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Effect of Rainfall Intensity and Road Crossfall on Skid Resistance of Asphalt Pavement

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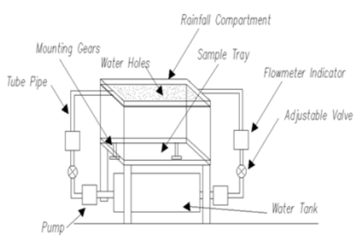
Graphical abstract



Abstract

Skidding is one of the major factors to road accidents during wet weather condition. Skidding during wet weather happens when water film presents between the tyre and pavement reducing the friction of tyre onto the road surface. This laboratory study was carried out to investigate the factors affecting Pendulum Test Value on Asphaltic Concrete surfaces. The main objective of this study is to determine the pavement type and the crossfall percentage that best resist skid during wet weather condition. Three different types of dense graded mixes were used in this study which are AC10, AC14 and AC20. Those three constructed mixes were tested using Sand Patch Test (SPT) and were then subjected to various rainfall conditions and crossfall percentages using Rainfall Simulator. The rainfall conditions are categorized as low rainfall, medium rainfall and high rainfall while the crossfalls were increased 2% from 0% to 10% crossfalls. During the event of rainfall on each pavement surfaces, a British Pendulum Tester (BPT) was used on the pavements to obtain the Pendulum Test Value (PTV) at different crossfalls. Collected data are analyzed using analysis of variance (ANOVA) to justify the objectives. Results from PTV shows that 4% to 10% crossfall is the best crossfall and AC20 is the best surface type in resisting skid.

Keywords: Rainfall conditions; crossfalls; asphaltic concrete type; ANOVA; SPT; PTV

1.0 INTRODUCTION

Malaysia is currently having one of the best road systems in Asia. Eventhough Malaysia has the best road system, accident rates in Malaysia increased at an average rate of 9.7% yearly [1]. Several studies have dealt with the effects of rain on traffic, accident risk and traffic demand changes [2, 3]. Road accidents are high in Malaysia due to many factors such as the drivers' carelessness, vehicle speed, braking distance, insufficient head distance and skidding especially on wet condition. The major factor contributes to road accident is skidding as there is connection between vehicle tyre and pavement. The worst skidding ever happen is during wet pavement condition during rainy day. A research proves that 25% of wet road accidents in United Kingdom happened due to skidding [4].

Skid occurs when the available friction between the pavement surface and the tire is insufficient to respond to the maneuver a driver is attempting to make. This happens when the vehicle is maneuvered by the exerted forces at that stationary area where the friction between the tire and the road surface opposes to the maneuvering force. A dry road surface condition produces high road and tyre friction for normal driving maneuvers while the wet road surfaces decreases the friction effect significantly causing skidding accidents [4].

Skidding can happens due to the insufficient of pavement crossfall and pavement surface characteristics. Skidding can be avoided if there is effective friction between tyre and pavement. Pavement surface characteristics, both the macrotexture and microtexture play important roles in providing comfortable driving and safety to drivers. The frequency of rainfall intensity also conduces to pavement friction. Rainfall develops water film on pavement which exists between the tyre-pavement contacts. This could eventually create hydroplaning thus contributes to skidding. Pavement crossfall is another important element in providing friction between tyre and pavement. Crossfall is essential in highway construction since it functions to reduce waterponding on pavement during rainy weather.

Since Malaysia is located within the Equatorial climate region and utilizes more Asphaltic Concrete pavements, this laboratory study is essential to be carried out and justified. The objectives of conducting this study are to investigate the effect of PTV on various rainfall intensities, various crossfalls and different Asphaltic Concrete surfaces during rainfall and to recommend the crossfall and pavement type that best resist skid during wet pavement condition.

2.0 METHODOLOGY

2.1 Materials and Sample Preparation

The materials used in the design of asphaltic concrete mix were crushed granite aggregates and bitumen grade 80/100 PEN. Design of asphaltic concrete mix was based on specifications from Malaysia Public Works Department known as Jabatan Kerja Raya [6] and Urban Stormwater Management Manual or also known as Manual Saliran Mesra Alam [7]. Obtimum Bitumen Content (OBC) from the Superpave Method was used and assumption of 4% air void was made based on National Asphalt Pavement Association (NAPA) [6] for three different mixes which were AC10, AC14 ad AC20 mixes.

The total aggregate weight was determined and placed into the oven on trays a day before the mixing process. This is to ensure that the aggregate is completely dry before the mixing process can take place. The temperature of the oven has been set to 110ºC. Four hours before the sample mixing, the bitumen has been heated in the oven for melting process. The temperature for bitumen melting process is within 130ºC and 145ºC. The aggregates and the bitumen were mixed on mixer to be filled onto the rainfall simulator mould.

The preparation of mix samples involved the 118 cm x 61 cm x 5 cm sample mould. Based on the calculation, the mass of sample need to be filled into the mould is based on the TMD and Air Void of the samples. The mass needed to fill the mould was expressed as the percentage of sample without void multiply with Theoretical Maximum Density (TMD) and volume of the mould. Three mix moulds were prepared for AC10, AC14 and AC20 mix. Each sample mix was prepared into four mixers. All four mixers of mix samples were needed to fill into the mould fully. Therefore, mix of each mixer has been poured into the mould creating four layers of mix. The temperature of mix from each wok has been consistent at 170°C before pouring into the mould. When each layer is poured into the mould, the compaction is done front and back using a hot steel roller compacter. The samples are cooled for a day at 40°C.

2.2 Development of Rainfall Simulator

Rainfall Simulator shown in Figure 1 is an apparatus used to simulate rain onto the constructed mixes. Rainfall simulator consists of water tank for water storage, adjustable valves and rainfall flowmeter to control the water flowrate, 1500 water holes of 1mm width to simulate rain, a tray compartment to place the mix samples and mounting gears to provide camber effect to the mix samples. Water from water tank is pressured into the pipe tubes using motor. The water is controlled using the valves and the flowmeter reads the desired water flowrate entering the rainfall compartment tray. The water fills the rainfall compartment tray and drops as water droplets into the 1500 water holes creating rainfall which simulates the actual rainfall effect. Each mix sample is placed on the tray compartment provided acting as the road surface structure. Mounting gears is used to mount the mix sample mould creating slope gradient to provide road camber.

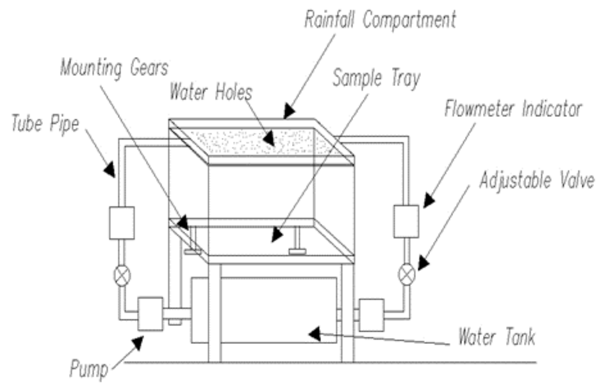


Figure 1 Schematic diagram of rainfall simulator

In order to generate rainfall on the rainfall simulator, the rainfall intensity of low, medium and heavy rainfall intensity based on Manual Saliran Mesra Alam [7] specification is calculated. High rainfall intensity of 432.40 mm/hr at 100 years Average Recurrence Interval (ARI) , medium rainfall intensity of 220.50 mm/hr at 20 years ARI, low rainfall intensity of 30 mm/hr at 2 years ARI and normal condition where no rainfall intensity is present are used in this study based on Rational Method calculation with the C =0.95 and A = 7.2 x 10-7 km^2. The rainfall intensity is converted into flowrate using the Rational Method as in Equation 1 so that it can be set with the flowmeter of the rainfall simulator.

Flowrate (Q) = Runoff Coefficient (C) x Intensity (I) x Area (A) (1)

Crossfall of the mould filled with mix is adjusted ranging from 0% to 10% crossfall with the increase of 2% at a time using the lever gear located at the rainfall simulator. Higher crossfall percentages as 8% and 10% are used to determine the trend of PTV affecting the crossfall eventhough the Arahan Teknik Jalan (8/86) [7] recommends crossfall of 2.5%-6% only. The crossfall of the mix mould is expressed as percentage of differences in height to differences in horizontal given in Equation 2.

$$Slope\ (\%) = \frac{Height\ differences}{Horizontal\ differences} \quad (2)$$

The runoff flowrate and the water film thickness were obtained during the rainfall event on the rainfall simulator. The water film thickness is measured on the pavement where the water depth on the surface is measured using a ruler. The water runoff from the pavement is recorded for 1 minute. The water runoff value should be almost or closer to the flowrate of the rainfall since the air void of the asphaltic concrete is 4% only. Water runoff from the pavement is collected into the runoff collector basin and the volume is measured. The volume per minute is converted into liter per minute as a comparison with the flowrate of rainfall.

2.3 Pendulum Test Value and Texture Depth Determination

The sand patch test was carried first before the rainfall simulation could take place. This test was conducted based on BS EN 13036-1[10]. Five sand patch tests were carried out for each mix. Sand

Patch Method was used to determine the texture depth of the constructed pavement mix. Once completed, the pavement was placed into the rainfall simulator apparatus and the British Pendulum Tester (BPT) was placed on pavement to measure the Pendulum Test Value (PTV). BPT has been positioned onto the mix sample longitudinally with wheel path and against the water. PTV was measured at normal conditions where the procedure of measuring PTV follows the British Standard BS-EN 13036-4 [11] and no rainfall intensity is present. Then, the PTV was measured according to the low rainfall intensity, medium rainfall and high intensity using adjustable valve and flowmeter. Average PTV of five swings has been recorded during the rainfall event. The rainfall simulation process has been repeated for different mix types at different rainfall flowrates and at different crossfalls.

3.0 RESULTS AND DISCUSSION

3.1 The Effect of Rainfall Intensity on Pendulum Test Value

Figure 2 and Figure 3 show that the PTV decreases as the rainfall intensity increase for AC10, AC14 and AC20. The PTV decreases due to the excessive water on pavement surface during high rainfall intensity compared to the low rainfall intensity where only small water film thickness is present on the pavement surface. As the crossfall increases, the PTV increases for all three rainfall intensities. At 0% crossfall, the trendline for each surface type is close to each other. However, the trendline tends to move away within the three surface types as the crossfall increases. This shows that small water film thickness is present on the surface at 10% crossfall as the macrotexture effectively drains off the water increasing the microtexture thus resulting to higher PTV value.

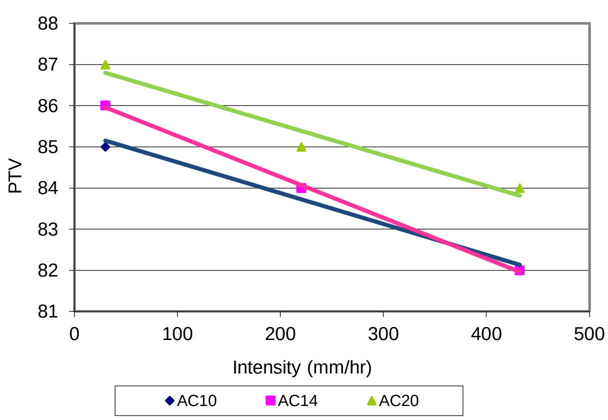


Figure 2 Pendulum test value vs intensity at 0% crossfall

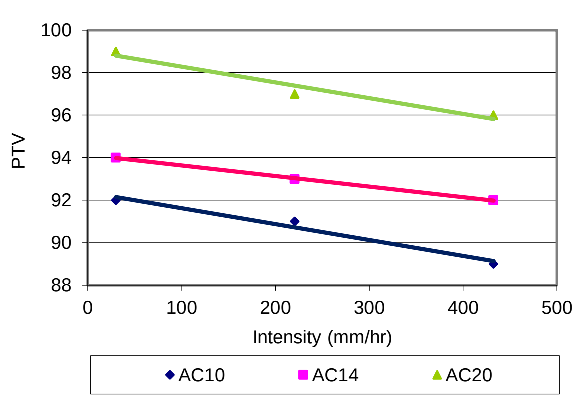


Figure 3 Pendulum test value vs intensity at 10% crossfall

3.2 The Effect of Crossfall on Pendulum Test Value

Figure 4 to Figure 6 show that the PTV increase as the crossfall percentages increase. The 10% crossfall shows a higher PTV compared to 0% crossfall. The 10% crossfall produces higher PTV because it is good in runoff and water drainage. Besides that, the water film thickness at 10% crossfall is minimal between 0.5 to 2.0 mm compared to water film thickness of 2.0 mm to 7 mm at 0% crossfall where waterponding occurs on the pavement surface. At 10% crossfall, the PTV gets closer to the normal condition for different types of rainfall intensities for AC14 and AC20 indicating that the water film thickness is at the least and the runoff is efficient. However, for the 0% crossfall, the PTV does not get closer to the normal condition and has a big difference between low, medium and high rainfall intensity. High rainfall intensity at 0% crossfall, the PTV is small because bigger water film thickness at 6 mm to 7 mm and the water runoff from the pavement is inefficient.

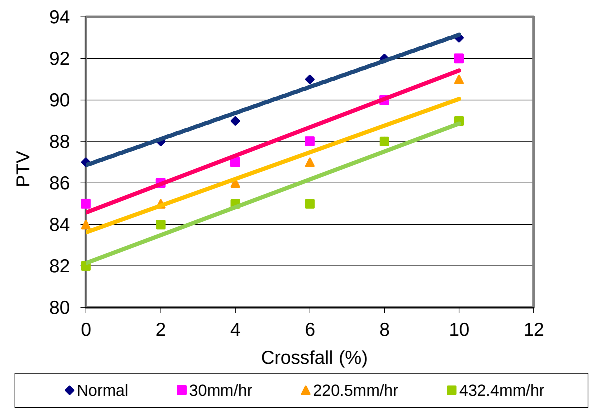


Figure 4 Pendulum test value vs crossfall for AC10

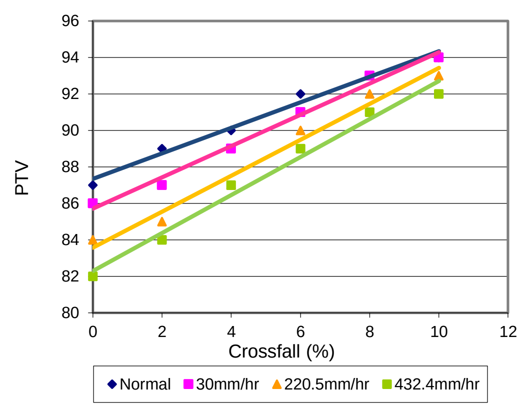


Figure 5 Pendulum test value vs crossfall for AC14

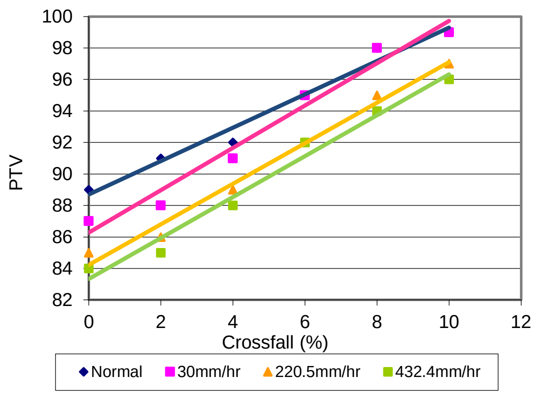


Figure 6 Pendulum test value vs crossfall for AC20

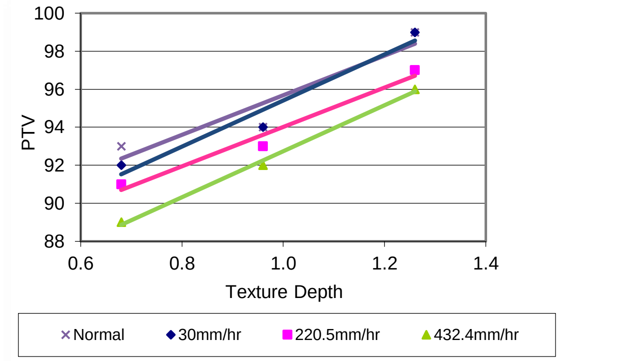


Figure 8 Pendulum test Value vs Texture Depth at 10% Crossfall

3.3 The Effect of Surface Texture on Pendulum Test Value

Figure 7 and Figure 8 show that increase in the texture depth has resulted to the increase in the PTV. This is due to the influence of macrotexture effect on the aggregate surface. When the texture depth of the pavement increases, the macrotexture plays an important role in draining off the water. AC20 represents bigger texture depth while the AC10 represents a smaller texture depth. At 0% crossfall, the PTV is the least compared to the PTV for 10% crossfall which is the highest. At 0% crossfall, water tends to fill up the macrotexture affecting the texture depth. Therefore, the macrotexture of the smallest texture depth of AC10 is filled with water faster than the AC20 because its texture depth is smaller. Apart from that, the AC10 does not have a good macrotexture as the AC20 which is important in draining water and keeping the aggregates in contact with tyre. At 0% crossfall, since the runoff is slow and thicker water film is present on the pavement surface, the AC10, AC14 and AC20 do not show big difference in PTV. However, at 10% crossfall when the water runoff is fast and the water film thickness is small, the AC20 tends to produce better PTV since the bigger macrotexture or bigger texture depth is capable of draining the water efficiently.

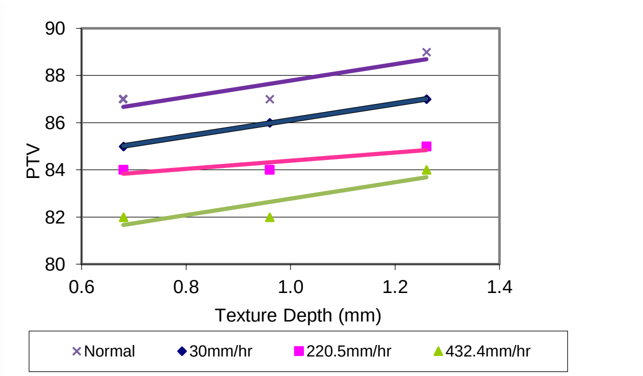


Figure 7 Pendulum test value vs texture depth at 0% crossfall

3.4 Analysis of Variance (ANOVA)

ANOVA analysis shown in Table 1 specify that 4% to 10% crossfall has no significant difference on PTV between rainfall intensities which proves that 4% to 10% crossfalls is good in draining water even at high intensity. Besides that, Table 2 shows that the 0%-2% crossfall has no significant difference on PTV between surface types but from 4% to 10% crossfall shows significant differences on PTV between surface types. This proves that 4% to 10% crossfall drains water efficiently providing different PTV according to the surface type where the surface texture plays an important role in determining PTV. Table 3 indicates that the AC10, AC14 and AC20 show significant differences on PTV between crossfalls indicating that the surface textures are good in resisting skid as the crossfall percentage gets bigger. As a result, AC20 is the best surface type to drain water efficiently at all crossfalls because of the bigger macrotexture it has compared to AC10 and AC14.

Table 1 ANOVA of rainfall intensity on crossfall

Crossfall	**Pvalue**	**Pcrit**	**Condition**	**Significant**
0%	0.014247	0.05	$P < P_{crit}$	Yes
2%	0.012875	0.05	$P < P_{crit}$	Yes
4%	0.296296	0.05	$P > P_{crit}$	No
6%	0.615448	0.05	$P > P_{crit}$	No
8%	0.651732	0.05	$P > P_{crit}$	No
10%	0.650963	0.05	$P > P_{crit}$	No

Table 2 ANOVA of surface type on crossfall

Crossfall	Pvalue	Pcrit	Condition	Significant
0%	0.489078	0.05	$P > P_{crit}$	No
2%	0.506023	0.05	$P > P_{crit}$	No
4%	0.046258	0.05	$P < P_{crit}$	Yes
6%	0.005248	0.05	$P < P_{crit}$	Yes
8%	0.003613	0.05	$P < P_{crit}$	Yes
10%	0.002843	0.05	$P < P_{crit}$	Yes

Table 3 ANOVA of crossfall on surface type

Variables	Pvalue	Pcrit	Condition	Significant
AC10	0.001384	0.05	$P < P_{crit}$	Yes
AC14	2.36E-06	0.05	$P < P_{crit}$	Yes
AC20	5.24E-07	0.05	$P < P_{crit}$	Yes

4.0 CONCLUSION

Based on the results, the following conclusions can be made:

- The PTV on 432.4 mm/hr intensity is smaller than the PTV of 220.5 mm/hr and 30 mm/hr. The 30 mm/hr PTV has the highest PTV because of the existence of small water film thickness on the pavement.
- The PTV for 0% crossfall is smaller than the 10% crossfall. The 10% crossfall has a greater PTV because it is efficient in water drainage creating smaller water film thickness thus resulting to a bigger PTV. However, the 10% crossfall could not be implemented since it affects the drivers' comfort. Therefore, this study recommends 4% crossfall since the ANOVA results proved that crossfall ranging from 4% to 10% is efficient in water drainage from the pavement.
- The PTV for AC20 is bigger than the AC14 and AC10. This is because the AC20 surface texture is rough and good in water drainage since it has a high macrotexture depth.
- It can also be concluded that the three factors of intensity, crossfall and texture depth are interrelated and significant in influencing PTV besides producing strong correlations of R^2 values. The conclusions also prove that the lower rainfall intensities, bigger crossfalls and bigger surface texture generate a bigger PTV which indicates a good tyre pavement contact. Bigger crossfall and bigger surface texture will eventually helps to minimize skid thus increasing the safety of road users.
- Dynamic load or tyre is suggested to be located into the rainfall simulator in order to obtain speed that could cause hydroplaning and skidding since speed is one of the major contributors to skidding during rainy climate.

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