IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

The effect of aggregate micro and macro texture on pavement skid resistance of Malaysia road network

To cite this article: M N M Taher *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1347** 012054

The effect of aggregate micro and macro texture on pavement skid resistance of Malaysia road network

M N M Taher[1*], M Y Aman[1] and H Bujang[2]

[1] Smart Driving Research Centre, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA
[2] Department of Civil Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, 84600 Panchor, Johor, MALAYSIA
*Corresponding author: nasirt@uthm.edu.my

Abstract. The skid resistance of the surface of the highway is controlled by its microtexture and macrotexture. Microtexture refers to irregularities in the surfaces of the stone particles (fine-scale texture) that affect adhesion and make the stone particles feel smooth or rough to the touch. Macrotexture refers to the larger irregularities in the road surface (coarse-scale texture) that effect hysteresis and associated with voids between stone particles. This paper evaluates the effect of aggregate microtexture, macrotexture and influence of pavement surface under dry and wet condition to skid resistance. Three (3) different types of pavement surface were selected to obtain friction value on Continuously Reinforced Concrete Pavement (CRCP), Hot Mixture Asphalt pavement (HMA), and Ralumac Micro-Asphalt. In addition, skid resistance value was calculated from British Pendulum Tester and texture depth by using sand patch method. From the field test conducted and statistical analyses of the data, there were strong relationship between microtexture, macrotexture and types of surface pavement subjected to different dry and wet conditions.

1. Introduction

An important aspect of safety during travel using road transport is the interaction between vehicle tyres and the road surface. Two main factors that have high influence in this case are the skid resistance between the tyre and the road surface, and the texture depth of the pavement. Skid resistance is the friction force developed when a tyre that is fully or partially prevented from rolling slides along a pavement surface under lubricated conditions. Friction is developed with the close contact between the tyre and the pavement aggregates [1]. The opposing force created at the point where a tire contacts a surface during a skid is known as pavement skid resistance. Skid resistance, in other terms, is the force that prevents a tire from slid-ing across a paved surface. Due to its importance in retaining vehicle control and shortening the stopping distance in emergency braking circumstances, skid resistance, also known as skid friction, is a crucial component of traffic safety. [2]. However, both the surface microtexture and macrotexture affect skid resistance. Pavement macrotexture is defined as "a deviation of 0.5 mm - 50 mm from a true planar surface," whereas pavement microtexture is defined as "a deviation of a pavement surface from true planar surface with characteristic dimensions along the surface of less than 0.5 mm." [2]. Adhesion and hysteresis are the two main factors that affect skid resistance. When the tire rubber is forced into close contact with the particles of the pavement surface, it forms molecular connections that eventually shear, resulting in adhesion. Hysteresis is caused by energy loss when the tire rubber deforms when traveling across asperities on a rough pavement surface. These two components of skid resistance are related to the microtexture and macrotexture as shown in figure 1 [3].

According to the NHTSA (2007), up to 35% of accidents on wet pavement are caused by skidding. Highway safety consequently heavily depends on pavement surface friction. Additionally, owing to surface cleaning and seasonal variations, the skid resistance weakens with time. These put the pavement at an elevated danger of sliding collisions. For safety throughout the service life of the pavement surface, a suitable surface friction that takes into account seasonal and long-term fluctuations is crucial.

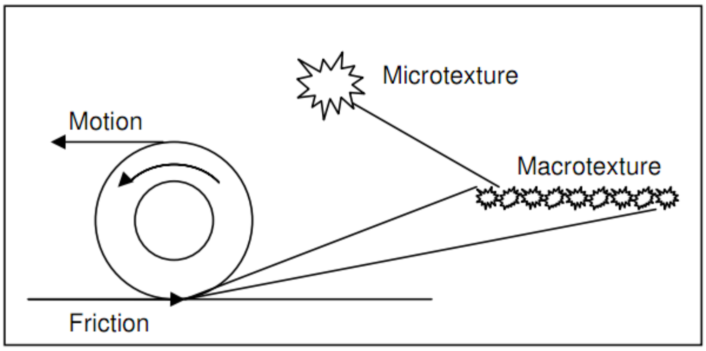

Figure 1. Friction force and its properties [2].

Inadequate supply of skid resistance may be caused by pavement deterioration (smoothing or polishing of the pavement surface), surface water collection in the form of rain, snow, or ice, and both. Skid-related collisions may occur more frequently if there is insufficient skid resistance. According to Blake 2017 [4], despite a substantial amount of study being done, there is presently no consensus on the standards to be applied for maximizing skid resistance.

Because of the constant passage of cars, the environment, and occasionally inadequate pavement maintenance, road pavements degrade with time. The degree of surface distress that might impair skid resistance can rise and be detrimental to traffic if this degradation is not appropriately treated. This is because the properties of the pavement surface have a big impact on maintaining traffic safety. Maintaining these qualities during pavement repair or construction might reduce or even eliminate accidents and occurrences involving loss of control, hydroplaning, and excessive sliding [5].

Studies have shown that reducing the friction of the pavement surface can prevent skid-related incidents [6]. It also mentioned that an improvement of surface friction coefficient of 0.1 could reduce the wet-accident rate by 13 percent [6-7]. The wet-weather accidents have been shown to reduce by 35% with a net return of 540% after laying anti-skid surfacing at more than 2,000 sites in London, UK [8]. The smoothness, safety, and comfort of a roadway are all influenced by the friction of the pavement surface.

Texture provides a retarding force at the tire-pavement interface that resist sliding when a braking force applied [9]. This facilitates controlled driving maneuvers, especially on wet surfaces. In fact, 70% of the wet weather crashes are preventable with improved texture/friction on pavement surfaces. A key factor in lowering wet-pavement skid incidents is pavement surface friction, which serves as a gauge of riding safety on the pavement. [10], [11]. The interaction of the vehicle with the pavement is mostly dependent on the friction force between the tire and the surface. It enables the vehicle to accelerate, turn, corner, and stop safely [12]. Skid resistance is the friction force developed at the tire-pavement contact area [13]. The skid resistance is an interaction between many factors.

The roughness of the pavement, the speed of the vehicle, and the presence of water are just a few elements that might cause friction to form between rubber tires and a pavement surface. [13-14]. figure 2 illustrates how the friction phenomena between a tire and pavement revealed that adhesion and hysteresis components made up most of the frictional forces in elastomers. Vehicle stopping distance when skidding on wet pavement is influenced by a complicated interaction between adhesion and hysteresis forces [15-16]. Therefore, this study aims to evaluate microtexture and macrotexture under different types of pavement surfaces.

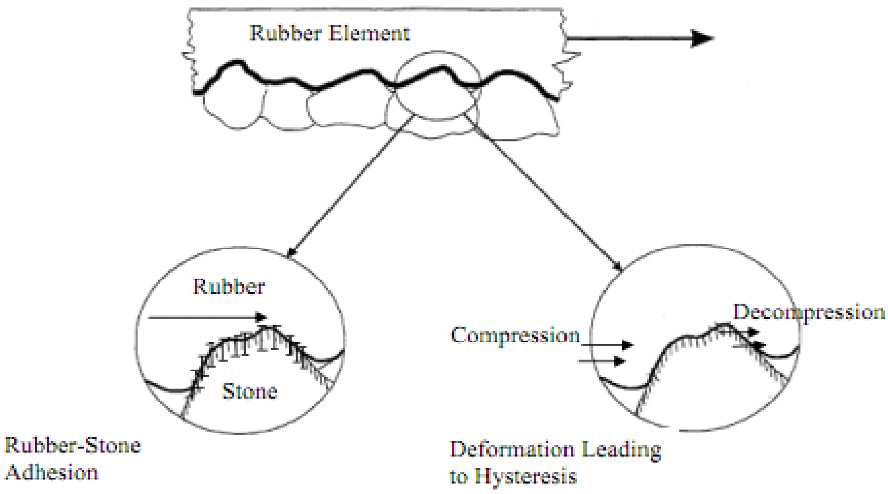

Figure 2. Schematic plot of hysteresis and adhesion [14].

2. Field measurement programme

This subsection describes material and field measurement of skid resistance and mean texture depth (MTD) at selected site location. Skid resistance was evaluated on three (3) different pavement surfaces which were Continuously Reinforced Concrete Pavement (CRCP), Hot Mixture Asphalt pavement (HMA), and Ralumac Micro-Asphalt pavement under wet and dry condition.

2.1 British pendulum tester (BPT)

The British Pendulum Tester (BPT) was conducted in measuring microtexture according to ASTM E 303-83. The BPT is a simple machine that provides highly consistent readings. It works by releasing a pendulum with uniform force by gravity from height. A rubber slider is attached to the end of the pendulum, which comes in contact with the pavement or specimen upon release. When the pendulum is released and swing down making contact with the pavement or specimen surface, it pushes a pointer up along a calibrated measuring device and leaves it at the highest point reached by pendulum. The less friction encountered by the rubber slider, the higher the pendulum reaches on the calibrated dial resulting in a lower value [17-19].

2.2 Sand patch test

The Sand Patch Test is performed according to ASTM E965 [20] use a spreading instrument and a specified amount of the substance. Ottawa sand, which retains on the number 100 sieve and passes the number 50 sieve, is the material often utilized for this test. If the sand adheres to the necessary requirements, the test findings utilizing Ottawa sand are acceptable. Until the sand is evenly distributed around the cracks in the pavement surface, it is spread out in a circular motion. To determine the mean texture depth of the pavement macrotexture, the diameter of the area covered with sand is measured. The mean texture depth is calculated from the test results using equation 1:

$$MTD = \frac{4V}{\pi D^2} \tag{1}$$

Where: MTD = Mean texture depth of the pavement macrotexture, V = Volume of the sample material used, and D = Average diameter of the area covered by the material.

3. Result and Discussion

The following subsection describe the further analysis of macro and microtexture analysis and its relationship between skid resistance value (SRV) and mean texture depth (MTD).

3.1. Macrotexture measurement

Field test on selected roadways was performed to analyze the macrotexture depth of Continuously Reinforce Concrete Pavement, Hot Mix Asphalt Pavement and Ralumac Micro-Asphalt Pavement. A total of 30 subsections over three test sites were selected in PLUS expressway, south bound. Measurements from the selected roadways were used to determine the relationship of friction and MTD. From Sand Patch Test conducted on three study sites, mean texture depth was obtained and results of Sand Patch Test are tabulated in table 1, 2 and 3 for Continuously Reinforced Concrete Pavement (CRCP), Hot Mixture Asphalt pavement (HMA) and Ralumac Micro-Asphalt pavement, respectively.

Table 1. Sand patch test results of continuously reinforced concrete pavement (CRCP*).*

No	Chainage (KM)	Test track (m)	Diameter of Sand, D (mm)				Mean Diameter (mm)	Texture Depth $49197/D^2$ (mm)
			D1	D2	D3	D4		
1	TP1/S	10	470	450	480	450	462.50	0.23
2	TP1/S	10	540	510	490	530	517.50	0.18
3	TP2/S	10	440	460	440	430	442.50	0.25
4	TP2/S	10	420	440	420	420	425.00	0.27
5	TP1/N	10	450	440	470	470	482.50	0.21
6	TP1/N	10	450	455	450	455	452.50	0.24
7	TP3/N	10	440	440	435	445	440.00	0.25
8	TP4/N	10	450	460	450	455	453.75	0.24
9	TP4/N	10	430	440	430	430	432.50	0.20
10	TP2/N	10	450	460	450	440	450.00	0.24

This test was conducted at Kempas Toll Plaza located at kilometer 7.8 both south and north bound with section of sand patch test was in range of 10 meter. From the results, it was found that the maximum MTD of concrete pavement was 0.27 mm at average diameter of 425 mm while the minimum MTD was 0.18 mm at average diameter of 517.5 mm. These shown that large diameter of sand produces a lower MTD as the sand spread evenly on the concrete surface. Based on study conducted by Wen and Kim , it was found that fracture energy was highly associated with field fatigue performance. It also indicated that asphalt mixture with higher fracture energy has higher resistance to fatigue cracking. The result was further analyzed using a statistical analysis. The ANOVA with confidence interval of 95% (a=0.05) was adopted to distinguish the significant difference on the Skid Resistance Value (SRV) to Mean texture depth (MTD) Subjected to wet and dry conditions.

Table 2 shows the result of sand patch on hot mixture asphalt pavement on second site, located at Pulai heading to Tuas kilometer 21.3 to 21.4 souths bound, PLUS expressway. MTD were obtained by the similar method to Concrete Pavement. The result shows the highest MTD was 0.35 mm at average sand diameter of 372.50 mm while the minimum MTD was 0.17 mm at average diameter of 538.75 mm. The finding in this study is slightly similar to table 1 data, where MTD value is generally higher which is mainly due to macrotexture surface.

Table 2. Sand patch test results of hot mixture asphalt pavement (HMA).

No	Chainage (KM)	Test track (m)	Diameter of Sand, D (mm)				Mean Diameter (mm)	Texture Depth 49197/D^2 (mm)
			D1	D2	D3	D4		
1	21.30	10	470	450	480	450	430.0	0.22
2	21.31	10	540	510	490	530	481.25	0.21
3	21.32	10	440	460	440	430	538.75	0.17
4	21.33	10	420	440	420	420	468.75	0.22
5	21.34	10	450	440	470	470	372.50	0.35
6	21.35	10	450	455	450	455	460.00	0.23
7	21.36	10	440	440	435	445	450.00	0.24
8	21.37	10	450	460	450	455	482.50	0.21
9	21.38	10	430	440	430	430	465.00	0.23
10	21.39	10	450	460	450	440	432.50	0.24

Table 3. Sand patch test results of ralumac micro-asphalt pavement.

No	Chainage (KM)	Test track (m)	Diameter of Sand, D (mm)				Mean Diameter (mm)	Texture Depth 49197/D^2 (mm)
			D1	D2	D3	D4		
1	29.40	10	180	181	180	182	180.75	3.54
2	29.41	10	179	179	179	179	179.00	3.54
3	29.42	10	178	173	176	176	176.35	3.52
4	29.43	10	175	174	174	173	174.00	3.62
5	29.44	10	172	172	170	169	170.75	3.69
6	29.45	10	168	168	168	168	168.25	3.74
7	29.46	10	166	165	166	167	166.00	3.79
8	29.47	10	166	166	165	165	165.50	3.80
9	29.48	10	162	162	162	163	162.50	3.80
10	29.49	10	160	161	160	162	160.75	3.90

The results on Ralumac Micro-asphalt pavement tested on third site located at Seremban to Port Dickson expressway, kilometer 29.4 to 30.0 eastbound indicate that maximum MTD value obtained by was 1.90 mm at average sand diameter of 160.75 mm while the minimum MTD was 1.51 mm at average diameter of 180.75 mm. The higher diameter results in lower texture depth. Based on the result, Both the micro- and macro-texture of the pavement surface had a substantial impact on the skid resistance at low speeds of the wet pavement surfaces.

3.2. Microtexture Measurement

In this analysis, figure 3 shows the general trend of SRV for dry and wet condition recorded on concrete pavement surface. The range of data skid resistance value (SRV) obtained for dry condition on concrete pavement was recorded in range 77.25 to 83.50. According to WSDOT Pavement Guide (2004), SRV above 65 represent a good skid resistance. Thus, this concrete pavement was a good surface friction. In addition, the skid resistance value (SRV) on wet concrete surface indicate that the minimum and maximum SRV was 71.00 and 75.5. Thus, this concrete pavement was a good surface friction even though in wet condition according to WSDOT Pavement Guide (2004). Surface frictions at low range on wetted condition as the water filled the irregular surface and make the surface smooth to the touch. As the temperature of wetted surface pavement was decrease, this is also affected the corrected SRV.

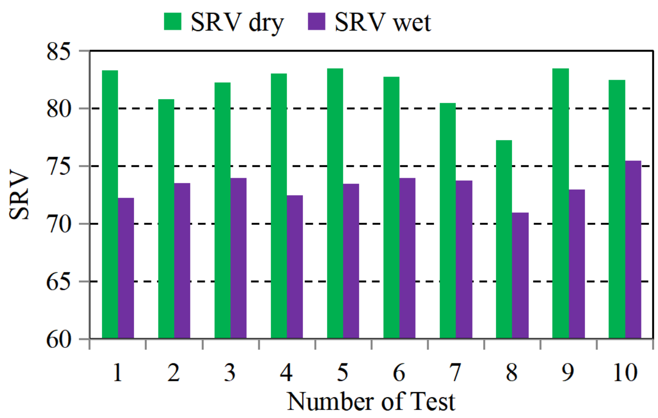

Figure 3. Comparisons on concrete pavement SRV of wet and dry condition.

Figure 4 depicts the skid resistance value (SRV) of asphalt pavement on dry and wet condition. In general, the SRV on wet condition have lower value compared to dry surface for both concrete pavement and asphalt pavement.

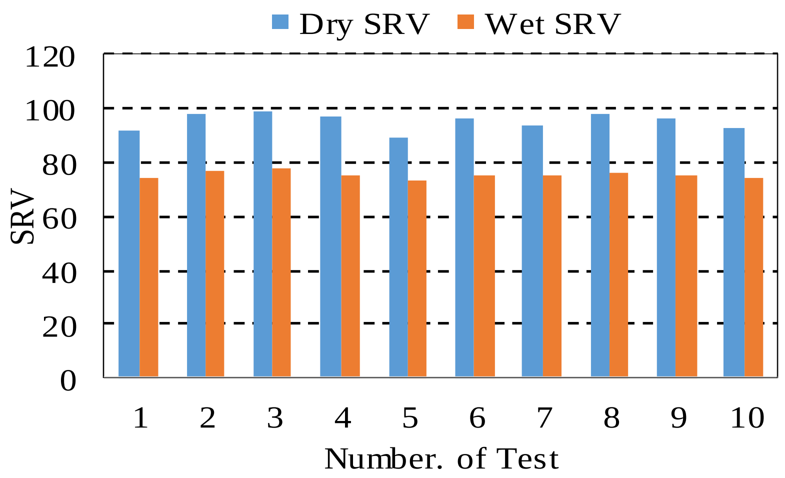

Figure 4. Comparisons on asphalt pavement SRV of wet and dry condition.

From data obtained, the minimum and maximum SRV for dry condition on Asphalt pavement was 91.30 and 98.75 respectively. From standard and specification ASTM E303 [16], SRV above 65 represent a good skid resistance. Thus, this Asphalt pavement was a good surface friction. Meanwhile, the skid resistance value (SRV) on wet Asphalt surface show the minimum and maximum SRV for wet condition on Asphalt pavement was 73.30 and 77.5 respectively. Based on the results shown in figure 5, the skid resistance value (SRV) of Ralumac Micro-asphalt pavement on dry at the minimum and maximum SRV for on Ralumac Micro-asphalt pavement was 74.90 and 75.95 respectively. Meanwhile, the minimum and maximum SRV for wet condition was 73.05 and 74.50. This can be explained by the SRV, whereas micro asphalt pavement surface tends to have higher and provide more resistance which resulted on skid resistance.

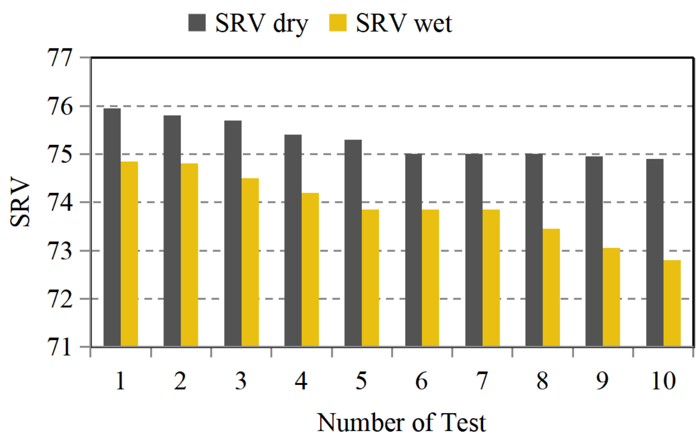

Figure 5. Comparisons on ralumac micro-asphalt pavement SRV of wet and dry condition.

3.3. Relationship Analysis of SRV and MTD

Figure 6 depicts the fitness of linear function with R^2 of 0.5327 for wet and 0.8546 for dry conditions. Similar function with high R^2 can be developed for other types of pavement surfaces. From the result tabulated in table 4, it is proven that the relationship of SRV and MTD higher compared to concrete and asphalt pavement.

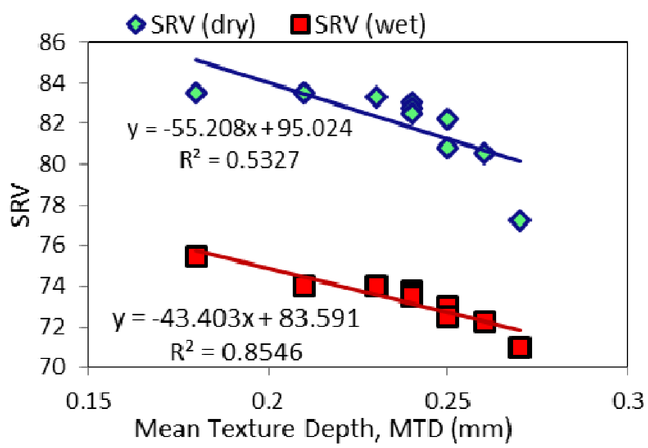

Figure 6. Correlation between SRV and MTD for concrete pavement.

Table 4. Statistical analysis of SRV and MTD at wet and dry condition

Site Location	Condition	*p*-Value[a]	Significant
Concrete Pavement (KM 7.8 Kempas Toll Plaza)	Wet	<0.001	Yes
	Dry	<0.001	Yes
Asphalt Pavement (KM 21.3 -KM 21.4 Pulai ,South Bound)	Wet	<0.001	Yes
	Dry	<0.001	Yes
Ralumac Microsursafing Pavement (KM29.4-KM 29.5 Seremban-Port Dickson)	Wet	<0.001	Yes
	Dry	<0.001	Yes

[a] Based on 95% confidence interval (α = 0.05)

On top of that, figure 7 shows the correlation between the MTD and the SRV of asphalt surfaces investigated in this study. The result indicates a decrease in the SRV as mean texture depth (MTD) value increases for the surfaces investigated, with low R^2 indicating strong correlation between SRV and MTD. On the other hand, results in table 4 and figure 6 show that MTD value is significantly higher in dry compared to wet conditions. However, higher SRV obtained for asphalt compared to concrete and micro asphalt pavement surfaces.

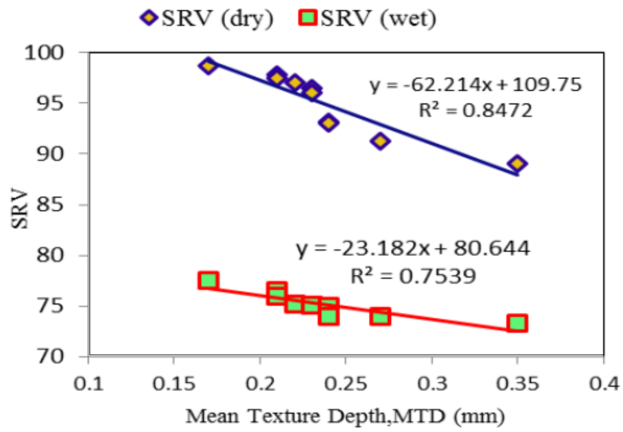

Figure 7. Correlation between SRV and MTD for asphalt pavement.

The figure 6 shows the correlation between the MTD and the SRV of Ralumac Micro asphalt surfaces. From the result tabulated in table 4, it is proven that the relationship of SRV and MTD higher. This can be explained by decrease in the SRV as mean texture depth (MTD) value increases for the surfaces investigated, with low R^2 indicating strong correlation between SRV and MTD.

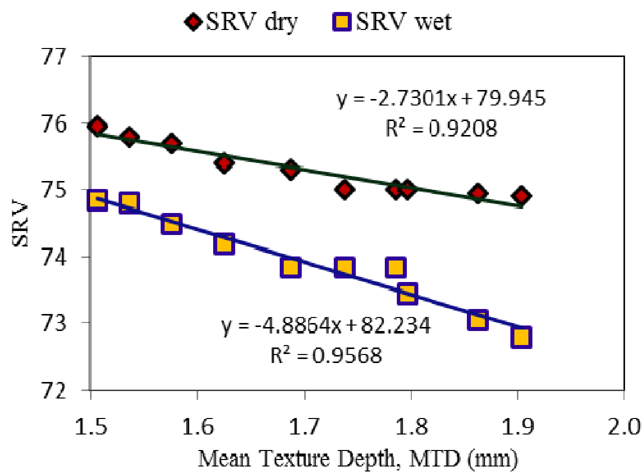

Figure 8. Correlation between SRV and MTD of Ralumac Micro-Asphalt Pavement.

4. Conclusion

Macrotexture is a potential indication of friction on high-speed roads. Thus, the combination of friction information and macrotexture (measured as MTD) was of significant interest in this study. It was anticipated that both variables would be directly proportional to one anotherIn other words, it was anticipated that the SRV would increase in proportion to the MTD value for a particular length of pavement. The data analysis showed that the association had the opposite effect for the study parts. Although it was obvious that the bigger SRVs were concentrated in low MTD values, plots of MTD and SRV values did not clearly reveal a link between the two values. The prediction of pavement skid friction using volumetric data could be possible if MTD and pavement skid friction are correlated. In the end, utilizing volumetric data to forecast pavement skid friction might aid in the creation of pavement mixtures that produce high SRVs and improve road safety by increasing tire-to-pavement tractionIt is unclear why, as opposed to being exactly proportional as predicted, the connection between MTD and friction was discovered to be more inversely proportional. The pavement made of Ralumac Micro-asphalt, according to data, provides superior skid resistance. The Ralumac Micro-asphalt pavement tested has the lowest Skid Resistance Value but the highest MTD values. The measurement of friction using a ribbed tire may be the cause of the inconsistent association between SRV and MTD. The areas with high MTD had poor microtexture, which might account for the unexpectedly exactly proportional forms of the graphs. It is evident from statistically significant data that skid resistance is a crucial factor to take into consideration when assessing roadway safety. The contribution of aggregate microtexture and macrotexture on skid resistance under wet and dry conditions have been shown using statistical analysis data. The three different types of pavements studied in this study—concrete, asphalt, and ralumac micro-asphalt—have an impact on both the SRV and MTD.

References

[1] Aminuddin Suhaimi and Abdul Rahman Baharuddin 2019 Threshold value of skid resistance and texture depth for Malaysia road. *IOP Conference Series: Materials Science and Engineering* **512** 1

[2] Binshuang, Z., Jiaying, C., Runmin, Z., and Xiaoming, H. 2019 Skid resistance demands of asphalt pavement during the braking process of autonomous vehicles. *MATEC Web of Conferences* **275** 04002

[3] Meegoda, J. N., and Gao, S. 2015 Evaluation of pavement skid resistance using high speed texture measurement *J. Traffic Transp. Eng.* **6** p38

[4] H Bujang, M Y Aman, M.N.M Taher 2022 Volumetric Properties of Asphalt Mixture Containing Fly Ash *Geopolymer IOP Conference Series: Earth and Environmental Science* **1022** 012034

[5] Kamal, I., and Bas, Y. 2021 Materials and technologies in road pavements-an overview *Materials Today: Proceedings* **42** 2660

[6] Taher, M. N. M., and Aman, M. Y. 2020 Resilient modulus of Advera® warm mixture asphalt incorporating reclaimed asphalt pavement (RAP) materials *IOP Conference Series: Earth and Environmental Science* **498** 12015

[7] Bujang, H., Aman, M. Y., Arumugam, T. N., and Taher, M. N. M. 2023 Physical Characterization of Modified Asphalt Binder with Differing Fly Ash Geopolymer Contents Int. *J. Integr. Eng.* **15** 331

[8] Measurement of Skidding Resistance and Surface Texture and the Use of Results in the United Kingdom." Surface Characteristics of Roadways *International Research and Technologies, American Society for Testing and Materials* Philadelphia, **ST P1031** 870102.

[9] Mataei, B., Zakeri, H., Zahedi, M., and Nejad, F. M. 2016 Pavement friction and skid resistance measurement methods: A literature review *Open J. Civ. Eng.* **6** p537.

[10] Yu, W. 2019 *Characterizing Pavement Skid Resistance for Roadway Crash Prediction in Oklahoma* Doctoral dissertation (Oklahoma State University).

[11] Li, S., Zhu, K., Noureldin, S., and Harris, D. 2005 Identifying Friction Variations with the Standard Smooth Tire for Network Pavement Inventory Friction Testing. *Presented in Transportation Research Board 84th Annual Meeting*, Washington D.C.

[12] Schutt, B., Braun, T., Otten, S., and Sax, E. 2020 A graphical modeling framework for scenario-based testing of autonomous vehicles. *Proceedings of the 23rd ACM/IEEE International Conference on Model Driven Engineering Languages and Systems* pp114

[13] Elkhazindar, A., Hafez, M., and Ksaibati, K. 2022 Incorporating pavement friction management into pavement asset management systems: *State department of transportation experience. Civil Eng* **3** 541-561.

[14] Noyce, D. A., Bahia, H. U., Yambó, J. M., and Kim, G. 2005 Incorporating road safety into pavement management: Maximizing asphalt pavement surface friction for road safety improvements. *Literature Review and State Surveys, Midwest Regional University Transportation Center* (UMTRI), Madison, Wisconsin.

[15] Ueckermann, A., Wang, D., Oeser, M., and Steinauer, B. 2015 Calculation of skid resistance from texture measurements., *J. Traffic Transp. Eng.* **2** 3

[16] Taher, M. M., Aman, M. Y., Nazir, M. M., & Bujang, H. 2022 Dynamic Creep Performance of Hot Mix Asphalt Mixture Incorporating *Fibre. Int. J. Integr. Eng.* **14** 49

[17] Choubane, B., Holzschuher, C.R., and Gokhale, S. 2004. Precision of Locked- Wheel Testers for Measurement of Roadway Surface Friction Characteristics. *Transportation Research Record 1869, Transportation Research Board, TRB,* National Research Council, Washington, D.C.

[18] Han, S., Liu, M., AND Fwa, T. F. 2020 Testing for low-speed skid resistance of road pavements. *Road Mater. Pavement Des.* **21(5)** pp1312-1325.

[19] ASTM E303 2022 American Society for Testing Material: *Laboratory and Field Device Measurement of Skid Resistance* (ANSI, US) pp 1-6

[20] ASTM E965 2019 American Society for Testing Material: *Volumetric Technique for Texture Depth Measurement* (ANSI, US) pp 1-5

Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through TIER 1 (Vot Q471). The authors would also like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for the technical support.