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RESEARCH PAPER

An Investigation of the Relationship among Skid Resistance, Mean Texture Depth and Abrasion Resistance for Different Macrotextures of Concrete Pavements

Jalalkamali, R.[1], Dibaee, M.M.[2], Hassani, A.[3*] and Jalal Kamali, M.H.[4]

[1] Assistant Professor, Civil Engineering Department, Shahid Bahonar University of Kerman, Kerman, Iran.
[2] Ph.D. in Highway Engineering, Civil and Environmental Engineering Faculty, Tarbiat Modares University, Tehran, Iran.
[3] Professor in Highway Engineering, Civil and Environmental Engineering Faculty, Tarbiat Modares University, Tehran, Iran.
[4] Ph.D. in Highway Engineering, Tarbiat Modares University, Tehran, Iran; Currently: Assistant Professor, Civil Engineering Department, University of Gonabad, Gonabad, Iran.

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ABSTRACT: Road accidents are one of the ten major causes of death in the world. Lack of enough friction and skid resistance of the pavement surface are known as important factors in traffic accidents. In this study, to evaluate the relationship between skid resistance and pavement surface macrotexture, five methods of creating macrotexture on concrete pavements were used. Sand Patch test, British Pendulum and Wide Wheel Abrasion tests were employed to obtain mean texture depth, skid resistance and abrasion resistance of the surface, respectively. Results showed that brushing on fresh concrete surface (parallel or perpendicular to the traffic direction) can improve frictional properties of pavement surface, drastically. This method increased British Pendulum Number (BPN) and friction coefficient by 32% and 38% (in average), respectively. Friction coefficient of parallel brushing was quite similar to perpendicular (0.2% discrepancy), while its abrasion resistance was 4% higher. Hence, as a finding, parallel brushing is the most recommended texturing technique in respect to friction. Generally, concrete pavement texturing decreases surface abrasion resistance, but burlap dragging improved this index by 2.5%. Nevertheless, burlap dragging results could be deceptive due to the high sensitivity to initial setup conditions. In other words, measurement scale of the studied testing procedures are small in respect to the scale of protuberances caused by burlap dragging method.

Keywords: Abrasion Resistance, British Pendulum Number, Macrotexture, Mean Texture Depth, Skid Resistance.

[*] Corresponding author E-mail: jalalkamali@gonabad.ac.ir

1. Introduction

According to the official records reported by Legal Medicine Authority of Iran, more than 14500 people lost their lives in road accidents in 2019 in Iran (ILMO, 2020). In a research, carried out on casualties of road accidents in Iran, Rasouli et al. (2008) showed that death toll rates of the accidents have increased from 22.1 in 1997, to 40.5 per 100,000 people in 2005, which categorizes Iran under high-risk countries in the area of road accidents.

Any life, lost in road accidents, costs the country's economy a huge loss, which was estimated, in 2012, to be 8.53 billion Rials (244,000 USD) per person, in Iran (Monajjem et al., 2013). The investigation showed that many road geometrical parameters and pavement characteristics such as skid resistance, have a great impact on accidents rate (Viner et al., 2004). Four important factors affecting the friction between road surface and vehicle tires are surface specifications, vehicle performance specifications, tire characteristics and environmental conditions (Wu et al., 2012; Hall et al., 2009).

2. Literature Review

2.1. The Relationship between Friction Coefficient and Accidents

Friction coefficient plays an important role in the frequency and severity of traffic accidents. Surface friction constitutes skid resistance providing maneuver ability of the vehicle, which is a vital factor of road safety, especially during braking and turning on curves. Therefore, many countries have specified a minimum friction coefficient in the regulations for road construction (Teekman, 2012).

The frictional properties of road pavements have a great impact on drivers' reaction. It has been proved that most drivers have violent reaction (such as braking, steering, accelerating or combination of these actions) when they encounter a hazardous situation. All these action are related to frictional properties of road pavements (Ahmadinejad et al., 2018; Monajjem et al., 2013)

Several studies have been carried out on the relationship between friction coefficient of pavement surface and road accidents, all indicating that increasing the friction coefficient improves road safety. Table 1 presents the relationship between surface friction and accident rate, studied in a research, performed in Sweden. It was found that an increase in pavement friction significantly reduces the rate of accidents (Wallman et al., 2001). Other studies have also yielded similar results (Viner et al., 2004).

Table 1. Changes in rate of accidents with respect to changes in friction coefficient (Wallman et al., 2001)

Accidents rate (Accidents per million vehicle-kilometers)	Friction coefficient range
0.80	Less than 0.15
0.55	Between 0.15 and 0.24
0.25	Between 0.25 and 0.34
0.2	Between 0.35 and 0.44

2.2. Skid Resistance of the Pavement

Resistance to skidding, i.e. friction between the locked wheel of a vehicle and pavement surface is called "skid resistance". It can be measured by the British pendulum test, and the value is expressed in form of Skid Number (SN). SN is equal to friction coefficient (in percent), measured using locked wheel test (flat or ribbed) (Wallman et al., 2001).

The British Pendulum Number (BPN), which is also measured by British pendulum apparatus, is another commonly used criterion to measure skid resistance of pavements. In many references, BPN is considered as an index of friction at low speeds (less than 64 km/h) indicating the microtexture of pavement (ASTM E303, 2013; Lu et al., 2006; Kuttesch, 2004).

Hence the pavement surface is directly in contact with vehicle tire, skid resistance properties (as an important factor affecting the road safety) need to be investigated to be used in Pavement Management System

(PMS) analysis. Prediction of pavement behavior (including frictional and abrasion properties) is vital during its service life for providing appropriate rehabilitation procedures to prevent the pavement from reaching critical condition (Solatifar and Lavasani, 2020).

Many researches have been done to investigate the parameters affecting skid resistance. Some of them concluded that aggregate polishing resistance and bitumen aging status have impact on skid resistance of asphalt pavement. Aging of asphalt binder, while it is not still removed from aggregates surface, results in higher friction coefficient in asphalt pavements (Dan Zhao et al., 2010). Others have investigated skid resistance variation during time and derived the following factors, as the most determinant parameters affecting frictional properties of the surface: Surface polishing of the asphalt pavement, seasonal variation, binder removal, and bitumen aging (Do et al., 2007).

Do et al. (2009) studied the impact of aggregate polishing properties introducing aggregate hardness parameter, based on mineralogical composition, and showed that micro-texture of aggregates with higher mineralogical hardness are less vulnerable to polishing, which results in more endurable friction (Do et al., 2009b). Moreover, Do et al. (2009a) investigated the effect of aggregate asperity properties on surface polishing of asphalt pavements. Three key factors were employed to represent surface roughness: The profile root mean square, and two introduced texture angularity parameters, named shape and relief of surface asperity.

Although BPN is believed, in some studies, to be solely related to pavement microtexture, detailed analysis of British Pendulum Test procedure, supports the hypothesis of existence of a relationship between BPN and the pavement macrotexture. In this test method, a rubber slider, dimensioned at 2.54 cm by 7.6 cm, is dragged 12.5 cm on the pavement surface, traversing an area of 95 cm^2. Clearly, the pendulum slider can engage pavement macrotexture and affect the pendulum number under any circumstances (Jalal Kamali et al., 2019a)

A study conducted in 2008, to investigate the relationship between macrotexture and skid resistance of grooved concrete pavements, showed that pendulum number has a rather good correlation with texture depth (R^2 = 0.86). The research considered the maximum effective mean texture depth to be 1.8 mm, and showed that by increasing the mean texture depth, the pendulum number initially increases and then decreases (Ahammed et al., 2008).

In another research, pavement macrotexture was manually created by grooving, and it was concluded that BPN strongly depends on the macrotexture. It was indicated that BPN increases by increasing the number and width of the grooves, especially the transverse ones (Pancar and Karaca, 2016).

Skid resistance and noise characteristics on concrete pavements were investigated by Fang et al. (2020) and the results declared that traditional grooved cement concrete pavement had poor skid resistance. The initial skid-resistance level was high, but the skid-resistance level decreased rapidly soon after exposure to traffic.

By evaluating the effect of aggregates gradation and various methods of creating grooves to improve skid resistance of concrete pavements, Fakhri and Taribakhsh (2012) found that macrotexture parameters, including the largest aggregate size in concrete, grooving angle and width of the grooves, can affect BPN value. It was also discussed that grooving is a good choice to enhance the surface friction of concrete pavements.

By investigating the relationship between Mean Texture Depth and BPN in a new constructed highway, Jalal Kamali et al. (2020) showed that increasing MTD leads to BPN decrease and then increase. It was also illustrated that the asphalt content of Hot Mix Asphalt has the similar effect on BPN (the lowest BPN occur at 4.4% of asphalt content).

As mentioned before, BPN is a good indicator of friction at speeds below 64 km/h. Considering the fact that friction plays a very important role in frequency and severity of road accidents, it seems vital to estimate the BPN value as well as the amount of friction during pavement construction. In this study, different types of conventional textures in concrete pavements are compared in terms of mean texture depth, BPN and abrasion resistance, and the best type of texture is introduced according to the mentioned factors.

2.3. Macrotexture in Concrete Pavements

During pavement lifetime, traffic loading polishes the microtexture, sooner or later. Therefore, adequate macrotexture should be created during/after construction, on the surface, to provide satisfactory friction during pavement life span. Various factors such as traffic characteristics, type and gradation of aggregates, weather conditions, pavement surface noise, and the amount of friction required need to be considered to choose the type of arranged macrotexture (Hall et al., 2009).

Depth, spacing and orientation of pavement macrotexture have significant impact on frictional properties, noise and ride quality (Ardani, 2006). As for macrotexture orientation, longitudinal texturing is more effective on lateral slopes and horizontal curves, while, transverse texture provides higher head-on skid resistance. Concerning rainfall drainage and highway lateral slopes, transversal texturing discharges the water faster and thus, a hydroplaning incident is less likely to occur (ACI-211, 2002).

Concrete pavement macro texture can be arranged using several methods. The most common ones are (ACI-211, 2002):

- Dragging artificial turf transversally and longitudinally on fresh concrete;
- Longitudinal or transversal brushing on fresh concrete;
- Longitudinal or transverse brooming on fresh concrete;
- Burlap dragging on the surface of fresh concrete;
- Grooving or grinding the hardened concrete.

2.4. Surface Abrasion and the Impact on Friction

Abrasion resistance in concrete is a term to address the ability of the surface to resist being worn away by rubbing and friction. A concrete with high abrasion resistance must possess both parameters of abrasion resistance and macrotexture durability under traffic.

Wang et al. (2014) counted the abrasion of an asphalt pavement surface, as one of the factors affecting friction and presented a model to predict the surface skid resistance, based on initial surface skid resistance and abrasion duration. They found that the skid resistance of surface decrease by the abrasion of pavement surface and the rate of skid resistance changes decrease by abrasion duration increases.

Kassem et al. (2013) determined the drop rate of International Friction Index (IFI) in regard to the number of abrasion cycles, by studying skid resistance reduction of hot mix asphalt. The IFI index may drop up to 60% depending on the type of aggregate and mix design.

The effect of fly ash on the abrasion resistance of concrete pavements has been investigated in another study. Based on the results, wet conditioned BPN decreases during the abrasion for the majority of specimens. As explained before, BPN reduction indicates the reduction of friction and skidding resistance (Yoshitake et al., 2016).

The impact of Nanomaterials on abrasion resistance of concrete pavements was also studied in a research, and it was shown that both micro and macrotexture significantly affect the surface friction. The research focused on the need for creating macrotexture with high resistance against abrasion. It was noted that macrotexture resistance against abrasion can reduce the costs of providing friction during pavement maintenance process (Gonzalez et al., 2014).

Jalal Kamali et al. (2019b) investigated the effect of abrasion on five type of concrete macro textures. It was showed that brushed sample (transverse or longitudinal) experience the most abrasion among other macro texture. On the other hand, the brushed surfaces have the most skid resistance.

Long-term skid resistance of concrete pavements was investigated by Rith et al. (2020). The results showed that the decreasing rate of skid resistance in transverse and longitudinal tining was more rapid than the exposed aggregate concrete texture under traffic loading.

Najafi Alamdarlo and Hesami (2019) investigated the effect of pavement Porosity filling on skid resistance by field test and numerical model. The results showed that between 1-4% reduction in mean texture depth results in 2% reduction in skid number in HMA pavements.

To summarize, skid number is a key parameter in road safety and it completely depends on pavement surface properties. On the other hand, concrete pavement properties are affected by many parameters such as material properties, aggregate gradation, and surface finishing. In concrete pavements, the surface is textured in order to improve frictional properties. Determination of the skid resistance of each texture type is vital to evaluate road safety characteristics.

3. Laboratory Procedure

In this section, properties of the material, used in the study, as well as laboratory procedures including concrete mix design, sample preparation, texture creation and testing procedures have been briefly described.

3.1. Aggregates

Coarse-grained and fine-grained aggregates required for performing the tests were all supplied from Metosak mine, located in the southwest of Tehran (Shahriar area). Common conventional tests were implemented on them and the results are given below. Some mechanical properties such as abrasion resistance values of aggregates, acquired from Los Angeles abrasion test, as well as the impact resistance for coarse-grained aggregates were determined as follows:

Aggregate Soundness: weight loss values in Soundness test for the aggregate with magnesium and sodium sulfate have been presented in Table 3.

Coarse-grained aggregates grading curves have been obtained, considering the upper and lower limits of ACI regulation. By taking the average of these two limits and the fine-grained aggregates, there is no need for further gradation with regard to the fact that they were within the permitted limits of regulation. Figure 1 shows gradation diagram of the fine-grained and coarse-grained aggregates used for concrete mixture.

3.2. Cement

The Qazvin's Abyek cement was used to create concrete pavement samples. The physical and chemical properties of the cement were assessed in Tarbiat Modarres University laboratories and their results are reported in Tables 4 and 5.

Table 2. Some specifications of fine-grained and coarse-grained aggregates

Variables	Standard code	Coarse aggregate	Fine aggregate
Specific gravity (g/cm^3)	ASTM C136	2.67	2.67
Bulk Specific gravity (g/cm^3)	ASTM C29	1.64	-
Water absorption in SSD	ASTM C127	1.3	2.6
Fineness modulus	ASTM C136	-	2.85
Sand equivalent	ASTM D2410	-	80
Los Angeles abrasion test	ASTM C131	12%	-
Impact resistance	BS 812	8.1%	-

Table 3. Results of coarse-grained soundness test

Coarse-grained aggregates	Soundness test with sodium sulfate (ASTM C88)	9.5% weight loss
	Soundness test with magnesium sulfate (ASTM C88)	12.6% weight loss

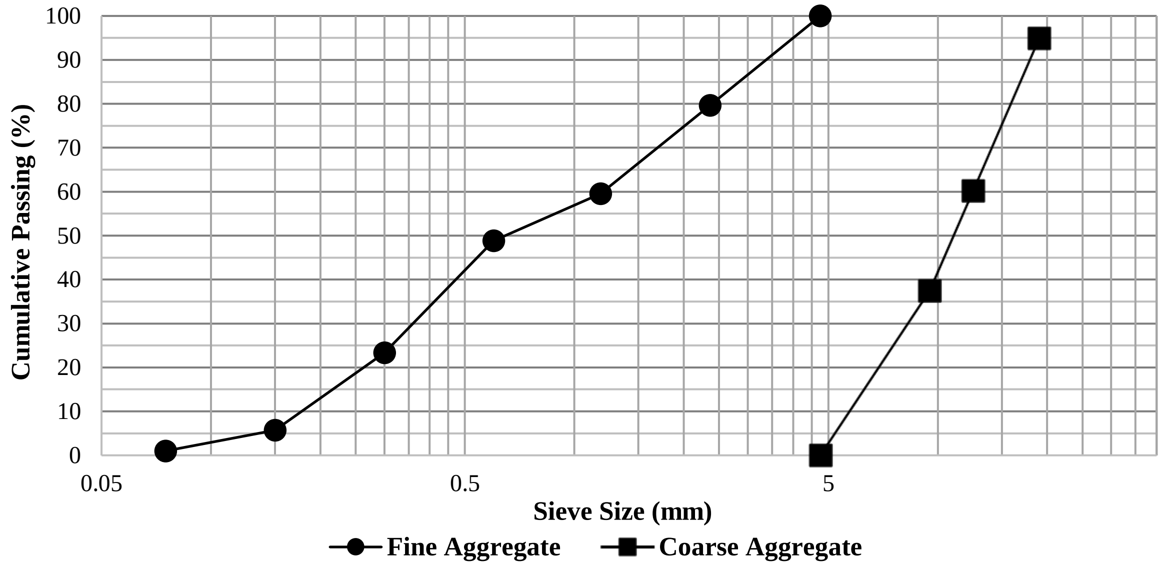


Fig. 1. Gradation diagram for fine-grained and coarse-grained aggregates

Table 4. Physical and mechanical specifications of the used cement

	Specific surface (ASTM C204)	**Specific gravity (ASTM C188)**	**3 day compressive strength (ASTM C109)**	**7 day compressive strength (ASTM C109)**
Minimum requirement	-	-	12 MPa	19 MPa
Abyek cement	3250 cm^2/gr	3.15 gr/cm^3	12.5 MPa	21.9 MPa

Table 5. Constituent compounds of the used cement

Component	L.O.I	CaO	Si2O	Al2O3	Fe2O3	SO3	MgO	K_2O	Ti_2O	Cl	**Total**
Percentage	1.85	62.21	18.492	4.026	3.777	3.208	2.731	0.811	0.366	0.173	97.642

3.3. Concrete Mix Design

The concrete mixture proportions are designed according to ACI-211 regulation. During design process, based on the dimensions of sample molds, the maximum aggregate size was chosen to be ¾ inch. Since the achievements, obtained in this research, may be used in concrete pavements construction, specifications of the designed mix should be as similar as possible to conventional concretes, used in pavements all over the world. Therefore, minimum compressive and flexural strength of concrete in the design process were considered to be 40 and 4.5 MPa, respectively (Delatte, 2014). Also, slump value was assumed to be between one and two inches. With regard to aggregates properties and expected specifications of the concrete, an initial mixture design was selected. After several modifications, final mixture proportions of the concrete were eventually determined, according to Table 6.

3.4. Preparation of Specimens

In this study, according to the achieved concrete mix design, forty eight 10×10×50 cm beams were constructed, and different macrotextures were created on them. As stated before, the created textures are among the most common methods for creating macrotexture on concrete surfaces (ACI-211, 2002). The following notation is used to address different types of texture:

- Without texture (no texture): NT;
- Texture created by dragging artificial turf (Turf dragging): TD;
- Texture created by grooving (Grooving): G;

- Texture created by dragging plastic brush parallel to traffic path (Parallel Brushing): ParB;
- Texture created by dragging plastic brush perpendicular to traffic path (Perpendicular Brushing): PerB;
- Texture created by dragging burlap parallel to traffic path (Burlap dragging): BD.

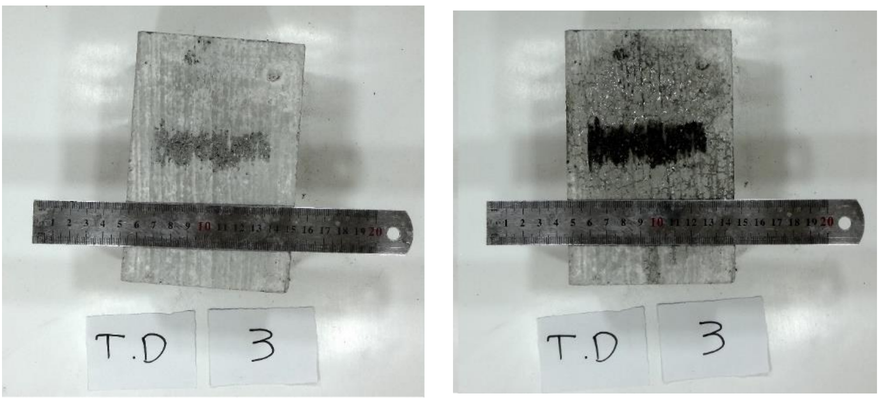
After being cured for 28 days, concrete beams were sawed into 10×10×15 cm pieces to obtain 127 samples (excluding wasted specimens). Afterward, the concrete beams were subjected to British Pendulum, Sand Patch and Wide Wheel Abrasion tests.

3.5. Wide Wheel Abrasion Test

In this research, an abrasion device made according to BS EN 1338: 2003 standard, was used to abrade the concrete specimens with different textures. According to the above-mentioned standard, the surface of concrete specimen was abraded in the vicinity of a steel wheel in the presence of alumina oxide (corundum). Figure 2 shows the abrasion device used in this research.

When the concrete sample was abraded for one minute, size of the groove left by the abrasion process was measured accurately. In this research, in order to increase the accuracy and also to facilitate the measurement of dimensions of the created groove, a high-quality photo was taken from the surface of specimen with a ruler placed next to it. Then, using AUTOCAD software and by performing the related calculations, dimensions of the groove were measured. Also, to enhance the accuracy of picture, the specimens were wetted before taking the photos to make the abraded area well defined and specified. Figure 3 shows a concrete specimen that has been textured by dragging artificial turf on fresh concrete after performing the abrasion test in both wet and dry condition.

Fig. 2. The employed abrasion machine



(a) **(b)**

Fig. 3. Concrete specimen (Turf dragged) after abrasion in: a) Dry; and b) Wet condition

Table 6. Mix design of the employed concrete

	Gravel (kg/m^3)	Sand (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	W/C ratio
Mix design proportion	1091	670	400	176	0.44

3.6. Measuring Friction by Tribometer

In this research the tribometer produced in Tarbiat Modares University (Kashani et al., 2011; Kashani and Nisiany, 2011), shown in Figure 4, was utilized to measure the friction coefficient of concrete pavements. The output data of the test for a specimen, over time, is depicted in Figure 5. In this procedure, the friction of surface is measured by rotating a rubber ring (with specific composition) on the surface at standard speed and vertical force. The area of the ring is 260.93 mm^2 and the traveling speed of rubber over specimen surface can vary between 1 to 2200 mm/sec. The applied vertical force can be set between 0.1-1.25 MPa.

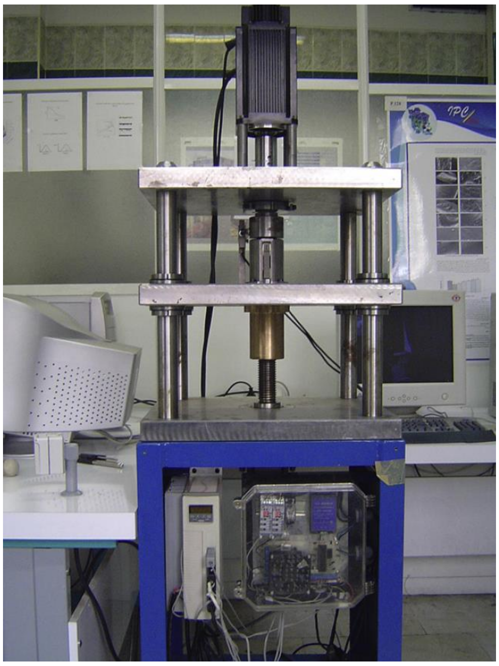


Fig. 4. Friction Test Machine (Kashani et al., 2011)

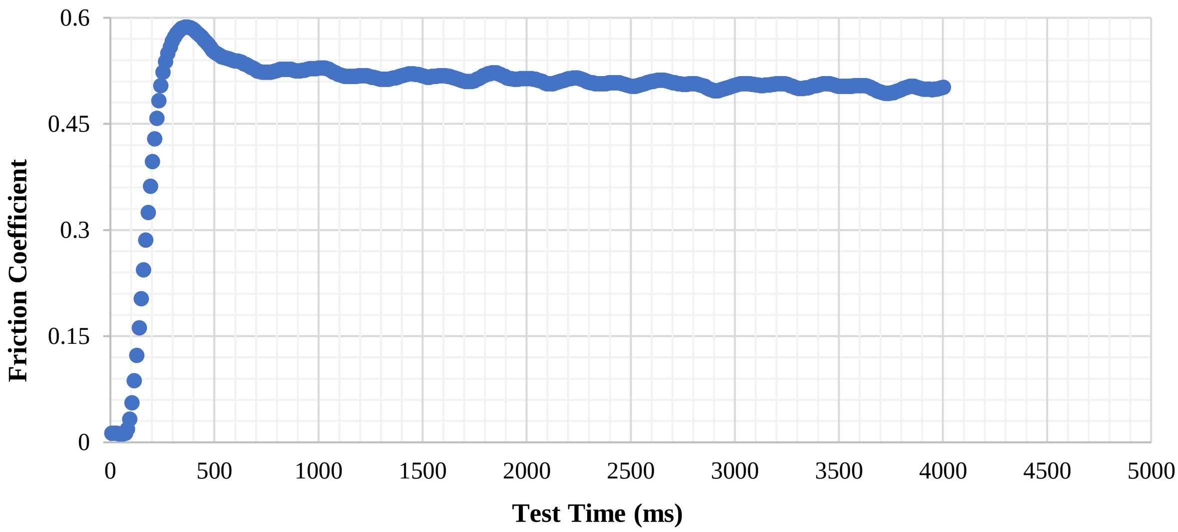


Fig. 5. Wet friction coefficient of the G sample

4. Results

After performing British pendulum, sand patch, abrasion resistance and friction coefficient tests on concrete specimens, the mean values of BPN, MTD, Abrasion Resistance and Friction Coefficient for each specimen of the pavement texture were calculated, which are given in Figures 6 to 9, respectively. As predicted, the pavement with no macrotexture created on it, has allocated the lowest amount of BPN, MTD and Friction Coefficient to itself.

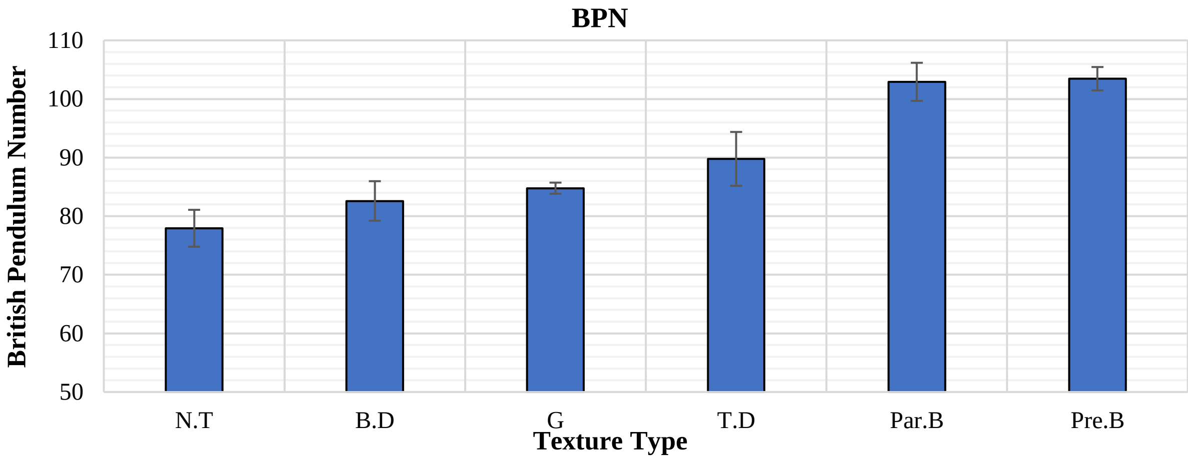


Fig. 6. Comparison of BPN values for different pavement texture

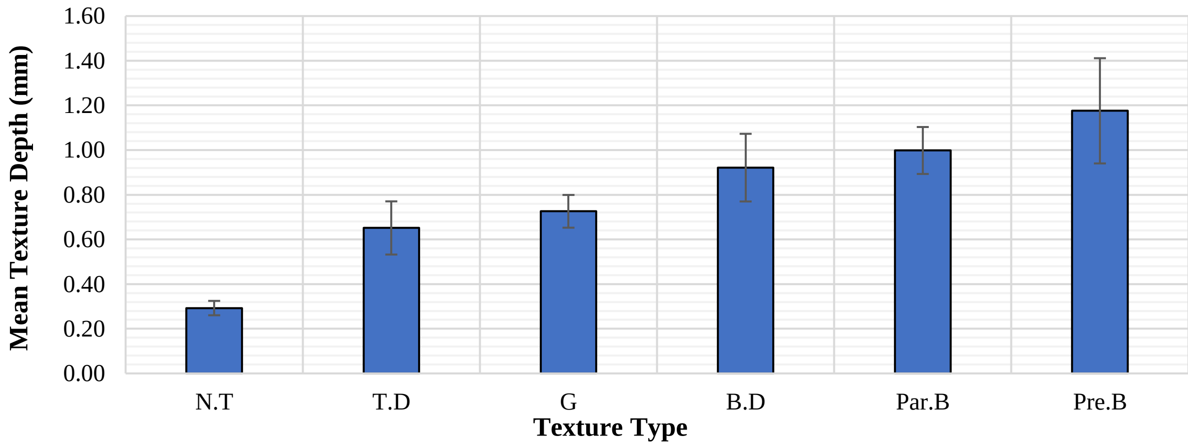


Fig. 7. Comparison of MTD values for different pavement texture

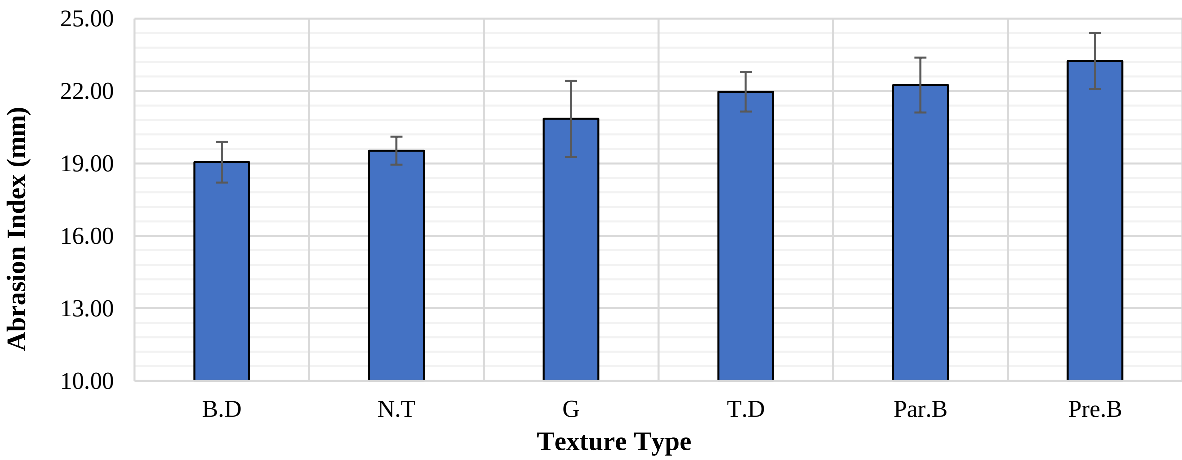


Fig. 8. Comparison of abrasion index values for different pavement texture

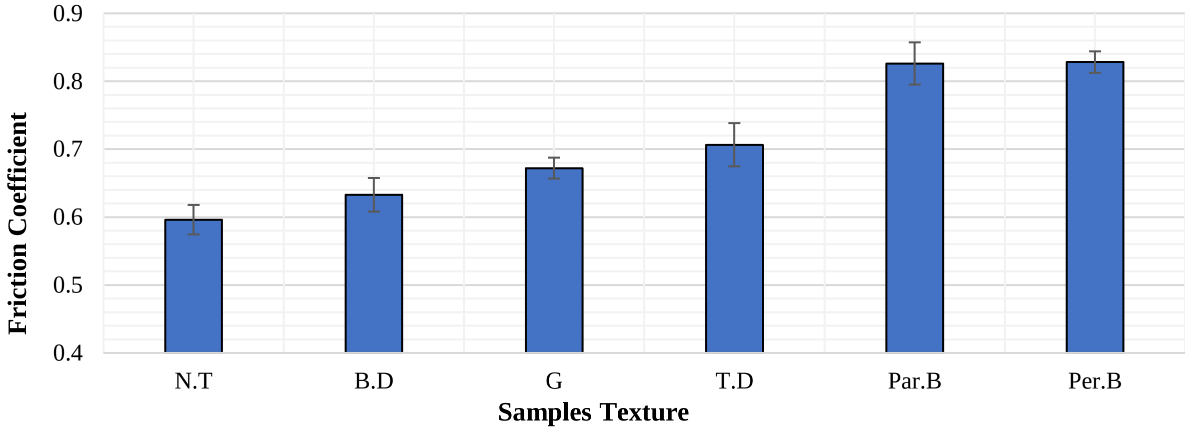


Fig. 9. Comparison of friction coefficient values for different pavement texture

Table 7. ANOVA statistical analysis on the test results

		Sum of squares	df	Mean square	F	Sig.
	Between groups	10.249	5	2.050	103.941	0.000
MTD	Within groups	2.386	121	0.020		
	Total	12.636	126			
	Between Groups	12194.862	5	2438.972	234.369	0.000
BPN	Within groups	1259.192	121	10.407		
	Total	13454.054	126			
A.I	Between groups	285.252	5	57.050	40.056	0.000
	Within groups	172.335	121	1.424		
	Total	457.587	126			
	Between groups	1.015	5	0.203	321.541	0.000
Friction	Within groups	0.076	121	0.001		
	Total	1.091	126			

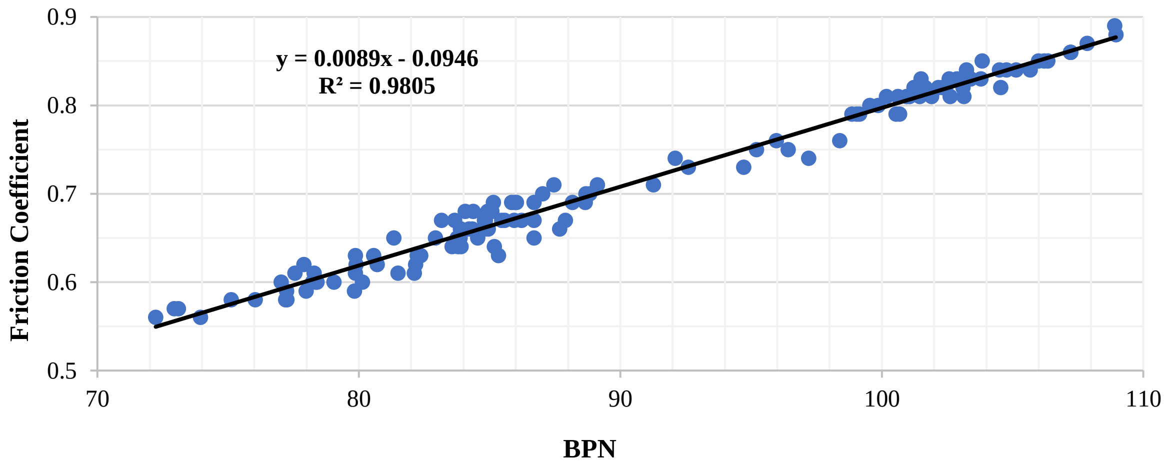


Fig. 10. The relationship between BPN and friction coefficient

Table 7 shows the ANOVA statistical analysis on the results of the sand patch, British pendulum number and wide wheel abrasion tests. With regard to the numerical values of the F and Sig. statistics, it is determined that the difference of the means reported for each of the values of BPN, MTD, AI (Abrasion Index) and friction coefficient is statistically significant. Figure 10 shows the relationship between friction coefficient and BPN in all differently textured samples. As expected, the friction coefficient directly depends on BPN (R^2 = 0.9805).

For concrete specimens constructed with different types of texture, the diagram of the variations of the pendulum number versus Mean Texture Depth has been depicted, which its governing relationships have been described in detail in the discussion and conclusion section. In Figures 11 to 16 the best line or second-degree parabola that can express the relationship between these two variables has been drawn and its equation has also been mentioned. The R^2 parameter was also reported as an indicator of the amount of correlation between the two abovementioned variables.

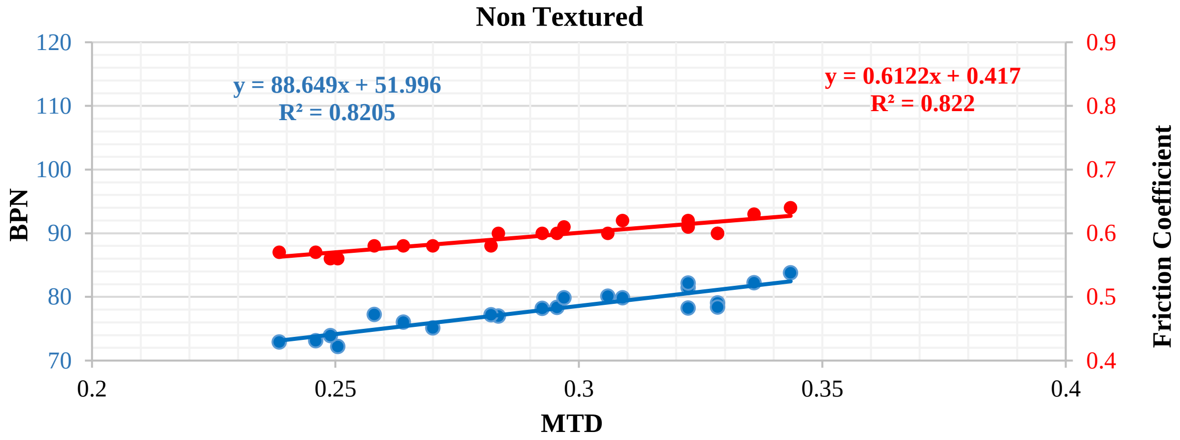


Fig. 11. The relationship between BPN and friction coefficient in N.T. pavement

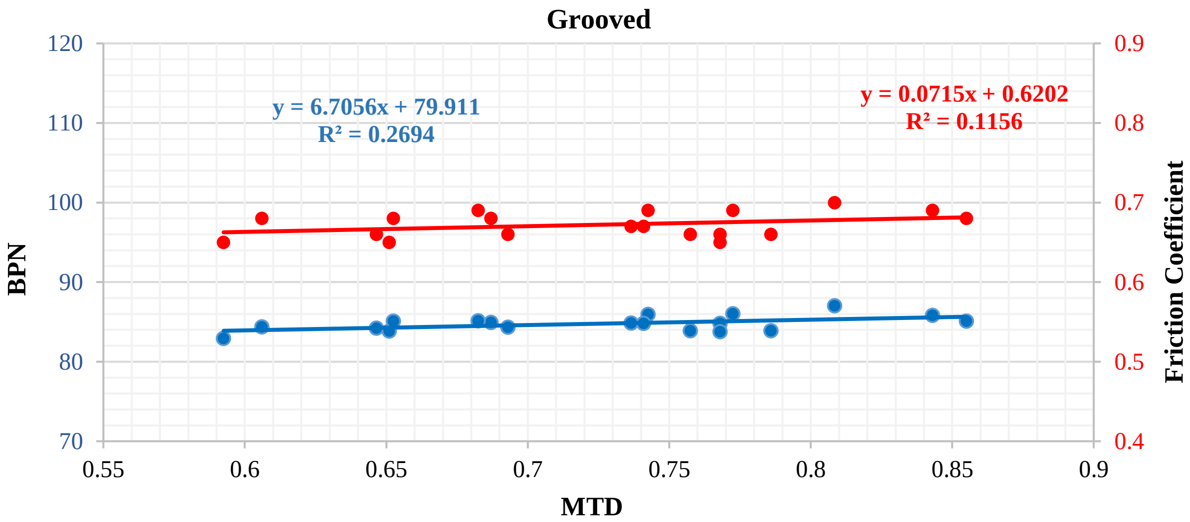


Fig. 12. The relationship between BPN and friction coefficient in G. pavement

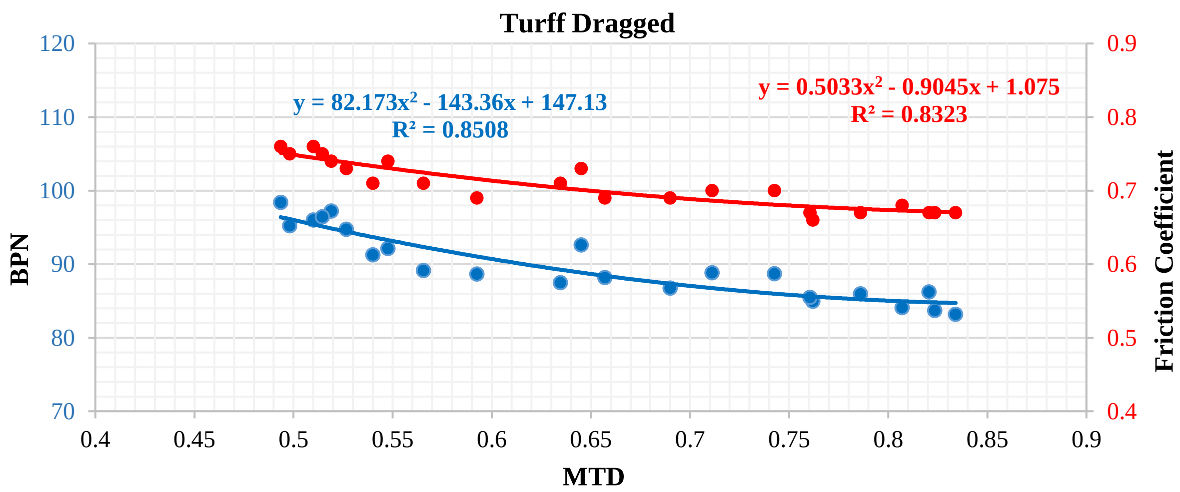


Fig. 13. The relationship between BPN and friction coefficient in T.D. pavement

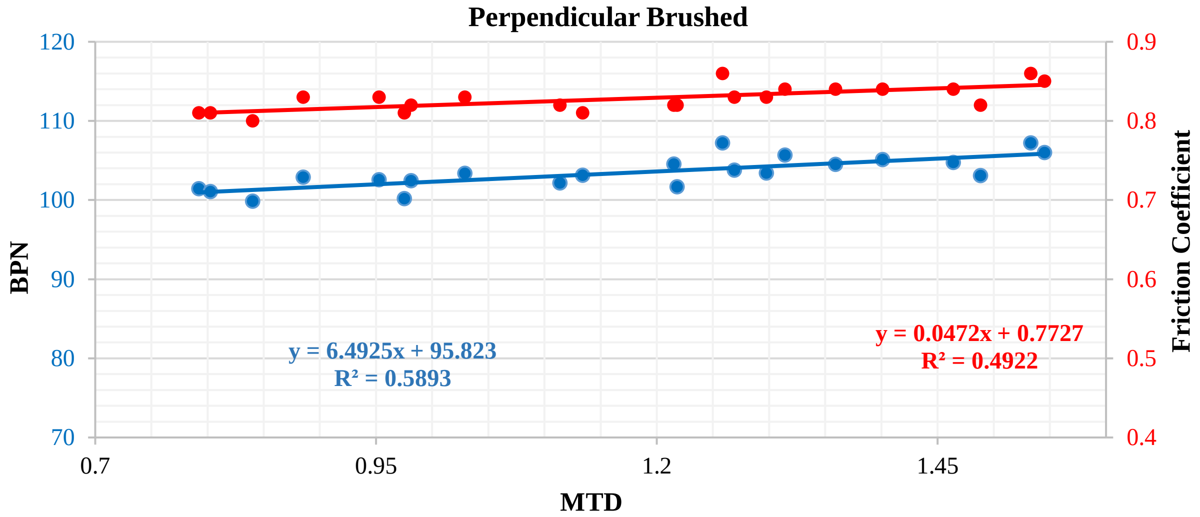


Fig. 14. The relationship between BPN and friction coefficient in Per.B. pavement

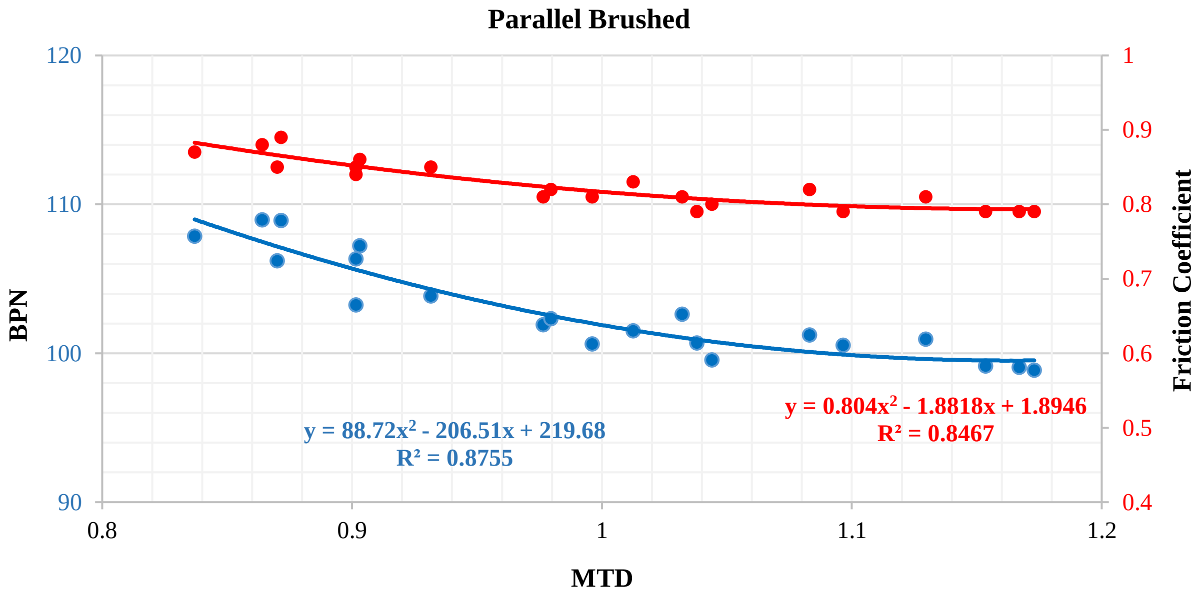


Fig. 15. The relationship between BPN and friction coefficient in Par.B. pavement

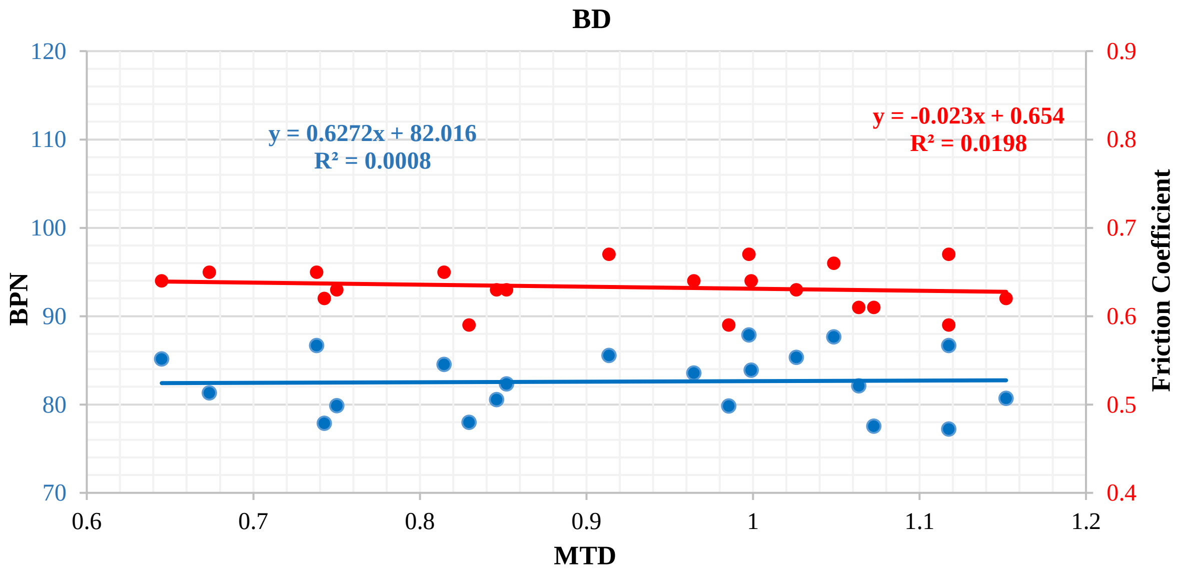


Fig. 16. The relationship between BPN and friction coefficient in B.D. pavement

5. Discussion

Figures 11-16 depict British Pendulum Number (BPN) and friction coefficient variations versus Mean Texture Depth (MTD). With regard to different behaviors of BPN against MTD, this section the relationship between these two variables is investigated in the following four subsections and afterward, the results of Wide Wheel Abrasion test are also assessed.

5.1. The Relationship between BPN and MTD in Per.B and N.T Samples

In untextured samples, the surface of pavement is approximately smooth and the mean texture depth is very small (less than 0.4 mm). In this type of texture, with an increase in amount of MTD, BPN also increases. By increasing 0.1 mm of MTD, the BPN increase about 8.9 units. MTD in these specimens is very small and the pendulum rubber slider drags its path easily. Figure 6 confirms that the average BPN for these pavements is much lower than other pavements. By increasing MTD of pavement, on a very small scale, coarseness is added to the surface of pavement. Interaction of this coarse surface with the rubber causes an increase in the friction coefficient. The opposite trend can be seen in parking lots with concrete paving where usually the pavement is constructed without texture so the surface friction decreases rapidly due to abrasion caused by vehicle traffic. In a pavement that has acquired a macro texture by brushing in perpendicular direction, MTD is higher than the other texturing types, which causes the rubber, while dragging the surface of the pavement, to get stuck in fine grooves created on the concrete that are perpendicular to traffic direction. This leads to an increase in longitudinal friction coefficient and consequently BPN. In Figure 17, which shows a perpendicularly brushed pavement, the created grooves are clearly distinguishable. Given that brushing is performed when the concrete is wet, sometimes during the brushing process some of mortar on the surface transfigure and after hardening, they become an obstacle to the movement of tires.

5.2. The Relationship between BPN and MTD in T.D and Par.B Samples

Artificial turf and plastic brush have similar behaviors when pulled over fresh concrete. Having thin fibers, they both leave thin grooves by passing over fresh concrete, but due to different structure of plastic brush and artificial turf, depths of these grooves are slightly different. As can be observed in Figure 18 the grooves created by artificial turf have lower depth.

Since rubber is a flexible material when compressed in one direction, if there is an empty space, its volume increases in the other directions. In other words, when the rubber under pressure from the vehicle (in this research, under standard pressure of British Pendulum) passes over the pavement with grooves (longitudinal or transverse), due to compression of the rubber, a part of rubber that is on the empty space between the two grooves slightly increases in volume and penetrates in it.

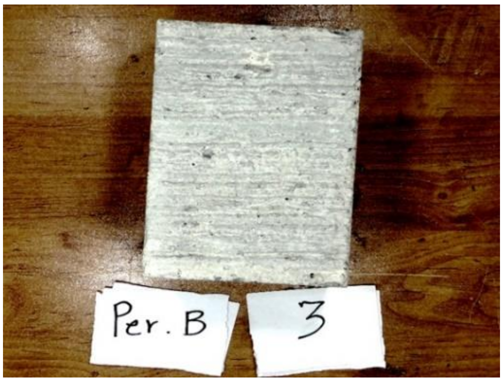


Fig. 17. A specimen with perpendicular brushing texture on it

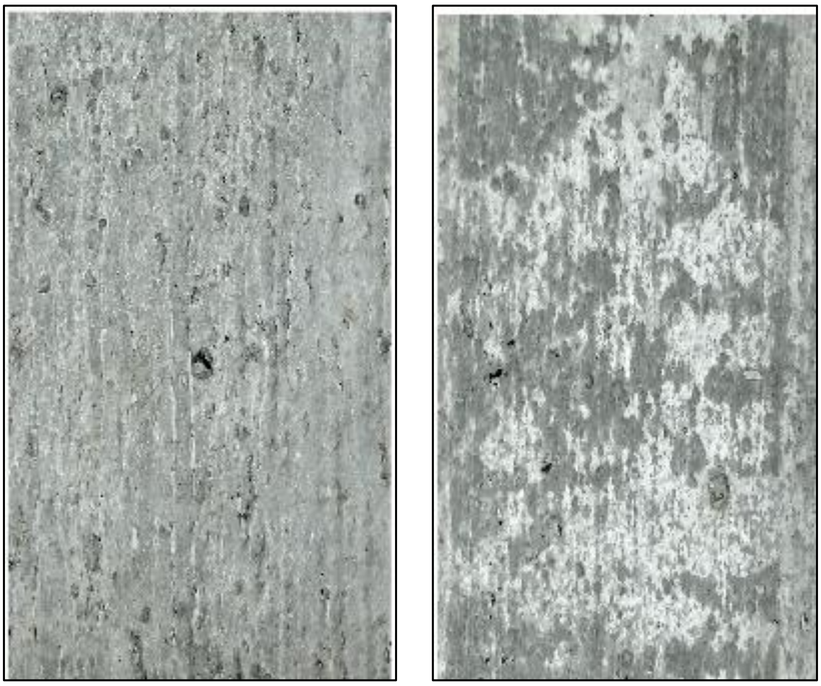
In these cases, since grooves are parallel to rubber movement (or traffic) direction, when the depth of groove is small, the rubber which is pulled between the two grooves is dragged against its walls and bottom and as a result, the friction between rubber and pavement is high. But when these grooves get deeper, the rubber no longer comes in contact with the bottom of the groove when passing over and the friction between the rubber and the concrete surface decreases. Thus, with an increase in depth of parallel grooves (produced by artificial turf dragging or plastic brushing), BPN slightly decreases. It is worth mentioning that this decrease has a higher rate at first and with a further increase in depth of the groove, the rate of decrease in BPN decreases, as well. This is clearly evident in Figures 13 and 15.

5.3. The Relationship between BPN and MTD on G Samples

The grooving of specimens is performed after hardening of the concrete and, due to spacing between the grooves (2.5 cm in average), a major section of surface is similar to untextured pavement. But the presence of grooves has caused BPN to increase by seven units on average. The trend of changes in BPN versus the changes in MTD of pavement is similar to that of untextured pavements, but the equations governing these two cases are completely different which can be attributed to different variation range of macrotexture. Due to relative similarity of distance and depth of the grooves, the amount of increase in MTD is approximately limited.

Contrary to brush or turf dragging specimens, depth of the grooves in grooved specimens is much higher and practically the rubber does not come in contact with the bottom of the groove when it passes over it. In fact, as explained earlier, a further increase in depth of the grooves does not lead to an increase in skid resistance. It is worth noting that deeper grooves have a significant effect on proper drainage during the rain and prevent the occurrence of hydroplaning which is not the subject of this research.

A weak correlation coefficient shows that we cannot make an accurate judgment with regard to the exact amount of slope of the line or ratio of the changes in BPN versus MTD. But what is clear is an increase in BPN versus an increase in MTD.



(a) (b)

Fig. 18. Specimen with: a) Parallel brushing; and b) Turf dragging texture on it

5.4. The Relationship between BPN and MTD in B.D Samples

As it can be seen in Figure 16 in burlap dragged pavements the variations of MTD and BPN occur in relatively large ranges and no specific relationship is observable between these two parameters. Lack of uniformity of the process of texturing by burlap dragging can be mentioned as one of the reasons for extensive variations in MTD and BPN. Although burlap used in this research were made of the same material, they showed different patterns when dragged on concrete. Displacement of fine grains (granules) of the surface of the concrete by burlap can be mentioned as one of the reasons for this matter. These displacements cause the track of dragging to remain on concrete and consequently major variations in MTD and BPN. Figure 19 shows a concrete specimen textured with burlap dragging where the path of movement of some of the granules on the surface of concrete is distinguishable.

5.5. Abrasion Resistance in Various Textures of Concrete Pavements

As mentioned before, in the current research, the abrasion test is implemented in accordance with BS EN-1338 to measure abrasion resistance of various textures created on concrete pavements. For each specimen of each texture, the height of abraded section was determined and its average has been shown in Figure 8. According to EN 1338, the height of abraded part should not exceed 23 mm. By considering the results of this research, it can be concluded that perpendicular brushed texture, with an average of 23.2 mm, is not an abrasion resistant texture. On the other hand, dragged burlap and untextured pavement, with an abrasion less than 20 mm, are classified in the category of pavements with suitable abrasion resistance.

Although for each texture, abrasion increases with an increase in MTD, this trend is not valid among all data obtained from different textures. In other words, an increase in MTD in each particular texture will cause an increase in the amount of abrasion (abrasion resistance decrease) of the pavement.

6. Conclusions

- Macrotexture of the concrete pavement had significant effect on wet skid resistance of the surface. Thus, it is possible to achieve the desired skid resistance using different methods of creating macrotexture on concrete pavements.
- For untextured pavements, the rate of BPN variation versus MTD was severe (87 unit change of BPN versus 1 mm change of MTD). Despite good abrasion resistance, these pavements are not recommended for use in roads due to low skid resistance.
- Brushing on fresh concrete parallel and perpendicular to traffic direction resulted in the highest skid resistance (minimum increase of friction coefficient to 0.8). Shallow grooves appeared on the concrete using these methods led to higher engagement of tire and surface of the pavement as a result of an increase in the skid resistance.

Fig. 19. Specimen with burlap dragging on it

- Dragging artificial turf on the concrete created a macrotexture similar to the texture of parallel brushing, with the difference that the turf dragged specimen had lower mean texture depth, lower skid resistance and consequently lower friction coefficient.
- Macrotexture created by turf dragging and brushing perpendicular to traffic direction can be used on the roads with medium traffic volume due to large amounts of BPN as well as proper abrasion resistance.
- Depth of the grooves created on hardened concrete had no significant effect on skid resistance of the concrete, but deeper and wider grooves can provide better drainage of overland flow and prevent the occurrence of hydroplaning during rain.
- Burlap dragging is not a good texturing method in the concrete pavements because of the lack of uniformity in the created texture. But, this type of texturing led to abrasion resistant pavement. Burlap dragging does not create a uniform texture due to displacement of some granules by the burlap dragging on the fresh concrete. This method showed better abrasion resistance compared to other texturing methods, so it can be used as a suitable method provided that some modifications are applied to the procedure of achieving a more uniform surface.

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