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RESEARCH ARTICLE

RELIABILITY OF BRITISH PENDULUM TEST ON MACROTEXTURED SURFACES

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ABSTRACT

The British pendulum test is a common laboratory test for measurement low-speed friction of pavement surface which is related to surface microtexture of road surface. Transverse or longitudinal grooving is used to improve skid resistance on concrete pavements. In this study, experiments were made on different size and shape of transverse and longitudinal grooved surfaces by using British pendulum tester to find their skid resistances. The experimental results presented in this paper showed that the British pendulum test is also affected by macrotexture. Although some experimental studies have been made on determining the effect of macrotexture on BPN value, this paper implies that the microtexture must also be taken into account when examining macrotexture effect on skid resistance while using British pendulum tester. The importance of microtexture effect on British pendulum test is different if there is a penetration of rubber into gaps. This penetration has a big effect on skid resistance and different amount of penetration can be obtained when the first horizontal contact point between the rubber and the testing surface is changed. The results demonstrated that when there is any macrotextured surface, there are too many parameters to be considered to investigate the reliability of BPN values.

Key Words: Concrete Pavement, Grooved Surface, Macrotexture, British Pendulum Test, Skid Resistance.

INTRODUCTION

The British pendulum test as described in ASTM E303 (2000) is a laboratory testing method to find the skid resistance of pavement surface. It is a low-speed (10 km/hr) test and many researches have considered that British pendulum test can be used as an assessment of the micro-texture of the material surface (Foerster, 1989; Huang, 1993; Kummer, 1966; Croney *et al.*, 1992). Some experimental researches mentioned that British pendulum test is also affected by macro-texture. In those experiments, the effects of aggregate gap and aggregate size parameters were examined and they determined that BPN decreases by increasing the aggregate gap width (Liu *et al.*, 2004). It is also mentioned that BPN decreases by increasing transverse groove width (Lee *et al*., 2005) and also BPN decreases by increasing groove spacing (Purushothaman *et al.*, 1990). The test results demonstrated that the edge impacts between coarse-textured surface features and the pendulum slider would give rise to unreliable test measurements (Lee *et al*., 2005). Transverse and longitudinal grooving is a surface texturing treatment to concrete road pavements. It is claimed that longitudinal grooves provide extra micro-texture on the surface and hence improve skid resistance (Purushothaman *et al.*, 1990). Transverse grooves provide better drainage which allows dry contact surface between the tire and the road surface and this property improves the skid resistance and more resisting force against sliding of tire occurs by increasing transverse groove width and this leads to bigger skid resistance. The effect of groove width on concrete roads which are examined in some researches supports the above idea (Ong and Fwa, 2006).

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The present research project was conducted to study the effect of macrotexture parameters on transverse and longitudinal grooving by British pendulum tester by examining the microtexture. In this study, the effect of groove width, groove spacing, groove shape, direction of swing and the effect of the number of test surface grooves on BPN values were considered and the leading skid resistance reasons were examined.

Experimental Program

The aim of the experimental program was to study how groove width, groove spacing, groove shape, number of grooves on the test area and the microtexture effect BPN values. The results obtained at experiments were considered with the friction measurement obtained byOng and Fwa, 2006. The program consisted of four parts. Part I of the experimental program involved testing ontransverse and longitudinal grooved surfaces with changing groove width at constant groove spacing and groove depth to determine the effect of groove width on British pendulum test results.

Part II of the experimental program involved testing different shape of groove edges by rounding them to determine the effect of rounded groove edges on British pendulum test for transverse and longitudinal grooving. Part III of the experimental program involved testing variable transverse groove width and groove spacing with constant groove depth. Then the test results were compared with the results obtained for Part I to determine the effect of the number of grooves, which sliding rubber contacts at testing area, on British pendulum test results.

Part IV of the experimental program involved comparing BPN test results of transverse grooved surfaces obtained at part I-II-

III with friction values determined byOng and Fwa, 2006. The standard sliding distance for the slider was 127 mm. The slider consisted of a rubber piece of 76 by 24 by 6 mm. The angle between the first contact point of the test surface and the lower face of the rubber slider was 18º. The static normal force for sliding distance is shown in Figure 1 (Liu *et al.*, 2003).

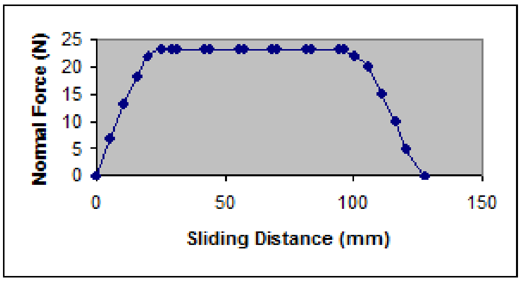

Figure 1. Static normal force for 127 mm sliding distance

PART I - Test on Transverse and Longitudinal Grooved Surfaces with Constant Groove Spacing and Depth

Specimen Preparation

Standard 15x15x15 cm cube C40 (compressive strength of 40 N/mm²) type of concrete specimens were prepared for the testing program. Plastic grooved plates were used to give the surface shape of the concrete specimens. Five different specimens with varied groove widths of 2 mm, 3 mm, 4 mm, 5 mm, and 6 mm with a constant groove spacing (center to center) of 13 mm and a depth of 6 mm were obtained to be tested by British pendulum tester in two perpendicular ways. One way represents the transverse grooving and the other one represents the longitudinal grooving. Pavementsurfaces were almost smooth with an average value of 0.02 mm micro-texture.

Analysis of Part I Results

Five types of textured surfaces were considered as shown in Figure 2. First type of consideration was for transverse grooved surfaces and the other was for longitudinal grooved surfaces which had perpendicular sliding path according to transverse grooved surfaces. The test results for transverse and longitudinal grooved surfaces are presented in Table 1. The second column of the table lists the groove width of five specimens. The third and fourth columns of the table list BPN values for dry and wet surfaces and the fifth column of the table lists the surface area of paving.

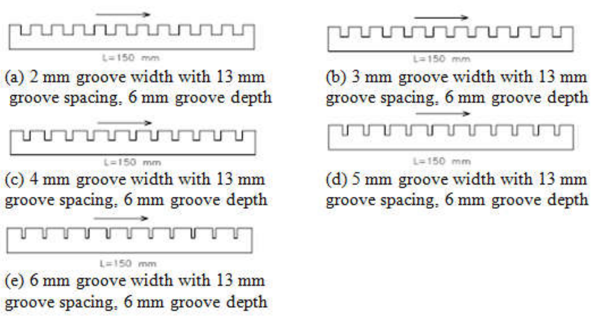

Figure 2. Transverse grooved surfaces from front view with variable groove widths (Note: Arrows denotes sliding direction)

Table 1. British pendulum test results of transverse and longitudinal grooving

Sliding Face	Groove Width (mm)	BPN Value (Dry)	BPN Value (Wet)	Surface Area (mm²)
Longitudinal	2	86	72	8128
	3	85	72	7366
	4	85	73	6604
	5	84	74	5842
	6	84	76	5080
Transverse	2	92	77	8132
	3	96	80	7372
	4	98	81	6612
	5	101	88	5852
	6	114	99	5092

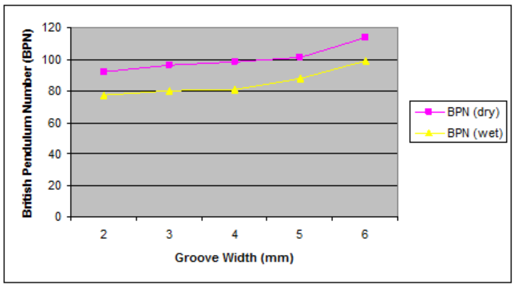

Figure 3. British pendulum measurements for transverse grooved surfaces with variable groove width, constant groove spacing and constant groove depth

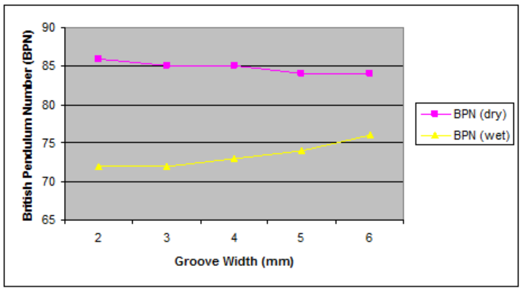

Figure 4. British pendulum measurements for longitudinal grooved surfaces with variable groove width, constant groove spacing and constant groove depth

Test results are plotted in Fig.3. and Fig.4. It was found that the effect of groove width on BPN value is different for transverse and longitudinal grooving and also for dry and wet testing. The main findings are summarized as follows:

- Dry and wet BPN values increased when transverse groove width increased. BPN values decreased a little for dry surface and increased for wet surface when longitudinal groove width increased.
- When the longitudinal groove width increases with almost zero microtexture, the difference between BPN values of dry and wet surfaces is decreasing because of the good drainage properties of grooves.
- The vertical contact area is more effective on BPN than horizontal contact area between the rubber and the surface.
- Microtexture of the surface must be considered when comparing the macrotexture effect of the surface on BPN. Because if there is no microtexture on the surface, obtained BPN values during the test may be in the opposite way of the expected values.

PART II - Test on Transverse and Longitudinal Grooved Surfaces After Rounding the Groove Edges

Specimen Preparation

The concrete specimens were prepared as it is described in Part I with plastic grooved plates. But in this part, groove edges of plates were rounded with radius of 1.5 mm so that the surface of the new concrete specimens had rounded grooves (Fig.5.). Five different specimens were tested by British pendulum tester in two perpendicular ways. One way is for transverse grooving and the other is for longitudinal grooving. Same procedure was followed as it was made in Part I (specimens were waited in water bath for 28 days, micro-texure of each surface is measured by laser profilometer) and the same micro-texture of pavement surfaces was obtained (0.02 mm).

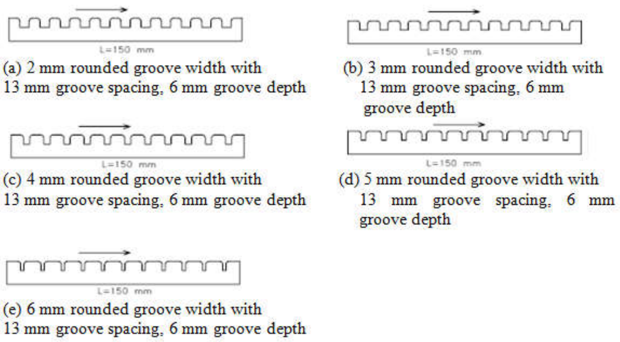

Figure 5. Transverse rounded groove surfaces from front view with variable groove width

Analysis of Part II Results

The test results for the transverse and longitudinal grooved surfaces are presented in Table 2. The second column of the table lists the groove width of five specimens. The third column of the table lists the radius of groove edge and the fourth and fifth columns of the table list BPN values for dry and wet surfaces and the sixth column of the table lists the surface area of paving.

Table 2. British pendulum test results of transverse and longitudinal rounded groove surfaces

Sliding Face	Groove Width (mm)	Radius of Groove Edge (mm)	BPN Value (Dry)	BPN Value (Wet)	Surface Area (mm²)
Longitudinal	2	1.5	85	73	5842
	3	1.5	85	75	5080
	4	1.5	84	75	4318
	5	1.5	83	78	3556
	6	1.5	83	80	2794
Transverse	2	1.5	85	74	5852
	3	1.5	90	77	5092
	4	1.5	99	85	4332
	5	1.5	105	95	3572
	6	1.5	115	105	2812

Test results are plotted in Fig.6. and Fig.7.. It was found that BPN values of longitudinal grooves decreased for dry surfaces and increased for wet surfaces when the rounded edge groove width was increasing. When these BPN values for rounded grooves were compared with grooves with sharp edges, it was determined that sharp edge grooves'

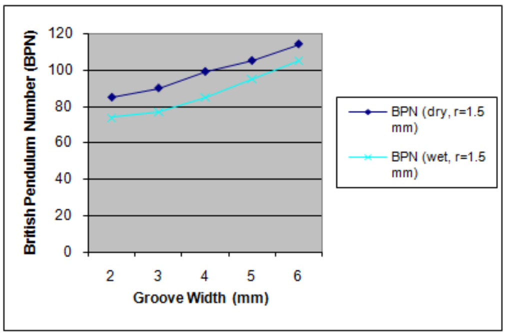

Figure 6. British pendulum measurements of rounded grooves for transverse tining

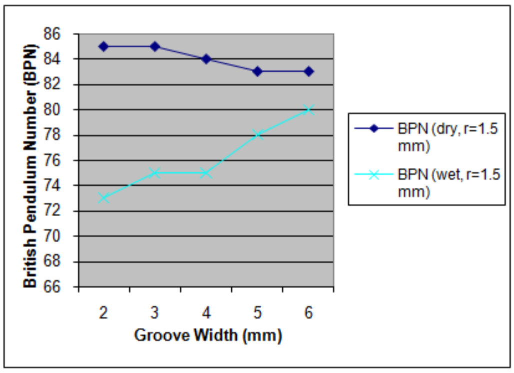

Figure 7. British pendulum measurements of rounded grooves for longitudinal tinning

BPN values were almost same with rounded ones for dry surfaces and less for wet surfaces for longitudinal grooved surfaces. BPN values were decreasing or increasing by rounding the grooves for transverse grooves for both dry and wet surfaces.

PART III - Test on Transverse Grooved Surfaces with Changing Groove Width and Spacing

Specimen Preparation

The concrete specimens were prepared as it is described in Part I with plastic grooved plates. But in this part, groove widths were 5 mm, 10 mm and 15 mm respectively and groove spacingwas 20 mm, 25 mm and 30 mm respectively with the constant groove depth of 6 mm (Fig.8.). Three different transverse grooved specimens were tested by British pendulum tester. Same procedure was followed as it was made in Part I. The same micro-texture of pavement surfaces was obtained (0.02 mm).

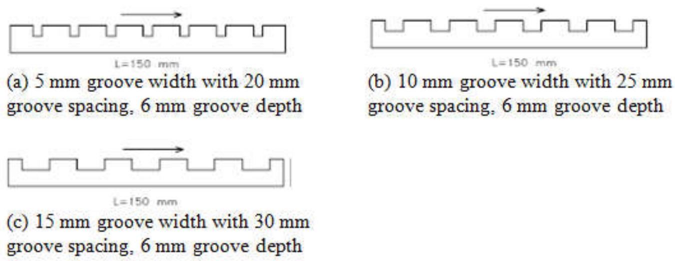

Figure 8. Transverse groove surfaces from front view with variable groove width and spacing

The test results for the transverse grooved surfaces are presented in Table 3. The second and third column of the table lists the groove width and groove spacing of specimens. The fourth and fifth column of the table lists BPN values for dry and wet surfaces and the sixth column of the table lists the surface area of paving.

Table 3. British pendulum test results of transverse grooving with variable width and spacing

Sliding Face	Groove Width (mm)	Groove Spacing (mm)	BPN Value (Dry)	BPN Value (Wet)	Surface Area (mm²)
Transverse	5	20	91	73	7372
	10	25	87	69	5852
	15	30	83	67	5092

Test results are plotted in Fig.7. It was found that BPN values of transverse grooves decreased as the groove width and groove spacing were increasing as it is determined in (Lee *et al.*, 2005).

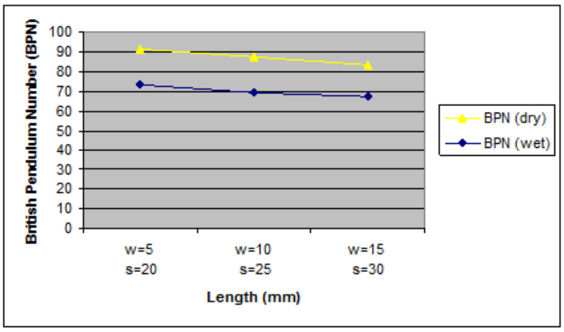

Figure 7. British pendulum measurements of varied groove width (w) and groove spacing (s)

PART IV - Comparing Laboratory BPN Values of Transverse Grooved Surfaces with Friction Numbers Obtained by Using Formula

In this part, the friction measurements according to formulas (For.1., For.2.) determinedbyOng and Fwa, 2006 were calculated. Test results which were obtained from the transverse grooved surfaces at Part I and Part III were compared with results obtained from formulas. Test results determinedbyPurushothaman *et al.*, 1990 were also analyzed in this part.

British pendulum test results and friction numbers in Ong and Fwa, 2006studyfor transverse grooved surfaces are presented in Table 4. The second and third column of the table lists the groove width and groove spacing of specimens. The fourth column of the table lists BPN values for wet surfaces at laboratory tests. The fifth column of the table lists friction numbers at 10 km/hr (sliding rubber speed) according to Ong and Fwa, 2006 and the sixth column of the table lists paving surface area/number of grooves on the tested surface.

$$\mu = 0.7360e^{bV} \qquad (1)$$

μ = coefficient of friction at vehicle speed V
V = vehicle speed
b = regression coefficient

$$\ln \mu = -1.05 - 0.185s + 0.488w + 0.214d + 0.00455s^2 - 0.0111w^2 - 0.0101d^2 - 0.00698sw + 0.00881wd - 0.00383sd \quad (r^2 = 0.976) \qquad (2)$$

s = groove spacing
w = groove width
d = groove depth

Analysis of Part IV Results

Test results showed that BPN values for transverse grooved surfaces with variable groove width, constant groove spacing and constant groove depth have similar increasing with the values obtained from formula and with the field experiments determined byOng and Fwa, 2006. Friction number calculated from the formula and BPN values at laboratory tests were decreasing when transverse groove spacing was increasing with a constant groove width and groove depth. Although the surface areas on the way of 127 mm sliding rubber distance for some specimens were same, because these specimens have different number of grooves on that distance, BPN values were also different. It was determined that test results may be different when BPN values of two specimens with almost same groove width and same groove spacing were compared to each other. For example, BPN test result for the specimen with 3 mm groove width and 13 mm groove spacing in this study was 80. But BPN value was 35 for specimen with 3 mm groove width and 12 mm groove spacing determinedby Purushothaman *et al.*, 1990.

Table 4.British pendulum test results of transverse grooved surface and friction numbers from formula

Sliding Face	Groove Width (mm)	Groove Spacing (mm)	BPN Value (Wet)	F.N. by Formula (Wet)	Surface Area (mm²) / Number of Gap
Transverse	2	13	77	0.69	8132 / 10
	3	13	80	0.72	7372 / 10
	4	13	81	0.73	6612 / 10
	5	13	88	0.74	5852 / 10
	6	13	99	0.75	5092 / 10
	5	20	91	0.72	7372 / 6
	10	25	87	0.74	5852 / 5
	15	30	83	-*	5092 / 4
	3	5	60**	0.75	3952 / 25
	3	7	50**	0.74	5548 / 18
	3	12	35**	0.72	7144 / 11
	3	24	30**	0.67	8284 / 6

* Friction number cannot be calculated by using formula obtained from (Ong and Fwa, 2006) for groove width of 15 mm and groove spacing of 30 mm.
** Values taken from (Purushothaman *et al.*, 1990)

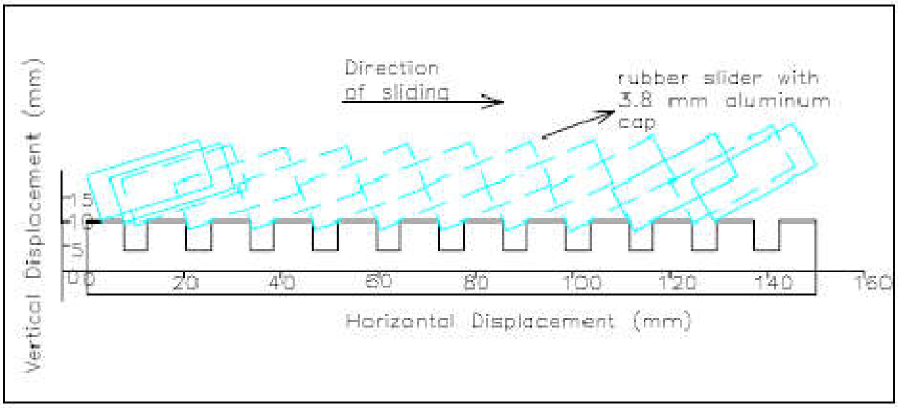

Fig. 8. Sliding path of rubber on transverse grooved surface with 5 mm groove width, 13 mm groove spacing and 6 mm groove depth (Note: Dashed lines denotes deepest penetration point of rubber into grooves)

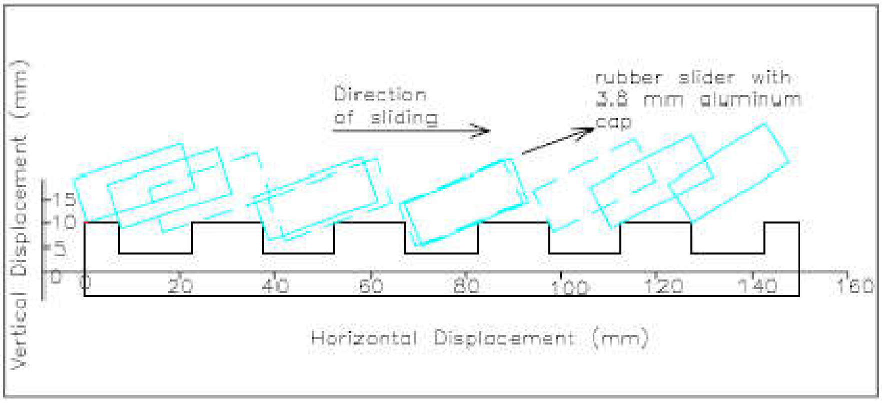

Fig. 9. Sliding path of rubber on transverse grooved surface with 15 mm groove width, 30 mm groove spacing and 6 mm groove depth (Note: Dashed lines denotes deepest penetration point of rubber into grooves)

One of the reason of that big difference may be the difference of groove depth of these specimens and the other one may be the difference of the first horizontal contact point between the rubber and the surface. Groove depth is important for friction number on road surfaces (Ong and Fwa, 2006). Groove depth for the specimens examined by British pendulum test in Purushothaman *et al.*, 1990was not given and when test results of that paper are compared with the BPN results obtained in this study and the friction values according to Ong and Fwa, 2006**,** it was found that BPN results in Purushothaman *et al.*, 1990 are doubtful. The importance of groove depth on BPN value can be clearly seen from Figure 8. and Figure 9. Because of the different static normal forces and different spring displacements for 127 mm sliding distance according to Liu *et al.*, 2003, sliding rubber penetrates into grooves with different amounts and it is very difficult to estimate the amount of penetration of rubber for each groove. The difference of first horizontal contact point of rubber and test surface may cause different sliding rubber path for same type of grooved surfaces and that causes different BPN values.

DISCUSSION

As it is mentioned in some studies (Liu *et al.*, 2004; Lee *et al.*, 2005; Purushothaman *et al.*, 1990),this study also demonstrated that British pendulum test results are significantly affected by macrotexture of test surface beside the microtexture of it. Microtexture and macrotexture of the test surface must be considered together to analyze the test results.

According to combination of these macrotexture and microtexture, BPN values may be affected in different ways. Wet surfaces always have less BPN value at about 15 unit according to dry surfaces. When the mictotexture of the test surface was kept constant at almost 0.02 mm, dry BPN values were decreasing a little (almost same). Wet BPN values were increasing when groove width was increasing with constant groove spacing and constant groove depth for longitudinal grooved surfaces which were the contrary results obtained from Lee *et al.*, 2005; Purushothaman *et al.*, 1990. It is because there is almost zero microtexture effect on skid resistance and when longitudinal groove width increases water doesn't accumulate on road surface.

BPN values were increasing with increasing groove width at constant groove spacing and constant groove depth for wet transverse grooved surfaces although the surface area of the specimen was decreasing because of the increasing width of grooves. These are opposite results according to Liu *et al.*, 2004. It is understood that sliding direction has an important role for BPN values. The reason of increasing BPN value for transverse grooved surfaces when increasing groove width was the effect of vertical contact between the rubber and the edge of each small pavement section between the grooves. That contact resists the sliding of the rubber on test surface which has similar effect on vehicle tire on the road. Test results showed that when the groove width and groove spacing were increasing together, BPN value for transverse grooved test surface was decreasing. It is because of decreasing number of grooves on test surface on which sliding rubber passes. When BPN values of two different transverse grooved surfaces with same surface area and different number of grooves on the way of sliding rubber are compared with each other, it is difficult to say which one will be bigger. It is because of the different vertical contacts between the rubber and the edge of each small pavement section between the grooves. The reason of obtaining different BPN values for rounded transverse grooved surfaces when compared with sharp edge grooves was because of these variables. The peak stress value decreases by rounding groove edges(Clapp *et al.*, 1988)and that causes less friction but the expected values were not obtained in British pendulum test for rounded grooves.

Different sliding rubber path may be obtained at same grooved surfaces because of different first horizontal contact between the rubber and test surface and that causes different BPN values. The depth of transverse grooved surfaces which affects the sliding rubber path is also important for British pendulum tester. BPN values are effected by microtexture so that by the surface area. When the amount of testing surface is decreasing, BPN value also decreases. It is because of decreasing amount of microtextured surface which rubber contacts. But when there is no microtexture and there is a macrotexture which causes good drainage on the testing surface, BPN values show opposite changings according to microtextured surfaces for wet surfaces.

Conclusion

This study demonstrated the effect of macrotexture on British pendulum measurements with considering microtexture. Four parts of the laboratory experimental program were conducted to examine the effect of the following four macrotexture parameters: groove width, groove spacing, groove shape and groove direction. The experimental measurements were compared with other studies. The test results show that macrotexture have an opposite influence on BPN values according to microtexture. The penetration of sliding rubber and the first horizontal contact point between the rubber and the transverse grooved surface changes the sliding path and that causes different BPN. The aim of using British pendulum tester is assumed to be practical and easy way to estimate skid resistance of the testing surface. The test results demonstrated that when there is a macrotexture on road surface there are too many parameters to be investigated to look for the reliability of British pendulum testing. Although experimental results were in the parallel variation with the numerical analysis for transverse grooves, recovery factor always change for every single parameter changing on road profile even if that changing is very little. This study does not recommend using British pendulum tester when there is a macrotextured surface. Because estimating every single parameter on road surface and to find the recovery factor for all these parameters take too much time. That is not suitable for the aim of using this tester.

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