diameter of the circle is measured in order to calculate the MTD values by using the Equation 2. The test results are effected by weather conditions, granulometer diversity or the shape of glass beads etc. (Choubane, 2007).

$$Avg.MTD = \frac{4V}{\Pi D^2 avg} \tag{2}$$

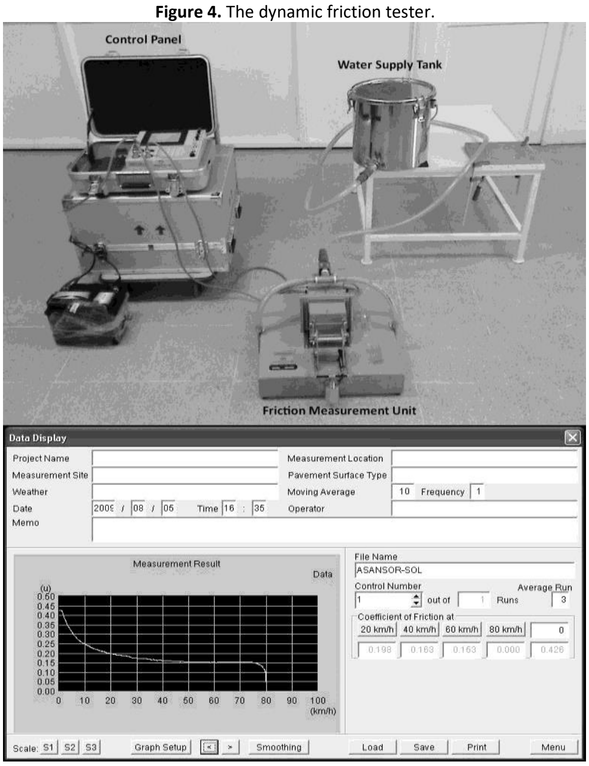
Where; V = Volume of glass spheres, mm3

D_{avg}= Average diameter of the circles, mm

Dynamic Friction Tester (DFT)

The DFT is a portable instrument for measuring pavement surface friction as a function of the speed under various conditions. The instrument is comprised of a measuring unit and a control unit; x-y plotter which can be used to record data and a water tank that is used in order to administer water at speed of 3.6 l/min. Electronic devices are employed to determine rotational speed, rotational torque, and downward load. The measuring unit consists of a disc made to rotate horizontally at a specified velocity (5 to 89 km/h) before being lowered onto a wetted test surface for measurement of friction. A relationship graph between the speed and the friction can be plotted by using the data recorded at 20, 40, 60, and 80 km/h. Figure 4 presents the segments of the DFT device. Friction at 20 km/h is usually taken into account for evaluation purposes and recorded as DFT20 value.

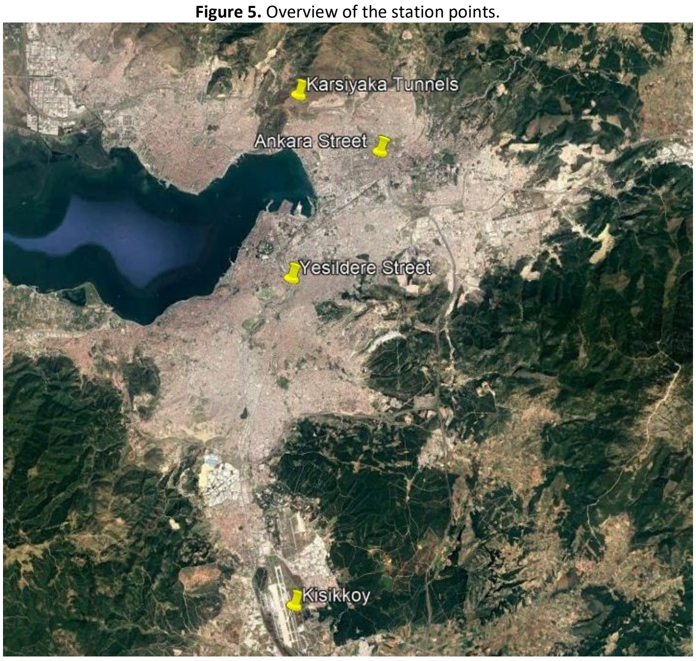
Figure 4. The dynamic friction tester.



Selection of Station Points

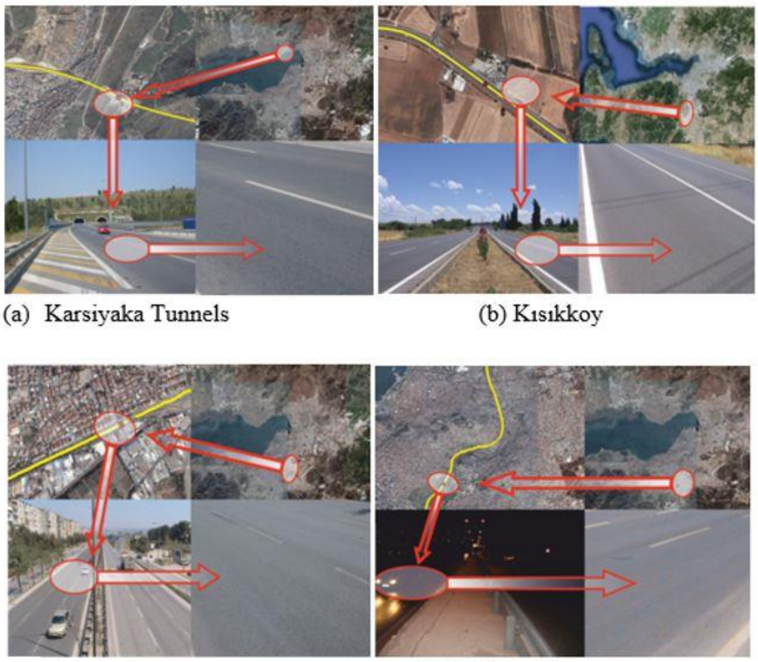
Considering the condition of the pavement surfaces and the probability of gathering continuous data, attention was paid to select different station points in Izmir/Turkey. The observation points, which should be critical in terms of traffic safety, were determined by the General Security Directorate of Izmir based on traffic accident reports. In the scope of this study, four different station points with similar flexible pavements (dense graded hot mix asphalt) were selected named as; Karsiyaka Tunnels, Kisikkoy, Yesildere Street and Ankara Street. Figure 5 presents a general view of the location of the investigated test pavement sections.

Figure 5. Overview of the station points.



The first observation point, Karsiyaka Tunnels, is located at the North of Izmir with 3 lanes at each direction and has been in service since 2007. Yesildere Street is about 4.5 km long, 25 m wide and provides the traffic from North side to Westside of the city. Ankara Street is a multilane divided road (2x3), which is about 6.7 km, and connects Izmir to the eastern side of Turkey. Kisikkoy is a highway having four lane (two ways for each direction) with 15 m wide. Figure 6 presents the detailed investigated sections with asphaltic overlays.

Figure 6. Station points in Izmir.



(a) Karsiyaka Tunnels (b) Kısıkkoy

(c) Ankara Street (d) Yesildere Street

Detailed traffic observations were made on the test sections via video camera. The types of vehicles were converted to passenger car unit. The cumulative values were taken into account for every 3 months. Figure 7 depicts the cumulative traffic volume (CTV) values of all observations points in terms of passenger car unit.

As seen in Figure 7, Yesildere Street has the highest CTV value among all observation points, while Karsiyaka Tunnels has the lowest one. Each test pavement has been manufactured with hot mix asphalt (HMA) wearing course with the aim of serving different level of service. The material properties of the pavements; such as bitumen properties and aggregate gradation, are the same for all station points, which ensure the possibility of accurate comparison. The type of the aggregate is limestone and chosen in conformity with the Type I wearing course of Turkish Specifications. The bitumen with 50/70 penetration grade supplied from Izmir Aliaga Petroleum Refinery was used as a binding material. The physical properties of the aggregate and the bitumen belonging to each station points are presented in Table 1-2 respectively.

Figure 7. Traffic volume (v/h) versus measurement period per each station point.

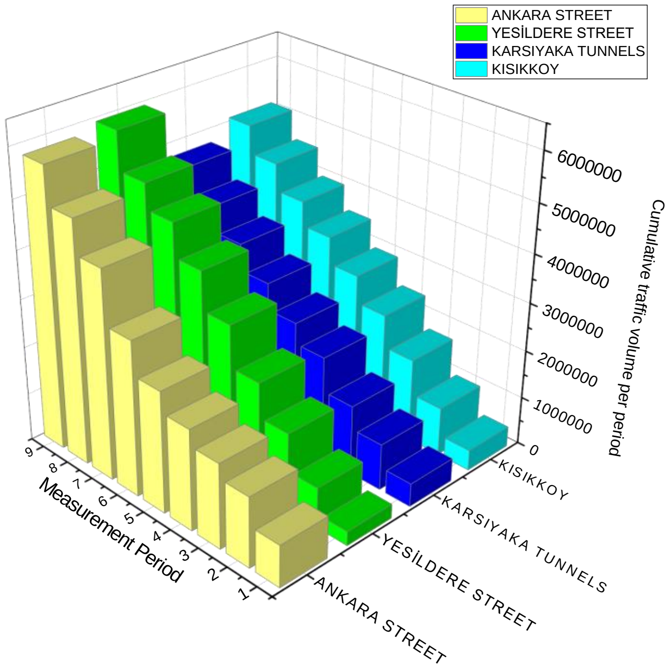


Table 1. Properties of limestone aggregates.

Test	Specification	Specification limits
Specific Gravity (Coarse Agg.)	ASTM C127	
Bulk		-
SSD		-
Apparent		-
Specific Gravity (Fine Agg.)	ASTM C128	
Bulk		-
SSD		-
Apparent		-
Specific Gravity (Filler)		-
Los Angeles Abrasion (%)	ASTM C 131	max. 45
Flat and Elongated Particles (%)	ASTM D 4791	max. 10
Fine Aggregate Angularity	ASTM C 1252	min. 40

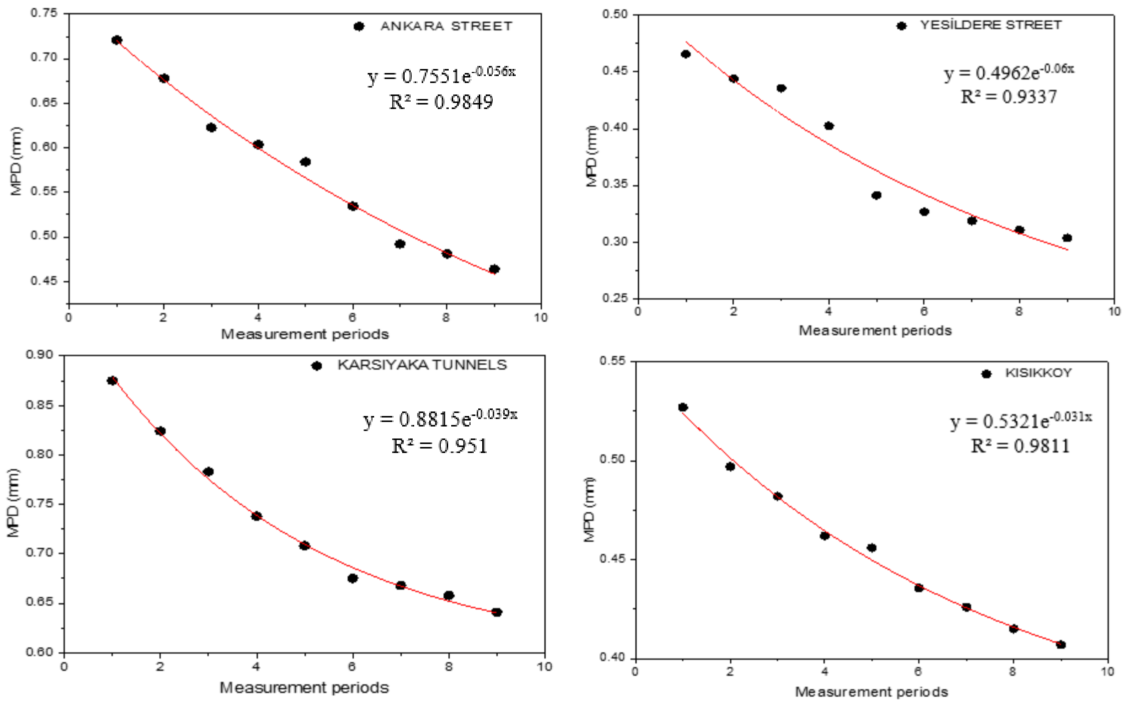
Table 2. Properties of the base bitumen with 50/70 penetration grade.

Test	Specification	Specification limits
Penetration (25 °C; 0.1 mm)	ASTM D5, EN 1426	50 – 70
Softening Point (°C)	ASTM D36, EN 1427	46 – 54
Viscosity at (135 °C)-Pa.s	ASTM D4402	-
Thin Film Oven Test (TFOT) (163°C; 5 h) Change of Mass (%)	ASTMD1754, EN 12607-1	0.5 (max.)
Retained Penetration after TFOT (%)	ASTM D5, EN 1426	-
Softening Point Diff. after TFOT (°C)	ASTM D36, EN 1427	48 (min)
Ductility (25°C)-cm	ASTM D113	-
Flash Point (°C)	ASTM D92, EN 22592	230 (min)

Results

MTD values of the investigated test sections obtained by SPT and MPD values obtained by LSS are presented in Figure 8 and Figure 9 respectively.

Figure 8. MPD values for all station points' pavement during measurement periods.



Based on the results, the decrease in the MPD and the MTD values were depicted throughout the measurement periods. The trend lines were drawn exponentially and regression coefficient together with equations, which shows the correlation between the axis, are presented on the graphs. The minimum decrease of MTD (30%) and MPD (33%) values were observed at Kisikkoy station. This result can be clarified by having the most oxidized pavement surface because Kisikkoy is the oldest station point among the others in terms of service life. The maximum decrease (57% for MTD, 37% for MPD) was obtained at Yesildere Street. This can be explained by the increased cumulative traffic volume. The more the cumulative traffic volume the more the abrasion of the surface which results in decreased MTD and MPD values. In order to evaluate this effect, the variation of MPD values (the percentage of the MPD value corresponding to measurement period to initial value) together with CTV rate (the ratio of the cumulative CTV value corresponding to measurement period to initial value) were drawn (Figure 10-a). Figure 11-a indicates that the higher increment in CTV values resulted in higher drop in MPD rate in the same manner as in CTV values. The MPD variation and CTV rate were investigated again together in Figure 10-b. As seen from Figure 10-b, these two values were highly correlated with each other (R^2=0.96~0.99) for test stations.

Figure 9. MTD values for all station points' pavement during measurement periods.

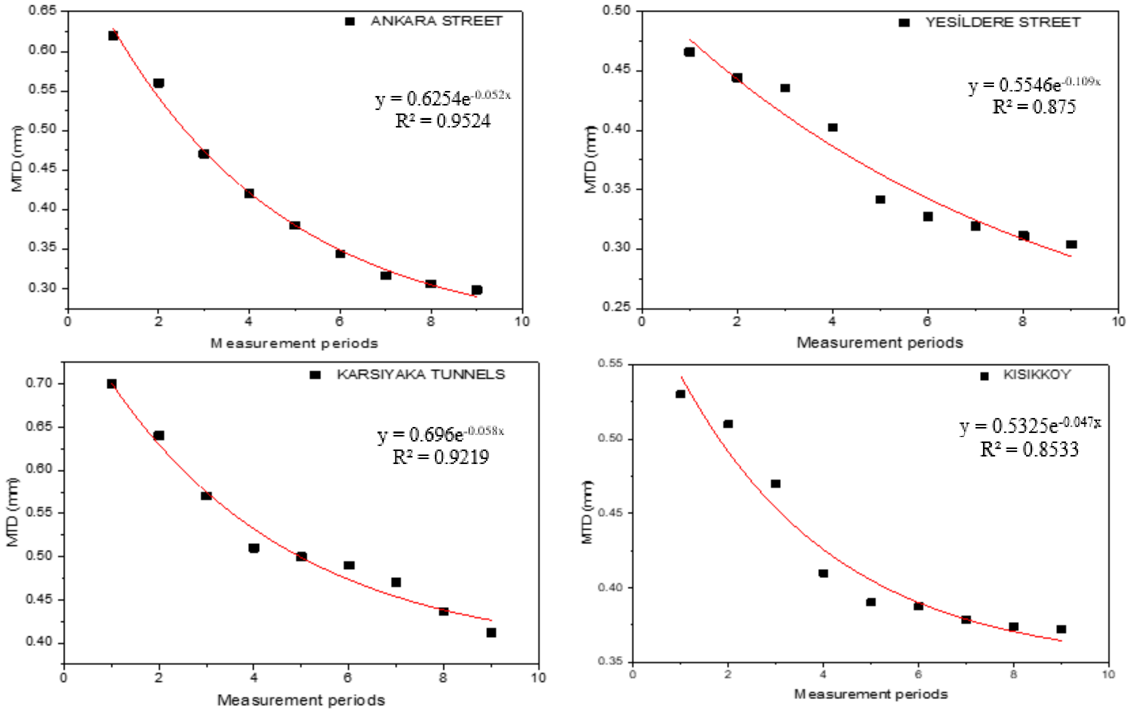
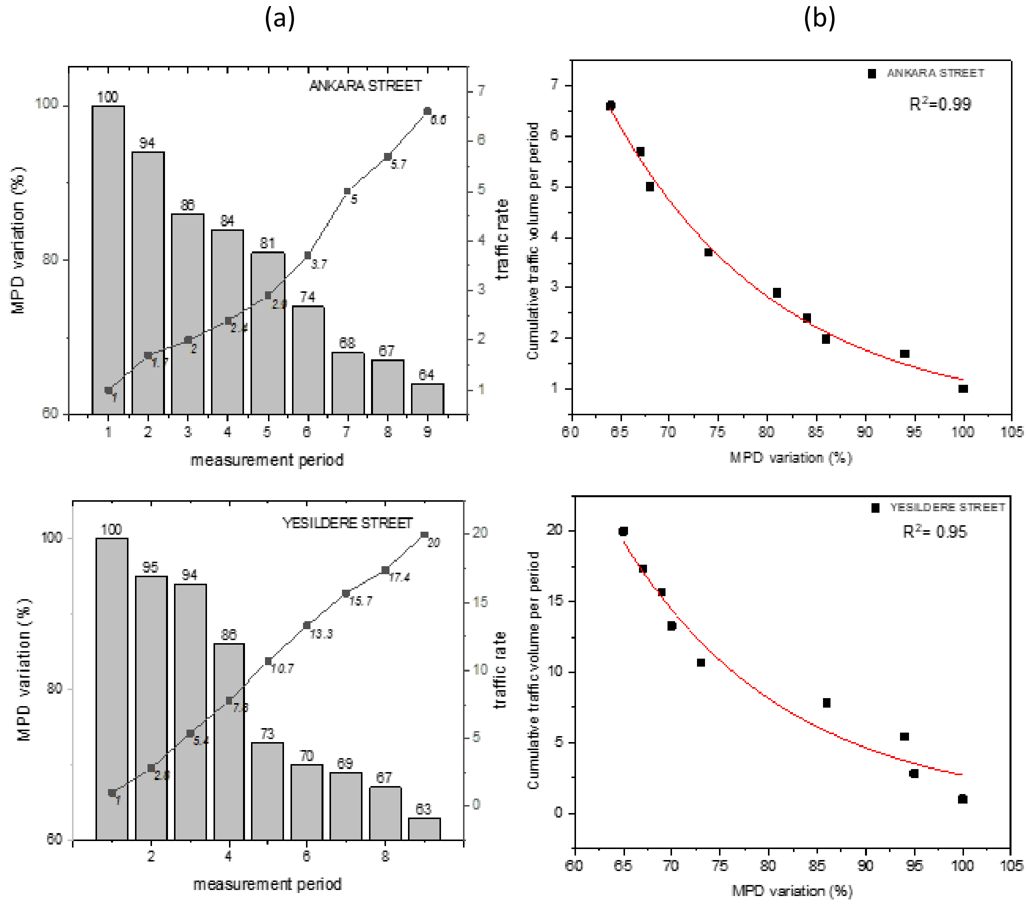
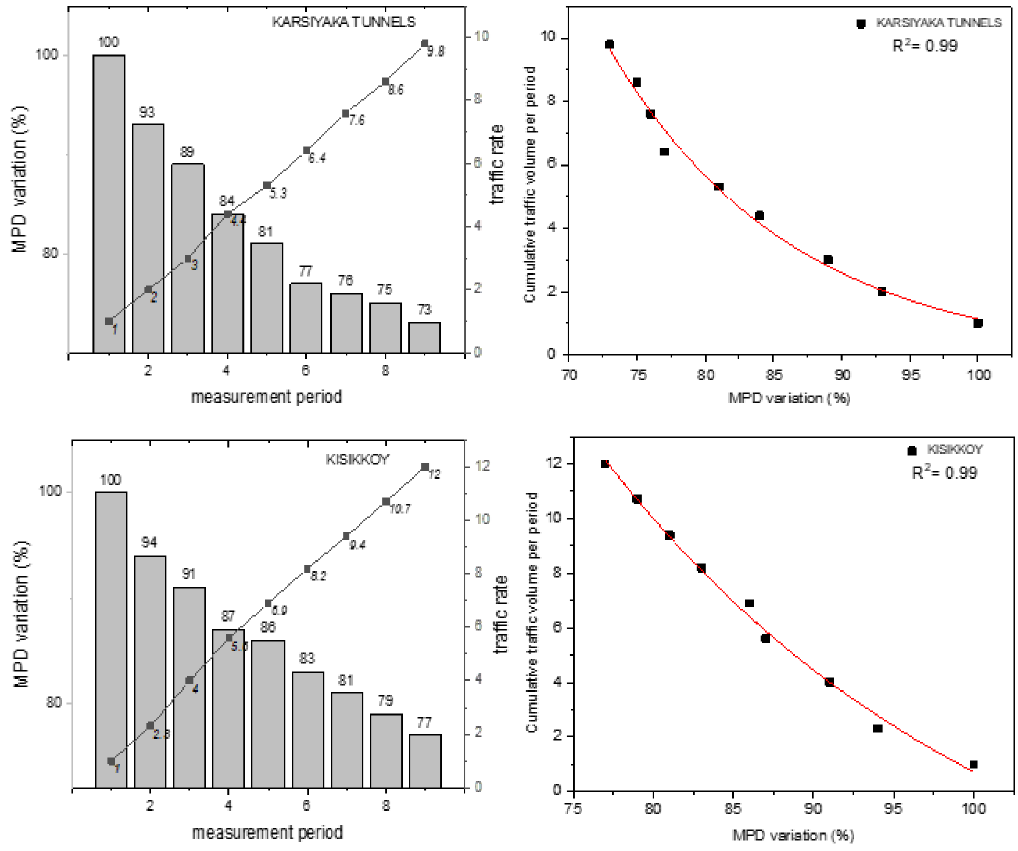


Figure 10. Variation of MPD and CTV per measurement period.

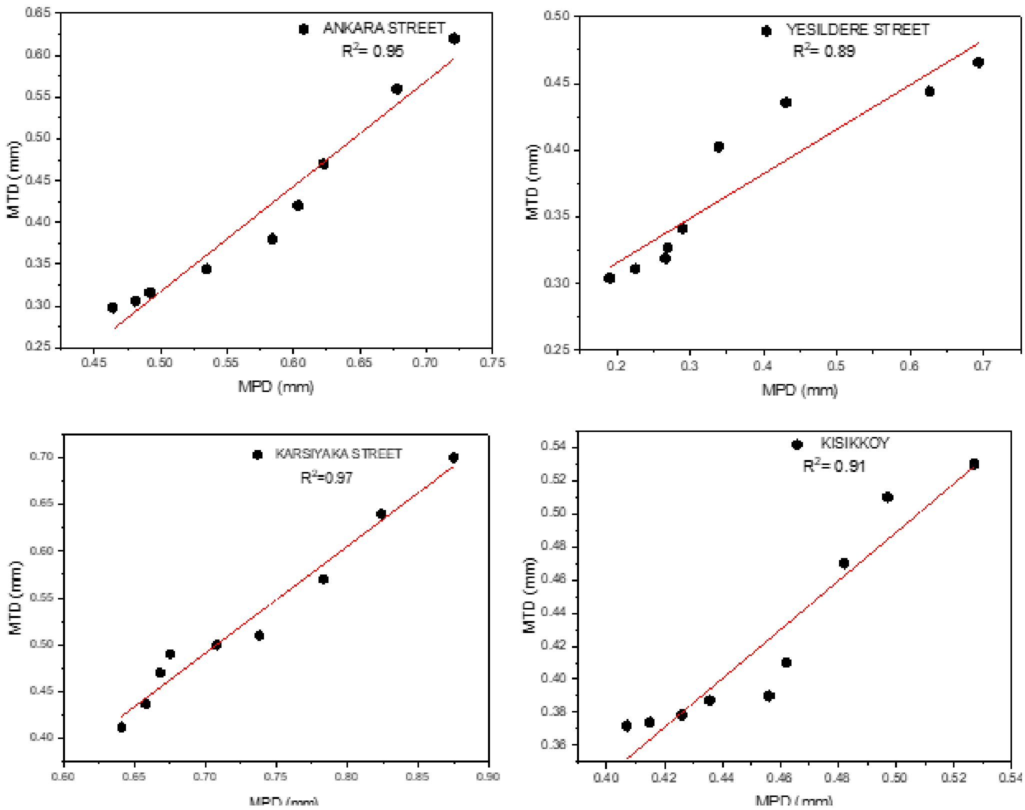




(a) (b)

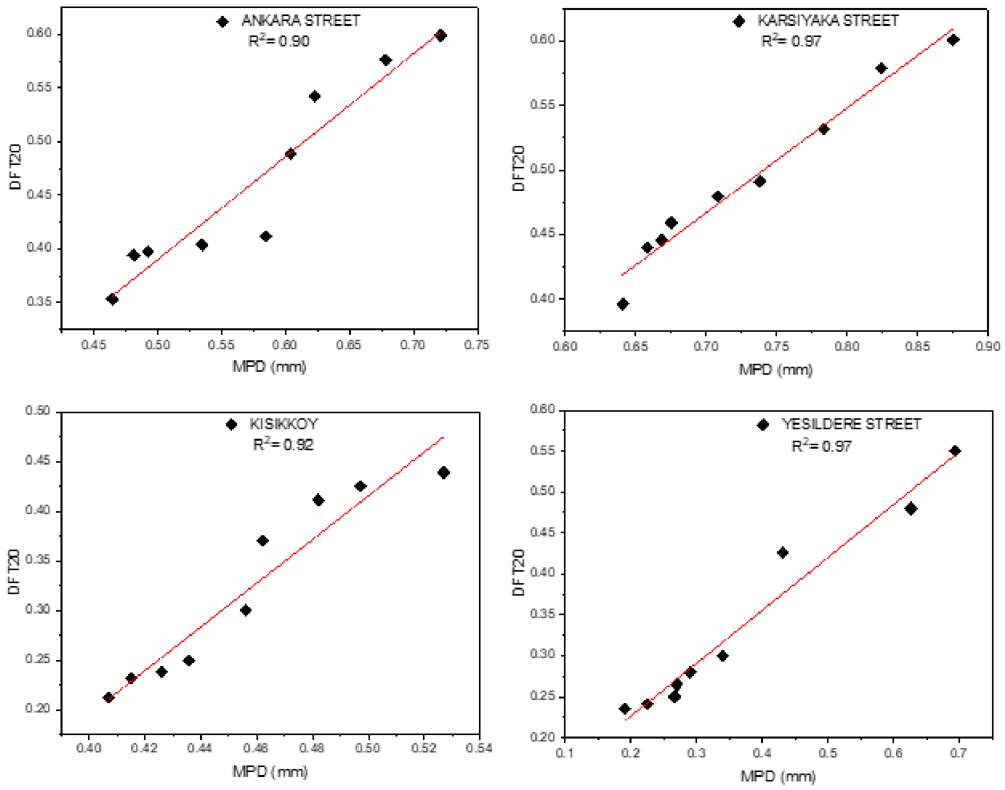
Additionally, MTD and MPD values were plotted together in Figure 11 for each station points in order to develop a correlation between these two parameters. High coefficient of correlation revealed a strong relation (R^2=0.89~0.97) between MTD and MPD values for all station points. Past studies have also revealed similar results (Abe, Tamai, Henry, & Wambold, 2001; Hanson & Prowell, 2004; Praticò & Vaiana, 2015; Sengoz, Topal, & Tanyel, 2012).

Figure 11. Relationship between MPD and MTD.



The relation between the frictional and textural characteristics of the station points were investigated by evaluating the MPD and DFT(20) values as depicted in Figure 12.

Figure 12. Relationship between MPD - DFT(20).



The results have shown that, there is a strong correlation between the MPD values and DFT(20) values of each station (R^2=0.90~0.97). This result indicates that, the better the textural characteristics, the better the frictional characteristics of the asphalt pavement.

Lastly, the coefficient of determination belongs to the all abovementioned parameters are given in Table 3, in order to analyze the relationship between the surface texture and traffic characteristics. As depicted in Table 3, all the coefficient of determinations are between 0.85~0.99, which means surface texture parameters and traffic characteristics are highly correlated with each other.

Table 3. The coefficient of determinations.

	Ankara Street	Yesildere Street	Karsiyaka Tunnels	Kisikkoy
Measurement Period-MTD	0.95	0.88	0.92	0.85
MTD-MPD	0.95	0.89	0.97	0.91
Measurement Period-MPD	0.98	0.93	0.95	0.98
CTV-MPD	0.99	0.95	0.99	0.99
DFT20-MPD	0.90	0.97	0.97	0.92

Conclusions and Recommendations

Asphalt pavement surface properties were evaluated on similar flexible pavement sections by employing the 3D Laser Scanner, the Sand Patch and Dynamic Friction Tests. Major findings of this study can be shown as below:

- MPD and MTD values of each station were decreased between (33~37% for MPD) and (30~57% for MTD) throughout the measurement periods due to the increased cumulative traffic. It is concluded that, traffic volume and the service life of the pavement is directly related with the textural characteristics of the asphalt pavement.

- The higher increment in CTV values resulted in higher drop in MPD rate throughout the measurement period. The MPD variation and CTV rate of the asphalt pavement are highly correlated (R^2=0.96~0.99).
- There is a reasonable linear correlation between the MPD and MTD values of the asphalt pavement (R^2=0.89~0.97).
- MPD values are interpreted together with DFT(20) values within the scope of this study. Based on the results, a high linear correlation existed between MPD and DFT(20) values (R^2=0.90~0.97).
- Overall, there are clear evidences about the relation between the frictional and textural characteristics of the asphalt pavement. However, only dense graded hot mix asphalt applications were investigated within the scope of this study, however, there are more pavement types like stone mastic asphalt, porous asphalt etc. can be investigated.

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